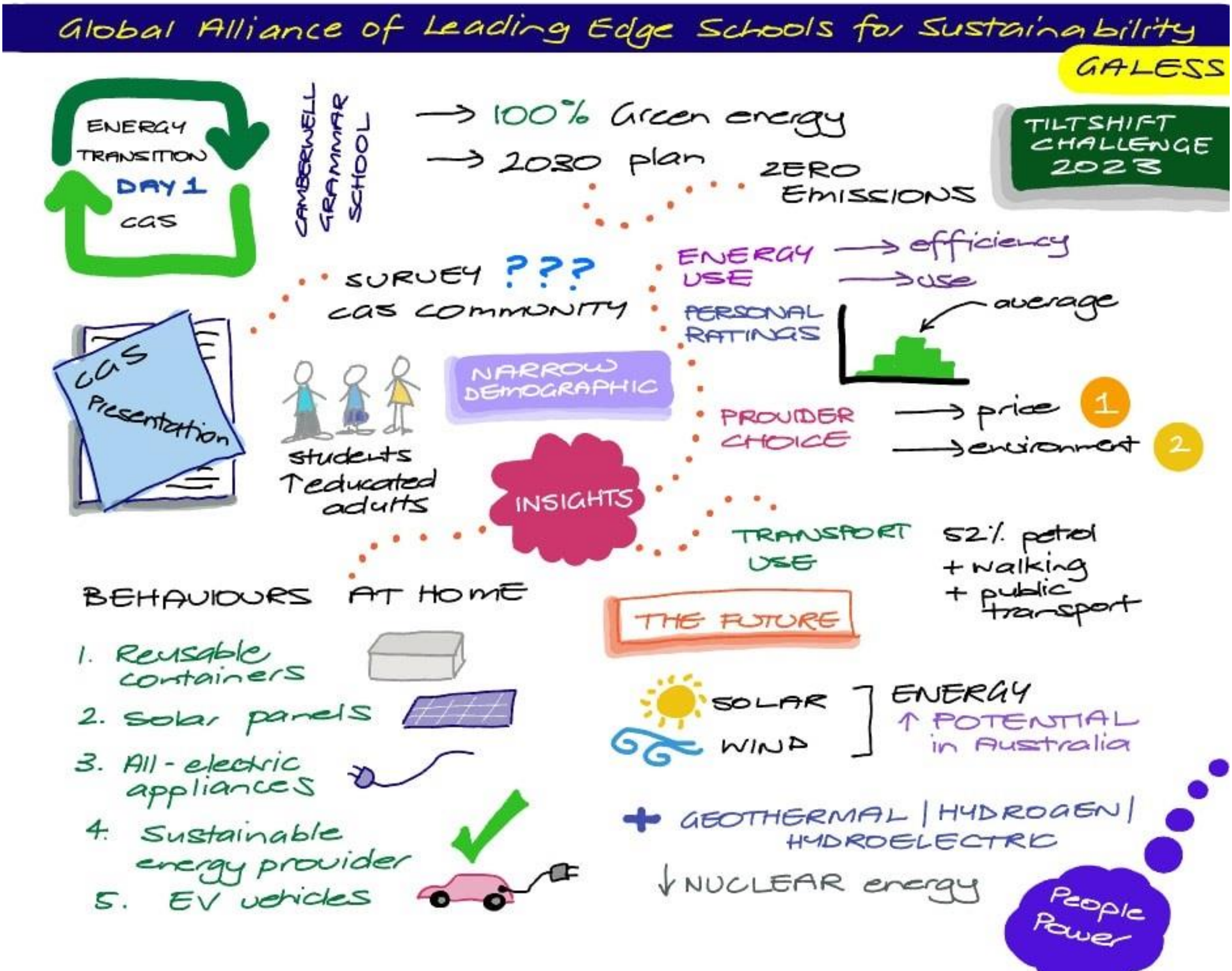
GALESS

TiltShift Challenge 2023

Energy Transition



GALESS TiltShift Challenge Energy Transition Project Research Book

The GALESS organization (Global Alliance of Leading Edge Schools for Sustainability) – www.galess.org proudly presents the results of the second TiltShift Challenge "Energy Transition" with this Project Research Book.

Students in the age-range of 16-19 years old from all parts of the world produced research-reports in small teams regarding the Energy Transition. They discussed their results during four different live conference weeks in 2023 in Boston (USA), Rybnik (Poland), Bali (Indonesia) and Melbourne (Australia) during the calendar year 2023.

The research was focused on three topics:

1. Investigation of your country's energy system,
2. A plan for transitioning your country's energy system away from carbon-based sources,
3. Examination of the global implications of your country's energy system transition.

The GALESS Jury Board was involved in the reports together with four different local jury-teams in four different conference-locations. Their comments were gathered and summarized in the GALESS certificates for each participating student and team in this year's TiltShift Challenge.

We would like to express our gratitude to all the students for all the creative ideas and solutions in their research reports. And we thank the guiding teachers, living libraries, jury, the local conference organizers, their supporting staff and logistic support. Their tremendous effort made a lifetime experience possible for our young generation students.

GALESS will continue to bring together young students in a meeting of hearts and minds, plant the seeds of friendship and dialogue, instill in them an awareness of issues facing humanity across the continents, produce valuable research results and empower our young generation towards impactful action within their communities.

The GALESS team

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GALESS 2023 – Research Reports “Energy Transition”

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Energy Transition

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Abstract

The Polish energy system is based mainly on coal. In addition to that, our energy sector also uses fossil fuels, imported mainly from US, Norway or Saudi Arabia, such as oil and gas. The share of gas in energy production in Poland is about 8%, and when it comes to oil >1%. In Poland in 2021 total emission of CO2 amounted to 192 mln tons - that's 11,5% more than in the previous year. Regrettably, the use of low-emission energy sources in Poland is still quite small. Renewable energy sources constitute only 17%. What's more, at the moment there is no nuclear power station in Poland. Fortunately, an increasing number of people are beginning to realize the seriousness of the matter. The current geopolitical situation, inflation and climate change is forcing Poles to find other ways to generate energy, move to low-emission energy sources that are safe and friendly for the environment.

In this research paper, the current state of energy in Poland and the possibilities of energy transformation will be discussed.

Introduction

Poland is a country lying on large deposits of hard coal and lignite (Fig1). In consequence our energy industry has always been mainly based on these raw materials.

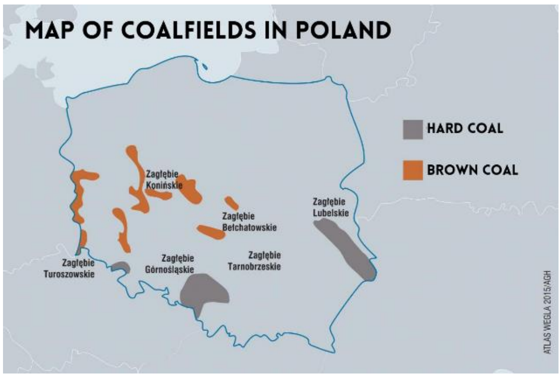

Fig. 1 Map of coalfields in Poland created by Forum Energii

It is also a factor contributing to the failure of carrying out the energy transformation, because it is a highly developed sector of our economy, therefore many people are employed in it and a lot of money is invested in mines (despite their frequent unprofitability). The departure from fossil fuels is associated with a major reform in the Polish energy sector, which the Polish government is constantly postponing. Rybnik is a city in Silesia, which currently has 2 hard coal mines (there are 2 more in neighboring towns). As a consequence, a large part of the Rybnik community has been employed in mines or mining-related companies for generations. Miners have many additional benefits to their dangerous work, such as early retirement or coal allowances, where they get coal from the employer free of charge. Thanks to these privileges working as a miner despite the danger, is tempting. Moreover many people are against the closure of mines and the implementation of the energy transition, because it is connected to loss of jobs, even for entire families. For the last few years despite some imperfections, this situation has been beneficial for many people. However in the current energy crisis and the problem with the demand for coal, the Silesian population as well as the entire Polish population, is aware of the need to switch to another source of energy. As for now, many households have switched to gas or heat pumps. There are also many campaigns promoting and supporting the transition from old furnaces to the new ones or switching to green energy. Our country is going in the right direction, but it is a time-consuming process and requires greater involvement on the part of residents and higher institutions.

1. What does the Polish energy system look like?

1.1.1 Hard Coal

In Poland, we mine thermal and coking or metallurgical coal. In 2021, hard coal mining in Poland amounted to about 55 million tons [1], and its share in electricity production in 2021 was more than 46% [2]. It is mined by using the deep mining method, currently from seams at depth of about one kilometer. The calorific value of thermal coal varies between 23 and 30 MJ/kg[3].

A significant part of hard coal production goes to electricity generators, so Polish mines are unable to meet the needs of private consumers, therefore the imported coal goes mainly to them. In 2021, 12.55 million tons of this carbon were imported into Poland [4]. Currently, imported coal comes from Colombia, Australia, the US, Kazakhstan and others, where it is mined by open-pit methods. Unfortunately, it is a low-grained coal, so after screening you get about 25% coarser coal, which is used for fuel [5]. That's the reason why imported coal can give much less heat. In 2021, the Jastrzębie Coal Company alone exported 10 million tones of coking coal, mainly used in steel production [6].

Thermal coal is used in households, schools, company buildings, industrial plants, power plants, industrial power installations, in the production of plastics, fertilizers, plant protection products and others.

1.1.2 Brown coal

Poland is abundant in lignite deposits, which are very diverse in terms of species.

It is mined only by the opencast method so accordingly, only five operated opencast mines are currently opened in the country. As a result of their activity, around 30-40 mln tons[7] are mined every year. According to the Polish Geological Institute, Poland's geological balance resources amount to 23.14 billion tonnes (where almost all of it constitutes thermal coal) including developed resources of 1.04 billion tons (results from data in 2021)[8].

Lignite is used by Poles mainly to produce electricity, thermal energy and fuels. Besides that, it is also used in the chemical industry and in the production of fertilizers.

Polish residents are often eager to start using lignite mostly because it is much cheaper than hard coal and easily available. Unfortunately, they usually don't realize how destructive it actually is. Despite its practicality in many fields, it's much more toxic considering emissions from its combustion. Its CO2 emission equals 1.22 Mg CO2/MWh (the highest of all sources)[9].

Lignite is characterized by high sulfur content (up to 6%), ash content and humidity.

Because of these features, which makes a fuel of much lower quality comparing to hard coal.

Significantly larger amount of ash, higher sulphation and the same amount of volatile substances as in hard coal, means that you need to buy 2-3 times more lignite than hard coal to get the same amount of heat. Due to its traits, brown coal must be completely burned close to where it is mined, as it loses its calorific value during transport, and in consequence loses its overall value. Another disadvantage regarding transport is the fact that lignite is soft in its raw state and due to the high affinity for water (it absorbs water more easily and is very moist itself) it begins to crumble in the drying process. The cracking of the coal causes such a big problem with unloading and in winter by freezing, that the delivery is completely pointless.

The damage caused by lignite in Poland was so intense, that in 2018 it was formally forbidden to use it in most voivodeships based on anti-smog resolutions

1.1.3 Natural gas

It's a fossil fuel that is considered as transition fuel, because it causes lower CO2 emissions than other fossil fuels. Unfortunately it is not among the zero-emission fuels we are aiming for. There is not a lot of natural gas in Poland, which is why it is mainly imported. According to the Polish Geological Institute, in 2021, 4.86 billion m³[10] of natural gas was extracted in Poland, where the annual consumption of natural gas, according to Eurostat, amounted to 23.3 billion m³. In previous years, Poland imported natural gas mainly from Russia, in 2021 9.9 bcm of gas was imported to Poland in this way. Russia's attack on Ukraine caused a significant reduction in the transmission of natural gas from Russia, which was aimed at becoming independent from this country. Alternatives include the Terminal in Świnoujście, which receives LNG (liquefied natural gas) transported by sea. Its regasification capacity is 5 billion m³, but it's planned to increase it to 10 billion m³. LNG is mainly purchased from the United States, Qatar and Norway. In October 2022, the Baltic Pipe was built. It transmits natural gas from Norway through Denmark to Poland. In 2022, its capacity is supposed to amount to 2 billion m³ per year, but in 2023 it is to be ultimately increased to 10 billion m³ per year. There are also connections between Poland and Germany, Ukraine, Slovakia or the Czech Republic, but the gas transmitted through them is Russian gas. There are also gas storage facilities in Poland with a capacity of approx. 3.2 billion m³. The construction of the FSRU unit - is a floating terminal for receiving LNG with a receiving capacity of up to 12 billion m³ is planned to be finished by 2027.[11]

1.1.4 Petroleum (Oil)

The oil sourced today is neither easy nor cheap to extract compared to previous years. As the world's oil reserves profitable for extraction are diminishing over the years, it is necessary to venture into hard-to-reach areas such as the Arctic, the Amazon, the Arctic Ocean. This entails greater expenses - the construction of a platform to enable its extraction in such places is estimated at about $3 billion[12]. Increasing expenses for oil extraction are associated with an increase in prices on the economic market.

Poland has very few oil deposits. Currently, 87 oil fields are documented in Poland, in which 57 fields are in production. The largest deposits are in the Polish Lowlands, as much as 66%, and the rest are in the Baltic Sea [13]. In 2021, we mined 733,000 tons by ourselves. About 64% was oil imported from Russia. Because of the war, the price of oil increased to $100 for a barrel, while in our country we consume 568,000 barrels of oil per day. Poland is trying to reduce oil imports from Russia, replacing them with imports from Saudi Arabia, Kazakhstan, Nigeria, Norway, the USA and the UK. This is made possible by having liquid fuel transshipment bases on the Baltic Sea.

Oil is the second largest source of primary energy right after coal, as it covers 25% of our country's needs. It is used to produce fuels, mainly gasoline and oil, as much as 50%, and the rest is lubricants, petroleum jelly, asphaltenes, paraffins, etc.[14]

1.2 Emission-free energy sources

Although in recent years Poles have been trying to switch to renewable energy by investing in photovoltaics or biomass, energy production from RES still totals around 15%. The economic possibilities of the society related to financial subsidies for both private individuals and enterprises cause more and more interest, which affects investments in emission-free energy sources. This can be seen on the graph showing how the share of RES in energy production has increased over the last decade.

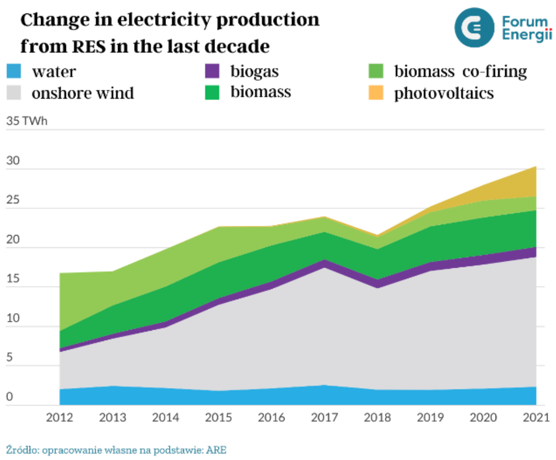

Fig. 2 Change in electricity production from RES in the last decade in Poland created by Forum Energii

1.2.1 Photovoltaics

Photovoltaics involves the conversion of energy from the sun's rays into electricity using photovoltaic panels. The amount of energy obtained depends on the solar radiation in a given area, which in Polish conditions gives a production of 1,000 kWh per year with 1 kWp of photovoltaic installation. The installed capacity of photovoltaics in Poland at the end of 2022 is more than 11 GW [15], or more than half of the installed capacity of RES, and the peak of energy production from photovoltaic panels, falls during the summer months. In 2021, photovoltaics alone produced 3.8 TWh that year, or about 13% of RES energy production [16]. In the Polish climate, it’s very expensive to equip a building with a heating system and provide energy only from photovoltaics, because you need to use very large energy storage in winter, when there is low energy production from panels, and a large cost of energy consumption for heating. Therefore, photovoltaics is an additional source of energy production for the buildings in Poland.

1.2.2 Wind Energy

Wind energy is the cheapest energy from emission-free sources, which we can obtain for Poland on a large scale. Market share of wind farms in energy production in 2019 amounted 10%, in 2020 10,8%, and it has decreased to 9,4% in 2021. Wind farms construction in 2015 cost 1,9 mln euro, however in the last few years it has changed and today the cost equals 1,3 mln euro.

As for the disadvantages of the wind power plant, the most significant one is the cost of construction.

The problems that we have to deal with because of windmills are: a lot of energy needed to build a windmill, their lower efficiency in the summer, deaths of birds caused by them or the noise they make [17].

During the year we are not able to produce the same amount of energy every month, because of changing weather conditions.

The advantage is the access to the Baltic sea so we can develop the Polish offshore wind energy system. It has huge perspectives to evolve and a chance to play an important role in energy transition, because they do not apply to land distance limits and have minor effects on the environment.

1.2.3 Biomass

In Poland we have been burning biomass for around 12-15 years, so it is a relatively new way to generate energy. About 85% of biomass in Poland is imported, mostly from Russia, Belarus, Ukraine, Hungary, Bulgaria, and Latvia. According to the Polish Economic Institute biomass import from Russia and Belarus continued until June 2022, but after tightening EU sanctions on wood and wooden articles, pellet import from the United States, Canada, Ukraine and Turkey is growing. In comparison to other renewable energy sources, energy gain from biomass is minor (in Poland biomass provides only 7% primary energy). Biomass plants are one of the best methods to obtain biomass. They are using animal waste from farms and breeding’s regardless of sun exposure or wind power. At the same time it has a good effect on cleanness of surface waters where animal waste often gets. Sewer system wastes also can be used in biomass plants, taking into account the fact that they are a burden to society with high costs of utilization (1000-2000 zloty per ton [18]). It is important to mention disadvantages of using biomass like for example high costs of getting and processing it. In Poland there are also energy crops - mostly plantations of various types of birches, because they do not need any special conditions.

They are characterized by high calorific value, low humidity and small amounts of ash residues. Their energy value totals 19,23MJ/kg [19].

1.3 Statistics

The graphs underneath show the actual impact of given raw materials in the Polish energy sector and Poland's current energy mix.

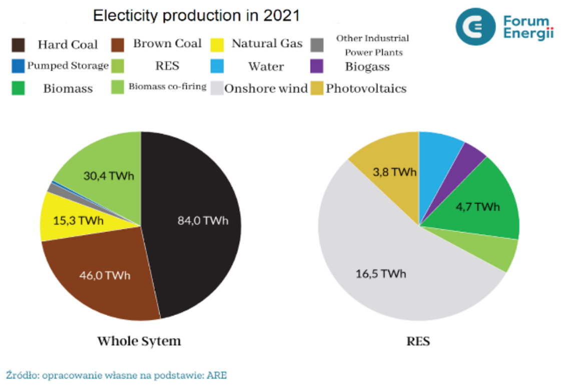

Fig. 3 Electricity production in 2021 in Poland created by Forum Energii

Hard coal has a big advantage over other energy sources, which shows how important it is to carry out the energy transformation as soon as possible in order to reduce the share of emission of raw materials.

To show how important it is to educate young people in the field of energy, our team conducted a survey on knowledge and awareness in this topic among Polish youth. The survey was completed by 400 people aged 15-19. The questions concerned knowledge about the energy mix in Poland, renewable energy sources and opinions on nuclear energy.

Based on the analysis of the feedback, we found out that despite the fact that all of the respondents indicated hard coal as the main source of energy, young people have limited knowledge about the energy mix in their own country.

Teenagers associate renewable energy mainly with photovoltaics, while other sources of green energy are little known to them.

Opinions on nuclear energy are very divided. Many people are afraid of the presence of a nuclear power plant in Poland and point to the failure of the Chernobyl nuclear power plant as the cause of fear.

After research, we realized that:

- young generations should be educated more about renewable energy sources and the need to use them

- the functioning of modern technologies in the field of nuclear energy should be explained to the people

- we should keep the public aware of the harmful impact of the use of fossil energy sources on health and the environment.

We are convinced that by raising our awareness and knowledge, we will be able to pass it on in our local environment and significantly contribute to positive changes in Poland.

1.4 Politics

The Polish government has always been convinced that coal will be the basis of our energy sector for the next few decades. They presume in the assumptions of the country's energy policy that by 2040 energy production will increase by 40%, which is why they try their hardest to stick to coal mining and the theory of increasing energy supply. At the same time, the European Union declares the reduction of energy consumption, therefore moving away from burning coal. Furthermore, through these desperate attempts to save the mining industry in the country, individual governments are driving Poles into the so-called political trap with consequences for the whole state. The trap consists that by promising to maintain the mines and continuing to draw energy from them, these particular governments are buying themselves time and votes of a very large group of electors, which includes miners, their families, companies gathered around mining, etc. therefore, most mining unions are not interested in the changes that would result from moving away from hard coal as the main energy source, in fear of losing their jobs and earnings, while ignoring the consequences it brings.

Another obstacle to the transition to renewable energy is the lack of vision and resources.

Poland can allocate 560PLN billion in the so-called national envelope for energy transformation in the long-term EU budget until 2027. Almost 190PLN billion has been assigned to the Polish energy transformation and climate protection so far and another 370PLN billion within a decade may come from emissions trading[20]. The government must assemble public and private entities to prepare good projects that will bring long-term effects, because without this, it will be impossible to use a significant sum of money. On the other hand, unwise and weak projects will consume considerable amounts of money, not contributing to the protection of Polish households and enterprises against price increases, which at the moment are already a problem for our country due to constantly increasing inflation.

The amounts related to Poland's energy transformation are so large that energy producing companies and the state will not be able to bear them, therefore they may affect our deficit.

Another barrier is the wind farm act brought to life in 2017[21]. Its purpose is to increase the distance between the windmills and residential buildings or valuable natural objects. As a result, there are few places in Poland where windmills can be built, in consequence the possibility of generating energy from them is automatically limited.

In fact, during our work on the report, several changes related to the act on wind farms were introduced. In December 2022, the Polish government established a self-amendment, which states that at least 10% of the energy produced should be transferred to the residents of the municipality where the farm is located. An additional requirement is the power of the wind turbine, which is to be within the scope of RES micro-installations i.e. up to 50 kW. Another modification was set in motion in February 2023, in which the parameters of the distance of the windmills from the buildings and the protected landscapes were altered. This change puts our country in a much more favorable situation, as the distance of the windmill from the facilities is to be 700 meters, which allows them to be built in larger quantities than before. Additionally, at the same time, the commission lifted the ban on the construction of residential buildings next to wind turbines.

2. How can we reduce the impact of fossil fuels on the Polish energy system?

2.1 Don’t make the same mistakes

The Polish energy sector has always been based mainly on hard coal. This is due to geology, as there are many coal deposits in Poland, mainly in Silesia. During the times of the Polish People's Republic, a gigantic coal sector was created, where extraction in the best years amounted to as much as 200 million tons and the employment was then very large. The 1970s and 1980s were the best period for the Polish mining industry, but since then mining and employment have been declining. The Third Republic took over this sector, which at that time was the backbone of the country's economy. In the late 1990s, the then Prime Minister Jerzy Buzek wanted to reform the Polish mining industry. As part of this reform, employment was reduced and unprofitable mines began to be closed. The years 2002-2011 on the global market were a period of prosperity for coal, which the Polish authorities did not take advantage of in any way. At that time, despite high prices for coal, Polish mines were not profitable, because the money was not invested in any way in new technologies or innovations of the Polish mining industry. Failure to take advantage of these opportunities contributed to the lack of development of the Polish mining industry, in contrast to mining around the world. Over the next 4 years, Kompania Węglowa (Coal Company), which at that time was the largest mining company in Europe, almost went bankrupt. The Polish state government , wanting to save jobs, and at the same time being under the strong influence of trade unions operating in the mining industry, was forced to support the entire mining industry. In the following years, despite the change of the ruling party, which also planned an energy transformation in its electoral program, it failed to create a good energy mix based on fossil fuels and low-emission energy sources. The rulers, wanting to maintain the Polish mining industry, invested in the entire coal sector, instead of focusing on reforming the mining industry by closing unprofitable mines, restructuring and investing in new technologies. Over the last 3 decades, Polish taxpayers have invested 260 billion zloty in the Polish mining industry, which was poorly invested money, as it could have been spent on innovations in the Polish energy sector. Currently, most of the mines are unprofitable and survive only thanks to state support. Coal is currently mined at greater depths, and thus is of poorer quality. It is also very important that its extraction costs are high and methane is very dangerous. The existing mining plants are located in heavily urbanized areas, which means that possible mining damage poses a risk of mining related seismic events to the inhabitants of these areas. The actions presented above show the incompetence of the rulers in the 21st century. Investing in future-proof solutions led to the collapse of the Polish energy market, which we found out in 2022 [22].

2.2.1 Changes

To move away from non-renewable energy sources a clear and explicit action plan is needed. We must be aware that it will be a long and demanding process that will lead us to create a better world together. In order to start this process and encourage Poles to choose green energy sources, the inflation rate in Poland should first be stabilized and preferably reduced. According to the GUS (Central Statistical Office), in 2022 inflation ranged between 13% and 18%, and in 2023 the National Bank of Poland is forecast to increase prices by 10% to 15%. As believed by NBP, the worst case scenario for Poland is 27% inflation [23]. High inflation causes less interest in switching to green energy, because the cost of purchasing and installing a heat pump or photovoltaics is high, as well as adapting the building to a given energy source. An important issue is also the development of wind energy. The ongoing work on the wind farm act in the Sejm gives hope for the development of this industry through less stringent legal requirements for the construction of wind farms. It is worth noting that before 2017 it was the fastest growing branch of RES in Poland. We should therefore develop wind energy, while considering the possibility of short-term energy storage in the form of heat storage, which we can also use in photovoltaics. In a situation where we obtain a surplus of electricity from the sun or wind, we will be able to store it and then use it when we run out of it. However, it must be remembered that such warehouses are able to meet our needs for a few weeks. It is crucial to remember the essence of the energy mix and that we cannot focus on one energy source. At the moment, photovoltaics in Poland is developing strongly, but the big problem is the datedness and maladjustment of Polish power grids to obtain energy in this way. Polish energy concerns should carry out full modernization of the network on an ongoing basis, along with its adaptation to the needs of the use of modern energy sources. It is important to expand Poland's hydrogen potential through the increased development of the hydrogen economy through the cooperation of the Ministry of State Assets and private companies. At the moment, the Polish hydrogen potential, compared to highly developed countries, is small. Thanks to this cooperation, we are able to create a thriving way of obtaining energy. However, this is not a solution that we are able to implement quickly, but it is very profitable and the development of this sector of the economy can be seen on the domestic market. In the energy transformation, the most important is the departure from hard coal. The Polish government should ensure that the mining sector and the industries cooperating with it can smoothly change industries. The government should ensure that the process of liquidation of the mining industry is closely related to the development of energy transmission networks and energy storage facilities, because only such a solution will allow for the full use of green energy. The development of energy networks also determines the construction of nuclear power plants, the launch of which in Poland is planned for 2043. However, it is necessary to take into account the frequent extension of these investments. Therefore we should focus on the development of currently available low-emission sources of energy, while preparing the Polish energy system for nuclear energy. As you can see, the process of energy transformation is extremely expensive, while the Polish budget includes poorly managed money from CO2 emissions. In 2021, Poland earned the most from the sale of CO2 emissions in Europe, because this profit amounted to as much as PLN 25 billion, and less than 4% of this amount was allocated to the development of the energy sector [24], which is definitely not enough. These funds should be invested in the development of Polish energy or co-financing for citizens switching to renewable energy.

2.2.3 How ordinary people can help in energy transition

Many people think that only governments or other very influential public figures have an impact on the energy transformation. However, we are also able to help the energy transition by implementing new habits. One of the most important things is to save energy as it will be good for the environment and we can save money. Saving energy does not have to rely on constant sacrifices and we do not have to give up the comfortable life. The fact that we will start using electrical devices wisely, is enough.

It is best to start by checking all the devices in our home and see how much energy they use. There are many that we use for a short time, and then they remain in the standby mode, drawing energy in the process. There are devices whose energy consumption can be easily checked, but there are also those for which we will need a special tool, such as an electricity meter. Thanks to this gadget, we'll be able to check the energy consumed by home appliances. All we have to do is put it into the socket and connect the device to it to check the electricity consumption. Thanks to familiarization with the electricity consumption in our home, we can determine which one of the devices operating time should we limit, which turn off to avoid the energy-consuming standby mode and which to switch to energy-saving devices when replacing the device [25].

3. Global implications of the Polish energy system transition

3.1 Potential impacts of the Polish transition on other countries.

The Polish strategy expects that the demand for hard coal would be covered by the mines located in the country, and the raw material should be imported only in justified cases [26]. At the moment, Poland imports coal mainly from Australia, Colombia, the USA and others and in result affects the energy sector of these countries by driving their demand for coal mining. As a result, we're not simplifying the energy transition, constantly importing huge amounts of non-renewable raw materials like coal, instead, we should focus on investing in RES.

In the near future, the first nuclear power plant will be built in Poland. Polish company "Polish Nuclear Power Plants" has signed a cooperation agreement with Westinghouse Electric Company - an American corporation specializing in the production of equipment using nuclear energy. According to energynews:

"The signing of today's [...] contributes to further strengthening our strong partnership with the US. It's also an important signal for the domestic industry, enabling its development in the construction and use of a nuclear power plant. The implementation of the program to build new nuclear capacity means generous benefits for the economy, but also ensures predicted prices of energy for consumers, which is especially important for energy-intensive companies affected by the current crisis and high energy prices" said Anna Moscow, Minister of Climate and Environment.

Considering all these facts, we came to the conclusion that Poland needs cooperation and partnership from abroad, which would result in a gradual transition to green energy sources and investments in foreign companies.

3.2 How can we help other countries in their transition to decarbonized energy systems?

We need to start making progress, beginning with showing that Poland is already changing in terms of energy and that we are advancing the energy transition in our country.

Setting a good example for other countries may prompt them to take action and cooperate to create a better future together.

Additionally we can continue to export various types of electric vehicles to other countries seeing as it is possible thanks to the factory of electric delivery vehicles operating in our country, as well as the plants producing electric microcars and one-track vehicles. By the end of 2024, Polish brand "Izera" is planning to launch the production of zero-emission cars that will also be exportable.

It's worth mentioning that Poland is a European leader in the production of car batteries used in electric and hybrid cars. Their export already reaches about 2 percent of all our exports, and by continuing it, we will also support and push the development of the energy transformation of other countries.

4. Summary

Concluding all of the points mentioned above, we can see that the path chosen by the government is the right one in concept, but some modifications are definitely needed.

The ongoing measures do not entirely allow us to fully use the current potential. Accordingly, in our opinion, broadly understood social education, full modernization and expansion of energy networks in Poland will enable full and effective use of our dormant potential in low-emission energy sources.

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ENERGY TRANSITION

HOW CAN GERMANY'S ENERGY SUPPLY BE TRANSFORMED TO ACCOMPLISH ITS CLIMATE GOALS?

Energy sources in question of sustainability

GYMNASIUM DER STADT ALSDORF, GERMANY

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SUMMARY

Our planet's climate has been experiencing an all-time high in recent years. Ecological consequences have long since ceased to be theoretical assumptions and have become a serious reality. There is a direct correlation between climate change and our use of energy sources to secure our energy needs. Climate-related disasters are increasing not only worldwide, but also in Germany. [1]

The German power mix for energy supply shares responsibility for the future estimated 250,000 annual deaths between 2030 and 2050 due to climate change. [2] These casualties are consequences of the rise in temperature, which has numerous ecological effects such as the rise in sea levels and thus flooding, but also hurricanes and other climate-related natural disasters. To further delay global warming, the Paris agreement in 2015 has agreed upon climate goals, that are to be reached until 2045, to lower a rise in temperature from 2 degrees Celsius to 0.5 degrees Celsius.

Many scientists, including those in our local research center located in Jülich, North-Rhine-Westphalia, have researched and simulated different renewable energy sources to further delay an increase of temperature.

Surveys led us to realize that sustainability is not yet being lived and that our energy mix needs to be changed to our goal: Gaining knowledge and spreading awareness of sustainable energy resources and finding a way to improve efficiency, while decreasing our ecological footprint.

In dedication to the topic, we want to optimize our current energy mix to support the goals the Paris Agreement has set for Germany, maintaining a net zero-balance, as well as produce renewable energy for the power demanding industry and personal usage.

KEY WORDS

Global challenges, Energy transition, Systemic issues, Alternative energy sources, Climate goals

[1] United Nations. (n.d.). *Causes and effects of climate change | united nations*. Retrieved February 13, 2023, from https://www.un.org/en/climatechange/science/causes-effects-climate-change

[2] *Climate change and health*. (n.d.). Who.int. Retrieved February 13, 2023, from https://www.who.int/news-room/fact-sheets/detail/climate-change-and-health

INTRODUCTION

The future of our lives is related to the current use of energy regarding the climate crisis, which therefore urgently needs to be optimized. In our essay, we, the Going Green group of the Gymnasium in Alsdorf, want to look at the current state of the energy mix in Germany, considering ecological as well as socio-economic and technological aspects. Interviewing people from the field, scientists from the Jülich Research Centre (Forschungszentrum Jülich) and local politicians (e.g., the mayor of Alsdorf) served to explore the topic in detail. The research institute in Jülich focuses primarily on the field of renewable energies and therefore our work places an emphasis on the potential of "green hydrogen" in our region.

Our goal is to acquire knowledge and raise awareness for sustainable energy supply. The aim is also to improve the efficiency of energy use to conserve resources and at the same time reduce our ecological footprint.

Only about one third of Germany's energy consumption is covered by domestic energy sources and here predominantly from non-renewable energy sources, the rest is provided by energy imports. The use of fossil fuels for energy production in particular leads to the emission of greenhouse gases, which are partly responsible for climate change. [3]

A sustainable energy source is proven to be a crucial aspect of a long-lasting earth environment. Energy is essential; while the global demand for energy rises the sparsity of our supply remains. Global warming is human made and caused by the greenhouse effect. Since the discovery in the late 1930's by Guy Callendar, many scientists and engineers have continued to study alternative energy sources in question of sustainability. [4]

Germany obtains a large share of its energy from Russia, which shows a dependence of its energy supply on other exporting countries and has become a political problem in the recent past. To solve future political challenges the finding of alternative energy sources is important.

ALTERNATIVE ENERGY SOURCES

Alternative energy includes hydroelectric energy, solar energy, geothermal energy, wind energy, nuclear energy, and biomass energy. The goal: saving on emissions, protecting the environment, and avoiding harvesting of limited valuable resources. The Forschungszentrum Jülich, a local research facility, research on these energy sources by conducting complex simulations and big-data-analysis. Central aspects of research are focused on environmental impact including the release of carbon dioxide into the atmosphere, contributing to the greenhouse effect.

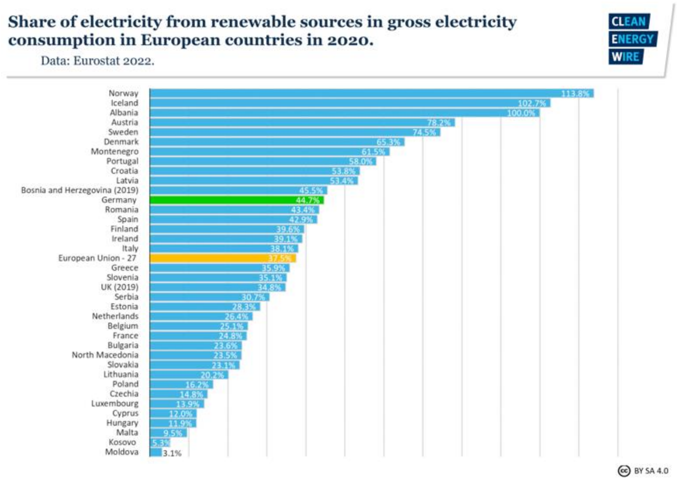

Fig 1 Share of electricity from renewable sources in gross electricity consumption in European countries in 2020. [5]

Germany is a global leader in the use of renewable energy and has made significant progress in lowering its reliance on fossil fuels. The nation has made sizeable investments in wind and solar power and has set ambitious goals for the growth of renewable energy.
Over 40% of Germany's electricity in 2020 came from renewable sources, including wind, solar, hydro, and biomass. The biggest contributor is wind power, followed by solar power. By 2050, the German government wants renewable

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[3] *Energieerzeugung*. (n.d.). Statistisches Bundesamt. Retrieved February 13, 2023, from https://www.destatis.de/DE/Themen/Branchen-Unternehmen/Energie/Erzeugung/_inhalt.html

[4] G. S. Callendar: *The artificial production of carbon dioxide and its influence on temperature*. In: *Quarterly Journal of the Royal Meteorological Society*. April 1938, doi:10.1002/qj.49706427503

[5] *Germany's energy consumption and power mix in charts*. (2015, 17th June). Clean Energy Wire. https://www.cleanenergywire.org/factsheets/germanys-energy-consumption-and-power-mix-charts

energy to account for 80% of the nation's energy consumption (see Fig. 1).

In recent years, Germany has also begun to phase out nuclear power. In 2011 the German government decided to phase out nuclear power by 2022 and to increase the proportion of renewable energy in the nation's energy mix. This choice was made in response to the 2011 nuclear accident in Fukushima, Japan. Germany has been able to lessen its reliance on nuclear power without increasing its reliance on fossil fuels, with only a small number of nuclear power plants still in operation as of 2020.

Energy efficiency is a crucial component of Germany's energy strategy. To lower energy use and boost energy efficiency in buildings, industry, and transportation, the nation has put in place several policies and programs. Along with financial incentives to encourage businesses and homeowners to invest in energy-efficient technologies, this also includes building codes that mandate that new buildings be extremely energy efficient.

So, Germany still has a way to go before it meets its lofty renewable energy goals, despite these efforts. The expense of developing and maintaining the infrastructure for renewable energy sources, particularly for offshore wind power, is one of the major obstacles. Furthermore, Germany continues to rely heavily on coal and natural gas for transportation and heating, and switching to alternative energy sources will require a substantial investment.

In conclusion, Germany has made significant progress in reducing its dependence on fossil fuels. The country has set targets for the expansion of renewable energy and has implemented several policies and challenges to improve energy efficiency. However, achieving these goals will require notable investments in renewable energy infrastructure and alternative technology. [6,7]

CLIMATE GOALS

The nation is dedicated to achieving the goals of the Paris Agreement, which include limiting global warming to 1.5 degrees Celsius and keeping it below 2 degrees Celsius.

Germany has set achieving climate neutrality by 2050 as one of its main climate goals. This implies that the nation will have to cut its greenhouse gas emissions to zero, with any remaining emissions having to be offset by actions like planting trees or investing in carbon capture technologies and protecting wildlife and private property. Germany will need to drastically reduce its emissions from the building, industrial, and transportation sectors in order to meet this objective.

By 2050, the government wants to see 80% of all energy sources come from renewable sources. Large-scale investments will be needed in renewable energy sources like hydro and biomass, in addition to those in wind and solar energy.

Germany has put in place several policies and programs to help it achieve these objectives. These consist of:

The "Energiewende" (energy transition) strategy, which will increase the share of renewable energy and reduce dependence on fossil fuels.

The "Klimaschutzplan 2050" (Climate Protection Plan 2050), which sets out a comprehensive strategy to reduce greenhouse gas emissions and achieve climate neutrality.

The "National Platform for Electric Mobility" which aims to promote the use of electric cars and charging infrastructure.

The "National Climate Protection Initiative" which will improve energy efficiency in buildings, industry, and transportation.

To reduce greenhouse gas emissions and achieve climate neutrality, Germany has established ambitious climate goals and implemented numerous policies and programs. The nation is committed to the Paris Agreement and desires to increase the proportion of renewable energy sources and enhance energy efficiency. However, achieving these goals

[6] Lüdtke, L. (2019, December 2). *Focus Germany: Balancing the energiewende*. GIS Reports; Geopolitical Intelligence Services AG. https://www.gisreportsonline.com/r/germany-energy-transition-2/

[7] *Energy in Germany*. (n.d.). Profilbaru.com. Retrieved February 13, 2023, from https://profilbaru.com/article/Energy_in_Germany

will demand important financial outlays and prove to be exceedingly difficult. [8,9]

ENERGY TRANSITION

A particularly important aspect regarding the energy transition is scientific progress because it tells us how achievable some of the most crucial goals in the energy transition are. If we know that we are lacking in our progress then we can focus more on retaining our goals, for example not emitting too much carbon dioxide. Our current situation in scientific progress is concerning because we are emitting way too much greenhouse gases and we cannot change that if our progress does not allow us to. If we pressurize people and try to force them into new climate-friendly measures, the probability of them pushing back against those measures will be higher. It is vital for society to show their willpower for the climate and act so that politicians will be pressured to comply. We must focus on scientific progress about the research of many ways for transportation or alternative energy sources so we can gather substitutes to the current systems which we currently use.

Scientists research various aspects like efficiency, because the goal is to achieve the best result with the lowest usage of money. For renewable energy, Germany requires storage and carrier, so for hydrogen the need to develop a new infrastructure to transport it effectively and safely increases. Afterwards hydrogen must be converted safely into electricity. To store energy, we must research in the areas of chemistry and electricity to increase the efficiency of batteries. These key aspects become increasingly complex and there is always the possibility to research further in electricity and chemistry, for example lithium-ion batteries. The biggest challenge concerning scientific progress is that the researchers are dependent on financial support from the government. However, governmental funds fail to cover the needed expenses for research in renewable energies.

A key response is to transition the current fossil fuel-intensive energy system to renewable energy, increasing energy efficiency and energy conservation. As this transformation will bring profound structural changes to societies and economies, we cannot overlook the socio-economic aspects of the energy transition.

Although there is a significant initial cost associated with the switch, it would result in savings over a long-term period. The report from the International Renewable Energy Agency (IRENA) shows that this energy transition - aligned with the goal of limiting the rise in global average temperature to 1.5°C above pre-industrial levels - is having positive impacts on economic growth and the creation of jobs and human well-being. [10]

Energy transition requires enormous investments in renewable measures to achieve energy efficiency, conservation, and accessibility. This investment leads to added demand and output across economic sectors, such as construction and manufacturing, therefore having a positive effect on the global Gross Domestic Product (GDP). Due to this added output, the energy transition would yield a higher global GDP compared to the less ambitious reference scenario, where the other financial flows will be smaller (Fig. 2).

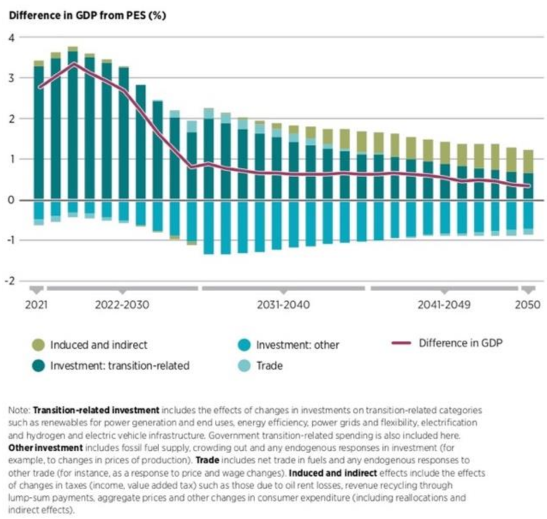

Fig 2 GDP difference of the 1.5°C Scenario from Planned Energy Scenario (PES) which is based on existing energy poli-cies and targets. (see Fig 3)[11]

[8] *Climate action*. (n.d.). Gtai.de. Retrieved February 13, 2023, from https://www.gtai.de/en/invest/hot-topics/climate-action-business-opportunities

[9] BMWK-Bundesministerium für Wirtschaft und Klimaschutz. (n.d.). *Klimaschutzplan 2050*. BMWI. Retrieved February 13, 2023, from https://www.bmwk.de/Redaktion/DE/Artikel/Industrie/klimaschutz-klimaschutzplan-2050.html

[10] (N.d.). Www.un.org. Retrieved February 13, 2023, from https://www.un.org/sites/un2.un.org/files/2021-twg_2-062321.pdf

[11] Õunmaa, L. (n.d.). *What are the socio-economic impacts of an energy transition?* UNDP. Retrieved February 13, 2023, from https://www.undp.org/eurasia/blog/what-are-socio-economic-impacts-energy-transition

The clean energy transition requires equipment, technologies, and several services, and as such offers significant job opportunities worldwide. This increased transition-related demand for jobs is projected to result in an average one percent increase in employment throughout the transition (planned and hoped for 2050). The additional jobs will peak around 2030 at 51 million (26 million in the energy sector alone). However, job creation goes beyond the energy sector. Experts in law, taxes, coordination, safety, and the environment, as well as specialists such as truck and crane drivers will also play a key role in the changeover. Despite the demand for specialized workers in various fields, today's working society remains to leave a gap in said fields. There is an estimated shortage of specialists of about 200.000 employees, jeopardizing Germany´s way to climate neutrality and sustainability.

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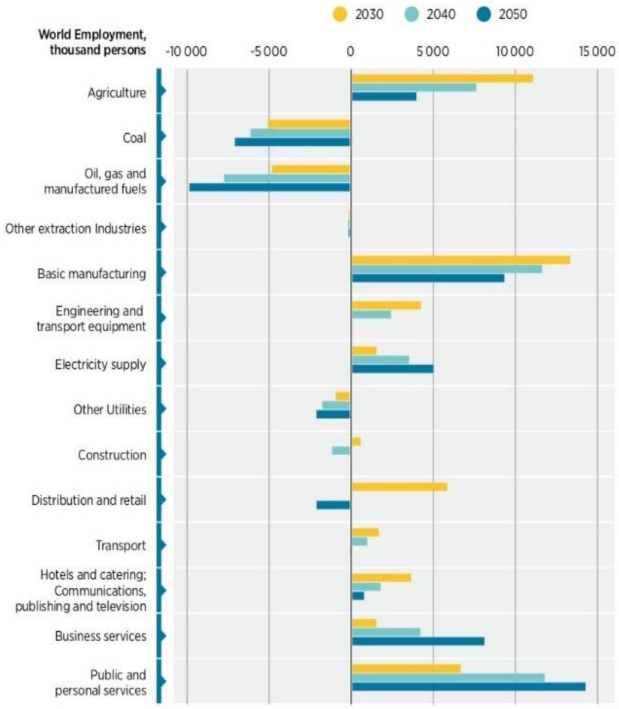

Fig 3 Difference in employment by sector between the baseline and the 1.5°C scenario, thousand jobs.[12]

IMPACT ON THE INDUSTRY

Suppliers will feel the most pressure as the transition to electric powertrains triggers a range of component redesigns and new players step in to seize the opportunity. The severity of this relative threat to established businesses varies by device category. For example, demand for batteries, electric drivetrains and power electronics will increase, while demand for hydraulics will decrease, while demand for cabs and tires will remain steady.

Regardless of category, however, incumbents will need to change their business strategies, go-to-market models, and product and service mixes. Startups are taking a more targeted approach, offering specific modules and technologies such as batteries, electric motors, electric drivetrains, battery charging infrastructure, hydrogen fuel cell systems, and more. This ecosystem is suitable for entrepreneurship and investment by funds and financial institutions.

Threatened by non-traditional competitors such as startups, the industry must move quickly to develop new products. They must also consider several tradeoffs, including:

Relevant technologies must be selected for each selected powertrain option. Companies can choose to develop these technologies in-house or procure them through partnerships, alliances, or supply agreements. Their decisions about which technologies to control internally should be part of their overall product strategy, and they should consider how they want to differentiate their products.

Operations must decide which platforms to upgrade and which to build from scratch to achieve optimal performance, quality, and cost. New platform development requires additional time for testing, validation, and regulatory approval. Aftermarket Impact is an appendix that urges industry to consider the impact of the energy transition on their aftermarket business. Replacing mechanical components with electronic components could cut their needs in half, according to a McKinsey simulation of a product's total life cycle cost.

[12] Õunmaa, L. (n.d.). *What are the socio-economic impacts of an energy transition?* UNDP. Retrieved February 13, 2023, from https://www.undp.org/eurasia/blog/what-are-socio-economic-impacts-energy-transition

To offset potential lost revenue from aftermarket parts and service, operations can create new revenue streams such as: Expansion of the company for special production according to customer requirements [13]

IMPACT ON CONSUMERS

If the cost increase is accepted, consumers will face capital costs and may have to spend more on electricity in the short term.
Moving to net zero can also affect consumer spending. Consumers may face higher prices and upfront investments in the short term, which may change their consumption patterns if significant emissions reductions are to be achieved. Low-income households are particularly vulnerable. [14]

First, consumer consumption patterns may be affected by decarbonization efforts, including the need to replace fossil-burning vehicles and fossil-fuel-based home heating systems, and potential dietary changes to increase rather than decrease consumption of beef and lamb.

Second, any increase in electricity prices will affect consumers, especially low-income consumers whose energy bills make up a substantial portion of their budgets. But it depends on how the compensation is distributed among the consumers, and thus the increase in the cost of electricity supply is passed on to the end consumers.

Third, consumers bear the initial capital costs, especially those related to mobility and building conversions. For example, if internal combustion engines are eliminated, household costs will shift from similar internal combustion engines to more expensive electric vehicles due to larger battery sizes. While consumers will benefit in the long term from asset life savings, such as savings from lower total cost of ownership or the energy efficiency of electric cars, the initial investment can be difficult, especially for low-income households. One area where consumer costs could come down is the dietary changes needed to decarbonize agriculture and food costs reflected in the food industry, namely proteins such as poultry.

In other areas, higher production costs also affect the prices of consumer goods and services. Low emission transport costs are high and can be transferred to international recommended consumers but may differ from consumers with higher costs generated by the state and products. Similarly, the cost of difficulties can reduce steel and cement production costs by increasing the cost of the final product, but the effect depends on the cost of these materials in the final products and services. All this can be solved by a set of compensation mechanisms for a smooth transition. Therefore the German Federal Ministry of Education and Research funds basic research because modern technologies and innovations make the energy transition possible. [15]

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[13] Goel, U., Rittstieg, M., & Sanders, J. (2021, August 19). *Implications of the 'energy transition' across the machinery value chain*. Mckinsey.com; McKinsey & Company. https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/implications-of-the-energy-transition-across-the-machinery-value-chain

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[15] Krishnan, M., Samandari, H., Woetzel, J., Smit, S., Pacthod, D., Pinner, D., Nauclér, T., Tai, H., Farr, A., Wu, W., & Imperato, D. (2022, January 25). *The economic transformation: What would change in the net-zero transition*. Mckinsey.com; McKinsey & Company. https://www.mckinsey.com/capabilities/sustainability/our-insights/the-economic-transformation-what-would-change-in-the-net-zero-transition

GLOBAL ENERGY CRISIS

As the world grapples with the unprecedented humanitarian crisis caused by the COVID-19 pandemic and the consequent situation in Ukraine, there are calls for post-riot recovery plans to align with international agreements such as the Sustainable Development Goals (SDGs) and the Paris Agreement. [16] The latest report on the climate crisis makes this more urgent than ever. [17]

The current global energy crisis did not begin with the February 2022 invasion of Ukraine. Instead, it started in late summer 2021. The economic recovery following the end of the global COVID-19 lockdown has led to an increase in global energy consumption. Oil, gas, and coal markets are shrinking through late 2021, pushing up prices as demand widens the resulting supply gap. In November 2021, three months before the invasion, the US government announced the first release of the Strategic Petroleum Reserve. What is clear is that a "cautious lack of investment" has prevented the development of sufficient new oil and gas resources. There are several reasons for underinvestment – government policies and regulations; ESG (Environmental, Social and Governance) considerations for investors; and uncertainty about future demand. The size of the investment is "cautious" because of the false assumption that many large-scale alternatives to oil and gas already exist. [18,19]

Political differences have forced many governments to reconsider their policies. This analysis shows that the energy transition must be based on energy savings, i.e., an adequate and affordable supply, to secure public support and avoid serious economic losses and dangerous political consequences. [20]

FUTURE PROGNOSIS

Renewable energy has been a prevalent topic regarding the ongoing climate change as a key alternative to push back against the process of the steadily increasing global temperature. As scientists continue to research ways of transitioning to more sustainable energy sources, we are fighting a battle against time to make these changes happen as soon as possible. Amidst heated discussions to prevent the deterioration of our planet, one question concerns people most – when are we able to achieve the goals we have set for ourselves? Many politicians promised net-zero emissions and a switch to renewable energy by 2040, but is that deadline a realistic goal, or is it a promise that is just too good to be true?

Dr. Hannes Stadtler works for Helmholtz, a Cluster that strives to build a sustainable infrastructure for the hydrogen economy. Their goal is to demonstrate hydrogen technologies and promote them as a genuine replacement to our current energy sources. To put hydrogen technology to successful use, a lot more work is required than what is currently done with Diesel. Hydrogen possesses a lot less energy density than fuel, so to save any hydrogen energy, a massive volume of it is required. By liquefying it, the requirement of massive amounts of volume would fall away. The liquefaction however is dependent on the necessary infrastructure to make this technology happen, so Dr. Stadtler said to use hydrogen as a chemical energy storage instead. He introduces the idea of hydrocarbon, which has similar magnitude to diesel fuel and can bind hydrogen chemically. Thus, the hydrogen can be reused. Although Dr. Stadtler describes an elaborate and thought-out process of using hydrogen to produce energy, he adds that hydrogen does not have a broad market for “green” hydrogen production since it is still produced with natural gas. His introduction to the

[16] *AboutOECC /OverseasEnvironmentalCooperationCenter,japan*. (n.d.). Overseas Environmental Cooperation Center, Japan. Retrieved February 13, 2023, from https://www.oecc.or.jp/en/about/about_oecc/

[17] Õunmaa, L. (n.d.). *What are the socio-economic impacts of an energy transition?* UNDP. Retrieved February 13, 2023, from https://www.undp.org/eurasia/blog/what-are-socio-economic-impacts-energy-transition

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[20] Õunmaa, L. (n.d.). *What are the socio-economic impacts of an energy transition?* UNDP. Retrieved February 13, 2023, from https://www.undp.org/eurasia/blog/what-are-socio-economic-impacts-energy-transition

works of the hydrogen economy seems promising and has solid grounds, but overall lacks the resources needed to realize it as a legitimate substitute to our current energy sources. Hydrogen would be wasted in excessive amounts which would lead to trouble with resource management and balancing out the disproportionality in hydrogen production. To make the idea of hydrogen energy a reality, the infrastructure necessary to liquefy hydrogen and create hydrocarbons would need financial support to cover the costs and a plan on how to waste less hydrogen than necessary. The hydrogen market would have to separate itself from its association with natural gas and become an entirely green production on the global market, which requires global players that support the green hydrogen economy on a wider scale.

Another alternative for renewable energy is photovoltaics – light is converted into energy by solar cells which are implemented in solar modules. Through this technology, electrical power is generated for various establishments, may it be large company buildings or ordinary private homes. Tobias Steffen works as the authorized signatory of the public utilities Alsdorf and specializes in the construction of photovoltaics for a climate-neutral alternative to harmful energy sources like fuel and coal. He explains that setting up photovoltaics includes a set of regulations which you must abide by UVP ("Umweltverträglichkeitsprüfungen") in order to ensure a safe setup. This is done to take special environmental factors into consideration before constructing these solar panels, one of those factors instructing to not build where species of animals find their permanent home in nature. A long and complicated process, which Steffen describes as such, stating that the protocols for photovoltaic construction significantly slow down the progress of establishing photovoltaic panels as an energy generator on a grand scale. Because large-scale setups of solar panels must be approved by regulations, Steffen says that the panels are most profitable for private people and their properties, since the panels are easy to install wherever you want, may it be on your roof, mounted to the wall or on the ground of your property. The panels are a terrific way to save energy and money when it comes to paying electricity bills and are a great solution when it comes to single-individual goals. When solar panels are used for a larger area to save electricity, the area must be bought for photovoltaic use, which is a great financial investment before panel construction can begin. This makes photovoltaics a climate-neutral alternative that highly depends on finances and passing complicated regulations before it can become a reliant energy source. Photovoltaics also have major requirements for production, which make them non-sustainable until they produce enough energy to make up for the resources lost in production.

In the area of aerospace engineering, Kai Wieghardt from the DLR (Deutsches Zentrum für Luft- & Raumfahrt) has been questioned to talk about getting energy from sunlight. This technology is not equal to photovoltaics, because it catches sunlight directly and bundles it into warmth to turn it into electricity. The energy drawn from sunlight can also be used to split water into hydrogen and oxygen. The financing for this concept is promising, Wieghardt says, since the research is funded by the state and industrial interest is existent. A combination of funding by research and the state is the result. This makes the growing technology for this strongly dependent on money from the investors until it can stand on its own. Turning sunlight into energy will prove to be difficult during the winter as well, since the power of this technology would be reduced to 20-30%. Until the technology of turning sunlight into energy has its first concrete breakthrough, it remains a major work in progress.

Finally, two predictions have been stated by both Kai Wieghardt from the DLR and the mayor of Alsdorf, Alfred Sonders. Both have made solid predictions for how photovoltaics could be implemented in the future as a climate-neutral alternative. Kai Wieghardt is convinced that solar energy has exciting potential, stating that 90% of all renewable energy sources originate from solar energy. Alfred Sonders went into detail about photovoltaics and how certain photovoltaic technologies could be put into old buildings to heat them through solar energy. The ability to renew solar technologies and change certain mechanisms for upgraded ones is what gives photovoltaics a vision for the future. Kai Wieghardt states that if we could find a way to use more solar energy than what we are already receiving, we could end the energy crisis and provide every household with solar energy. For this, a lot of financial support is needed. Alfred Sonders talks about this in detail, explaining that the country and federal state calculate the budget for every commune. Over the years, plans have been made for how to use the money. 5 million Euros has been the budget for the past couple of years, which is not enough for the regional projects that require money. The financing for those is heavily reliant on investors, which makes progress on developing renewable energy as slow as it currently is. For photovoltaic technology to be used on a grand scale, Alfred Sonders says that companies depend upon individual contracts from every single user, which makes the process of generating electricity much harder. He goes into general challenges such as fire protection and if renewable energies can make a profit out of their use, declaring that it must be worth it or else too much money is lost. Sonders makes it clear that on a regional scale, the investment into renewable energy is one we must make happen on our own, since the state does not raise the budget on such projects. He stresses that for this technology to gain success, flexibility is necessary, and that financial dependency must be lessened so financing becomes less of a significant factor to include in developing new technologies. Sonders concludes that reaching climate-neutral goals until 2030 is unrealistic due to lack of incentives and structure necessary to cause a shift in our current society. The concrete development of renewable energies toward a proper result alone requires time until 2040. What plays into the developmental delay is that an overarching agreement amongst political parties has yet to be established so that a larger consensus about renewable energy is created and can be acted upon. Through this, the budgets across different commutes can be distributed in a way that would finance technological development better than it currently is. Alfred Sonders closes his stance by discussing how photovoltaic development must be coupled with hydrogen energy because photovoltaics cannot stand on their own. Compression of water must be an innovation as Dr. Stadtler also affirmed so that hydrogen can replace the energy density diesel provides.

All in all, the development of renewable energy to a degree that can replace our current sources of energy would make us need more time than the 2040 deadline we have set for ourselves. The main reasons for these extensive delays being the lack of financial support to help research on renewable energy stay steady. Technologies such as turning sunlight into thermal energy has yet to reach its breakthrough to be considered a valid alternative on a bigger scale, while promising technologies such as photovoltaics and hydrogen lack the conditions to work on the same scale as fuel and coal. Many of these must be developed properly to replace our current sources, which automatically includes the factor of money and how there is not enough of it due to lack of funding regarding research projects. Until funding can be equally distributed and a wider consensus on pushing the development of renewable energy can be reached, progress will remain low and dependence on polluting energies high.

CONCLUSION - A SOLUTION TO A GLOBAL CHALLENGE

The perfect mix of renewable energy sources for Germany is essential for the country to meet its energy needs and combat climate change. Solar, wind and hydro energy are two important sources of renewable energy that are particularly relevant to Germany and play a significant role in the country's energy mix.

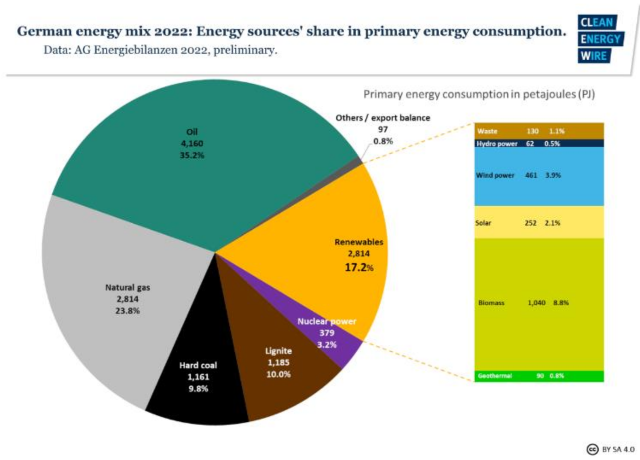

Fig 4 German energy mix 2022: Energy sources' share in primary energy consumption.[21]

Only 17,2% of Germany's primary energy consumption are renewable energies and only 3,9% of these are wind power, 2,1% are solar energy and 0,5% are hydro power

[21] *Germany's energy consumption and power mix in charts*. (2015, June 17). Clean Energy Wire. https://www.cleanenergywire.org/factsheets/germanys-energy-consumption-and-power-mix-charts

(see Fig 4). Based off this diagram alone you can tell that we need to improve fundings on renewable energies and significantly decrease our usage of fossil fuels.
Hierarchy and bureaucracy are monumental factors for deficits in our political system, such as a profit-oriented climate, in which parties turn against each other rather than pulling on one strand to combat our energy crisis. A political unity would stimulate Germany's lack of funding and innovative mindset to further enable research and systemic change in favor of our climate. Furthermore, the dependency on energy imports can cause tension especially in crisis. The imported energy should be sustainable.
Alfred Sonders proposes a plan consisting of an employment pool that focuses on the countries commutes to equally distribute funding.
Unfortunately, the climate goals Germany has set for itself cannot be accomplished. A higher reduction in emissions is needed, to achieve net zero by 2045. Drastic measures need to be taken. The resources necessary for innovation simply do not cover expenses needed for the energy transition. In addition to financial coverage, Governmental regulations complicate the process of installment.
The perfect mix of renewable energy sources for Germany would effectively utilize the strengths of both solar and hydro energy in combination with wind energy while mitigating their respective challenges. A combination of solar, wind and hydro energy can provide a reliable source of electricity that can meet the demands of the energy grid even during periods of low solar generation. By incorporating hydro energy into the mix, the intermittent issues associated with solar energy can be addressed, ensuring a stable and consistent energy supply.

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Col·legi Mare de Déu del Carme
Pares Carmelites

Energy of the future

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Abstract

It is often said that energy is important in our daily lives. Even so, most of us usually forget to preserve this basic necessity. Millions of people do not have access to electricity, and governments are investing money for the cause. But it is not as easy as it may seem. It needs a huge organization. So, what will the energy sources of the future be?

In order to answer this question we must understand the importance of energy in different fields. Our team will carry out experiments to confirm or disprove our hypothesis. Searching for new and revolutionary ways of mobility that are being created now will be vital to discover the real importance of energy. We will continue with the research of why today's means of transport are not sustainable and must change.

To conclude, our principal objective is not only to discover alternatives to energy waste but also to try to find solutions for our country's energy system.

Keywords

Green hydrogen, energy transition, pollution, photocatalysis

1. Introduction

In a constantly evolving and growing world, energy demand is also rising. However, in Spain, a critical energy situation has been found due to the dependence on non-renewable energy sources and the lack of a sustainable strategy to address this increasing demand. For this reason, it is crucial to look for innovative and sustainable solutions for future energy supply. So the question then arises, how could we improve this situation?

This is where green hydrogen plays an important role. In this project, we will explore in detail the applications, advantages and disadvantages of green hydrogen. We will analyze how green hydrogen can be a viable solution to the current poor energy situation in Spain, and how its use can help to improve independence and sustainability in energy production. In addition, we will examine the barriers and challenges that must be addressed to make green hydrogen a practical and accessible solution at a national level.

2. Energy situation in Spain

In order to understand the current situation and the changes that need to be made to increase energy savings, it is essential to know Spain's relationship with energy and the trend in energy consumption, as well as its possible adaptation and compliance with the objectives and commitments acquired with the different European directives. The degree of energy self-sufficiency in Spain is small, although it shows a positive trend due to the different development of energy plans. The building sector is the third largest consumer of energy. These data show the importance of energy saving in the residential construction sector, with two well differentiated paths, coordinated by different regulations, such as new construction and the rehabilitation of existing buildings. [1]

2.1. Energy production in Spain

In our country there is energy production, both renewable and non-renewable. In 2021, the amount of renewable energy produced was 121,371 GWh, which is 46.7% of the total energy produced in the country. In contrast, 138,534 GWh of non-renewable energy was produced, accounting for 53.3% of the total. [2]

2.2. Exports and imports

There is a relationship of energy imports and exports between our country and other countries in the world.

Spain exports 7,388 GWh to France, while the amount received from this country is 13,442 GWh.

In reference to Portugal, the amount exported is 8,673 GWh and 4,124 GWh are imported.

From Morocco, 182 GWh are imported and 298 GWh are exported.

Finally, 225 GWh are exported to Andorra.

All this demonstrates the existing cooperation between countries and Spain's energy dependence. [2]

2.3. Current situation

Historically, the scarcity of energy resources in Spain has characterized our country, mainly of fossil fuels. This means that our country has always been highly dependent on the outside world in this respect and, consequently, the energy situation in Spain is in deficit.

Spain is a country with an energy deficit, with great dependence on the outside world in this respect. In 2019, Spain's degree of energy dependence on the exterior stood at 75%, the highest record since 2011.

With one foot in fossil fuels and the other in renewables, our country faces many energy challenges in the near future if it is to meet the zero emissions target of the Paris Agreement.

Climate change and the resulting energy transition have accelerated in recent times and is a problem facing the oil and gas industry.

Knowing the risks facing energy companies is key to being able to manage them appropriately. The pandemic, for example, has had a major impact on energy demand, and hitherto secure energy markets, such as oil and gas, are now also faltering, forcing companies to innovate further.

Our country faces many energy challenges, in a context of growing uncertainty due to the crisis in the sector.

In a context of rising energy prices, the conflict in Ukraine contributed to further price increases due to limited supplies from producer countries.

Many countries were forced to improvise a change of energy strategy and Spain took advantage of its position with the boom in the renewable energy sector in Spain to try to control its electricity bill, although the challenge is whether this commitment to clean energy will enable it to achieve energy independence.

The generalized inflation affecting Spain and Europe also has its effects on the energy sector. The armed conflict in Ukraine, the energy dependence on Russian gas and the lack of renewable energies are influencing the rise in prices.

The big question is whether Spain can move from energy dependence to leading the renewables market.

Experts see renewable energies as the salvation plank and are betting on self-production to finally turn the tables and stop importing most of the energy we need in our country. Moreover, if Spain produces green energy, it could export it to other countries.

Indeed, Spain's big problem is that it only produces a quarter of the energy it needs to function.

The key will be to accelerate the transition of the energy sector in Spain to achieve a model based on renewable, clean, cheap and independent energy. Although the question is whether it will manage to do so in order to move from energy dependence to leading the renewables market. [3]

2.4. Hydrogen in Spain

Hydrogen production in Spain is approximately 500.000 tons per year. Most of this production is gray, but it is estimated that about 1% is green hydrogen produced from renewable energy sources, that is 5,000 tons. However, it is important to know that these numbers are steadily improving, and green hydrogen production is expected to increase significantly in the future. [4]

The Spanish government wants the country to produce 6,500 tons of green hydrogen per year by 2030 and 40,000 tons per year by 2040. In addition, they are working on the creation of a network of green hydrogen fueling points for transport vehicles and the implementation of hydrogen storage technologies in public and private buildings. [4]

Pilot projects are currently being developed in several areas, such as the production of green hydrogen through water electrolysis, the use of green hydrogen in goods and passenger transport, and improving the way hydrogen is stored in buildings and in the electricity network. [4]

Investment is being made to research and develop more efficient and cost-effective ways to produce green hydrogen and to improve hydrogen storage technology. [4]

In addition to the government's effort to produce green hydrogen, there are also many private companies interested in investing in projects to produce green hydrogen. Some Spanish companies have announced plans to build green hydrogen production plants, using technologies such as water electrolysis. [4]

In conclusion, the current hydrogen situation in Spain is of growth and development, with ambitious objectives and pilot projects in progress, and significant investment in research and development to improve production and storage technologies. [4]

3. Hydrogen

The universe is made up of 75% hydrogen, which makes this element the most abundant of all. However, it is never found alone, but together with other chemical elements such as oxygen, forming water; or carbon, forming organic components. [5]

Hydrogen cannot be obtained directly from nature in its pure state; it needs to be "manufactured". That is why the method used to obtain hydrogen is what determines if it is a clean and sustainable fuel or not. [5]

Green hydrogen is the one that has been obtained without generating polluting emissions, in other words, it is sustainable. It is a fuel that is considered key to achieving the decarbonization of the planet and achieving the 2050 objectives in the fight against climate change. [5]

But why is hydrogen so important?

There are several methods for producing hydrogen. The most popular today is molecular transformation, which consists of using a variety of chemical reactions to obtain hydrogen. High-temperature water vapor is used to separate the carbon from the hydrogen that makes up natural gas (CH4). However, this method is very polluting, since CO2 is released into the atmosphere and fossil fuels need to be extracted. This hydrogen is called gray hydrogen. [5]

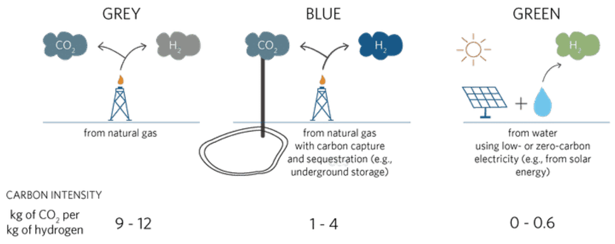

Figure 1: Different types of hydrogen. [6]

The most sustainable method is water electrolysis, which consists of breaking the water molecule (H2O) into oxygen and hydrogen with a continuous electric charge that is connected to the water by electrodes. This method, if it is done with green energy, does not generate any type of polluting emissions into the atmosphere and the green hydrogen is obtained. However, only 0.1% of the hydrogen produced annually is green, the rest is gray, which means that to generate 70 million tons of hydrogen annually, 830 million tons of carbon dioxide are released into the atmosphere. [5]

There are also other methods, such as photocatalysis, which consists of obtaining hydrogen from water through the use of catalysts and photoreactors. By using this technique, green hydrogen could be obtained thanks to sunlight, making it a good renewable energy option. [7, 8]

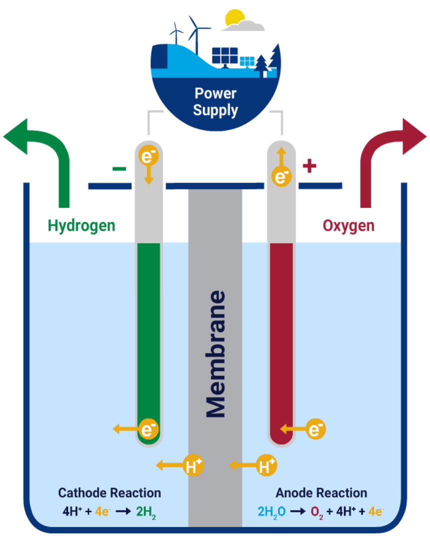

Figure 2: Water electrolysis. [9]

The hydrogen is collected in special tanks, and to convert the hydrogen into energy, it is first transported to a fuel battery, where it is combined again with oxygen from the air and electrical energy is obtained from this reaction. So, the only waste left by the process is water vapor. [5]

Table 1: Advantages and disadvantages of green hydrogen [4]

Advantages	**Disadvantages**
Clean energy: the only waste generated is water vapor.	Green hydrogen is significantly more expensive to produce than gray hydrogen.
Renewable energy: it uses resources that do not run out.	It needs a global investment of more than 300 billion dollars for infrastructure and research in the next few years.
It is easily stored: it can be kept in storage tanks for a long time.	As it is a very light gas, it can easily escape through joints and valves.
It is easy to transport as it is very light.	

3.1. Challenges and difficulties

Some expected challenges to overcome are that green Hydrogen is not yet part of the Spanish energy system due to lack of investment.

Another challenge expected to be overcome is that green hydrogen is currently more expensive to produce than grey hydrogen. However, the falling price of renewable energies has made their cost increasingly competitive: solar electricity is 10 times cheaper than it was a decade ago and wind energy is less than half the price, which means that the electricity needed for the electrolysis process can be reduced in price.

Some challenges can be overcome by investing in green hydrogen projects. Europe is already promoting initiatives such as the manufacture of electrolyzers, construction of a transport network or the installation of hydrogen plants for road transport. [10]

3.2. Current projects

Basque Hydrogen Corridor

The Basque Hydrogen Corridor project aims to produce up to 20,000 tonnes of green hydrogen per year. It has a planned investment of more than 1.3 billion euros, distributed in several phases. The first phase is the installation of a 2 MW hydrogen production plant to supply the Abanto Technology Park. The second plant will be operational by 2024 and will be located in the Port of

Bilbao. The plant will have a capacity of 10 MW and will be dedicated to the production of synthetic fuels. The last plant is planned for 2025 and will have a capacity of 100 MW. [10]

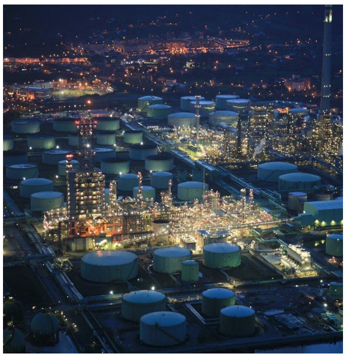

Figure 3: Basque Hydrogen Corridor. [10]

Hydrogen Valley of Catalonia

This initiative includes a project called Green Crane-Tarragona which has the objective of producing on a large scale (up to 50 tonnes per day) for industrial uses, as well as a plan to supply hydro generators (hydrogen pumps for vehicles), and a line of work destined for the injection of green hydrogen into the natural gas network. [10]

Hydrogen Valley of Aragon

The Ebro Hydrogen Corridor will promote actions in all areas, including production, transport, uses and storage.

It is planned as a connecting point between the country's renewable hydrogen infrastructures developed in the north of Spain, including those of the Basque Country and Catalonia. It includes plans for production, transport and storage, as well as an industrial infrastructure with the capacity to produce up to 400 MW of this green fuel by 2025. It also includes the construction of a prototype train powered by green hydrogen. [10]

Figure 4: Hydrogen Valley of Aragon. [10]

Hydrogen Cluster of Castilla-La Mancha

It is located at the National Hydrogen Centre, one of the most important research and storage centers in Spain, in Puertollano, in the province of Ciudad Real. One of the projects is a photoelectrocatalysis plant, a new technology that makes the electrolysis process easier by using solar energy. [10]

Figure 5: Hydrogen Cluster of Castilla La Mancha. [10]

Green Hydrogen Valley Platform of the Murcia Region

The hydrogen production and distribution projects for industrial uses include new canalisation and distribution systems.

The Escombreras valley in Cartagena has one of the country's main petrochemical plants, an industrial system that is expected to become a center of reference in the production of green hydrogen. The project aims to create plans to generate green hydrogen efficiently and economically. [10]

Figure 6: Green Hydrogen Valley Platform of the Murcia Region. [10]

Power to green hydrogen Mallorca

It is a project to generate green hydrogen from photovoltaic power located on the island of Mallorca (Spain). The plant will generate and distribute more than 300 tonnes of H_2 per year, which will serve as fuel for public and commercial bus fleets, and as an auxiliary fuel for ferries and port operations, avoiding the emission of 16,000 tonnes of CO_2 per year. [11]

3.3. Uses of green hydrogen

One of the main attractions of hydrogen is its versatility, as it can be used not only as an energy carrier, but also as a raw material. Let's take a look at some of the most promising applications of green hydrogen to contribute to the decarbonisation of the planet.

Heavy industry

Hydrogen is used as a feedstock in the chemical industry to produce ammonia and fertilizers, in the petrochemical industry for oil refining and in metallurgy to produce steel.

The use of hydrogen in these three industries produces a large amount of carbon dioxide emissions, for example, steel manufacturing accounts for 6-7% of global CO_2

emissions. We could use green hydrogen as a feedstock and produce emission-free steel, which would be a very important step to the urgent decarbonisation of these industries. [5]

Figure 7: Chemical industry. [5]

Energy storage

Green hydrogen can be used as an energy storage system due to its large volume and long lifetime in a similar way to how we now use strategic reserves of natural gas or oil. In this way, we could supply renewable hydrogen reserves to support the electricity network. [5]

Figure 8: Storage of Green Hydrogen in Tanks. [5]

Clean and renewable fuel

The use of green hydrogen as a fuel will be one of the keys to help decarbonise transport, especially long-distance and air transport.

In the maritime transport sector, where very cheap but highly polluting fuels have traditionally been used, green hydrogen is a crucial alternative for large ships travelling long distances. In aviation, green hydrogen can be the basis for synthetic fuels that radically reduce emissions in this sector. It will also be essential for other types of transport such as trains and trucks. [5]

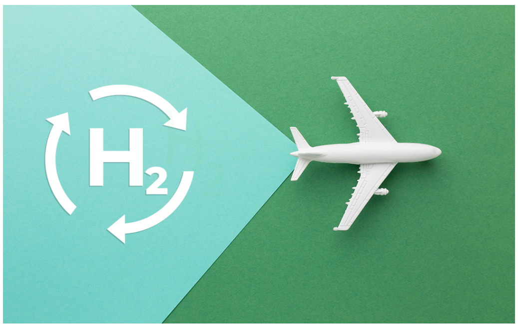

Figure 9: Green Hydrogen in Aviation. [12]

Domestic use

Green hydrogen is able to reach temperatures that are difficult to obtain with other clean processes. That is why its use in electricity and home heating is one of the most promising applications of green hydrogen. [5]

Figure 10: Green Hydrogen used in a House. [13]

Cars

A battery has an electric motor that is powered by electricity. This electricity is obtained from a plug socket. A hydrogen car has a similar motor and mechanics; the difference is that instead of a battery, it gets its electricity from a liquid hydrogen fuel cell. [5]

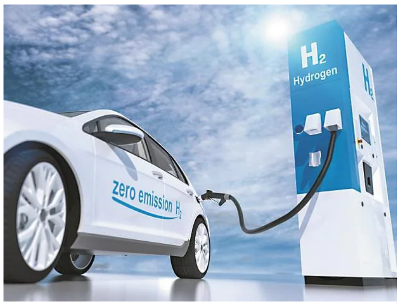

Figure 11: Green Hydrogen as a Fuel. [14]

Hydrogen Motor Function

The hydrogen stored in storage tanks supplies the fuel cell.

Oxygen is injected into the fuel cells that make up the fuel cell.

The reaction of the oxygen in the air and the hydrogen stored inside the cells generates electricity and water. The electricity produced powers the battery, which in turn powers the motor. The excess water vapour is expelled through the exhaust system.

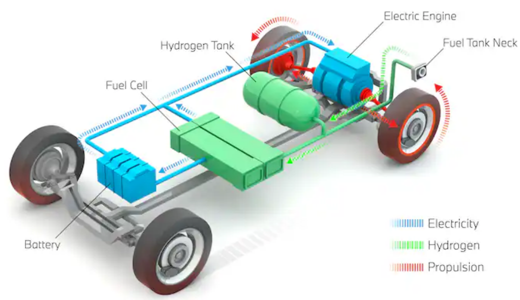

Figure 12: Hydrogen Fuel Cell Vehicle. [15]

The main advantage that manufacturers point out in fuel cell vehicles compared to electric vehicles is the time for a full recharge. Brands claim it is usually close to five minutes.

Refuelling the hydrogen tank is practically identical to refuelling with traditional fuels: it is done through a hose, which is sealed to the tank while the tank is being refuelled.

The autonomy of this type of vehicle is very similar compared to combustion vehicles. Hyundai's first generation of fuel cell vehicles had a range of almost 430 km, while this second generation, with the Nexo, has a range of close to 600 km. [16, 17]

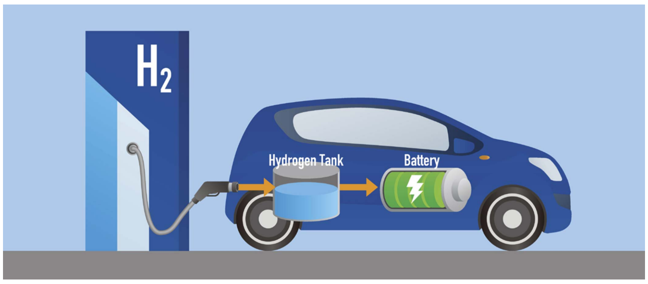

Figure 13: Refuelling a car with Green Hydrogen. [18]

Benefits and problems of hydrogen cars

These type of cars could be an alternative to electric cars, with the advantage that filling up with hydrogen can be as fast as filling up with petrol. But they also have disadvantages.

Table 2: Advantages and disadvantages of hydrogen cars. [17]

Advantages	**Disadvantages**
-They do not pollute in any part of the process (if the fuel is green hydrogen and is produced by renewable energy).	-There are almost no refuelling points
-Refuelling hydrogen cars is faster than refuelling a battery electric car (similar in time to filling the fuel tank).[	-The price of fuel is expensive
	There are few models on sale, and they are also very expensive cars.

4. Energy transition

The energy transition is a group of actions carried out to move from the current energy system based on fossil sources, with a high level of pollution and greenhouse gas emissions, to a model driven by renewable sources. With the energy transition, the decarbonization of the electrical system is intended.

The challenges that the energy transition pursues are:

- Reduce greenhouse gas emissions and global warming.
- Secure energy supply.
- Reduce energy consumption.
- Ensure the safety and health of the population.
- Promote electrical self-consumption. [19]

4.1. Objectives

At this moment, in Spain and a large part of the world, a process never seen before in the history of mankind is taking place. The high concentration of greenhouse gases has led the top leaders of most countries to take urgent measures to halt the advance of climate change. This set of measures falls under what is commonly referred to as the energy transition.

Over the last decades and centuries, human beings have been destroying the planet little by little. Now, we are beginning to feel the consequences of many years of pollution and a global production model based on fossil fuels.

The Paris Agreement signed in 2015 within the United Nations Framework Convention on Climate Change involved an unprecedented collaboration between 195 countries. Its objective is to reduce greenhouse gas emissions and curb global warming.

This agreement determines the immediate future of the global energy industry and sets the course of action for countries in the years to come. But it also sets out the trends in the energy sector between now and 2050, a period considered to be one of energy transition.

In Spain, in order to adhere to this change, the so-called 2030 Agenda for Sustainable Development was established, which is the Government's roadmap to ensure access to affordable, safe, sustainable and modern energy for all people.

However, the energy crisis unleashed above all as a result of the outbreak of war in Ukraine poses major challenges for all countries -including ours-, as the fulfillment of commitments becomes more complicated. [3]

5. Scientific investigation to hydrogen production

To do our experiment, we contacted the Polytechnic University of Catalonia (UPC). We met Lluís Soler, a researcher and professor who explained to us different ways of producing hydrogen, some polluting, some clean, and the scientific explanation of all of this. From this class we can extract the following information.

The research group in which Lluís participates aims to achieve the most efficient hydrogen production possible. To this end, they are working with photoreactors that make it possible to obtain hydrogen from water. A TiO2 photocatalyst with 1% gold is used. This Au is incorporated in the form of nanoparticles obtained by a process called ball milling through mechanochemistry. This mechanochemistry has gained interest among researchers as it is a greener process. [8]

H2 photogeneration was performed in a tubular glass photoreactor at atmospheric pressure. It was found that a loading of 2 mg of photocatalyst showed an optimal rate of hydrogen photoproduction, so, by means of ultrasound, this amount was mixed with ethanol and this mixture was poured as drops on a circular cellulose paper, to be subsequently dried at 50ºC for 1h. This cellulose paper was placed between the two parts of the glass photoreactor and properly sealed. An argon gas mixture containing a liquid mixture of H2O and ethanol, in a 9:1 water:ethanol vapor ratio, was circulated through the photoreactor.

Externally, the temperature of the photoreactor was controlled by a hot air blower, while monitoring the temperature of the photoreactor. In addition, the gas products produced during the reaction were monitored. [7]

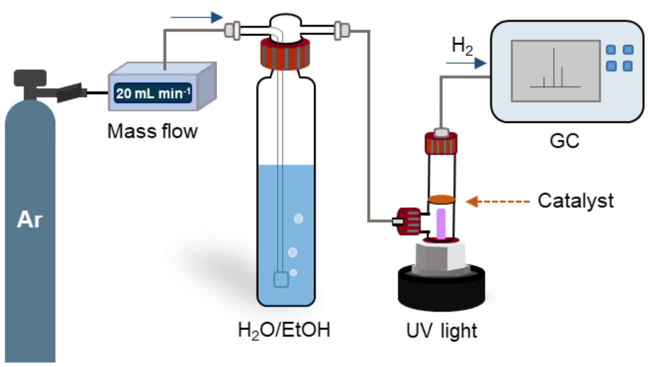

Figure 14: Photocatalytic reactor for hydrogen production [20]

The photoreactor was equipped with a UV light source and a UV-visible light source. Both light sources emitted at a certain wavelength and irradiances suitable for the experiment were obtained. The amount of photocatalyst used ensured an optimal use of the emitted photons. [7]

To check the effect of the different light sources, we performed a series of tests, obtaining varying hydrogen production values. The results can be seen in the graph (Fig. 15). We started the experiment by applying only UV light at a temperature of approximately 42ºC. As we lowered the temperature to about 37ºC, the hydrogen production decreased very slightly (left purple band). We then applied UV light and visible light, observing a considerable increase in hydrogen production up to 10 mmol/h-gcat (mmol/h normalized per gram of photocatalyst). At this point, the temperature increased due to the effect of visible light (yellow band). Subsequently, we returned to using only UV light, observing a decrease in hydrogen production and temperature to the initial values (second purple band). Later, we wanted to check how the hydrogen production varied with a significant increase in temperature, so heat was applied to the photoreactor using a hot air blower until it reached 51º. The hydrogen production was slightly increased by the effect of the applied heat (red band). Then, UV light irradiation was stopped, obtaining a drastic decrease in hydrogen production to a value of approximately 1 mmol/h-gcat (white band). Finally, the initial conditions of the experiment were resumed, obtaining stabilized temperature and H2 production values (last purple band). [7]

After performing this experiment, we can conclude that a proper experimental design is indispensable for optimal H2 production. The concentration of Au used must be controlled, since an excess can cause its accumulation on the TiO2 surface, decreasing the amount of H2 produced.

Furthermore, we can conclude that a suitable combination of Au and TiO2 leads to higher photoactivity under UV and visible light.

Conclusion

In conclusion, the energy market in Spain is facing many challenges, including high levels of dependence on external sources, limited self-sufficiency, and rising energy prices. The building and industrial sector are two of the largest consumers of energy and highlights the importance of energy saving in the residential construction sector. The key to meeting the zero emissions target of the Paris Agreement is to accelerate the transition of the energy sector to a model based on renewable, clean, cheap, and independent energy. Green hydrogen is considered a key element in achieving the decarbonization of the planet and combating climate change. However, green hydrogen is more expensive to produce than gray hydrogen and requires significant investment in green energy. Despite these challenges, the advantages of green hydrogen, such as clean energy, renewable energy, easy storage, and easy transportation, make it a worthwhile investment. In order to move from energy dependence to leading the renewables market, it is necessary to prioritize the production and use of green hydrogen in Spain.

Further research is crucial in order to reach a higher yield in H2 production in a sustainable way so that it can be used as a main energy source in the future. In this way, it will be possible to achieve an energy transition that will help to reduce polluting emissions.

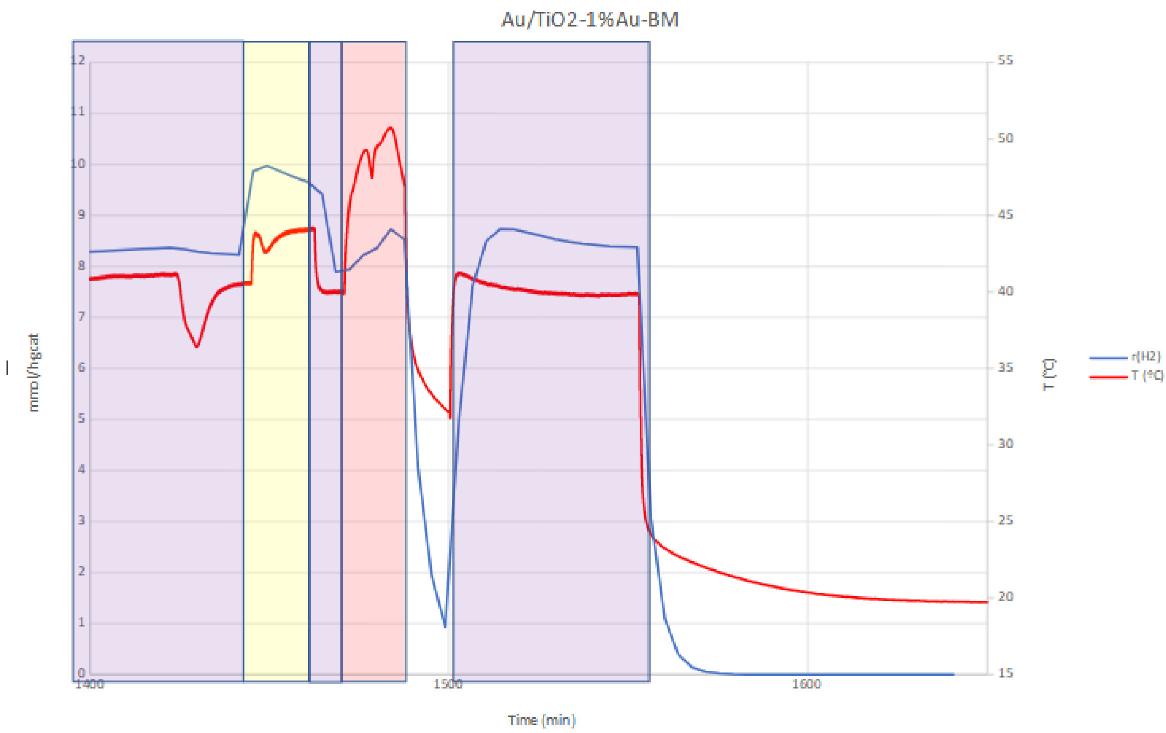

Figure 15: photocatalysis results (own elaboration).

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We would also like to thank our English teacher, Paul Tompkins, for his help with the language.

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Japan's Past, Present and Future: A Look into Japan's Power Systems and Possible Implementation of a Renewable Energy Mix and Decentralization

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Summary

In recent years, the Japanese government has been under heavy criticism from the international community in regards to its dependency on imported fossil fuels and coal. Though most agree that change needs to happen soon, numerous obstacles have prevented the country from a smooth transition to clean energy.

Our proposal is this: Japan should encourage an energy mix by phasing out nuclear energy while increasing its self-sufficiency in renewable energy through new ways of generation and distribution. Since this both encourages local development and decreases dependency on the major power plants, it is the most efficient way for Japan to achieve decarbonization.

To prove the plan's proficiency, we will provide case studies on past examples and calculations on the predicted future and analyze its effects from the aspects of energy security, environment, and economic sufficiency. With that information in hand, we will propose a hybrid system of decentralization and centralization aimed at increasing self-sufficiency, overall expediting Japan's decarbonization. This paper will attempt to prove how our policy will bring both short-term and long-term benefits to Japan regarding energy stability and sustainability. Furthermore, we think other countries could implement this policy in other countries, especially those with underdeveloped energy networks.

Keywords

Japan, energy mix, decentralization, micro hydropower

Introduction

Formerly a pioneer in energy efficiency, Japan has a complicated history with energy supply. Now a regular recipient of the "fossil award" at COP, the road to decarbonization looks darker than ever. In the world, the need for decarbonization is dire as global CO2 emissions reached an all-time high in 2022. Japan's relationship with energy is riddled with issues, such as lack of resources and nuclear energy. However, Japan must rethink their entire energy system to ensure a safe world for the future generation.

1. Japan's Status Quo

Japan is one of the biggest energy-consuming countries in the world, coming in fifth place behind China, the United States, India, and Russia. Japan currently consumes 943.70 billion kWh of electric energy per year with an average of 7,509 kWh of electricity consumed per capita [1].

The impacts of COVID-19 have shown an increase in household energy consumption, but a decrease in the business sector as production volume dwindled in almost all manufacturing industries. However, as the country found ways to recover from the pandemic, those numbers have been returning to pre-COVID levels [2].

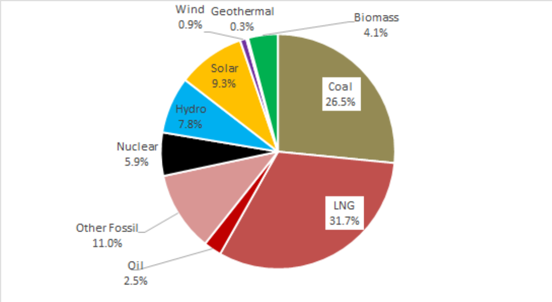

Figure 1: Source of power generation in Japan as preliminary data for 2021 [3]

Japan largely depends on imported fossil fuels such as oil, coal and liquefied natural gas. The natural environment of Japan allows renewable energy production, such as nuclear energy, solar, wind, and geothermal. However, the usage of such sources is still minimal compared to those of imported crude oils. As of 2020, 71.7% of Japan's energy sources were fossil fuels, with only 28.3% comprising either nuclear or renewable energy [3]. The table below shows Japan's imports of crude oil, liquified natural gas, liquefied petroleum gas, and coal.

Crude oil	LNG	LP gas	Coal	
			Coking	Thermal
Saudi Arabia 42.5%	Australia 37.2%	USA 67.0%	Australia 49.9%	Australia 66.3%
UAE 29.9%	Malaysia 13.7%	Australia 10.1%	Indonesia 21.0%	Russia 14.5%
Kuwait 8.6%	Russia 8.4%	Canada 9.7%	USA 10.2%	Indonesia 11.5%

Figure 2: Japan's imports on fossil fuels (self work; information taken from [4])

According to Yasunori Kikuchi, a professor in Tokyo University, one of the reasons why Japan continues to import carbon-based resources is its Japan's foreign policy. It is difficult to stop importing the resources because these trades help Japan make strong relationships with the importing countries. For example, importing large amounts of coal from Australia helps industries in Australia and builds the connection.

Liquid fuel accounts for about 40% of Japan's primary energy supply, and more than 80% of it comes from the politically unstable Middle East. Moreover, prospects for importing electricity from neighboring countries are abysmal with an island nation like Japan [5]. In addition, there is an urgent need for global warming countermeasures, such as reducing carbon dioxide emissions from energy use.

Japan's government has set up a policy of 3E+S (Energy Security, Economic Efficiency, Environment, Safety) when dealing with their energy problem. The idea is to develop an energy system that is stable, cheap, green, and safe [6]. Their current system meets one of these criteria (cost efficiency) but is critically lacking the other three.

To ensure Japan's stable electricity supply, it is crucial to establish an optimal combination of power sources that can concurrently deliver energy security, economic efficiency, and environmental conservation while placing top priority on safety.

2. Content

2.1. The scope of the investigation

Based on our research, we identified Japan's ideal state as being able to meet its energy demands by generating a mix of non-carbon-based sources within the nation. Japan's current self-sufficiency of energy stands at a meager 11.8% [7]. Low self-sufficiency in energy poses a severe threat to energy security. If Japan's supplying countries become involved in a political or environmental disaster, the supply route could be cut off, leading to an energy crisis. Japan is constantly exposed to environmental disasters compared to other countries, as seen in the East Japan earthquake. In fact, there is an estimated 70% chance of a magnitude-7 quake hitting Tokyo before 2050 [8]. Therefore, fortifying energy security is crucial to Japan's decarbonization. This poses a vital question: Is energy autonomy in Japan possible?

In this paper, we analyze how Japan can increase the production of non-carbon-based energy sources with a decentralized and centralized hybrid approach; it aims to raise self-sufficiency by 2050 through these methods.

Our plan can be divided into three layers: the past, current, and future. "Past" refers to nuclear energy – a source that formally held a significant presence within Japan's energy system. "Current" refers to renewable sources such as solar and hydro, both of which are currently gaining traction. "Future" refers to emerging energy policies (i.e., carbon tax) that are still underutilized in Japan.

The first major step in our plan is the strategic continuation of nuclear energy. It is crucial to note, the continuation of nuclear energy serves as the transitional step; it will suppress the carbon emissions while developments of other energy sources continue. In our plan, nuclear power generation will only be conducted with the existing plants which have passed or are awaiting approval for a restart. From an environmental standpoint, the generation, specifically the disposal of chemicals, is not easy to sustain. The construction of new nuclear power plants will not take place within our plan.

In addition, the limitation for a nuclear energy plant is decided as 40 years–with an additional 20 years if approved by the government. Based on our calculations, around 66% of the nuclear plants, both functioning and nonfunctioning, will reach their limit around 2050 [. Therefore, there will be a gradual discontinuation after 2050; during these years, there will be a growth in renewable energy supply.

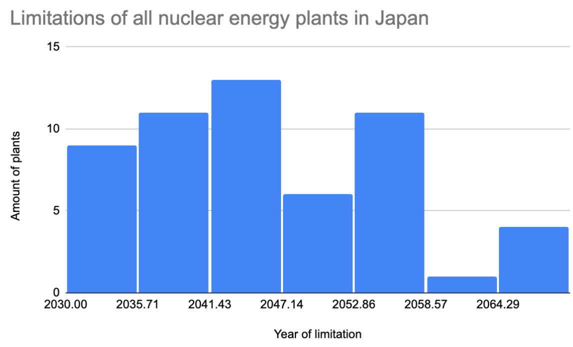

Figure 3: Limitations of all nuclear energy plants in Japan (self work; information taken from [9])

To transition back into the safe and proficient use of nuclear energy, Japan must go through layers of re-education of workers, careful reviews of facilities, and disaster manuals. In our plan, there will be no new constructions of nuclear energy plants; the main focus will be the sustainable utilization of the plants chosen through scrutinized investigations.

This leads us to the second layer of the plan: Present. Currently, Japan's main renewable energy sources are solar and hydro. Our plan focuses mainly on the development of these sources. As mentioned before, our plan is based on the balance between decentralization and centralization; therefore, the development of newer energy sources will also focus on the regional aspects. As a major example, we will focus on the implementation of micro hydropower systems throughout the country.

The last layer of the plan is the implementation of carbon tax. The Japanese government's stance has always been hesitant regarding this issue. However, in order to create an initiative for companies to opt for the use of renewable energy, such new measures are required. Therefore, our plan incorporates carbon tax as a way to secure compliance from companies.

2.2. Method of the investigation

To prove the feasibility of our plan, we investigated three main points: structure, resources, and cost. The structure of power generation and its distribution correlates with energy security, the resources tie up with the environmental aspect, and its cost is connected to the aspect of economic sufficiency.

For structure, we investigated the applicability of the decentralized and centralized hybrid system. At first, we carried out two interviews with experts to gain professional insight. In addition, we conducted individual research of past cases within Japan. With this information, we conducted a comparison of the pros and cons of each style.

Regarding our selection of energy sources, we looked into past implementations of three major renewable energy sources: solar, hydro, and wind. We dug deeper into the problems associated with current renewable energy sources – centralized solar power, large hydropower, and offshore wind power – and explained why micro hydro fit the 3E+S policy better.

To determine the probability of our plan's success, we calculated the progression of installation costs for solar and micro hydropower. In addition, we also calculated the capacity.

2.3. Results of investigation

In this paper, centralized energy systems are large-scale energy generation. Decentralized energy systems are defined as small-scale energy generation and distribution to the nearby region. This section will analyze and compare the two systems from the 3E aspects.

2.3.1. Centralized energy systems

The two major characteristics of centralized energy systems are the distance between the plants and the consumers and the immense energy production. Currently, Japan's energy distribution is characterized as centralized; the country relies heavily on fossil fuels that are used in large industrial plants. The pros and cons of centralized systems are as the below chart states.

	Cons	Pros
Environment	・Deforestation caused during construction of plants	・Increased generation of renewable energy
Economic sufficiency	・Electricity transmission loss ・Financial burden of grid construction	・Efficient power generation
Energy Security	・More people at risk in case of an outage	・Larger power generation capacity ・Generation of nuclear energy is possible

Table 1: Pros and cons of centralized systems

Based on Table 1, the current system imposes risks on all three aspects of 3E. The large amount of land needed for such plants are provided through the sacrifices of nature and wildlife. In addition, the long distance with the consumers causes significant loss of electricity that could have been fully utilized. Energy Security wise, the possible damage in a case of natural disaster or emergencies is critical as seen in past cases.

One notable example is the area-wide outage during the Hokkaido earthquake in 2018. Major coal-fired thermal power plants immediately shut down after the earthquake. To support the supply-demand, they tried to procure electricity from other regions but the limited capacity of the connecting lines proved to be a difficulty. Consequently, Hokkaido experienced a widespread power outage for several days, a prime example showcasing the vulnerability of centralization.

2.3.2. Decentralized energy systems

Compared to its counterpart, decentralized systems are still minor but after Japan's numerous encounters with power outages caused by natural disasters, more people look towards decentralization as the solution.

	Cons	Pros
Environment		・Easier integration of non carbon based sources
Economic sufficiency	・Lower efficiency of generation ・Construction of multiple plants	・Reduction in vulnerability to terrorism/social movements ・Less transmission loss
Energy Security	・Smaller power generation capacity	・Improved resilience ・Operating reserves ・Improves self sufficiency

Table 2: Pros and cons of decentralized systems

Based on Table 2, it is clear both systems have their flaws and benefits. From the Environment aspect, decentralized systems will mitigate the problems occuring in current Japan. However, the latter two sections indicate the impracticability of decentralized systems providing the entire energy demand in Japan.

To meet the current needs of Japan, the strategic utilization of both systems will become crucial. The next section will explore how energy sources can be applied to decentralization and centralization systems–in order to achieve the ideal energy mix.

2.3.3. Comparison to other energy sources

Centralized Solar Power

Although solar is the most common renewable energy source in Japan as of 2022, there are still major problems with it and its low compatibility with Japan's limited land means there is little room for improvement [10]. A survey found that 80% of the 47 prefectures in Japan have reported having issues with solar power plants and that they were worried about future problems that could arise [11]. Many of these prefectures have said the installation of mega solar plants in their areas has led to mudslides, damage to the landscape, and environmental destruction.

For example, the prefecture of Okayama is home to one of the biggest solar plants in Japan. However, the concentration of solar panels on the slopes made the once-beautiful Okayama mountains appear to be coated in black "sumi" ink [10].

Japan's mountainous terrain means many solar panels are built on rocks and hilly areas, which can be high-risk places for landslides [12]. Many organizations have reported that panels have to be replaced frequently in those areas since they are easily susceptible to damage. Furthermore, these solar panels' power generation efficiency has been declining at an average rate of 1.6% per year as a result of poor maintenance [13].

Moreover, entire forests must be cut down to make space for these mega solar plants. This increases the damage brought to people in the area when mudslides happen.

"My rice paddies were buried in sand and mud," a 62-year-old local farmer explained to the Mainichi Shimbun [11]. "Things like this didn't used to happen." Another farmer said, "Sand and mud have come flowing down and muddied the waters, and I'm worried about how it'll affect rice cultivation." Other problems like boars and other wildlife descending from the highlands have also been reported [11].

Centralized hydropower

Although Japan has a number of hydroelectric power plants, multiple problems arise if the government were to increase the number of these large power plants. Since micro-hydroelectric power plants minimize these issues, they are the better alternative.

Large hydroelectric power plants have huge detrimental effects on the environment. New roads and electricity cables are needed to build a dam, all of which damage the environment [13]. Since many of Japan's potential hydro areas are deep in the mountains, starting construction will require cutting down forests and destroying natural habitats. Furthermore, dams frequently generate reservoirs that flood enormous regions and displace natural ecosystems. When dams flood areas, they generate areas of stagnant water, which kills flora and emits greenhouse gasses as it rots [14].

Water quality is often lower as a direct result of hydroelectric plants. Dams restrict the flow of water, lowering oxygen levels behind the dam. When there is less oxygen in the water, some fish species have a harder time surviving, affecting river ecosystems. A hydropower plant's increased carbon dioxide and methane emissions can also impact various aquatic plant life [15]. Increased pollution from greenhouse gasses can cause plant life beneath the sea to decay, wreaking havoc on the surrounding ecology.

The construction of these power plants also force locals into relocation [16]. This drawback of hydroelectric electricity can have a significant impact on communities. People who have lived in the same place their whole lives may be forced to relocate, and while they are usually paid for their relocation, it cannot compensate for what they have lost. Dams have destroyed cities, towns, and villages, and local cultures have been uprooted. If residents refuse to relocate due to development, they are at times forcibly evicted from their homes. For example, then-Chinese Prime Minister Wen Jiabao revealed that China had relocated 22.9 million people to make way for water projects in 2007 [17].

Thus, even if Japan were to continue using hydropower, the country should restrain from creating more large power plants. Making more would use up unnecessary resources – money, energy, manpower and land; it is not worth it no matter how much energy we can produce.

Wind power

Recently, offshore wind power has seen a surge of popularity in Japan. Some offshore wind turbines have been built in seaside towns in south Japan, but looking at the data, we should not be diverting a vast portion of our budget onto it. There are two main reasons offshore wind power projects are not worth it: environmental damage and implementation difficulties.

The main concern with these offshore wind transmissions is their effect on the seafloor, fragile coastal environments, and other marine life. Offshore wind developments increase "noise levels, risk of collisions, changes to benthic and pelagic habitats, alterations to food webs, and pollution from increased vessel traffic or release of contaminants from seabed sediments [18]."

For these offshore wind turbines, cables are necessary to bring the energy created to land. However, there are numerous problems when companies try to procure these cables. According to Ralph Kurth, a senior principle of energy at Stantec [19],

> "Due to the significant increase in global demand for submarine cables, most of the world's cable manufacturers are currently operating at full capacity. This means that procuring and installing offshore submarine cable systems takes longer than it used to. The increase in demand may also lead to cable manufacturers being more selective of the projects they bid on. This can result in fewer competitive bids and higher associated costs."

Furthermore, according to research conducted by Japan Wind Energy Consulting (WINC), "Japan's complex and mountainous terrain, its deep coastal waters, and its earthquakes and typhoon winds will need to draw on expert local knowledge to make the most of its wind energy resources [20]." That means it will take years for the energy source to develop enough, and that it will take the limited scientific resources we currently have.

Result of comparison

In comparison to all of these energy sources, micro hydropower and household solar are much better for three core reasons.

First of all, they can be decentralized (unlike wind power) so governments and companies do not have to fund massive construction projects that will cause environmental and societal harms but instead can just build the necessary materials for households and communities to use.

Secondly, because it is going to be on a much smaller scale, we do not have to worry about environmental harms. Large solar power plants are harmful because they take up significant space. This problem would not exist with household solar systems. Similarly, hydropower harms surrounding lakes and rivers because it controls a large amount of water. If we use micro hydropower, this will not be an issue.

Finally, the technology and science behind micro hydro and household solar is relatively simple in comparison to large scale energy sources and do not require much more innovation and research to implement. This means that mainstream use of these energies can happen quickly, with usage prices decreasing as well (as explained later on).

Whilst it is important for Japan to find a sustainable energy source, it should not come at the expense of our citizens and precious wildlife. Instead of trying to improve something already difficult to implement, we should shift our perspective.

2.3.4. Cost of installation

One of the problems with micro hydro energy is its installation cost. Generally speaking, the smaller a power plant is, the more expensive it is. However, the construction of micro hydropower systems is cheaper than usual hydropower energy because it utilizes water streams and requires no extra dam or reservoir to store water [21]. For example, in Japan, micro hydropower plants have been built next to agricultural water channels and generate energy from the run through the channels. To confirm its low prices, we calculated the predicted costs of micro hydropower systems both now and in the future.

First of all, we roughly calculated the installation cost. The installation cost per kW ranged from 1 million yen to 3 million yen in Japan [22]. We supposed the installation cost was 2 million yen and estimated other ratios based on this.

Although micro hydropower energy is relatively expensive, the cost usually decreases as more products are sold. Japan began to build many solar power plants and the cost (yen/kW) went down dramatically. Fig. 4 shows the decreased costs of solar power plants between 2008 and 2021.

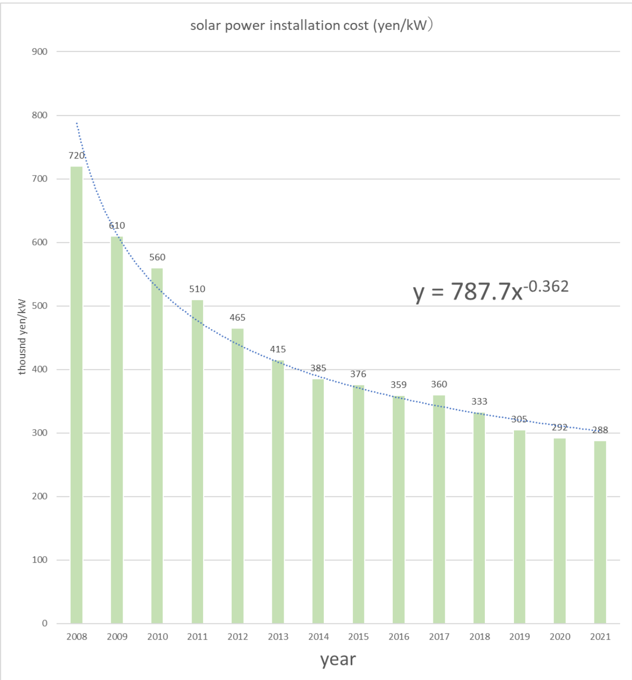

Figure 4: Drop in the cost of solar power installation in Japan (self work; information taken from [23, 24])

The function below is its approximate curve:

$$y = 787.7 \times x^{-0.362} \quad (1)$$

Since both 10 kW solar power plants and micro hydropower plants are small-scale and have low usage costs, we can say there will be a similar drop in costs as micro hydropower becomes more common. We deliberately selected data collected from 2008, so the chart would reflect the cost progression before and after the subsidization of solar energy in 2009.

With this information, we can roughly estimate the cost of micro hydropower in 2050. The function starts from 2 million yen/kW in 2023, and can be expressed in the form below.

$$y = 2099.6 \times x^{-0.362} \quad (2)$$

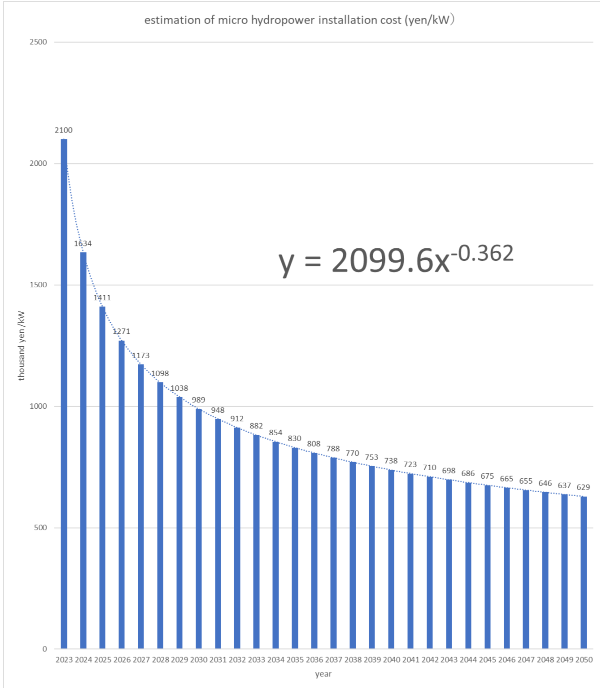

Figure 5: An estimated drop in the cost of micro hydropower [25]

The cost is predicted to decline to 629,000 yen/kW in 2050 (Fig. 5). Therefore, companies and local governments will face less expenditures in starting micro hydropower plants.

Moreover, we estimated the yearly benefit of selling energy. The Japanese government already introduced the FIT system, where the government guarantees that generated energy is sold to energy companies at a fixed price [26]. Micro hydropower is classified as hydropower with less than 200kW capacity, so micro hydropower companies earn 34 yen/kWh. Plus, the efficiency of energy production is necessary, and it is usually high at around 0.7 because the power plants never stopped energy production unless the run of water stopped [27]. The efficiency is a ratio calculated like this:

$$\text{Efficiency} = \text{Total Energy Production(kWh)} \div (\text{Installed Capacity(kW)} \times 24(\text{hour}) \times 365(\text{day})) \quad (3)$$

Considering these, the benefit which a micro hydropower plant with 50kW makes in a year would be;

$$34\ (\text{yen/kWh}) \times 50\ (\text{kW}) \times 24\ (\text{hours}) \times 365\ (\text{days}) \times 0.6\ (\text{kWh/kW} * \text{hour}) = 10.4\ \text{million/ year}\ (10{,}424{,}400) \quad (4)$$

Moreover, we can estimate the total installed capacity of domestic micro hydropower plants. Our goal is to achieve producing 30% of domestic electricity through micro hydropower plants by 2050. Since Japan consumes 86 billion kWh of electricity in a year, by 2050, the total installed capacity would be [28]:

$$(86\ \text{billion (kWh)} \times 0.30) \div (0.7\ (\text{efficiency}) \times 24\ (\text{hours}) \times 365\ (\text{days})) = 42.1\ \text{million kW}\ (42.0743639922\ \text{million}) \quad (5)$$

The current installed capacity of hydropower is about 22.7 million kW, so the amount of capacity we need to introduce by 2050 would be 19.6 million kW [29]. Supposing the same capacity of micro hydropower will be built in each year, the new power plants will have, in total, the capacity of 0.65 million kW.

As we mentioned above, the major problem is its cost, more specifically, its cost in the first several years after introducing micro hydropower. To overcome this challenge, the cost needs to be low enough to be attractive to companies or municipalities compared to other types of power. The solution we suggest is that the Japanese government subsidize the introduction of micro hydropower energy by companies and municipalities. This money comes from 30% of the budget of 827 billion yen in the economy, trade, and industry department brought for energy segments, which would be equivalent to 248 billion yen [30]. The average of money we can spend on building a 1 kW power plant is:

$$248 \text{ billion (yen)} \div 0.65 \text{ million (kW)} = 381 \text{ thousand (yen/kW)} \quad (6)$$

However, it will be more effective to invest them more than this average in the first decade and less in later years. Therefore, we think the Japanese government should subsidize 1/2 of the installation cost in 2023 to 2032, and subsidize 1/3 of that in 2033 to 2050. For example, in 2023, new owners of micro hydropower plants will invest 1050 thousand yen/kW while receiving subsidies as much as 1050 thousand yen/kW. This will be a huge incentive for those who are thinking about investing in energy and will lead to an increase in the domestic capacity of micro hydropower.

Therefore, it is very feasible to introduce micro hydropower and produce 30% of electricity in Japan in 2050.

2.4. Anticipated Challenges

2.4.1.Politics regarding nuclear energy

Despite nuclear power's undeniable benefits regarding self sufficiency, the reality in Japan is complex. Nuclear power generation in Japan started around the mid 1950s, becoming a major focus of national energy policy. After disaster struck during the 2011 earthquake, public opinion and national policy concerning nuclear energy took a drastic turn. Over 10 years since that accident, nuclear energy supplies 6.4% of Japan's total energy supply–a noticeable decrease from the 25% in 2015 [4].

Recent decisions made by the government about nuclear energy policies have took a massive turn. Most recently, the Cabinet agreed to allow plants to operate longer than the 60 years limit if they are granted the rights [31]. This announcement followed official reports stating the government planned on constructions of new nuclear power plants. For years, the government had made it clear they would not build more plants. The sudden change in government policy has caused disturbance within the general public. Around 37% oppose the change in the limitations; many raising the "lack of explanation" as a source of frustration [32].

In reality, the electricity companies are positively working towards the restart of nuclear power plants. For instance, TEPCO is taking action to restart the operation of the Kashiwazaki plant in Niigata prefecture. Despite their efforts to inform the public, Greenpeace reports that 70% of the residents are unaware of such policies and efforts [33].

These numbers indicate the main issues in the status quo as lack of communication and discourse. Therefore, our plan does not include drastic measures such as extensions of limitations. This point differentiates our stance with the current governments.

The benefits of nuclear energy run include the supply stability and efficiency, self-sufficiency, low operating costs, less susceptibility to fuel price fluctuations and zero CO2 emissions. In addition, the job opportunities created by nuclear energy plants is an undeniable benefit for the local community.

To alleviate this issue, we will utilize outlets such as social media, television and education to promote this entire plan for decarbonization. The government is not the only player in this situation. Companies, organizations, workers at the plants, experts, educational institutions, and the average consumer all have a duty and role in this matter. Companies and NPOs will be encouraged to create places for discourse, open and understandable to the public.

2.4.2. Compliance of corporations

For our plan to work, it is crucial that corporations take the initiative to transition into more renewable energy sources. We say this is likely for three reasons.

Social responsibility

A lot of companies now have to take up social responsibilities as more consumers become aware of current issues like climate change. The advancement of social media has led to more power to the public, who now can have companies losing massive profit through a single tweet.

Companies are profit-incentivized, and it is absolutely in their best interest to keep their consumer base happy. According to a 2019 survey, 70% of consumers want to know how the brands they support are addressing social and environmental issues, and 46% pay close attention to their efforts before purchasing [34]. This has created a trend of companies proving their social awareness as a marketing strategy and actually doing good to the environment to keep up with their competitors. All ten of Japan's electric companies have worked on renewable energy projects for years, and continue to do so as Japan's need for a stable clean source grows larger.

Carbon taxes

Although the Japanese government is delaying renewing its carbon tax due to economic instability, it is crucial that we continue efforts to deter companies from emitting CO2 through taxes.

Japan does currently have a carbon tax; it is small and does little to change the problem. The government is hesitant to do more for fear that industries "don't want to shoulder a heavier financial burden [35]". However, the overall costs are more preferable in contrast to other methods. According to an OECD study, for example, the average cost of reducing one ton of carbon emissions in the road transport sector can be up to eight times higher when methods other than fuel taxes are used [36].

The study also said that "countries could achieve higher levels of emission reductions at lower cost if they used smarter, market-based policy instruments [36]." Japan must review its carbon tax policies and strike down harder on such issues. Enforcing a carbon tax will encourage more companies to use cleaner energy sources, and even if they don't, the money from these taxes can be used to increase the government budget for renewable energy projects. Either way, the system works.

Expenses

As explained earlier, renewable energy has become easier to develop and use whilst in contrast, gas prices continue to rise steadily.

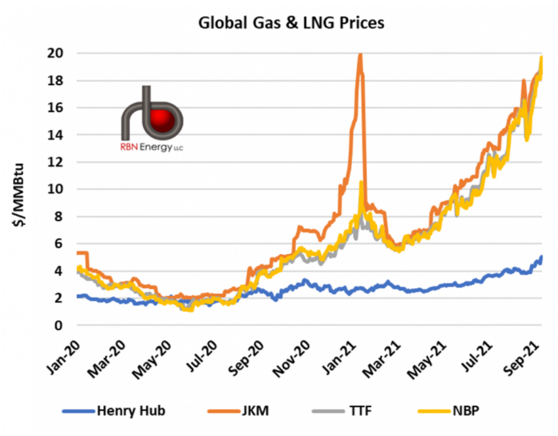

Figure 6: Global Gas and LNG Prices [37]

Dr. Rupert Way, a postdoctoral researcher at the Institute for New Economic Thinking and at the Smith School of Enterprise and the Environment, had this to say [38]:

> "Past models predicting high costs for transitioning to zero carbon energy have deterred companies from investing and made governments nervous about setting policies that will accelerate the energy transition and cut reliance on fossil fuels. 'But clean energy costs have fallen sharply over the last decade, much faster than those models expected."

If we continue with the analysis that the main purpose of companies is to make as much profit as possible, then it is very likely that more of them will start converting to cleaner energy sources, not only because it is more socially responsible for them, but because it is more cost-reductive.

3. Global implications

If our plan succeeds, there are two possible impacts: more aid to foreign countries via Japanese micro hydropower companies, and improved energy security through decentralization.

With more Japanese companies working in micro hydropower, such technology could expand into other countries. During this expansion, local businesses and workers will gain technological experience. This could spike motivation and incentive, while invigorating the local workforce. As some countries in Asia and Japan have similar topography, the introduction of micro hydropower will be an easy feat. Through this, the companies will create employment opportunities, thus invigorating the economy.

The over-reliance on centralized energy systems is a universal issue. Countries with underdeveloped grids in rural areas are generally in danger of power outages. If decentralization is introduced in such nations, it would greatly improve their energy security. Japanese corporations such as Mitsui & Co. are already investing in decentralized solar energy in rural parts of India [39]. An increase in such endeavors would improve and fortify energy security in other nations.

Therefore, the transition in Japan will have an impact on other countries in economic, technological, and sociological ways.

4. Conclusion

Our research illustrates the current situation in Japan and the implementation of new ideas such as micro-hydro and carbon tax. Our plan has clear potential to expedite Japan's decarbonization achieving 3E+S at the same time.

We live in an age where every little aspect of our lives is fueled by energy. If this pillar collapses, what is left for us? As environmental disasters struck our world daily, the government cannot sit around, ignoring the pleas for help.

In spite of urgent demand for decarbonization, switching to renewable energy must be a gradual and sustainable process. During the transition, the energy system will affect various aspects of society. Thus, companies and their employees will have to adjust to the new norm. This plan would be one of the core policies of the Japanese government, and therefore they must not leave anyone behind and listen to public opinions to improve the energy system in a sustainable way. 2050 is just around the corner; Japan must act now.

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Hydropower and Floating Solar Panels: What Water Can Offer to Japan's Energy System

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Summary

The team conducted extensive research centering around reading papers and contacting experts in the field of renewable energy. We concluded that a conversion to consumption of energy via hydroelectric power generation and floating solar panels from the current situation – heavy reliance on thermal power– would be best for Japan. The team identified impacts on biodiversity, water rights, and financial barriers as possible obstacles to the transition proposal, but came up with ways to overcome these obstacles. Through further investigation, we identified that the impacts of Japan's transition in its energy system to a more eco-friendly one will have impacts extending to the world, such as changes in political power and international trade regarding fossil fuels. Moreover, other countries will look to Japan as a leading country in clean energy, especially in the use of solar power, meaning that Japan would be able to offer aid to countries in need.

Methods of Investigation

Our investigation consisted of both group work and individual tasks. In the first few weeks of our research, the three team members each looked into Japan's current state of energy consumption, current problems the country faces, trade relationships in the energy sector, and potential conversion methods suitable for Japan. In the second phase, the team dug deeper into each renewable energy source and their merits and demerits to decide which methods we would focus on in creating our proposal. In the third phase, the team conducted further research into hydro-electric power, the main method in our proposal. Throughout the whole period, the team held weekly meetings on Tuesday for an hour, and spent additional time researching and discussing together during long breaks. We also contacted several experts from the energy generation industry.

Keywords

renewable energy, hydropower, floating solar panels, micro-hydroelectric power generation

Introduction to Japan's Energy System

Since its rapid economic development in the late 1900s, Japan's various activities have needed more and more energy. Whether that be for transportation, households, or for industrial use, Japan's current total energy consumption has increased to nearly eight times the amount consumed in 1960[1]. Japan's industrialization period (1950-1975) plays a significant role in this, with more energy being produced as well as being consumed. Furthermore, production for the population has created millions of new job opportunities, boosting the country's economy. However, the growth of energy consumption has led to negative impacts on Japanese society as well. First and foremost is the effect on the environment[2]. This is due largely to the increase in fossil fuel usage — with the renewable energy industry seeing little to no development — that has caused significant damage to the ecosystem[2].

Available Sources

Thermal power

Generation of electricity through thermal power is a process in which fossil fuel, namely liquid natural gas (LNG), coal, and petroleum, is burned to produce energy. Thermal energy has become key in Japan's energy production industry. This is concerning because Japan is very reliant on imports for its energy production and every form of thermal power leads to mass emissions of carbon dioxide. Relying on imports makes Japan susceptible to being swayed by environmental and political instabilities, as was shown through the Oil Crisis of the 1970s[3].

Hydropower

The next most consumed type of electricity is hydropower, which, despite Japan's abundant water sources and fast-flowing rivers constituting an ideal environment, has seen little increase in production over the past 60 years[Figure 1].

Other Sources

Other sources include solar power, wind power, and nuclear power. Although the first two are yet to be mass produced, both are crucial in achieving a carbon-neutral energy industry. In regards to nuclear power, Japan has become extremely hesitant about its use in recent years, which will be explained in further detail in the "Stigma Against Nuclear Energy" section.

Current Consumption of resources

As of 2019, Japan's total energy consumption per year has reached 1024.7 billion kWh[4, Figure 1]. Although annual consumption has recently declined from citizens' growing concerns about the environment, it is still many times the amount consumed 50 years ago. The dominant source within that is thermal power. A combination of fossil fuel (6.8%), liquid natural gas (37.1%), and coal (31.8%), energy supplied from thermal power amounts to 75.7% of the total energy consumption. Apart from that, hydropower comprises 7.8% – a number that has remained the same for the past 60 years – followed by nuclear power (6.2%) and other minor sources such as solar and wind power (10.1%).

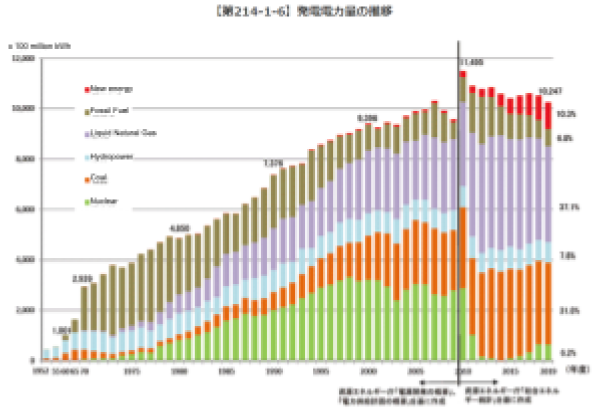

Figure 1: Transition of Power Generation [4]

Imports and Exports of Energy Sources

Japan, while it relies heavily on thermal energy, has few domestic sources of fossil fuels, meaning that Japan relies heavily on imports to supply power plants with the resources that they need. Its dependence on imports for fossil fuels in 2018 for crude oil, coal, and LNG were 99.7%, 99.3%, and 97.5% respectively.

Crude Oil

Japan imported approximately 1.1 billion barrels of crude oil in 2018, with 87.4% coming from the Middle East (38.6% from Saudi Arabia, 25.4% from United Arab Emirates(UAE), 7.9% from Qatar), 4.8% coming from Russia, and 2.8% coming from North and Central America (1.7% from the United States of America(USA) and 1.1% from Mexico). [5, Figure 2] gives a detailed description of Japan's fossil fuel imports from other countries.

Coal

Japan imported approximately 1113.67 million tons of coal in 2018, 84% from Asia Oceania (71.5% from Australia, 11.8% from Indonesia, 0.7% from China), 10.8% from Russia, and 4.5% from North and Central America (2.8% from USA, 1.7% from Canada).

LNG

Japan imported approximately 82.85 million tons of LNG in 2018, with 63.2% from Asia-Oceania (34.6% from Australia, 13.6% from Malaysia, 6.2% from Indonesia), 15.7% from the Middle East (12.0% from Qatar, 6.0% from UAE) and 8.1% from Russia.
Japan does not have the capacity to export resources to other countries, and its net import is 136 billion USD in 2018, which is the largest out of the G7 countries[6].

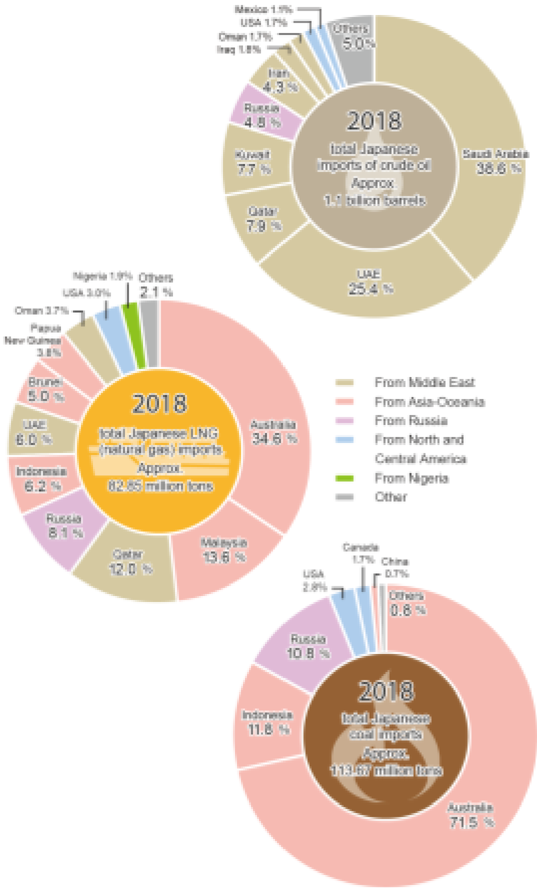

Figure 2: Japan's fossil fuel imports from different countries [5]

Problems in the Status Quo

Japan's Low Energy Self-sufficiency

Japan's energy self-sufficiency is a mere 9.6% as of 2020[7], which ranks 24th out of 26 Asian countries, and this low rate was exacerbated in 2011, when the 2011 Tohoku Earthquake caused a massive Tsunami to hit The North-Eastern parts of Japan. It destroyed the Fukushima Daiichi nuclear power plant, which had been in charge of a considerable portion of Japan's energy consumption[8]. The lingering effects of the accident has led the Japanese government to become reluctant to use nuclear power, severely cutting back on production.

Stigma Against Nuclear Energy

Compared to other methods, nuclear energy is widely known to be more eco-friendly as it generates power through fission, a process of splitting uranium atoms, uses up less land than other clean energy sources, and produces minimal waste[9]. The World Nuclear Association reports that "Nuclear power plants produce no greenhouse gas emissions during operation," and that it produces "about the same amount of carbon dioxide-equivalent emissions per unit of electricity as wind" over the course of its life-cycle. [10]
However, with the trauma and destruction of the environment caused by nuclear material from the Great East Japan Earthquake, a significant percentage of the Japanese population associates nuclear energy with negative connotations, with 68.3% and 44.6% feeling that it is dangerous and insecure respectively[11].

Target for 2030

The Sustainable Development Goals[12], a universal call to action adopted by the United Nations in 2015 focuses on a sustainable development of the world, including energy, having "Affordable and Clean Energy" as its seventh goal. Moreover, the Paris Agreement, a legally binding international treaty on climate change, aims to limit global warming to 1.5 degrees Celsius compared to pre-industrial levels[13]. Japan, as a member of the United Nations and having ratified the Paris Agreement, should convert its energy system to be in line with the UN and the Paris Agreement, therefore having 2030 as a checkpoint.

Background of Proposal

Hydropower

Japan has traditionally been a country rich in water sources. Its landscape is characterized by rapid rivers[14], and they flow at a much higher speed than other countries' rivers, as shown in the [figure 3].

Moreover, Japan's average annual precipitation is 1700mm, while the world's average annual precipitation is 880mm, which means that Japan's precipitation is almost twice as much as the world's, enabling Japan to conduct activities that require an abundance of water.

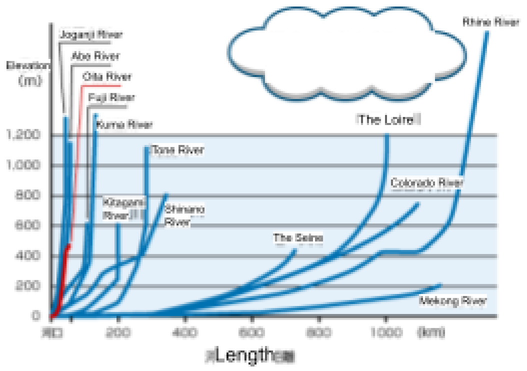

Figure 3: Distance and elevation from the mouths of major rivers in the world [15]

Because the amount of energy generated by hydro-electric power generation correlates with the amount of water and height difference, Japan's weather and terrain conditions make the country fit to utilize hydro-electricity as a major source of energy generation in its conversion from fossil fuels to renewable energy.

However, the percentage hydropower holds within Japan's annual energy consumption has not changed in 60 years[4] – a sign that it has not been fully utilized. Our plan maximizes the potential hydropower holds, giving the country a significant boost in energy generation.

Solar Energy

Because Japan's rivers tend to be short, the country has historically struggled to maintain a constant supply of water. This has led to the creation of reservoirs, with Japan having over 150,000 of them as of now[16]. The main usage has historically been for agriculture[17], and the team looked at this as an opportunity to further install solar panels onto the surface of the water. Japan currently ranks No.1 in the amount of energy generated by floating solar panels, and our plan further develops this capacity[18].

Energy Transition Proposal Overview

The team proposes an energy production and consumption system that uses hydropower and floating solar panels. Among the various types of hydropower generation, our team decided to focus on micro hydropower – a system involving hydropower stations with a maximum output of 1000kW[19]. This will mitigate the environmental impacts that building a dam and using heavy machinery would have, enabling the government/operators to take full advantage of Japan's water sources. Regarding the use of solar power, the proposal will specifically focus on the further installation of floating solar panels.

Micro-Hydroelectric Power Generation

The system uses smaller rivers and waterways to generate energy [20]. Turbines and converters are stationed alongside these rivers, so that the momentum of the flowing water automatically spins the propellers, producing electricity. There are four main structures that can be applied [figure 4, 20]: agricultural lands, water channels, dams/embankments, and sewers.

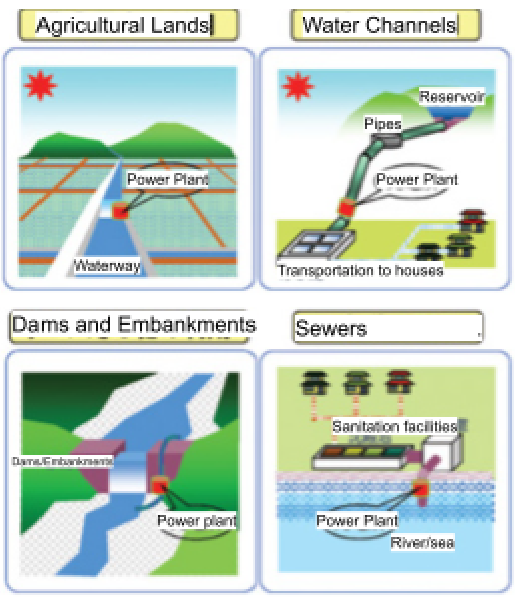

Figure 4: four main structures that can be applied[20]

Agricultural lands

The majority of Japanese agricultural fields have rows of trenches in order to provide water to vegetation. Power plants can be stationed within these waterways, and produce energy from the flow of water.

Water Channels

This makes use of the pipes that transport drinking water from rivers/lakes to reservoirs. Since the water has to be transported regardless, we should take advantage of this as much as possible.

Dams and Embankments

Although constructing dams for the sole purpose of generating electricity has impacts on the environment, Japan can make use of the dams and embankments that are already existing for different purposes.

Sewers

The fourth is sewers. This is a field that has not been looked into due to the hesitation of using unsanitary water sources. However, it is possible to station power plants after the water goes through filtration.

Review

Although this seems insignificant in comparison to large systems such as dams, research shows that each structure will be able to provide electricity to roughly 3000 homes[19]. There are roughly 20,000 possible locations in our plan, meaning that our plan will hold enormous potential. Especially considering that the various environmental issues will be mitigated by using micro-hydropower as well, it is the best form of energy production available for Japan today.

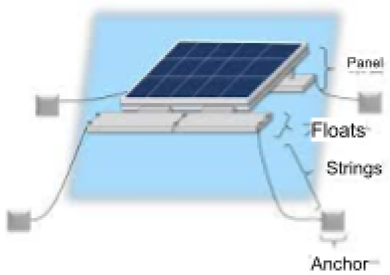

Figure 5: Structure of floating solar panels [21]

Floating Solar Panels

Floating solar panels are starting to be widely recognized as one form of eco-friendly energy production. Especially in the case of Japan, where limited land has been restricting the solar panel industry from achieving much, the introduction of solar panels on water will be an enormous boost.

Our plan consists of solar panels being attached to plastic structures called Floats, and being set on the surfaces of lakes and reservoirs. These Floats are held in place by strings attached to them from the outside[21, figure 5]. Since this field is still in the midst of research and development, we do not have specific numbers for our plan. However, it holds enormous potential.

Apart from the sheer amount of electricity it will enable Japan to produce, there are a number of other benefits floating solar panels bring to the table.

Simulation

For micro-hydropower, the team conducted a brief simulation using data provided by the Japanese Energy Ministry[22]. Although the definition of micro-hydropower differs according to institutions/researchers, our team concluded that the definition of micro-hydropower should be hydropower under 1000kWh.

We identified 20,848 possible new locations that could host micro-hydropower plants in the country, such as which all have the potential capacity of under 30,000 kWh, and the maximum installation cost of 2.6 million yen per kW. This means that approximately 80 billion kWh more electricity will be produced in one year.

Benefits

Power generation

Regarding floating solar panels, research has shown that the cooling effects brought on by the water increases productivity by 14%[23]. This means that floating solar panels will boost energy production. Taking into consideration the amount demonstrated in our simulation, we predict that our plan will enable the micro-hydropower industry to produce roughly 10% of Japan's electricity. With Japan's annual energy consumption amounting to 864 billion kWh[24], this will amount to a considerable amount of electricity. This is an immense improvement compared to the status quo, where production only amounts to 1.7%.

Environment

Our plan benefits the reservoirs and its owners themselves as well. By stationing floats on top of the water, it physically decreases evaporation – something that will be welcomed, considering how reservoirs are meant to store water for human use. Furthermore, the panels will block sunlight, preventing the growth of various algae and bacteria inside the water. Having these floating panels protecting the water will prove to be highly beneficial. Last but not least, owners will be able to charge companies who wish to utilize the space, giving them an extra opportunity to gain income.

Economy

The plan will provide financial benefits to the Japanese government. Assuming that the Japanese government provides financial aid that fully covers the expenses for installation, a maximum amount of 50 billion yen will be needed (20,848 locations x 2.6 million yen). In the meantime, Japan will be able to significantly cut down on imports from other countries, giving the government more than enough financial margin to pay for the expenses. Our specific calculations goes as follows:

In 2018, hydropower amounts for 3.5% of the total energy consumption. This means that an increase to 10%, as stated above, will allow the government to cut down 6.5 points from other sources.

On the other hand, imported fossil fuel amounts for 87% of the total energy consumption. In the case where they will be subject to most of the cutbacks, which will likely be the case considering recent global trends, a decrease in 6.5 points will mean that 7% (6.5/87%) of Imports can be cut. Japan's imports amount to 18 trillion yen as of 2021[6], creating 1.26 trillion yen (18T x 0.07) worth of margins for the government. When this is compared to the amount needed (50 billion yen), it is safe to say that the government will be more than capable of conducting assistance.

Floating Solar panels provide numerous advantages to the solar industry. It focuses on utilizing spaces that already exist, meaning that there is no need to purchase/look for new pieces of land. This is especially crucial since the islands of Japan are already packed, making it unfit for further development of solar panels. There is even data showing that Japan is ranked the first in the world with the number of panels per land area, indicating that they are running out of soil to develop solar panels[25].

As proved by our simulation, our plan – a nationwide introduction to micro-hydropower with the goal of covering 10% of Japan's consumption – provides enormous environmental and financial gains to the country.

Overview of the Challenges in the Transition

Although hydroelectric energy generation is beneficial in its friendliness to the environment, it comes with a few challenges, namely its possible impact on the local biodiversity, financial barriers in implementing this plan, and water rights.

Impact on Local Environment

The construction of power plants comes with concerns on impacts to local biodiversity, and hydroelectric power generation is no exception. Historically, Japan has experienced instances where the construction of dams was canceled due to protests by local citizens, such as the Akaishi dam in 1961[26] and Hosokawauchi dam in 2000[27]. Therefore, opposing opinions from local citizens are inevitable as well as the possibility of tangible drawbacks such as the loss of diversity in the local area.

The major effects of the construction of new energy generation methods are an increase in the amount of sand in river beds and an increase in alien species of planktons and other microorganisms. Both put stress on the various species of animals inhabiting the area. Especially regarding floating solar panels, reservoirs are a crucial habitat for creatures living in freshwater, meaning that their existence is dependent on reservoirs being preserved in a healthy state.

Changes in the Amount of Sand in River Beds

According to Japan River Keeper Alliance, dams cause sand to mound in the upper parts of the river, making it vulnerable to floods after heavy rain falls[28], while the amount of sand decreases near the ocean, causing shorelines to recede.

Increase in Alien Species of Planktons and Other Microorganisms

Due to Japan's rivers being short and fast-flowing, it is unlikely for rivers in Japan to have any zooplanktons or phytoplanktons. However, research by The National Aqua Restoration Research Center has proven that rivers that have dams have significant amounts of these microorganisms in lower areas of the river.

Financial Barriers

Another major barrier that impedes the process of converting to hydroelectric power generation and installation of floating solar panels is financial barriers.

Japan is known to have national bonds, and as of 2022, only two thirds of its annual budgets is funded by tax revenue[29], meaning that Japan does not have much financial capacity to implement new plans. This situation is even worse in local public authorities, with many of them facing a declining population and young generations moving out into the city, leaving them with little source of tax income, with the Ministry of Internal Affairs and Communications reporting that the population of Japan will decline by 25% by 2050[30].

Water Rights

Water rights is an issue in the transition to hydroelectric power generation. Currently, procedures to acquire rights are very complicated. Moreover, regarding rivers, in order to maintain the amount of water flowing in the river, the amount of usable water is limited.

Solutions to Challenges

Impacts on Local Biodiversity

Negative effects to biodiversity can be overcome by utilizing micro-hydroelectric power generation, which is a method where power plants are created in places such as sewers and agricultural waterways, mitigating the harms inflicted on local biodiversity. The definition of micro-hydroelectric power generation is that its maximum output is under 1,000 kW[19].

Furthermore, new technology such as the control of water temperature and scour gates enable the sustenance of local biodiversity. Water temperature control can already be seen in the Hinachi Dam[31], where it makes use of the difference in temperature according to the water depth. Scour gates are becoming widespread in Japan, such as the Kurobe dam using this technology to ensure that problems such as coastal erosion and decrease in power generation productivity does not occur.

Water Rights

The underlying problem in the complicated procedures of water rights is the lack of publicity in hydroelectric power generation, especially micro-hydroelectric power. By measures such as government advertisements and campaigns by companies and local communities, citizens' familiarity with water rights will increase, making water rights more widely known to the public. When the public is more aware and attentive of this topic, local authorities have no choice but to include policies, namely ones that simplify procedures to be more friendly to new installments of hydro-electric power plants.
On a more short-term scale, measures such as simplification of procedures and use of water resources in an eco-friendly and sustainable manner, at times creating special districts, can be put in action to combat the problems[32].

Financial Barriers

Although financial barriers pose a major threat to the implementation of this proposal, it is important to note that by lessening dependence on thermal energy, Japan can reduce its imports on fossil fuels. This means that the money that was previously allocated to fossil fuel imports can be used to fund the building of hydroelectric power plants.

According to Mitsubishi Research Institute, Japan imported approximately 136 billion USD of fossil fuels in 2022[6]. However, if our proposal succeeds and we achieve a 6.5% increase in the ratio of hydroelectric power generation in the country's total energy generation, the country would be able to cut this amount by 7% as the amount of fossil fuels needed would decrease by 6.5%. This means that approximately 10 billion USD can be allocated to the installation of new technologies related to hydroelectric power generation.

Other Arguments

Solar Energy

One method of power generation that is gaining prominence in Japan is through solar power. As of 2021, Japan produced 66 million kW of solar energy, growing by 12 times in the last ten years.
The Ministry of the Environment has set a target of increasing the percentage of solar power from 6.7% in 2019 to 14~16% in 2030, encouraging local authorities to endorse the further installment of solar panels in their communities.[33]

A merit of utilizing solar energy is that solar panels on land can be installed on a private scale, requiring no large facilities, hence no large amounts of government funds.

Furthermore, its maintenance costs are inexpensive, with silicon, the main component of solar panels, being usable almost indefinitely. [34]

However, one setback of solar energy is Japan's lack of land to further install them on the ground. Japan has a small flat surface area to begin with, ranking 61th in surface area[35] but having 75% of it covered in mountains.

Nuclear Energy

The Japanese government is also leaning slightly towards the restarting of nuclear power plants twelve years after the Great East Japan Earthquake, setting the percentage of nuclear energy out of the total energy production as 20~22% in 2030.[36]

A definite merit of further utilization of nuclear energy is that sufficient technology and equipment exists in Japan to increase production. There are already ten working nuclear power plants in the country as of 2022[37], and seven have passed the new regulatory standards to ensure safety of nuclear power plants, meaning that the country's capacity to produce nuclear energy will grow in the near future.

However, a major setback is the country's citizens' skepticism over the restarting of nuclear power plants. Many human lives are still endangered by the radiation emitted when the nuclear power plants in Fukushima were destroyed by the Great East Japan Earthquake in 2011, 38,000 people are still being affected by the disaster.[38]

Weighing Arguments

Public Opinion

Although technological and financial capacity are both important factors when deciding whether or not a proposal will be beneficial, moral frameworks are also very important as it relates to public opinion. With that being said, considering that the majority of Japanese citizens feel uncomfortable with the expansion of nuclear energy, the method is not the best fit for the country. Even considering the potential costs that come with building new hydro-electric power plants, our proposal respects citizen's opinions, which will likely gain more support.

Land capacity

In order to get immediate results, a large-scale installation of any kind of energy generation means is necessary. This means that regardless of the method used, drastic changes will have to occur. Considering this, utilizing solar power is not the best option for Japan because of its low land capacity to withhold such large facilities, as shown in the section "Other Arguments."

Overview of Global Implications of Japan's transition

Although our plan does not include a drastic change of Japan's energy industry, it will still create numerous ripple effects to politically and economically close countries.

Political Impacts

Since Japan is one of the great powers of the world today, as it is part of the G7, our proposed plan, if implemented, will have a substantial effect on other countries' governments. Specifically, by showing the world that Japan is actively implementing measures to protect the environment, it will motivate other nations to follow suit. At the same time, however, shifting towards clean energy also means shifting away from fossil fuel. Hence, it may cause some tension between oil producing countries that Japan has been importing a substantial amount from.

Economic Impacts

Japan is intertwined with many countries in energy trade. Because it is so dependent on imports, taking it away will affect other countries' economies as well. Below is a brief look into which countries Japan trades with[39].

Crude Oil

Saudi Arabia: Japan is its second largest trade partner, accounting for 15.8% of their crude oil exports.
United Arab Emirates: Japan is its largest trade partner, accounting for 28.8% of their crude oil exports.
Qatar: Japan is its largest trade partner, accounting for 32.6% of their crude oil exports.

Petroleum Gas

Australia: Japan is its largest trade partner, accounting for 28.8% of their petroleum gas exports.
Malaysia: Japan is its largest trade partner, accounting for 47.7% of their petroleum gas exports.
Russia: Japan is its largest trade partner, accounting for 32.5% of their petroleum gas exports.

Coal

Australia: Japan is its second largest trade partner, accounting for 24.1% of their coal exports.

Russia: Japan is its third largest trade partner, accounting for 10.6% of their coal exports.

Indonesia: Japan is its third largest trade partner, accounting for 11.9% of their coal exports.

Indeed, Japan is a significant trading partner for many countries, and its complete transition away from fossil fuel will have a tremendous impact on these nations. However, it must be noted that our plan only goes up to the transition of 10% of all energy sources, and the burden will be equally split between trading partners. Although it must be acknowledged that there are economic impacts to other nations, it can be said that it will not be too significant of an impact.

Aid Towards Other Countries

Japan is internationally recognized as technologically advanced and will be capable of aiding other countries in their energy transition by offering them technological aid, human resources, and exchange programs.

Main Targets of Aid

Assistance will be targeted to countries with high levels of precipitation –Areas that fit within the Af, Am, Aw, Cfa, Cfb, and Cfc ranges according to the Köppen-Geiger classifications – such as those in East Asia and South East Asia, as hydroelectric power generation requires a continuous flow of water.

Technological Assistance

Although Japan is not abundant in natural resources, it is extremely advanced in technology, ranking 13th out of 132 countries in the Global Innovation Index 2022 rankings[40]. Japan's main targets of aid in development – countries in Asia such as Malaysia, Viet Nam, and

Thailand – all rank lower, indicating that Japan's technology and innovation will boost those countries' development.

Especially in the field of floating solar panels, Japan has the largest installation area per land area according to the Energy & Electricity Newspaper[25], meaning that it leads the world in this field.

Allocation of Human Resources and Exchange Programs

First-hand experience is crucial to sustainable development for countries. This can be achieved by providing human resource aid, such as hydroelectric power generation specialists and advisors to guide the path towards a decarbonized energy system.

This type of human aid can already be seen in Japan International Cooperation Agency's Japan Overseas Cooperation Volunteers, a project where JICA provides human resources to countries in need, in order to aid their development[41].

Conclusion

Considering the merits and demerits of each energy source, the team concluded that a combination of micro-hydroelectric energy generation power plants and floating panels would maximize Japan's potential for energy transition. Japan's transition will have a considerable impact on the world, as it would be able to lead many countries technologically.

Acknowledgements

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Exploring Germany's transition to a carbon-free energy system: current trends, global impacts and future outlook

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Abstract

Decelerating climate change starts in each country's energy politics. It's not the population's lack of awareness that is hindering us from acting against climate change - it is the political power in energy politics. The energy system is a key to tackling climate change but is also essential to nearly every part of modern life. The German government has a plan called "Energiewende" to transition from fossil energy, however it does not consider the transition in the entire global system.

The purpose of this research report is to investigate Germany's energy system by assessing Germany's attempt to transition to a low carbon, environmentally friendly, affordable and reliable energy supply. First, we describe Germany's current energy system and politics. Next, we propose a possible plan for transitioning Germany's energy system away from carbon-based resources. This plan does not only focus on the sustainability of the energy sources but also the ethical dilemma that occurs. Finally, we will elaborate what implications Germany's energy transition has on a global scale and evaluate the role of hydrogen to transform the energy system to a carbon neutral one.

Keywords: energy transition, renewable energy, energy justice, green hydrogen, global energy networks

Main text word count: 4989words

Introduction

"Climate change is the single greatest threat to a sustainable future but, at the same time, addressing the climate challenge presents a golden opportunity to promote prosperity, security and a brighter future for all." (Ban Ki-Moon, former UN Secretary-General)

The heatwaves of 2018 and 2019 are estimated to have cost the German economy 35 billion Euros and a recent flood in 2021 is calculated to have created more than 40 billion Euros in damages [1]. As rapid climate change accelerates, these weather occurrences will only increase in frequency [2]. It is imperative for Germany to drastically reduce emissions. This has been declared as one of the highest priorities by the Federal Government [3]. But in the light of the European Energy Crisis caused by the Russian Invasion of Ukraine in February 2022, the government has been forced to reevaluate existing plans. Four new LNG (Liquified Natural Gas) Terminals in Germany are planned [4] to secure Germany's energy independence. This paper does not only aim to advocate for reducing Germany's carbon emissions but proposes and analyzes a sustainable plan incorporating international partners to achieve a long-lasting change in the global energy network.

The following research paper is divided into three parts. The first one will describe and analyze the German energy system and address its challenges created by the Russian invasion of Ukraine. The second part will propose a plan for the German energy transition that is 100% renewable by 2050 while also meeting energy justice concerns. Part three will evaluate the international implications and potentials of the proposed transition, using two examples, toward the goal of achieving a carbon neutral world.

1. Investigation of Germany's system

Germany is currently the sixth largest energy consumer in the world, has the largest national market of electricity in Europe and is the fifth-largest consumer of oil in the world [20]. In Germany there are three different types of energy sources currently available: Sources of fossil energies (oil, gas and lignite/coal), nuclear power and renewable energies (see Figure 4).

1.1 Sources of fossil energy

Germany sources a majority of its energy from fossil fuels. The main fossil fuels are hard coal, lignite, crude oil and natural gas [5, 7]. The *"Mittelplate*", which is Germany's largest oil field, is located off the German North Sea coast. Domestic production only accounts for around 2.6% of German crude oil demand, making it very reliant on other nations to fulfill its needs [6]. The crude oil is processed at 13 German refineries and either used for German power production or distributed throughout Europe. Germany is connected with the rest of Europe by oil and gas pipelines. Germany's main import partner for gas was Russia. As shown in Figure 1, the gas was distributed through the Nord-Stream pipelines (Nord-Stream 1 and 2) at a large scale. However, as a result of recent political tensions, the Nord Stream pipelines were bombed in September 2022, making them unusable. Norway also exports natural gas to Germany via the pipelines Europipe I and II.

Figure 1: The most important gas pipelines to Germany and their leaks [7]

Figure 2: "Brown Belt" distribution of lignite mining in Germany [11]

Coal power from lignite is the most commonly used and produced type of fossil fuel in Germany. Germany has large coal deposits and a long tradition of using coal as an energy source, and it's the 8th biggest coal consumer globally [8]. As shown in Figure 2, in Germany, lignite is mainly extracted in the State of Saxony (mid-eastern part of Germany) and in North-Rhine-Westphalia (mid-western part). Although the percentage of electricity generated from coal energy has dropped from 28,5% (9,6% hard coal and 18,9% lignite) to about 21,8% (9,3% hard coal and 18,8% lignite) in one year (from 2020 to 2021), coal was still the largest source of electricity in 2021 in Germany [9, 1].

Coal is currently phased out in Germany as it could not compete with cheaper sources elsewhere, and only lignite is mined in some parts. After ending the domestic production in 2018, Germany's import of hard coal increased to 31.8 million tones. The biggest suppliers were Russia, Australia and the US. Germany's long-term plan is to phase out coal by 2030, moving away from fossil fuels and switching to renewables [12].

1.2 Nuclear power plants and nuclear energy

The second main energy source in Germany is nuclear power. In 2021 nuclear power accounted for 13.3% of Germany's energy mix, generated by six nuclear power plants, three of them shut down in 2021 and three active ones until today [20] (see Figure 3). There has been a heated controversy over the use of nuclear energy in Germany reaching back to 1969, when first demonstrations started against the constructions of power plants anti-nuclear notions were established [13].

About three-quarter of the "German energy mix" from 2021 contain oil, natural gas, hard coal, lignite and nuclear power [9]. Since fossil fuels are not sustainable for the environment and society, and nuclear power is planned to be phased out in Germany, there has been a high need to switch to cleaner forms of energy: renewable energy sources.

1.3 Sources of Renewable energy

Besides fossil fuels and nuclear power, renewable energy plays a major role in Germany's energy mix (as shown in Figure 4). By definition, renewable energy is energy that comes from natural sources replenished at a higher rate than consumed [15]. The main renewable energy sources in Germany are wind energy 36.6%, biomass 22,5%, hydropower 14.7%, photovoltaics 21.2% (solar panels) and biowaste 3.6% [16]. These types of energy sources are labeled as "carbon-friendly" by Germany and the European Union. Although Germany does not have a very sunny climate, around 10,4% of the annual electricity consumption is made up of solar photovoltaic power [10]. Thus, Germany has currently been making huge efforts to increase the renewable energy share. Since the year 2000, Germany's share of electricity has risen from 6.3% to 25%. By 2030, the German government wants to raise the renewable energy target in the renewable power sector to a share of 80%.

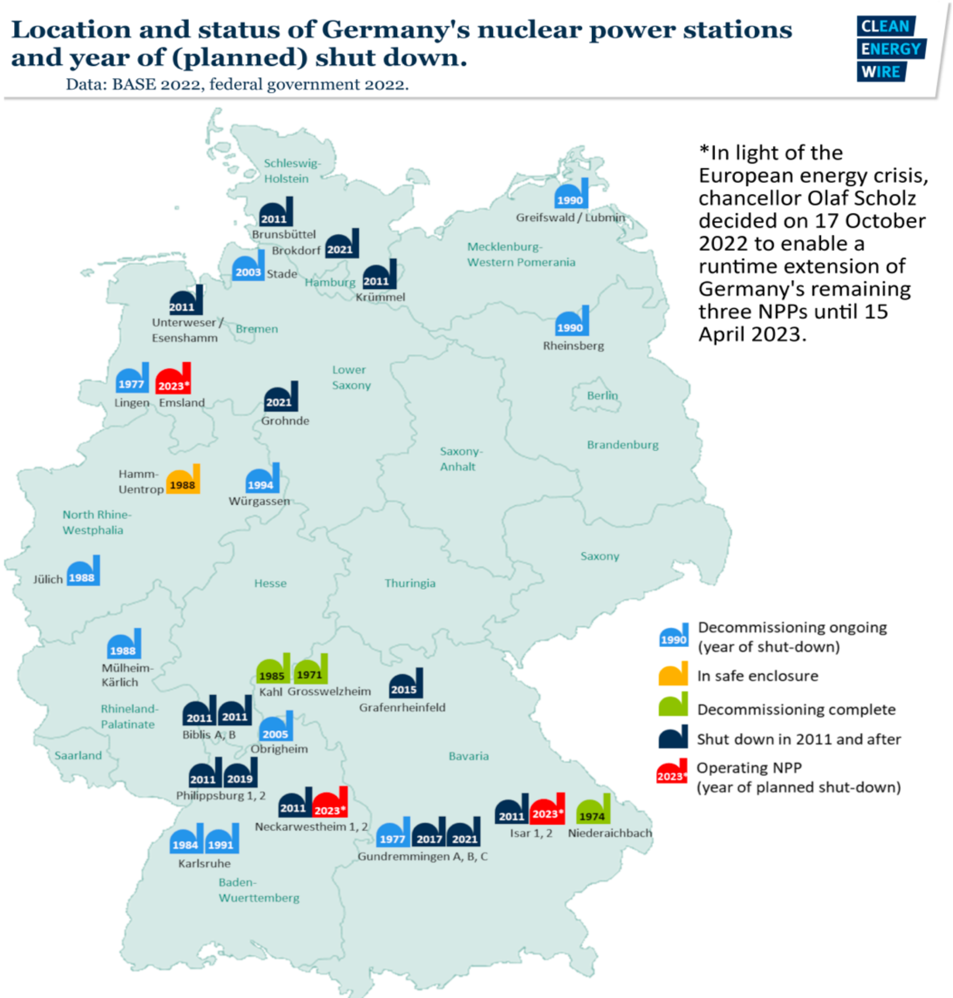

Figure 3: Germany's nuclear power stations [14]

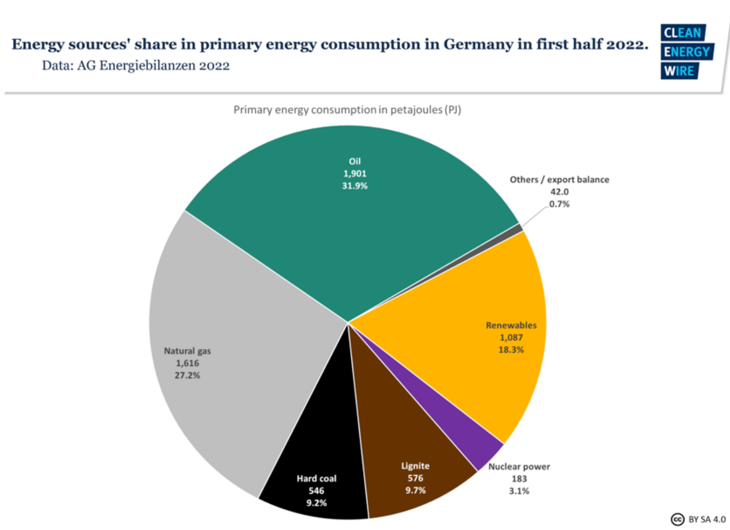

Figure 4: Energy sources' share in primary energy consumption in Germany [9]

1.4 Import and export of energy sources

1.4.1 Import of energy

In 2021, Germany imported around 64% of their energy from other countries. 98% of the oil consumption was imported by Russia (34.1%), the US (12.5%), Kazakhstan (9.8%) and Norway (9.6%) [9]. Also, Germany was the largest natural gas importer globally in 2021. Before the Russian invasion of 2022, it had no LNG terminals, since then it has built 2 terminals with 3 others under construction.

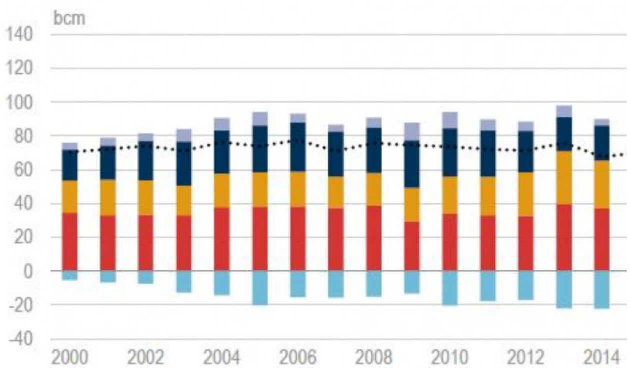

Figure 5: Germany's natural gas net imports [17]

Germany's energy consumption was immensely dependent on Russian energy companies since "[a]bout half of German gas and coal and about ⅓ of oil originated from Russia" [18]. We use gas in industries (37%), households (31%) and in trade and commerce (12%) as well as in heating (7%): This is why our transition-plan will be proposed mainly within these sectors (see part 2). The ban on imports of Russian gas, caused a price spike and the fear of energy insecurity in Germany and Europe. The newly built LNG terminals contributed to gas prices now having returned to pre-war levels [19]. Substituting coal and oil from Russia is bearable due to the several world markets exporting coal and oil from different countries to Germany. While oil and coal can be shipped from other countries, the situation in the gas market is more complex due it being transported by pipeline network [20]. To improve Germany's energy safety, Germany announced plans to build an LNG terminal at the North Sea port of "Brunsbüttel", as of 2022.

1.4.2 Export of energy

Thanks to more weather-driven renewable power sources, Germany was able to export more electricity to neighboring countries than it imported in 2022. Main export nations were Switzerland, Austria and France - a nuclear-reliant country. Germany's energy exports rose 7.3% in 2022 [21].

1.5 Emerging trends in the German energy system

The Russian-Ukrainian war has changed much in society, economy and also in energy politics. Germany wants to gain full independence from Russia's energy sources. Since renewables are currently not sufficient to supply enough energy, Germany now either has to further rely on other countries for gas or other energy sources, or they can restart operations in coal-fired power stations, which are being phased out due to their detrimental climate impact [22].
Another impact of the Russian-Ukrainian war is that Germany is questioning the decision to shut down all nuclear power plants. Originally, the plan was to phase out nuclear energy by the end of 2022. However, the country is threatened by the natural gas supply, due to the Russian invasion of Ukraine, and it would mean restarting the three power plants that shut down in 2021 (see Figure 3). The original goal was unrealistic, and a compromise has been made. In November 2022 the German government adopted a draft amendment to the nuclear law which allows the three nuclear power plants in Germany still in operation to continue operating until 15 April 2023 at the latest [14].
In December of 2022, the first LNG terminal, which is a huge milestone for Germany as it helps build independence from Russian pipelines. Likely this terminal should cover 6% of the annual German gas usage [23].
As recent events show, a country's wellbeing highly depends on the functioning of its energy system and its ability to supply the country with an amount of energy equivalent to the demand. However certain influences, like the Ukrainian-Russian War, have exposed the fragility of some energy systems. In addition to this parameter raising concerns about the stability of Germany's energy system, the need for change is conditioned by the negative impacts of carbon-based energy sources and their emissions on climate change.

2. A plan for Germany's 100% renewable energy transition by 2050

As laid out in the first part of our research report, Germany's energy system is already partly relying on renewable energy sources. In this second part of our research report we propose a plan for transitioning the entire energy system of Germany away from carbon-based sources to 100% renewable energy sources by 2050 [24]. However, while meeting this goal, we need to ensure that this transition is equitable, with benefits and costs distributed equally across society. In order to address these energy justice concerns, we apply the "energy justice framework" to our proposed plan. In our paper, energy justice is defined as a crosscutting discipline identifying "inequalities created by the system that produce and distribute energy" [25]. So, in the case of our proposed German energy transition, we should meet the following requirements: (1) the produced energy must be affordable; (2) accessible to all; and (3) reliable under disruptive events (e.g., armed conflict). Meeting these requirements will help to ensure that energy transition needs to be just and equitable and can benefit all of society.

2.1. Detailed elaboration on our proposed plan for the energy transition

In 2022 the percentage share of renewables in Germany's energy sources' consumption was at 18,3% (see Figure 4). Transitioning Germany's energy system to 100% renewable will drastically reduce Germany's greenhouse gas emissions. Therefore it is crucial to decrease primary energy demand in order to establish a sustainable climate-neutral system. As shown in Figure 6, primary energy refers to the product that is extracted directly from natural sources such as crude oil or natural gas. Secondary energy consists of products that have already been converted such as electricity. In the following, we propose widespread electrification, so increasing secondary energy production, for the following sectors: heating, mobility, and net electricity as well as keeping the demand for energy in these sectors as low as possible (see Figure 7 of depiction of sectors). Electrification is crucial to decarbonize energy supply chains and holds great potential for reducing energy demand overall. One reason is that electric technologies can have greater potential for efficiency compared to fossil-fuel-based technologies [26]. Electric technologies not only manage to facilitate CO2-emission reduction but also give the option to be generated 100% by renewables. The goal here is to use as much renewable supply as possible, while reducing the need for energy storing capacities.

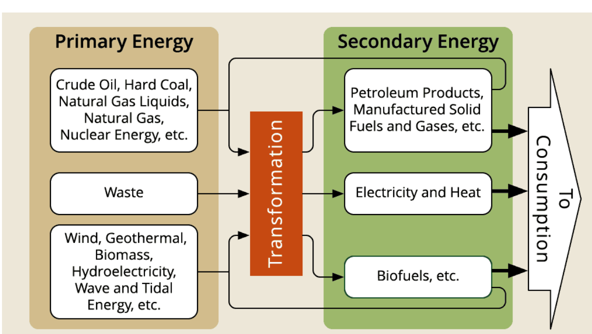

Figure 6: Primary vs. secondary energy resources [27]

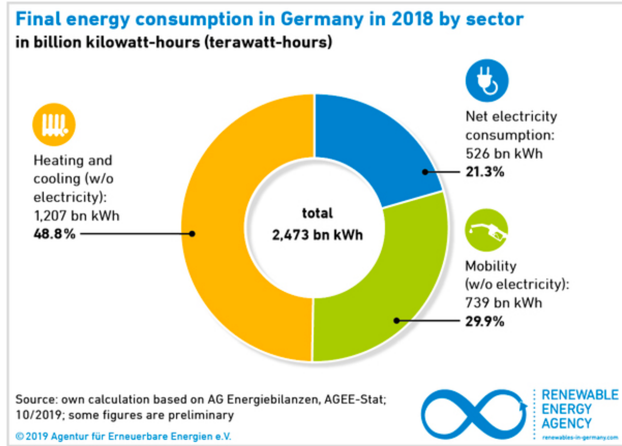

Figure 7: Final energy consumption by sector in Germany in 2018 [28]

2.1.1. Heating

In 2018, heating and cooling made up almost half of energy consumption. It is important to provide the demanded energy in the heating sector while introducing heat savings [24]. Heat savings can be achieved by increasing district heating share [24]. District heating are heat networks that distribute heat through a system of pipes for commercial use such as space or water heating [29]. Focusing on district heating is key for switching to an increased use in renewables since the existing district heating networks can be decarbonized by using 100% renewable sources [29]. The industry sector has the biggest share of Germany's energy consumption of electricity (see Figure 8). For our scenario in 2050, we assume that a large share of power demand in the industry sector applies to heating, as it does today [30].

2.1.2. Mobility

Also, the electrification of the mobility sector is a main component in our plan. This requires that 85% of all vehicles are converted to electric ones (EVs) [24]. With the conversion to electric driven cars, we save approximately 3% of primary energy demands, getting closer to the goal of an overall reduction of energy consumption [24]. We convert all remaining 15% of vehicles, mostly used for heavy transport like on sea or in the air, to hydrogen powered vehicles. With an electricity demand increase, the demand for hydrogen power in the transportation sector would go up [24]. We assume that the costs for the installation of a hydrogen energy grid and the infrastructure of the hydrogen charging stations, would equal the costs for the current supply for half of all the petrol stations in Germany. This calculation draws a threshold for the anticipated challenge of meeting energy equity and creates an

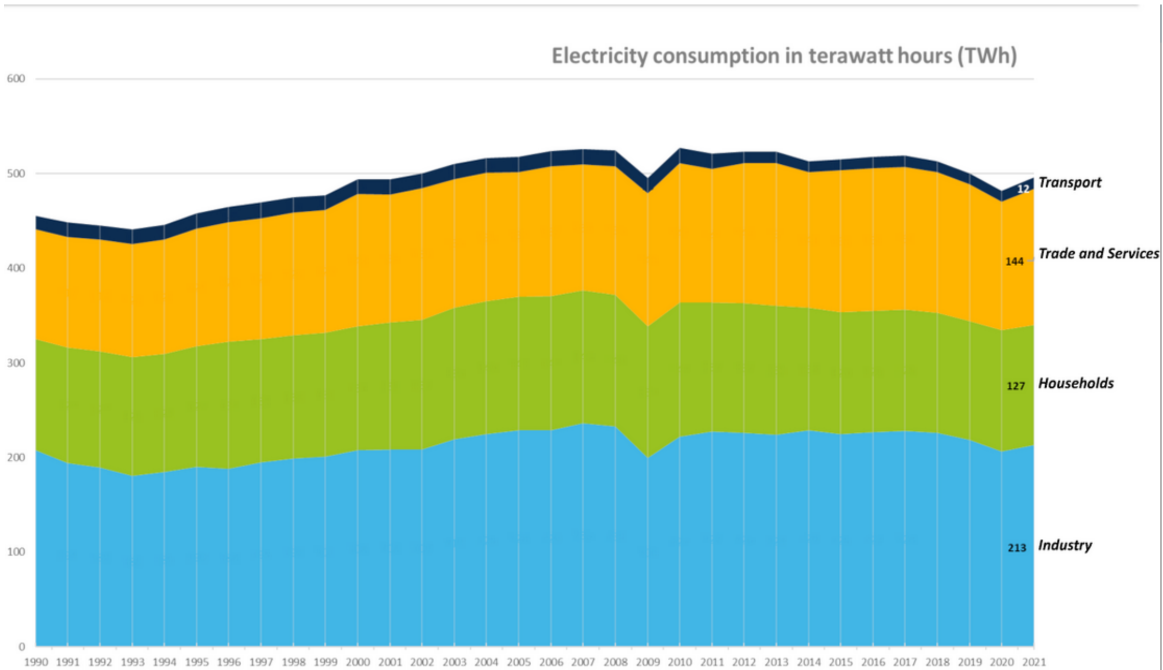

Figure 8: Energy consumption of electricity in Germany divided by the four sectors: Industry, Trade and Services, Households, Transport [9]

affordable energy system for all societal layers, for those who can barely afford energy prices currently too.

2.1.3. Net Electricity

Also for the electricity sector, the primary energy coming from fossil fuels needs to be reduced. Since electrification of all energy-based sectors is key in our plan, the net electricity demand will significantly increase. In order to accomplish providing the amount of energy for electricity that is needed, we would extend the wind and photovoltaic sources for electricity production [24]. However, availability of wind and sun in Germany is risk-based since both sources of energy are not consistently available (e.g., during nighttime for solar) and are not currently abundant enough in order to create sufficient energy storage. This anticipated challenge is discussed in the next part (2.2). Reducing the primary energy of fossil fuels and extending wind and photovoltaic sources requires global cooperation with other countries providing the clean energy we need, as we will elaborate in detail in the third part of the research report.

2.2 Anticipated challenges in our transition and how they can be overcome

2.2.1. Affordability equity

The way we currently consume the world's non-renewable resources puts unjust burdens on future generations. We must stop resource exploitation and intergenerational injustice by establishing an energy system relying on renewable sources. This represents one important step towards energy equity as shown in Figure 10. However, the measurements taken in the different sectors to enforce the energy transition, can implicate high costs (see 2.1.2. mobility). So, the investment in a fundamental energy transition causes an increase in energy prices in the first place [31]. But in the long run, the energy transition towards 100% renewables increases energy efficiency and thus reduces costs, once the efficient system is in place, as shown in Figure 9 [32]. Additionally, there are huge gaps between the more privileged and the unprivileged German society [33]. Well-being and living standards differ significantly. The German energy transition towards a 100% renewable requires maintaining social security and assistance for all people. We need to make sure everybody can still afford to heat their homes, when increasing the energy prices at first. Following the principles of energy equity (procedural, structural, distributional and transgenerational), we need to enable marginalized groups to participate in the energy transition in a fair way without causing further disadvantages. Clean energy programs should promote economic participation and community ownership [34].

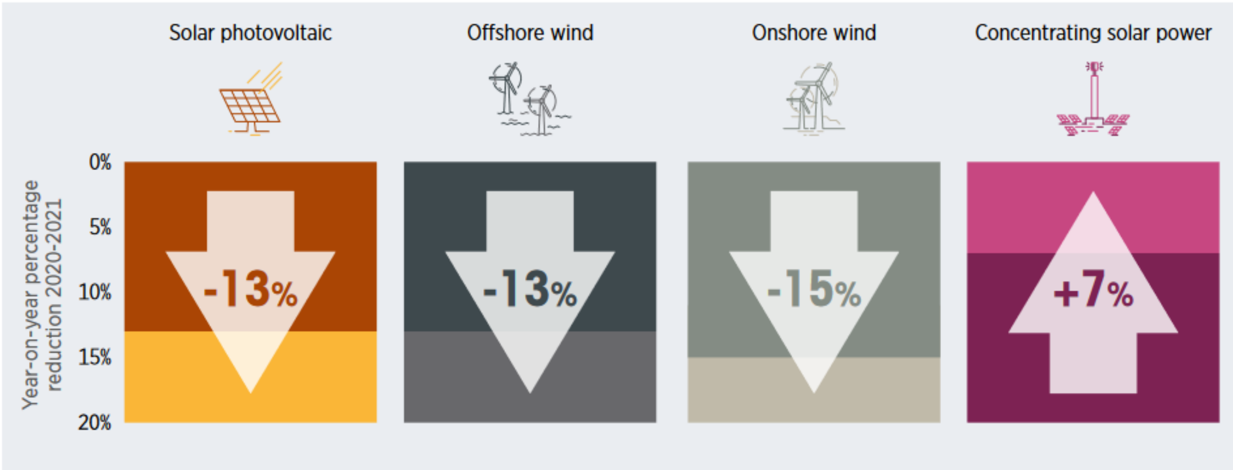

Figure 9: Annual reduction of cost percentage in comparison to the year before from 2020 to 2021 [32]

There is also an intergenerational difference in how the rural vs. the urban population contribute to a greener energy system and how to profit from them [35]. Renewable energy production can only be accomplished in rural areas with enough space to install onshore wind turbines, grow biomass or implement solar farms. So, energy injustice occurs, since the rural population is the one who experiences the most change regarding renewable energy production. When switching to 100% renewable energy, it is important to consider two main things in order to avoid rural energy injustice:

(1) We need to make sure that increased installations and infrastructure for renewable energy systems do not interfere with environmental devaluation of property and surroundings of rural communities.
(2) Increasing prices in power due to the expansion of renewable energy production has to be affordable for all community members, especially rural households with less income.

So, governments and other powerful institutions have the responsibility to introduce programs and policies that maintain a fair distribution of profits, without intergenerational nor intragenerational injustice [35]. One aspect of energy equity is that distribution is in line with demand, ensuring reliable electricity for all. Demand side management response is key in order to ensure equal representation rights of every community member leading to an equitable energy justice system (see figure 11).

Figure 10: Measurements that can be taken in order to reach energy equity [36]

2.2.2. Energy storage

The German word "Dunkelflaute" is a compound expression consisting of the words "dark" "wind" and "dull" [37] (Source). It describes the period of time in which little or no power can be produced from solar or wind power. As climate change is dominating our weather, we are facing a period of time with extreme weather conditions that will have a huge influence on the efficiency of our renewable energy sources [38], as solar panels only work if there is enough sunlight and hydro energy can only be acquired from water bodies which are moving. The word itself describes quite fittingly the reason why any energy transition will be unsuccessful without large-scale energy storage, because times of high demand will inevitably coincide with periods of low generation. Peak hours in Germany are 10am - 2pm and 6pm - 10pm [39]. Regarding the functioning of solar panels or wind turbines, the urgent need for a solution to store the renewable energy becomes clear. This storage need will be provided by multiple different technologies [40] and one of the major energy storage forms will be hydrogen which can also be used for international energy trade (see part 3) [41].

Based on our analysis of our plan, we have identified five essential objectives that need to be met for 100% renewable energy transition by 2050 and is affordable, accessible and reliable to all.

- Acquire renewable energy resources and replace fossil fuel based sources
- Reduce energy demand in all sectors
- Electrification of all sectors
- Follow energy equity principles
- Deployment of energy storage

In the following we will examine how our proposed plan switching to 100% renewables in Germany by 2050 will impact other countries.

3. The global impact of the German energy transition

3.1 German Hydrogen Diplomacy

As outlined in Section 2 of this research report, our plan for a 100% renewable energy system in Germany faces challenges when it comes to a complete electrification of energy and increasing the availability and storage of renewable energy. This shows that the German Energy Transition requires the availability of green hydrogen in order to decarbonize energy industries. Green hydrogen can contribute to reducing carbon emission where electrification would be difficult, especially in the steel and chemical industry. The steel industry makes up 30% of industrial emissions and more than 7% of Germany's total emissions [42]. To create a future of carbon-neutral German industry, it has been a priority to secure diverse sources of hydrogen. Hydrogen can act as a grid level storage for energy storage, but it can also be shipped in liquid form, or in the form of ammonia or other forms that are converted into ammonia or even "green" jet fuel. Ammonia has the major benefit of being much easier to store than hydrogen. For the past years, Germany has been engaging in what it is described as "Hydrogen Diplomacy" in an attempt to incentivize the construction of "Green Hydrogen", this being hydrogen created by electrolysis which is powered by solely renewable electricity [43].

Since Germany has limited land availability and low efficiency for Solar-PV (see Figure 11) [44, 45], it is subject to import much of its hydrogen demand. To secure imports, it has been a key interest of the German government to secure energy and hydrogen partnerships with potential suppliers. For this objective, Germany has opened hydrogen diplomacy offices and signed hydrogen partnerships with several countries. These projects' scope and progress vary, but in the following, we will analyze two exemplary international projects with Germany. The projects present vast opportunities, but they also form a pertinent example of the drawbacks.

3.2 Example 1: The Namibian-German Hydrogen Project, description and energy justice considerations

Namibia is one of the best suited regions on Earth for major green energy exports, since it has a solar electricity generation potential more than three times higher than Germany [45]. Its geographic location, including a long coastline, offers good access to natural ports. In 2020, the governments of Germany and Namibia signed a contract awarding more than 40 million Euro in support of local hydrogen projects [46, 47].

The most prominent of these projects is a facility planned in the Tsau ǁKhaeb Sperrgebiet National Park, an area with no human population that has been mainly used for diamond mining for over a century and is considered a restricted area ("Sperrgebiet") until today.

The project's plans are split into two phases; these combined will have an electricity generation capacity of 6GW and an electrolyser of 3GW. The facility plans to export 700.000 t/p.a. in stage 1, and 1.700.000t/p.a. in stage 2 [48].

International hydrogen projects help to establish a rapid energy transition to renewables in Germany but also come with challenges. For the following projects, we will also apply the energy equity approach analyzing whether the established projects are just. Since hydrogen is at the center in part 3, we will use the hydrogen justice model by Müller et al. (2022) [49], that is built on the energy equity approach used in part 2 of our paper. The hydrogen justice approach has six dimensions: (a) procedural justice; (b) relational justice; (c) recognitional justice; (d) distributive justice; (e) restorative justice; (f) epistemic justice.

Restorative justice: German-Namibian relations are complicated. Namibia, a former German colony, still suffers today under the consequences the German rule brought.

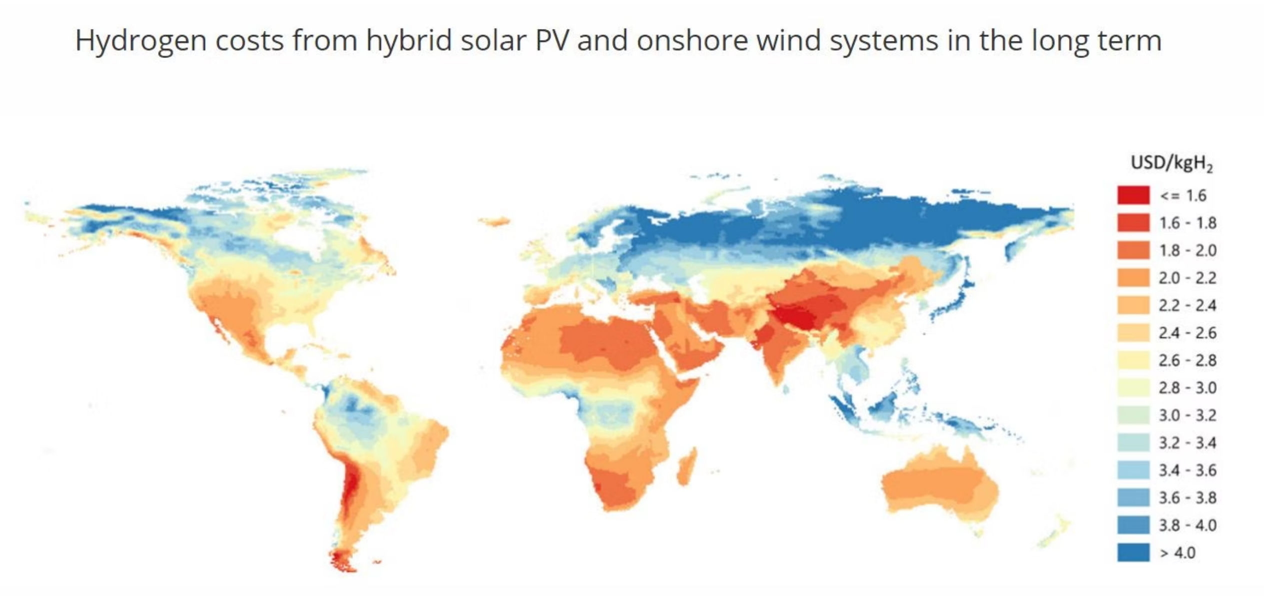

Figure 11: Long term cost of hydrogen production with green energy (IEA)

From 1904-07 Germany committed its first genocide in its former colony killing about 75% of the local Herero Population and 50% of the Nama Population [50]. Reconciliation between the two parties has been an ongoing process with Germany formally apologizing and agreeing to pay 1.1 Billion Euros in reparations over 30 years [51]. With this history looming over the project, it is imperative for this development to benefit all Namibians and protect their fragile wildlife.

Distributive justice: This project tries to achieve these goals by ensuring an oversized generation potential of desalinated water and clean electricity providing the local community with a secure water supply in this desert. The electricity unused for hydrogen production will flow into the very fossil fuel reliant Namibian grid, lowering prices and making Namibia less dependent on energy imports from South Africa [52]. The cheaper electricity will even benefit the population furthest away from the site. This goal of hydrogen justice is heavily dependent on the added capacity leading to increased electrification across the country.

Epistemic justice: Hyphen Energy, the developer, a Namibian registered green hydrogen development company, also guarantees that 90% of the jobs created by the facility will be filled by Namibians which will lower the 22% unemployment rate of the country [53]. The project will also create significant revenue for the Namibian treasury [53].

This project has the potential of becoming an exemplary project in addressing the goals of epistemic, restorative and distributive justice in order to achieve energy equity for Namibians while actively aiding the imperative mission of cutting Greenhouse gas emissions.

3.3 Example 2: Saudi-German hydrogen project, description and energy justice considerations

Not only does Germany reach out to nations of Sub-Saharan Africa for establishing hydrogen relations but also sets up programs on the Arabian Peninsula, another solar-PV-efficient region (see Figure 11). Saudi Arabia, an oil powerhouse, is trying to diversify its oil dependent economy with the government program “Saudi Vision 2030”. In the scope of this initiative, the Saudi government unveiled their plans for a Smart City at the Red Sea named “Neom”. The project includes a major facility for the production of green hydrogen [54]. The hydrogen plant is being constructed in part by the German company Thyssen-Krupp Nucera, a subsidiary of Germany's largest steel company. The plan is to generate up to 1,2mil t/p.a. starting production of hydrogen in 2026. This enterprise has received direct funding by the German government [55].

The “Noem”-project unveils that the Saudi government has a key interest in diversifying its economy away from an oil dependency. In order to achieve a global energy transition towards renewables, it is essential to cooperate with major oil producing nations taking on this huge chance for change. Only then, we move closer to achieve the goal of a carbon neutral economy. Only when putting the global need for all countries to reduce their emissions first, the system is able to change.

Epistemic and procedural justice: However, the Saudi hydrogen project has been engulfed in international controversy because of their land and labor practices [56]. The kingdom has been accused of exploratory practices regarding their large migrant work force which is required to construct such mega projects. While fulfilling the need for green hydrogen, the German government needs to ensure human rights to everyone as outlined in its values based foreign policy. We can see that the Saudi project has room for improvement in order to create a more equitable energy system. The Saudi government needs to address concerns of epistemic justice and procedural justice engaging with the local population and guaranteeing them benefits of the project e.g. access to cheaper green electricity.

3.4. Building equitable hydrogen partnerships and a trans-European Grid

Through its hydrogen diplomacy, Germany plays a major role in the financing of hydrogen facilities. It has the leverage to make German financial contributions dependent on action to specifically promote projects and policies that align with the ideals of energy justice and equity in order to make the global energy system more just. German institutions such as the German agency for international cooperation (GIZ) or the German investment and development bank (KfW) have offices in many emerging economies. They collaborate with commissioners from the United Nations, governments of other countries, and private and public partnerships. These organizations have the potential to easily expand on their existing network in partner nations to provide financing for renewable energy projects in emerging nations while ensuring equity and justice.

Having focused on international projects promoting hydrogen energy relations, we need to take into account that these projects do not only benefit the decarbonization of Germany's energy system, but they could potentially have a great effect for all of Europe. It is one of Europe's goals to create a European energy grid that will make sharing renewable electricity easier and reduce electricity cost. The Trans-European Networks for Energy (TENF) is a policy helping to facilitate grid integration in Europe [57]. The benefits of a better-connected grid are an improved utilization of renewable electricity in peak times and cheaper prices created by electricity being able to be sourced by a larger array of renewable energy sources. It would also allow European countries to utilize their diverse geographical potential to maximize electricity storage [58].

The development of this infrastructure is vital not just for the German energy transition, but it will allow for a connected and intertwined transition with shared resources and storage, to achieve the goal of a global carbon neutral energy community.

4. Conclusion

This research report does not only present Germany's complex energy system, but it also elaborates on why Germany needs a transition to a 100% renewable energy system. Germany relies on three main energy sources (see 1.1; 1.2; 1.3): fossil fuels, nuclear energy and renewable energy sources. The main reasons for Germany's energy transition are (1) that the energy transition enables sustainable economic development for Germany and climate resilience [59]; (2) that switching to clean sources of energy, such as renewables, thus helps address not only climate change but also air pollution and health of the entire population.

Decarbonizing the country means, in other words, to use energy sources more reliably. Ensuring renewable energy sources, which have the ability to last for a very long time without putting additional effort in maintaining the system are key.

Our plan laid out the necessity to first reduce energy demand in all sectors, second electrify all major sectors, such as industry and heating, and third that it is important to consider the deployment of short as well as long term storage in Germany. In the future, German politics need to prioritize investing into renewable energy storage projects in order to allow for the further construction and integration of green renewable energy into the German energy mix, while lowering hurdles for renewable energy construction. As a result, transitioning to a carbon-neutral, 100% renewable energy system brings several challenges (see next paragraph) with it, but still isn't impossible. Obstacles are still present on this way to transition but our report shows that those can be overcome.

The main challenge that occurs while decarbonizing the German energy system is to meet the needs of the entire German population while balancing carbon emissions. Despite those challenges, this paper demonstrates that decarbonizing Germany's energy system is possible and that the focus should be on renewable energy sources to secure Germany's energy supply while transitioning away from fossil fuel dependent companies. Energy cooperation can be beneficial (as we see in part 3.3 Saudi project) although we have to consider ethical norms and values, such as human rights. The government needs to put care into deciding which international projects to grant funding. The potential of large-scale hydrogen projects can only be fulfilled when it's closely coordinated with the local populations to benefit the nation sustainably and ensure equity. Germany has a key role to play in the international energy transition. Its demand for green hydrogen and other green energy can help make Germany, Europe and other nations around the world build resilient and carbon neutral economies and communities.

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Evaluation of Battery and Thermal Energy Storage Systems in Austria and beyond

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Summary

The aim of this paper is to compare different storage methods for solar energy. This is conducted by doing both a theoretical comparison between Battery Energy Storage Systems for Photovoltaic plants and between Thermal Energy Storage Systems for Concentrated Solar Power plants as well as building a simulation to practically compare these storage methods. Additionally, the significance of solar energy is assessed on the example of Austria and recommendations for the usage of more solar energy in Austria and worldwide are made. Furthermore, the role of solar energy in the transition to a renewable energy system is demonstrated.

Key Words

Austria, Solar Energy, Energy Storage, Battery and Thermal Storage, Simulation

1 Introduction

The gross national energy consumption in Austria has been dominated by fossil fuels for many years. For renewable energy sources to take over the lead nationally, it is vital to make renewable energy sources equally accessible to non-renewable energy sources, such as oil for instance. Solar energy has been playing a crucial role in the decarbonization of the energy system, however, its fluctuation in availability and dependence on various factors has prevented it from competing with other more established energy sources. When calling up solar energy, the unstable availability of the sun and energy loss raises a big problem. The key to this issue is the implementation of energy storage systems, for both Photovoltaic and Concentrated Solar Power, that capture solar energy whenever it is available and allow its usage for later periods.

2 Austria's Energy System

The majority of all the energy being produced in Austria (domestic production) is mainly composed of biogenic energy sources and hydropower. While biogenic energy sources and hydropower make up respectively 47.5 and 26.5 percent of all energy being produced in Austria, combustible waste takes up a minority of 5.3 percent and 5.1 percent consists of ambient heat. Furthermore, gas and oil both amount, as energy sources obtained from domestic production, to 4.5 percent each. Lastly, wind energy takes up 4.6 percent and Photovoltaic, as a source for solar energy makes up 1.9 percent of Austria's domestic energy production [1].

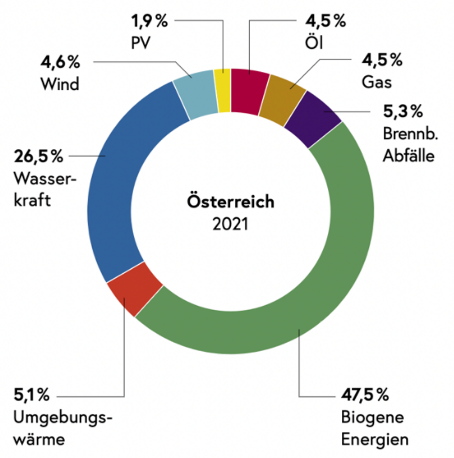

Figure 1: Primary energy generation (Primärenergieerzeugung im Vergleich)

However, Austria's domestic primary energy generation does not cover Austria's entire energy consumption. Consequently, additional energy has to be imported from abroad. So, although domestic primary energy generation in Austria is strongly dominated by renewable energy sources such as hydropower and biogenic energy sources, the majority of energy imports are fossil fuels.

The three main imported energy sources are oil (58.5 percent of all imports), gas (17 percent of all imports) and coal (11.1 percent of all imports). Additionally, 3.4 percent of biogenic energy and 9.8 percent of electrical energy are being imported [1].

Thus, the gross national energy consumption in Austria is still dominated by fossil fuels.

The fossil fuels oil, gas and coal account for the largest share of Austria's gross national energy consumption. Oil, gas and coal make up respectively 34.5 percent, 22.7 percent and 7.6 percent of the gross national energy consumption.

Overall, Austria consumed 1120,8 PJ in 2021, of which approximately a third was respectively used in private households, in traffic/transportation and in the producing sector. Regarding Austria's energy exports, the resource gas is exported the most, followed by oil and then electric power. Lastly, biogenic energy sources are exported the least [1].

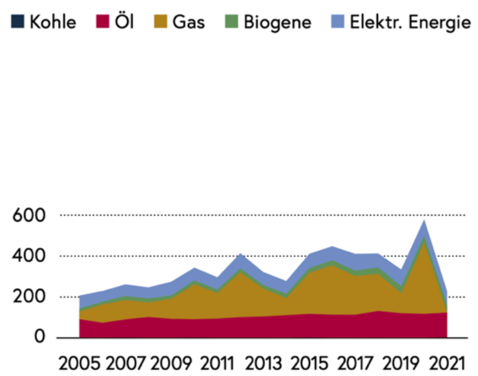

Figure 2: Energyexports 2005-2021 (Energieexporte 2005-2021)

This insight into Austria's energy system displays that although it is very advanced in its domestic production, where renewable sources such as hydropower and biogenic energy sources have taken the lead over fossil fuels, other renewable energy sources like solar power (PV and CSP) do not prevail. This is due to its fluctuation in availability and weather dependence. However, with the help of energy storage systems, solar energy can be stored and used in later periods, in which solar energy cannot be called up directly, at night for instance.

By implementing and expanding solar energy storage systems and hence Photovoltaic and CSPs, the amount of accessible solar energy increases and is therefore able to cover more of Austria's energy consumption. Consequently, fewer energy imports and additional non-renewable energy sources would be needed. Moreover, this obtained solar energy can also be exported to neighboring countries or across the EU, partially or fully replacing the most extracted non-renewable energy sources, such as oil or gas.

3 Solar Energy Production

There are two main systems for harnessing solar energy. The first and more conventional system is the Photovoltaic cell (PV), which can convert direct solar radiation into electricity. The second is the solar thermal system, where we focus on Concentrated Solar Power (CSP), which generates electricity by creating a temperature gradient.

3.1 Photovoltaic (PV)

PV materials and devices convert sunlight into electrical energy. A single PV device is called a cell. A single PV cell is usually small and typically generates about 1 or 2 watts of power. These cells are made of a variety of semiconductor materials, but the vast majority of today's solar cells are made of silicon, which offers both reasonable prices and good efficiency. Several of these solar cells are needed to construct a solar module, and many modules make up a photovoltaic system that is connected to the power grid. When solar cells absorb sunlight, free electrons and holes are created at positive/negative junctions. When the positive and negative terminals of the solar cell are connected to DC electrical devices, power is supplied to operate the electrical devices. Because of this modular structure, PV systems can be built to meet almost any electrical power need, small or large [2].

3.1.1 Types of photovoltaic cells

Photovoltaic cells or PV cells can be manufactured in many different ways and from a variety of different materials. Despite this difference, they all perform the same task of harvesting solar energy and converting it into useful electricity.

There are three types of PV cell technologies that dominate the global market: monocrystalline silicon cells, polycrystalline silicon cells and thin film.

Monocrystalline silicon cells

These widely used solar cells are made of pure silicon and are the most energy-efficient option. They tend to be on the higher end of the price spectrum but have a longer lifespan. Monocrystalline cells also perform better at higher temperatures and in shaded conditions. Monocrystalline silicon cells have an efficiency of 15 to 20 percent [3].

Polycrystalline silicon cells

These solar cells are made from molten silicon crystals. They are only moderately efficient due to internal efficiency losses. Polycrystalline is also about 20 percent cheaper to manufacture and produces less waste silicon in the process but has a shorter lifetime than monocrystalline silicon cells. Polycrystalline cells are about 13 to 16 percent efficient, which would require a much larger array of polycrystalline cells to produce the same amount of energy than using monocrystalline cells, which may not be suitable for limited area [4].

Although monocrystalline cells are generally more expensive, the total system price can often be less expensive than polycrystalline cells. Since more polycrystalline cells are required to produce the same amount of energy, more must be invested in installation costs, racking equipment, and possibly inverters [5]. Paying a higher upfront price for monocrystalline cells may be the most economical in the long run because it is likely to get a higher return on investment in the form of lower energy costs with higher efficiency and more energy generated.

Thin-film solar cells

Another commonly used photovoltaic technology is known as a thin-film solar cell, as it consists of very thin layers of semiconductor material such as cadmium telluride or silicon. Thin-film solar cells can be flexible and lightweight, making them ideal for portable applications, but they require a lot of space and are therefore mainly used in industrial environments. They tend to be the least efficient and have the shortest lifetime but are generally the least expensive. Some types of thin-film solar cells also benefit from manufacturing techniques that require less energy and are easier to scale than the manufacturing techniques required for silicon solar cells [6].

3.2 Concentrated Solar Power (CSP)

Concentrated Solar Power (CSP) is the technology developed to generate electricity using mirrors by converting concentrated sunlight into solar thermal energy. The mirrors reflect, concentrate and focus natural sunlight onto a thermal receiver. This collected solar energy is then absorbed and used to heat a fluid called a Heat Transfer Fluid (HFT). The heat contained in the fluid is stored and used to generate steam, which drives a turbine to produce electrical power [7]. The process can be repeated continuously, so since CSP technology is a Thermal Energy Storage (TES) system, the heat generated can be stored. This energy can therefore be used at a later time, during periods of low solar radiation and even at night, making it a flexible source of renewable energy.

3.2.1 Types of concentrated solar energy

There are four types of CSP technologies, which can be divided into line-focusing systems and point-focusing systems:

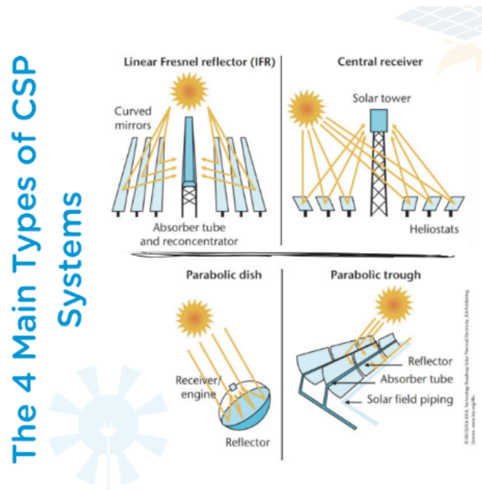

Figure 3: The 4 Main Types of CSP Systems

Linear Fresnel Reflector (IFR)

The system is so named because it resembles the Fresnel lens. It uses flat or slightly curved mirrors to reflect a linear concentration of sunlight. A large number of collectors are arranged in rows to reflect sunlight onto the receiver tube above [8].

Parabolic trough systems

In this system, solar energy is concentrated by curved, trough-shaped reflectors and directed onto a receiver tube. The tube usually contains thermal oil, which is heated and then used in the cogeneration plant to generate electricity in a steam generator.

Power-tower systems

These systems use mirrors called heliostats that track the sun and focus its energy on a receiver at the top of a tower, which serves as a concentration point for the solar energy. A Heat Transfer Fluid is heated in the receiver and used to generate steam that drives a turbine generator [9].

Parabolic dish systems

A parabolic dish serves as a concentrator that reflects solar energy onto the thermal receiver placed at the focal point, which is mounted on a structure with a tracking system that follows the sun. The collected heat is then generated by a thermal engine.

4 Solar Energy Storage Systems

While solar energy proposes one of the most promising renewable energy sources it must be connected to efficient storage in order to be used to its fullest potential and be competitive to other forms of energy generation such as oil or gas. It is vital that every solar power plant has a storage system attached to fully function and loose as little energy as possible. The storage systems help salvage hours of low demand where the plant still produces a lot of energy and bypass times of peak demand where the simultaneously produced energy might not be enough.

4.1 Battery Energy Storage Systems

In comparison to other types of energy storage systems, Battery Energy Storage Systems (BESS) allow for versatile application as its compact nature allows its usage in multiple settings. BESS are the leading storage method for PV. Other types of storage systems are often limited to geographical factors or need extensive facilities. For example, Pumped Hydro Energy Storage requires a large body of water while Compressed Air Energy Storage needs large underground chambers. In addition, most BESS are less expensive in comparison to other energy storage systems which allows them to even be used by smaller producers such as individual houses. This in combination with the compactness is important for future developments as it could enable solar power to be integrated into urban planning and a wide range of commercial applications.

4.1.1 Chemical functionality of batteries

Batteries store electrical energy in form of chemical energy and deliver direct current (DC) electricity. A battery is typically made of multiple cells which each consist of two electrodes (anode and cathode) and an electrolyte. The electrolyte allows for the flow of ions within the battery. The anode releases electrons during discharge through oxidation with the electrolyte. These then flow through the electric load connected to the battery giving up energy. The electrons are transported through the external load to the cathode where the reduction takes place. The cathode balances the negative charge by taking positive ions from the electrolyte or releasing negative ions [10]. The electric load creates the pathway for the electrodes and the electrolyte provides positive ions to balance the negative flow. During charging the whole process is reversed. Each of the reactions between the electrodes and the electrolyte has a standard potential. All of these potentials added together make up the voltage of the battery. The voltage can be changed by creating serial or parallel arrays with multiple battery cells [11].

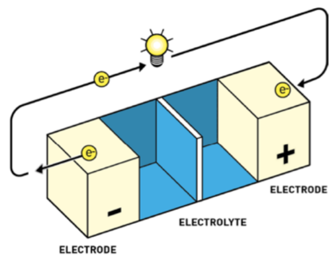

Figure 4: Simplified structure of a battery

A BESS typically also has a Power Conditioning System (PCS) which is responsible for converting the DC of the battery to alternating current (AC) and matching the AC to the AC of the electrical network the battery is connected to. A whole system is then made up of multiple modules which each have multiple individual battery cells (as described above). A System then also needs the PCS and in certain cases a thermal management system to prevent overheating [12].

4.1.2 Lead-Acid Battery

The Lead-Acid Battery is based on electrochemical charge and discharge reactions (as described above). The cathode contains lead dioxide (PbO_2) and the anode spongy lead (Pb). The electrolyte is an aqueous sulfuric acid.

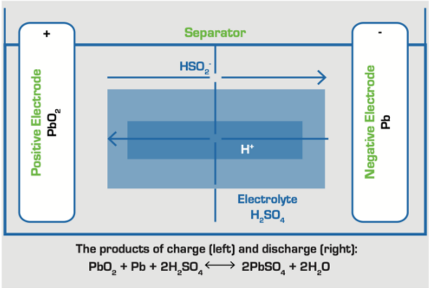

Figure 5: Process in a Lead-Acid Battery

Additionally, there are many design variants of Lead-Acid Batteries as it has been the leading battery type for large-scale energy storage. The main variant is the Valve-Regulated Lead-Acid (VRLA) Battery, which has the same electrochemical reaction as a normal Lead-Acid Battery but is closed with a pressure valve. The acid is therefore immobilized and there is no need to add water to the electrolyte to keep it functioning. The VRLA subsequently needs significantly less maintenance in comparison to a regular Lead-Acid Battery [12]. The Lead Acid Battery shows an efficiency of 75-85% with an average life span of 5-15 years. The average price for one kWh is between 100-200€. The battery typically lasts between 500 and 3000 cycles with an energy density of 25-35Wh/kg [13].

4.1.3 Lithium-Ion Battery

The Lithium-Ion Battery has a lithiated metal oxide as the cathode and carbon material as the anode. The electrolyte is made up of lithium salts which are dissolved in organic solutions. The electrodes are also separated by a porous polymeric material.

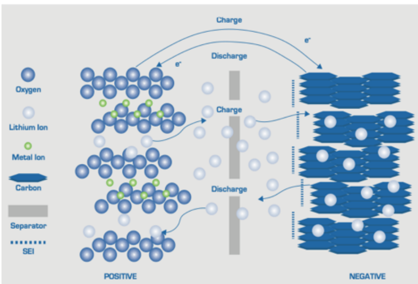

Figure 6: Process in a Lithium-Ion Battery

A Lithium-Ion Battery has an efficiency of 90-98%. The life duration can range between 15-20 years. However, the price per kWh lies between 700 and 1300€. This is because the preliminary products which are needed for lithium-ion production are very expensive, making large-scale applications costly. Additionally, it needs to be said that Lithium-Ion Batteries are still in the research stage, meaning they still need further development to ensure efficient application. The cycle life can range between 2000-10000 cycles with a power density of 120-180 Wh/kg [14].

4.1.4 Sodium-Sulfur Battery

A Sodium-Sulfur (NaS) Battery consists of liquid sulfur at the cathode and liquid sodium at the anode. To ensure the molten state of the electrodes the battery needs to be independently heated to 300°C-360°C. The electrodes are additionally separated by a solid beta alumina, which acts as the electrolyte.

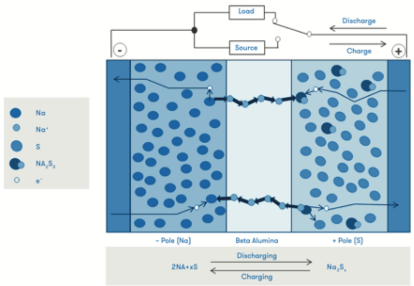

Figure 7: Process in a Sodium-Sulfur Battery

NaS-Batteries show a long life duration lasting from 15 to 20 years. However, they only have an efficiency of 70-80% which can be led back to the fact that NaS-Batteries typically self-charge the heating to a minimum of 300°C to ensure optimal work temperature. The high temperature that these batteries need is one of the main drawbacks as they are impractical for urban usage. NaS-Batteries are also rather expansive as they weigh in at 300-450€/kWh. They last at least 4500 cycles and show an average energy density of 180-230Wh/kg [15].

4.1.5 Redox Flow Battery

Redox Flow Batteries have two liquid electrolytes which are separated by an ion-selective membrane. The membrane allows for certain types to go through during charging and discharging. The electrolytes are only pumped into the battery when required. The storage capacity can be increased using larger storage tanks for the electrolytes. In terms of chemicals used there are multiple options such as vanadium (picture below) or zinc-bromine, the important part being that the chemicals used are redox couples.

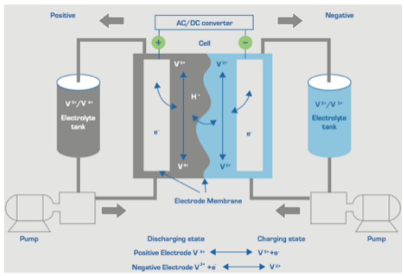

Figure 8: Process of a Vanadium Redox Flow Battery

Redox Flow Batteries last between 10 and 20 years and show an efficiency of 70-75% when already considering the conversion of the current. The average energy density is between 10-50Wh/kg [16]. The cost can vary between 100-400€/kWh and the battery lasts for over 12000 cycles, significantly more than other battery types [17].

4.1.6 Theoretical comparison

For a theoretical comparison between the battery storage methods, it is important to consider both the hard facts such as the energy density and costs as well as other factors such as extra maintenance. In this comparison only the four previously mentioned battery types are compared as others, such as Metal Airy Batteries, are not yet ready for commercial application.

It needs to be mentioned that both Lithium-Ion and Redox Flow batteries are still experimental and have fewer examples of usage. The Redox Flow Battery additionally also requires external pumps to properly function. The Sodium-Sulfur Battery needs to be heated to a minimum temperature of 300°C in order to work properly and the

Lead-Acid Battery needs regular water changes. This could be avoided by using a Valve-Regulated Lead-Acid Battery.

Table 1: Comparison between Battery Performance.

Energy Storage Type	Energy Density (Wh/kg)	Cycle Life	Energy Efficiency (%)	Life Duration (years)	Energy Cost (€/kWh)
Lead-Acid	25-35	500-3000	75-85	5-15	100-200
Lithium-Ion	120-180	2000-10000	90-98	15-20	700-1300
Sodium-Sulfur	180-230	>4500	70-80	15-20	300-450
Redox Flow	10-50	>12000	70-75	10-20	100-400

When looking at the performance (Table 1) of the different batteries it is apparent that the Lithium-Ion Battery performs the best, however it is also the most expensive. The Sodium-Sulfur Battery shows very high energy density with a higher price than Redox Flow and Lead-Acid but not to a decisive extend. The Sodium-Sulfur Battery also shows a good efficiency but a low cycle life. Lead-Acid and Redox Flow Batteries have about the same factors, but the Lead-Acid shows a higher efficiency while the Redox Flow shows a higher cycle life and lifespan.

To conclude it can be said that the Lithium-Ion Battery is best for big scale application when high efficiency is very important. A bigger company would then also be able to afford the higher price for the storage quality. When willing to build the adjacent infrastructure to ensure the heating Sodium-Sulfur is recommendable, especially for large storage quantities as it has the highest energy density. For commercial application Lead-Acid batteries are the best option as they already have a lot of empirical values. Redox Flow Batteries can be an alternative to Lead-Acid but from the considered facts in this paper it is not recommendable as they also need the external pumps to function.

4.2 Thermal Energy Storage Systems

As with PV power plants, CSP plants have the main issue of energy storage and covering the mismatch between supply and demand. To allow more of the thermal energy of CSP to be used there are Thermal Energy Storage (TES) systems which improve the value of a CSP by increasing the content of energy in the working fluid [18].

4.2.1 Sensible Heat Storage

Sensible Heat Storage stores energy in the form of a temperature difference in the storage medium which is then further used to perform work: molten salt is used to heat water; the steam of the water then starts spinning a turbine for electricity production similar to a wind power plant [19]. The molten salt can be replaced by different alternative such as ceramic particles which are about equally expensive as the molten salt at about 1$/kg or cheaper substitutes like rock and sand which cost about 0.1$/kg but are less used and researched and therefore less secure. A whole Sensible Heat Storage system then comes in at about 1-10$/MJ. In terms of energy density sensible heat storage can store between 200-500kJ/kg when achieving a temperature difference between 200-400°C [20].

4.2.2 Latent Heat Storage

Similar to Sensible Heat Storage, Latent Heat Storage uses storage mediums to store generated heat from CSP. However, it mainly utilizes the large latent heat change when a medium undergoes a phase change. During charging a solid is isothermally melted into a liquid, which is achieved by using the heat generated by CSP. To release the energy again the subsequent freezing of the material releases the energy again [19]. The energy density of a Latent Heat Storage system can widely vary depending on the medium used. For nitrate salts about 100-200kJ/kg, for metals about 200-500kJ/kg and for fluoride salts about 1000kJ/kg. The cost usually lays between 3-400$/kg with 10-100$/MJ looking at the whole system capital cost [20].

4.2.3 Thermochemical Energy Storage

For this type of energy storage, the storage medium is a reactive chemical compound. Energy is used as the heat in reversible chemical reactions [19]. The energy density for the storage method can range between 300-6000kJ/kg. There are widely varying prices for the used mediums in $/kg but it can be said that the system capital cost usually stays between 10-100$/MJ [20].

4.2.4 Theoretical Comparison

For making an overall comparison it is important to further address the advantages and challenges associated with each of the three methods to fully assess the usability in combination with cost and energy density. First of all, sensible heat storage has the highest maturity of the three, resulting in more security and resources to find a good fit for different energy producers. It is also the only method which is already used in certain residential areas demonstrating that it can help building green cities in the future to further support the energy transition [19]. In terms of facility size Thermochemical Energy Storage clearly takes the lead as it is the most compact storage system. Sensible Heat Storage requires large volumes as it has a small energy density. Latent Heat Storage needs a more complex system (cascades) to cope with bigger energy loads, adding complexity into building the storage system. In terms of energy density Thermochemical Energy Storage takes the lead as it can have up to 6000kJ/kg. However, this also comes at a higher system capital cost in comparison to Sensible Heat Storage [20].

To conclude it can be said that Sensible Heat Storage is best for large scale application as it has the highest maturity and grows in relation to the produced energy making the size of the storage predictable. Additionally, it is the cheapest option. Thermochemical Energy Storage is the best for long term storage, but the high cost makes it less attractive for larger applications therefore it can be predicted that with further development Thermochemical Heat Storage will be leading for urban planning as it is the most compact and shows little energy loss. A Latent Heat Storage Systems can't be recommended to the same extend as the other two, however, it has a great usage for enhancing Sensible Heat Storage. Together the two propose the most attractive option available at this point. The two can be combined as they both rely on the same method; however, the best combination always has to be assessed for every individual case.

5 Simulation

Apart from presenting the different energy storage methods for solar energy and conducting a theoretical comparison, this theoretical comparison was also turned into a more practical visualization. In the simulation, the above-presented batteries are being compared as energy storage systems and placed in relation to each other. Using data from the "European Association for Storage of Energy", the energy storage types Lead-Acid, Lithium-Ion, Sodium-Sulfur and Redox Flow are being displayed and looked at their performance in 5 different categories. This data is also shown in "Table 1" above.

The five different categories are Energy Density (Wh/kg), Life Cycle, Energy Efficiency (%), Life duration (years) and Energy Cost (€/kWh) [13, 14, 15, 17].

The simulation/visualization was created in Mathematica and programmed with Wolfram Language. The Images below show the performance of the different storage systems for each category. A video showcasing the simulation more precisely will be demonstrated at the conference.

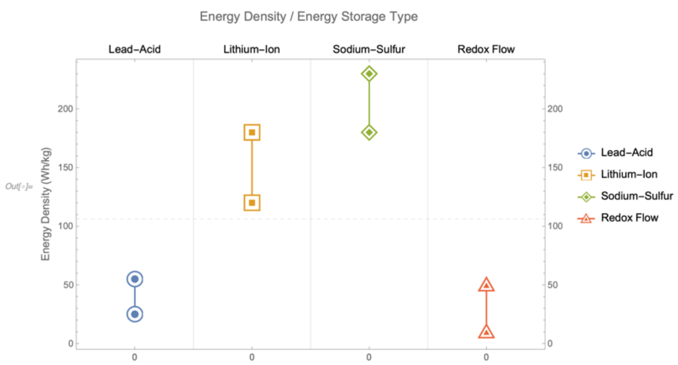

Figure 9: Energy Density (Wh/kg)

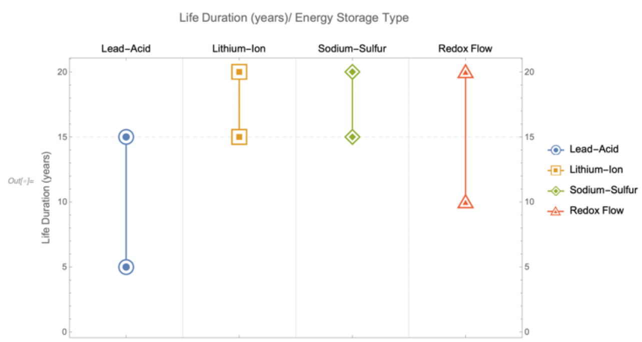

Figure 10: Life Duration (years)

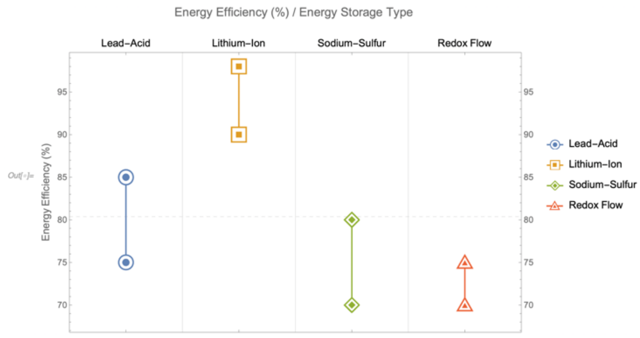

Figure 11: Energy Efficiency (%)

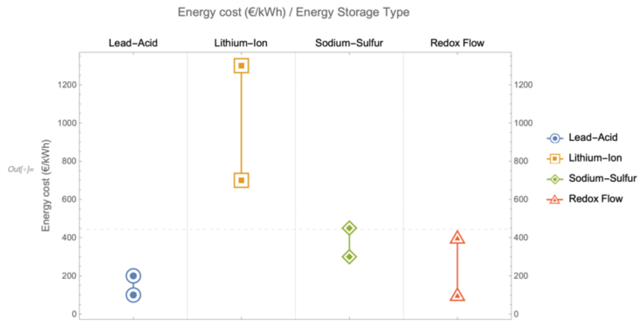

Figure 12: Energy Cost

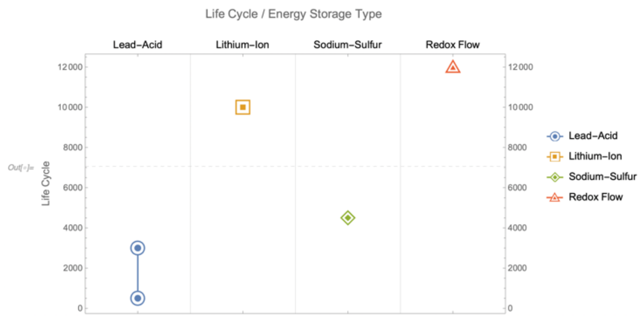

Figure 13: Cycle Life

6 Conclusion

In conclusion, it can be said that solar energy is one of the most promising renewable energies but has so far lacked efficient storage to make it the leading energy provider. In Austria, only 1.9% of the energy production is made with solar power even though there is a trend going toward renewable energy. This trend (of solar power being used significantly less) can be led back to insufficient storage methods. To ensure a transition from fossil fuels to solar energy not only in Austria but globally, it is vital to use the best-fitting storage method. As solar power plants are very versatile, they can be built practically everywhere which makes them great for international application. However, the biggest challenge is finding an optimized system for each individual solar energy production. This paper intends to get a step closer to optimizing energy storage and extending the usage of solar energy. It provides an insight into the different storage systems and makes an adequate and understandable comparison to demonstrate how useful solar energy can be if it is equipped with the right additional technologies.

Even if the start is just extending solar energy within Austria where there is already a trend of using more sustainable energy sources, it is already going to have an impact on the rest of the world: Austria will have to import less non-renewable energy from other countries and will be able to export solar energy. This will shrink the usage of non-renewable energy in Austria and other countries Austria could export to. Ideally, the stakeholders in other countries will then see the benefit of solar power application when using it in combination with an optimized storage system and incorporate it into their own energy transition. It is vital to extend the renewable energy sources which are not prevalent right now (like solar energy) to ensure that renewable energy takes over fossil fuels within the next few years.

For a bigger impact, the future goal of this simulation is to be made into an open-source material available globally. This will further promote solar energy and energy transition. To be able to do this the simulation needs to be further developed and more factors will need to be added to achieve more concise results. It could also be considered extending this simulation to include other renewable energy sources as storage is the key to a functioning energy system that differentiates itself from fossil fuels and other non-renewable sources.

Wordcount: 4494

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Appendix

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Figure 9: Created by the Authors.

Figure 10: Created by the Authors.

Figure 11: Created by the Authors.

Figure 12: Created by the Authors.

Figure 13: Created by the Authors.

Table 1: Created by the Authors.

GALESS 2023

African Leadership Academy

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Research Abstract

Over the last two decades, Morocco has made advancements toward achieving 100 percent electrification for its residents and developing towards 40% renewable energy generation capacity. Despite having a large renewable energy potential capacity, 90% of the country's energy needs are met by imported fossil fuels like coal and oil. This dependency pushes it to number 11 in African countries ranked by emissions. Being a country that lies in a geographical global warming hotspot, it should take actionable steps to reduce its carbon footprint and realize its renewable energy potential. This transition would be beneficial to the country's seeing its exponential growth in energy demand, the country's 2040 carbon emission trajectory, and the expense it has endured from coal imports. This transition will lower its emissions, wean the country from its dependency on imports from Russia, and promises significant economic, and social benefits. On the economic front, it will create jobs, boost sub-economies, and set up Morocco as a hub for renewable energy investment. The reduction of its carbon footprint will improve its international reputation and strengthen its trade relations. Socially, the energy transition will improve rural electricity access, reduce energy inequality, and potentially lower electricity prices. Overall, Morocco's energy transition is a step toward sustainable development that will set up Morocco as a global leader in clean energy. Consequently, this paper evaluates the country's existing energy systems and proposes an actionable plan to harness the country's renewable energy potential to help it become a self-sustaining green community.

Population and Energy Consumption in Morocco

Morocco with a population of approximately 37.08 million people, ranks as the 11th most populated African country and heavily relies on fossil fuels for electricity generation. In 2019, its energy consumption reached 33.63 billion kilowatt-hours (kWh) accounting for 0.14% of global energy consumption. However, according to the International Energy Agency, Morocco has made significant strides in increasing its energy capacity, particularly in solar and wind power. As a result, the country has consistently exceeded electricity production over consumption since 2015, with a surplus in electricity generation.

Electricity consumed every year per capita was estimated at an average of 1,237 kilowatt-hours (kWh) in 2019, according to the World Bank. Morocco, June 2022. As for the cost of electricity, households paid 0.114 U.S. Dollars per kWh, while businesses paid 0.105 U.S. Dollars per kWh, inclusive of all components such as power, distribution, and taxes. Notably, Morocco is a country that has managed to give access to electricity to everyone even in remote villages in the country. Given that the gross salary range for people working in Morocco in Electrical & Power Engineering is typically from 1,408 MAD (136,66USD) (minimum salary) to 4,764 (462,40) MAD (highest average, actual maximum salary is higher), the affordability and the widespread distribution of energy is one that has commendable improved public lives.

Morocco's progress in renewable energy.

Morocco has set an ambitious target to source at least 52% of its total installed power capacity from renewable sources by 2030. This goal was announced during the 21st Session of the United Nations Framework Convention on Climate Change Conference of the Parties in 2015 ("Morocco Renewable Energy Target 2030 – Policies" 2019). This goal was a reflection of the 2017 energy statistic where fossil fuels accounted for over 80% of the country's electricity generation. Wind accounted for 9%, hydroelectricity 5%, and solar 1%. making the generation of electricity from renewables notably low in the country. Seeing that the country heavily relies on imports for 89.4% of its primary energy needs and 17% of its electricity needs, as its indigenous production of fossil fuels is negligible. Due to this devastating reality, Morocco has made significant progress in expanding renewable energy capacity with 1.22 GW of wind capacity and 711 MW of solar capacity in 2018.

Energy Consumption and Generation in Morocco

In regard to energy consumption, the transport sector is considered Morocco's most energy-intensive sector, consuming 34% of the country's total energy output, followed by the residential (25%) and industrial sectors (21%). Furthermore, there has been a consistent increase in Moroccan energy demand observed across all sectors with Industrial energy consumption has been growing by more than 40% between 2004 and 2014 and has sustained a growth rate average of 4.38% per year. It is projected that Morocco's energy demand is expected to rise by approximately 5-6% annually, reaching over 30 Mtoe by 2025. Currently, the country's energy mix is dominated by oil (67.6% of the Total Primary Energy Supply), followed by coal (16.1% of TPES), biofuels and waste (7.4% of TPES), and natural gas (5.7% of TPES). Electricity imports 2.2% of TPES and renewable energy (RE), such as hydro power 0.7% of TPES and wind 0.3% of TPES, only contribute marginally to the TPES (IEA, 2014, p. 17)

Morocco's Carbon Footprint

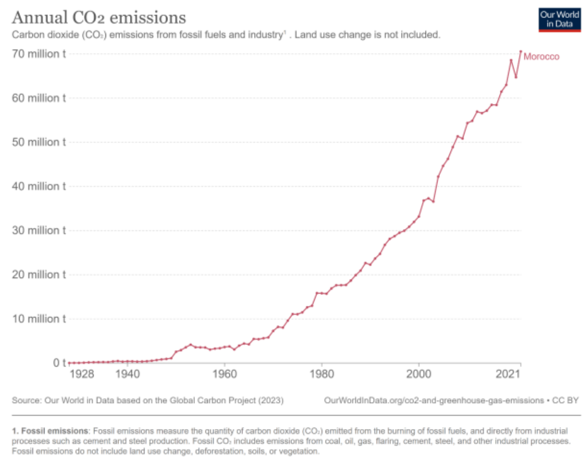

Figure 1.1 shows Morocco's long-term annual carbon emissions

Between 2007 and 2017. energy-related CO2 emissions increased by 2.4% per year in total and 1.0% per capita. Coal and other solid fossil fuels, the primary category of fossil fuels used in Morocco, accounted for 33.3% of CO2 emissions from energy use in 2017, up from 30.7% in 2007. However, non-combustible energy sources, like wind and solar in Morocco, accounts for 4.9% of primary energy use in 2017, up from 2.7% in 2007.

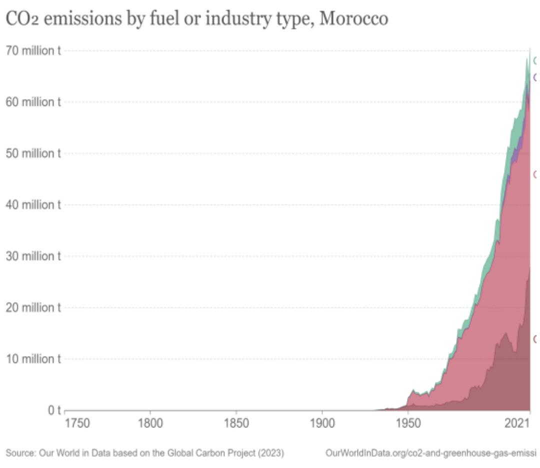

Fig1.2 Carbon emissions by fuel type

Morocco, as a net energy importer, has set an unconditional target to reduce its Greenhouse gas (GHG) emissions by 17% by 2030, compared to the business as usual (BAU) scenario. The country's tax-to-GDP ratio of 27.6% is lower than the OECD average1 of 33.9% but higher than the Latin America and the Caribbean (LAC) and Africa averages of 22.8% and 17.2%, respectively.

Morocco has made remarkable progress in ensuring energy access for its population. Having achieved 100% electrification, the country has established sustainable objectives to fulfill its low-carbon and environmentally friendly energy targets. Morocco utilizes solar energy, hydroelectric power, and wind energy to accomplish these goals. Its advantageous location in a sun-rich region enables it to harness three times more solar energy compared to a similar power plant in Europe (Birnbaum, 2023). Notably, Morocco is home to the Noor Ouarzazate complex, the world's largest concentrated solar power plant. However, this complex is currently underutilized, leading to heavy dependence on fossil fuels. Maximizing the capacity of existing plants, along with establishing more large-scale solar plants, can bring about a significant change. At its full capacity, the Noor Ouarzazate complex alone can produce 2,702 gigawatts of energy, surpassing the current output of 510 megawatts (Birnbaum, 2023).

Challenges in Transitioning to Renewable Energy and Strategies for an effective transition.

Additionally, the country should look into defunding the importation of coal briquettes from Russia. As of current, Morocco invests over 935 million dollars in the importation of coal from Russia alone(*Coal Briquettes in Morocco | OEC*, n.d.). Defunding the coal trade will make funds more available for progression towards a greener society.

Despite Morocco being seemingly economically stable enough to sustain a transition further into renewable energy, the transition will come with a few challenges for the Northern African country. The first is, Morocco has built a lot of eco-political relationships through trade with global powers like Russia. The strength of this partnership may pose difficulties in maintaining relationships and Morocco may lose international recognition due to reduced trade partnerships with global powers like Russia and China.

Moreover, Morocco will need to employ more people to man the power stations and invest money in restructuring energy distribution systems such as pylons and cabling. The compatibility of transformers may change resulting in a need for partial or full replacement of infrastructure to cater to the rising renewable energy production. Hence Morrocco will need to invest a substantial amount of time and money in restructuring the energy distribution system.

Lastly, it is important to acknowledge that moving towards renewable energy will mean the already existing energy stations and systems may be shut down or restructured. These systems employ over 8000 people, and defunding the coal industry would mean employees qualified to work the coal power stations are at risk of unemployment as the transition to a different system needing different skillset proceeds (Acuna, n.d.). The transition will bring about social challenges as people are displaced to make space for large-scale solar stations that take up a lot of space or they are forced to migrate due to the geographical shift in the availability of work.

Morocco however has great potential to transition effectively despite these challenges. To do this Morocco first needs to secure funding for its large-scale projects by allowing private institutions to engage in power distribution. By doing this, the government disburdens itself and decentralizes energy production and distribution.

Morocco should also provide stipends or incentives to households, farms, and institutions running on renewable energy. These could come in the form of tax credits to incentivize the transition and motivate civilians to increase the electricity supply from green energy. They could take the Indian 2015 tax credit as inspiration that increased renewable energy use by allowing quick recovery of expenses within the first year on renewable energy (Bahadur, n.d.). To ease the transition from coal dependency on the citizens, Morocco could replicate the 2014 energy policies that phased out diesel subsidies (Yaakoubi et al., 2014). By phasing out subsidies for coal, oil, and gas as they did for diesel in 2014, they reduce household incentives to remain fossil fuel dependent. Alternatively, they should seek to offer incentives like tax credits to subsidize households and companies that use solar energy so as to wean the citizens from foreign hydrocarbons.

The government should offer job transition training to former coal station workers so as to allow them to successfully transition to the changing workforce demand. It is evident that the transition to renewable energy will bring rise to new employment in construction, service provision, and system maintenance (Tyson, 2021). The government should utilize this opportunity to offer skill training to former coal station workers and youth interested in energy to provide a skilled workforce for the transition. This could ease the social implications of such a systematic change whilst also tackling the country's 25% youth unemployment rate (*Unemployment, Youth Total (% of Total Labor Force Ages 15-24) (Modeled ILO Estimate) - Morocco | Data*, n.d.).

Morocco in the international realm.

Despite the challenges faced by Morocco during its transition to renewable energy, the country's achievements in electrifying the entire nation, increasing the proportion of green energy in its energy generation, and implementing national reforms have positioned it as a standout among developing countries in the race against climate change. Morocco has become a role model and a significant contributor to Africa's energy transition. Its progress in the field has also attracted the attention of wealthy Western countries, leading to partnerships and investments in its renewable energy projects.

I - Building a distinguished reputation and accumulating foreign investments:

Morocco's successful implementation of notable renewable energy projects, including the Tarfaya Wind Farm, the Ain Beni Mathar Integrated Solar Thermal Combined Cycle Power Station, and over 25 hydropower plants, has propelled the Noor project (the Ouarzazate project) into the spotlight. The Noor project is the world's largest concentrated solar plant and has attracted more than $9 billion in investments (Neslen, 2016). The reputation that Morocco has cultivated as an initiator and innovator in green energy has enabled it to secure funding for the project from international organizations and leading countries. Major financial institutions such as the World Bank, the African Development Bank, and the International Bank for Reconstruction and Development have contributed to the project's funding. Moreover, companies from around the world, including the Chinese Shandong Electric Power Construction, the Spanish Acciona, and the Saudi Arabian ACWA, have also invested in the Ouarzazate solar station (Haddad et al., n.d., #400). These flagship projects, along with numerous successful green initiatives, have attracted additional investments to Morocco. In 2018, Qatar invested over 700 million euros in Moroccan electricity as part of its investment strategy in the country, which is valued at over a million euros (Africa: Following Morocco's Renewables Lead, n.d.). Furthermore, by 2022, more than 60 Moroccan green projects had attracted over $5 billion in investments since the beginning of the country's transition to green energy (Africa: Following Morocco's Renewables Lead, n.d.). In 2023, the European Union invested over 100 million euros as part of a 634 million euros cooperation program to support Morocco's renewable energy transition, with a particular focus on entrepreneurship, agriculture, forestry strategies, and social support for workers in the field (Africa: Following Morocco's Renewables Lead, n.d.). Morocco has also provided loans of 80 million euros through the MorSEFF (Morocco Sustainable Energy Financing Facility) from four international financial institutions: the AFD (Agence Française de Développement), the EIB (European Investment Bank), the EBRD (European Bank for Reconstruction and Development), and the KfW (Kreditanstalt für Wiederaufbau). These institutions are committed to enhancing initiatives and providing free technical services to support Morocco's green transition (International Support for Sustainable Energy Investments in Morocco – GEFF, n.d.).

II - Morocco: A leader in Africa’s transition towards green energy:

Morocco has made significant efforts to facilitate skill-building in the field of renewable energies and equip its workforce with the necessary expertise and knowledge for renewable energy projects. It has recently established three Training Institutes for Renewable Energy and Energy Efficiency in the regions of Oujda, Tangiers, and Ouarzazate. With experience in providing training in renewable energies and energy efficiency, thanks to its successful projects and substantial support from the EU in terms of both financial assistance and technical support, Morocco is committed to sharing knowledge and building capacities in renewable energy across Africa. The Moroccan International Cooperation Agency launched several training programs in Africa during COP22. Furthermore, Morocco has played a pivotal role in supporting other African countries during their transition to renewable energy. In 2018, the country organized training workshops in Marrakech focused on the theme of "Renewable energies and energy efficiency for decentralized electrification and solar pumping in Africa." Through these workshops, Morocco aimed to share its expertise and knowledge with other nations in the region (Ngounou, 2018).

One such country that Morocco has been supporting is Senegal. During COP24, both nations signed a memorandum of understanding in which Morocco committed to assisting Senegal in waste disposal and green energy initiatives, strengthening their cooperation in sustainability (Ngounou, 2018).

Moreover, Morocco has taken the lead in the "Desert to Power" initiative. This project aims to help African countries in the Sahel region develop renewable energy technologies that are specifically adapted to their unique environmental and climate conditions (Renewable Energy in Africa, 2018). By spearheading this initiative, Morocco demonstrates its commitment to fostering regional collaboration and driving the continent's sustainable energy transition.

Conclusion

Overall, Morocco's efforts extend beyond its own borders, as it actively shares knowledge, provides support, and initiates projects to accelerate the adoption of renewable energy solutions across Africa. Through these endeavors, Morocco solidifies its position as a leader in Africa's transition towards green energy.

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The Future of Electric Batteries and Transport Transformation

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ABSTRACT

Nowadays we are seeing how more and more car production is increasingly moving towards electric vehicles in order to substitute those with internal combustion engines and which use petroleum-based fuels. However, an increasing number of news sources are raising doubts as to whether the processes involved in the obtaining and production of electric batteries are really so ecological and are truly a significant reduction in pollution and contamination of our environment. Our project will consist of investigating the differences between pollution emitted during the production process in order to obtain electric batteries and the corresponding reduction in pollution compared to the amount of pollution emitted during a comparative lifetime of an internal combustion engine. We shall carry out an academic investigation from scientific sources and through personal interviews with experts in the field. We aim to determine whether electric batteries are indeed as "green" as companies state, which will truly help us to have a brighter, cleaner future or if industry is
simply pushing the pollution down the production chain.

Key vocabulary: *batteries, lithium, electric vehicles, pollution, cobalt*

1. Introduction

1.1. Ecology

Electric vehicles bring numerous benefits to society, primarily by significantly reducing CO2 emissions and minimizing acoustic pollution. Unlike gasoline-powered cars, electric vehicles produce only 0.7kg of polluting gasses per 15km, as opposed to the 2.4kg emitted by their conventional counterparts. **[1]**
According to a 2013 report by the World Wildlife Fund (WWF) on Greenhouse Gas Emissions, road transportation accounts for approximately 22% of total pollutant emissions. This statistic underscores the positive impact of electric cars, as highlighted by a 2014 study conducted by the World Health Organization (WHO). The WHO study estimated that around 2.7 million premature deaths occurred worldwide in 2012 due to atmospheric pollution caused by vehicle emissions. The fatalities were predominantly linked to cardiovascular, respiratory, and cancer-related diseases. **[1]**
To ensure the effectiveness of this transition, it is crucial that electric power is sourced from renewable alternatives such as wind energy, rather than traditional electricity production methods. The WWF report indicates that wind power contributes to 24% of greenhouse gas emissions.
Moreover, surplus energy generated by wind farms during nocturnal periods could be

harnessed to recharge electric vehicles, taking advantage of decreased energy demand and creating a notable dip in the consumption curve. This approach not only addresses the disparity in energy requirements but also maximizes environmental benefits. **[1]**
While it is worth noting that the pollution associated with electric vehicles primarily stems from battery factories located away from urban centers, in contrast, internal combustion engines emit harmful gasses directly within city cores. However, concerns surrounding the recycling of batteries, such as lithium-ion batteries, which can only be processed by a limited number of organizations, remain a significant environmental consideration, despite their potential for reuse. **[1]**

In terms of noise pollution, electric vehicles offer a distinct advantage over their traditional counterparts. Internal combustion engines generate noise through exhaust emissions and the combustion process itself. In contrast, electric car motors operate silently, especially at lower speeds. However, this inherent quietness can pose a challenge for pedestrians in detecting approaching electric vehicles. Consequently, the European Commission is actively exploring the incorporation of acoustic warning systems in electric vehicles to enhance their detectability and ensure pedestrian safety. **[1]**

The DGT environmental label identifies electric cars as zero-emission vehicles. However, the truth is that they still have a significant impact on the environment, both during production and when it comes to recharging and recycling at the end of their life cycle. **[2]**
While electric cars do not emit CO_2, carbon monoxide (CO), nitrogen oxides (NO_x), or particulate matter (PM) during operation, achieving emissions neutrality remains the primary goal. Currently, electric cars do emit less pollution than internal combustion engine vehicles. **[2]**

Volvo previously stated that the production of electric cars had a significantly higher carbon footprint compared to gasoline cars. However, this discrepancy is offset by the lower emissions generated during their lifespan. **[2]**
The majority of pollution associated with electric cars stems from battery production. **[2]**
Focusing on Volvo cars, the production of materials for the Volvo XC40 generates around 14 tons of CO_2, while the C40 Recharge produces 25 tons. **[2]**

1.2. Offsetting the carbon footprint is crucial.

The use of renewable energy sources such as wind and solar power can reduce dependence on fossil fuels, thereby significantly reducing greenhouse gas emissions. Additionally, promoting the use of recyclable and recycled materials, especially for internal components of the vehicle, is essential. The Linux Animal serves as a good example, being the first bio-based electric car. **[2]**
Planting trees could be considered to offset those unavoidable emissions, at least for the time being. Although recent events show that large corporations overestimate the impact that these measures actually have on the environment, and are simply a “greenwashing” strategy used by large corporations to improve their public image. **[2]**

1.3. Charging process pollution

Electric cars rely on charging stations connected to the electric grid. The environmental impact of this process varies depending on the energy source used. **[2]**
Recent data from Green NCAP, a scientific laboratory that assesses the environmental impact of cars in Europe, shows that in Spain, the production of 154 grams of CO_2 occurs per 1 kWh of electricity. As a result, a battery with a capacity of 50 to 60 kWh can generate an average of 7 million tons of CO_2 over its lifespan. The source of the electricity

significantly influences the amount of pollution. **[2]**

To mitigate this, there is a focus on using renewable energy sources, particularly solar power, to reduce the environmental impact of charging. Examples include integrating solar panels into electric cars to increase their autonomy and reduce the need for frequent charging, as well as establishing self-consumption systems linked to charging points. **[2]**

Some alternatives used to minimize this problem include wind energy, and to a lesser extent, geothermal and hydroelectric power. **[2]**

1.4. End-of-life cycle

The end of the battery's life cycle is a critical period when its environmental impact increases significantly. As mentioned before, the battery is the primary source of pollution. There are currently two primary options to maximize their usage. **[2]**

1. Since some electrical devices do not require high power, they can still function properly even with slightly degraded batteries. Therefore, reusing batteries in these devices before disposal is a viable option.**[2]**
2. Additionally, research can be conducted to improve the extraction process of potentially harmful materials, allowing for better recycling practices. Recycling steel and cables would help reduce pollution, while lithium and nickel can be reused to manufacture new batteries. **[2]**

1.5. Dependency on third countries

The European Union relies on third countries to obtain critical raw materials. Significant lithium reserves are found in Chile, Australia, and Argentina; manganese reserves in South Africa, Ukraine, and Brazil; cobalt reserves in the Republic of Congo; nickel reserves in Indonesia and Australia; and graphite reserves in Russia and China. **[3]**

These mines are sometimes located in countries with stricter environmental and social regulations than those in Europe (i.e. Australia and Chile). Therefore, the environmental footprint of mining would be lower if it were developed within Europe. Cobalt extracted from artisanal mines in the Republic of Congo, on the other hand, is known for its negative environmental and social impact. Extraction and exploration projects are currently on hold in Europe due to political reasons.**[3]**

We cannot ignore, as well, the political impact of the concentration of primary materials in a very limited number of countries. There is a real danger of an exploitation similar to the imperial colonialism that took place in Africa and Central/South America up to the mid 20th century. The economic interests of 1st world countries may cause a further deterioration of quality of life in these countries that produce cobalt and lithium, for example. **[3]**

1.6. Important data and information

Batteries have a lifespan of 6 to 8 years. If they are not recycled, the amount of waste generated would be unsustainable. Unfortunately, according to the European Union, currently only 5% of batteries are recycled, while the remaining 95% ends up in storage or is destroyed, which is not sustainable.**[3]**

Recycling is a complex process, but efforts are being made to automate it. This will improve the protection and safety of workers as this process can be dangerous. Recycling is becoming safer every day in this regard, making it an essential activity to reduce dependence on raw materials. With proper recycling processes, it is feasible to reuse around 70% of the battery's most critical elements.**[3]**

Electric vehicles have superior energy efficiency compared to those using fossil fuel-derived sources. Electric motors provide 100% of their latent power instantly and batteries are able to generally provide 100% energy delivery to the motors till depletion. **[3]**

European regulations stipulate that at least 40% of electricity generation must come from renewable sources. As a result, the effects on air quality and climate will be more positive, though a reduction in CO2 emissions from the vehicles.**[3]**

Considering production, the energy required for operation, component wear, and recycling, the European Environment Agency (AEMA) argues that electric vehicles can reduce greenhouse gas emissions by 17% to 30% compared to internal combustion engine vehicles. As renewable energies become more widely used and technological advancements improve, the percentage of pollution will significantly decrease.**[3]**

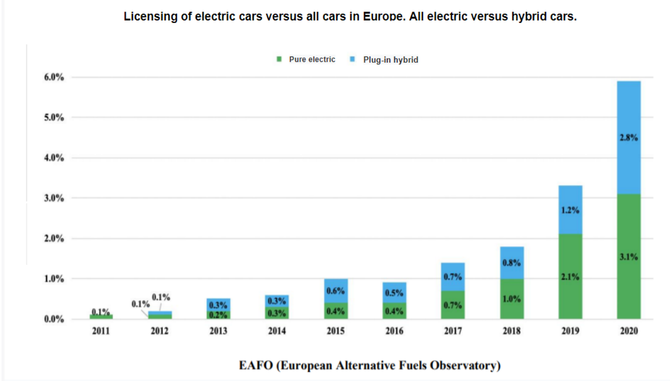
The projections of the European agency are encouraging: by 2050, it is estimated that the adoption of electric vehicles will reduce at least 73% of total carbon dioxide emissions associated with transportation. **[3]**

1.7. Acquiring an electric vehicle

2. Background material

Currently, electric cars have given us something that seemed impossible in the past: a safe and eco-friendly way to travel. **[4]**

However, in order to gain a larger market share, they need to improve. They should focus on enhancing battery life, increasing autonomy, and making charging points more accessible. Electric cars make up 5.9% of the total number of registered cars in Europe right now. But there is a growing interest among people to buy cars with these features. Recent graphs have shown a significant increase in the purchase of electric cars in the past few years. **[4]**

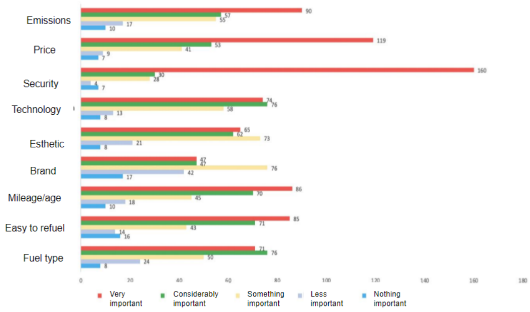


- When we compare them to traditional fuel-powered cars, we can see that electric motors are more efficient. The passive regenerative braking system converts energy during traffic stops, which minimizes battery usage. Electric cars are clean, simple, comfortable, and quiet to drive. The maintenance costs are also about 40% lower than traditional cars because they don't require oil changes or air filter replacements. This reduces production and maintenance expenses, benefiting both manufacturers and customers. **[4]**

Type of batery	Lifecycle	Density (Wh/Kg)	Need maintenance	Advantages	Disadvantages
Lead-acid	500-800	30-80	Yes, and periodic	Lower acquisition cost Efficient at low temperature	They're heavy Lead is toxic Slow loading
Nickel-cadmium (NiCd)	1500-2000	40-60	Yes, but less than lead-acid	Fewer failures compared to lead-acid Can be fully recycled	High acquisition cost Has memory effect It's polluting
Nickel-metal hydride (NiMh)	300-500	30-80	Yes and often	Has less memory effect than Nickel-cadmium	Less reliable than nickel-cadmium Does not support strong discharges and high charging currents It is not resistant to high temperatures
Lithium-ion (LiCo02)	400-1200	100-250	Does not require	High energy density Small size and light weight High efficiency and has no memory effect	High production cost It's fragile Need for safety circuit Need for careful storage
Lithium-ion with LiFeP04 cathode	2000	90-100	No	Greater security Greater stability Higher power	Higher energy density Higher acquisition cost
Lithium Polymer (LiPo)	1000	300	No	Higher energy density lighter More efficient	Very high price Short life cycle

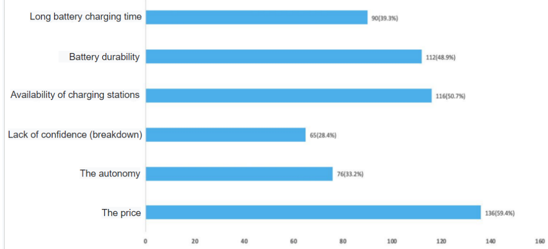
Since electric cars have fewer mechanical components, the chances of breakdowns are significantly reduced compared to traditional combustion engines. It is true that the initial purchase price of an electric car is higher, but the energy costs are much lower. Additionally, electric cars can reduce the impact on global warming by up to 24% compared to traditional combustion cars. However, it's important to note that the manufacturing process of batteries and motors for electric cars has a negative impact on the environment. Therefore, having more charging points available is crucial to incentivize the purchase of electric vehicles. People require the convenience of charging points as frequently as petrol stations are currently. **[4]**

- According to surveys, among people interested in buying a car, 21% of consumers are leaning towards electric vehicles, and over 50% are considering hybrid cars. However, consumer perception regarding electric cars and batteries varies based on factors such as age, gender, occupation, and family situation. More than 80% of the population considers electric cars as the future, but there is still a portion of the population that prefers traditional combustion engines. They value diesel or
- gasoline cars because they perceive them as more
- durable, affordable, and reliable, despite being more polluting and noisy. **[4]**
- A recent study shows however that safety and price are the main factors that influence the decision to buy a car. **[4]**



On the other hand, the factors that may discourage the purchase of an electric car include the price, battery durability, low range, and long charging times. **[4]**

Currently, lithium-ion batteries are the most stable type used in electric cars, as this type of battery is the safest, and the one that people value the most. **[4]**



2.1. Preliminary Conclusions

The demand for electric cars is increasing every year in the Spanish and European markets. However, compared to traditional combustion engine cars, they still have some significant disadvantages. According to surveys, electric cars are considered the cars of the future, but consumers are not fully ready to make this change in the short term. The selling price of batteries needs to improve to make electric cars more appealing. As technology evolves and market conditions improve, manufacturing costs will be standardized. This will increase the supply of electric cars and reduce the acquisition costs for consumers. **[4]**

3. The Manufacturing Process of Lithium Batteries

To understand our work better, let us first take a look inside the manufacturing process, specifically the steps involved in producing electric cars. **[5]**

There are three main phases in this process:

- **Electrode Manufacturing:** The electrodes can come in different formats like pouch, cylindrical, or prismatic. Regardless of the format, the first step is to produce two coated sheets called electrodes. The key focus in this phase is to avoid contamination. Gigafactories **[5]** play a crucial role here, as they are large-scale battery manufacturing facilities capable of storing gigawatt-hours of energy. These factories have two identical production lines: one for the anode, where oxidation occurs, and the other for the cathode, where reduction occurs. Within this phase, there are four activities that determine the production of electrodes: **[6]**

    - Mixing: During electrode production, there is a mixture called "slurry" that serves as the initial step and is essential for the final result. This slurry combines active materials in powder form with a liquid solvent to create a paste. **[6]**

    - Coating & Drying: Once the slurry is formed, it is transported through pipes to a priming area, where it is applied to a metal substrate or coil. The coated coil then goes through a drying oven to evaporate the solvent. These drying ovens can be up to 80 meters long. **[6]**

    - Calendering: After drying, the coated coils go through a finishing process known as calendering. In this step, the coils pass between two heated rollers, which compresses the material to achieve better adherence, consistent thickness, and desired density. **[6]**

    - Slitting: Slitting is the first cutting process in which the coils are cut into strips of individual electrodes. After calendering, the coils pass through a set of blades that narrow them down to the final design size. **[6]**

- **Cell Assembly (Dry Room):** After electrode manufacturing, the next step is cell assembly. This phase must take place in a dry environment to prevent moisture marks on the electrode. The electrodes pass through vacuum ovens to eliminate moisture, and the storage environment is climate-controlled. This controlled environment is known as a "dry room" and is maintained at around -40°C. **[6]**

- Within this stage, the electrodes are cut to size and placed into their casings. The specific activities in th63is phase can vary depending on the cell format (pouch, prismatic, cylindrical): **[6]**

- Notching: For pouch-type batteries, this step involves cutting the coils into individual electrodes for the cells. A machine unrolls the coil and produces rectangular-shaped electrodes. The cutting can be done mechanically or using lasers. **[6]**

- Stacking: After the second cutting, the cells are stacked together. This is the first stage where the cathode and anode lines are combined. The common stacking method is in a Z-shape, where the separator is folded in a zigzag pattern. Alternatively, lamination stacking can also be used, where each layer (separator, anode, separator) is stacked alternately with the cathode layers. **[6]**

- Pouch Assembly: After stacking, a welding process takes place. The cell is inserted into its packaging, leaving one edge open. The package is filled with electrolyte and sealed under vacuum using the open edge. The product is then soaked for hours before proceeding to the next step.**[6]**

- **Formation, Aging, and Validation:** Once the cell is packaged, it goes through a conditioning process known as Formation, Aging, and Testing (FA&T). This phase involves evaluating the cell's characteristics and performance. The duration of this stage can span weeks as every detail is carefully observed. At the end of this final stage, the finished cell is obtained.**[6]**

3.1. Preliminary Conclusion

We have seen the various phases and steps involved in electric battery manufacturing, which gives us an idea of the possibilities this technology offers in terms of environmental impact and sustainability. Over time, improvements are expected through ongoing testing, such as reducing waste residues resulting from the process. In summary, battery manufacturing is a complex process with many considerations. The materials used for lithium batteries include lithium iron phosphate alloy, lithium cobalt alloy with nickel and manganese, and high-quality lithium cobalt nickel aluminum oxide alloy. **[6]**

4 Final Conclusions and Recommendations

4.1 COBALT –Blue Gold

Some companies consider cobalt as the "new gold" of today. For example, a mobile phone contains around 5 to 10 grams of cobalt, while a battery can have up to 15 kilograms. Although cobalt production is facing a decline, the demand continues to increase. Cobalt has the quality of enhancing other metals like lithium, which is the most commonly used element in batteries. This property makes the batteries more durable and affordable. **[7]**

In the past, more cobalt was produced than consumed, but with the rise of electric cars, its price and interest have skyrocketed. However, efforts are being made to improve the cobalt manufacturing process, including calculating the waste residues generated. **[7]**

As a result, the mining of cobalt and its use in the production of lithium batteries is a major issue in pushing the pollution problem up the chain. Cars may be “emission free”, but the emissions are simply released into the environment earlier during the production process and later on in the recycling (or not) of the vehicles and their batteries. **[7]**

4.2. The future

There will probably never be a truly emission-free transportation system, but we are clearly on the right track. The primary obstacles that need to be overcome lie with:

1. Improved convenience and safety in the use of electric vehicles. The governments must play a primary role in incentivising the development of a grid that can deliver green electricity to a wide network of public and private charging stations. As well, manufacturers need to overcome stigmas associated with the danger of lithium-ion batteries, which have been associated with fires, injuries and deaths.

2. New types of electric batteries that come from plentiful and easily accessed sources, such as salt and salt water, are absolutely necessary if we wish to transition from hybrid and current electric batteries that are highly reliant on “dirty” mining practices and generally in third-world countries where human exploitation is rampant.

3. Overall cost is a significant impediment to a more widespread purchase and use of electric cars. All electric vehicles are not cheap, only accessible to the wealthy.

In conclusion, the burden of change falls on the shoulders of the government authorities to incentivize electric vehicles. The overall sentiment is that the general public is more than willing to purchase and use electric vehicles. Nevertheless, substantial public and private investment schemes are crucial to pave the way towards a future that is free of non-renewable energy powered vehicles.

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Energy in the Netherlands

Abstract

In 2015, the Netherlands, just like almost all the countries in the world, signed the climate agreement of Paris. The goal is that the temperature does not rise more than 1,5 °C above the temperature pre- industrial era. The CO2 emissions must therefore peak in 2025 and be reduced at least 43 percent before 2030. The Netherlands is still using a lot of carbon-based energy sources, and we will make a plan for transitioning these polluting energy sources. We have asked our questions to Dutch researchers, and have mainly focused our research on water energy, more specifically tidal energy, because in the Netherlands water always was, and will always be, an important piece of our lives.

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Summary:

In the Netherlands we are very aware of our pollution. And we're trying hard to reduce it. Even though we are a small country we need a lot energy, because we are very densely populated. So it's very hard to find one non carbon based source. In this research will be investigating multiple non carbon based sources and what they can mean for our country and other countries.

What sources of energy are currently available?

There are a lot of energy sources available in the Netherlands. A lot of them also already are sustainable energy sources, but there still are some traditional ones.

Sustainable sources

- Wind energy

In the Netherlands there are a lot of wind turbines in use. These wind turbines collect a lot of electricity, in a more climate neutral way than using fossil fuels. Most of them are placed at sea, because of the strength of the wind. At places like meadows there is less wind, which leads to less energy from wind turbines. At sea there is way more wind, which makes it more convenient to place the turbines at sea. [1]

- Solar energy

Placing solar panels on the roof of houses is getting more and more popular in the Netherlands. This makes it easy to use the energy that comes from the panels, because everyone can use the energy from their own panels. Solar energy is sustainable, which means it is for a big part free from greenhouse gases and it never runs out. It is not completely free from greenhouse gases, because for the making of the panels there still is a need for those gases. To encourage the use of solar energy, the government gives energy tax rebate to people who place their own solar panels [2]. If these people have surplus energy from their panels, they can send the energy back to the grid. They get credit for this energy. It also is possible that the panels sometimes will not collect enough sunlight to make the amount of energy the users of the panels need that day, like days in the winter or cloudy days. This makes it difficult to use this as the only energy source, so this energy source has yet to be combined with another or more other energy sources.

- Power of water

The Netherlands is a place with a lot of water on its sites. This makes the power of water a great change to use more sustainable energy. This energy source isn't a big thing yet. It is being used a little bit already, but to make it a bigger energy source there needs to be enlargement. There are several ways to get energy out of water. Think of tides energy, or a hydroelectric power station.

- Air and soil heat

This type of source is slowly becoming more popular in the Netherlands. The heat in the air and soil is used to warm up houses, using an electric heat pump. It is not the main source yet, but it would be a great option to use as a big source. A lot of houses could be warmed with this heat, which is way better for the environment.

- Biomass

Biomass is an energy source used for gas and electricity. It is made of manure, which consists of vegetables, fruit, and garden waste, but also wood. Because the CO_2 that disappears into the atmosphere during combustion has only recently been absorbed from the atmosphere during the growth of the plants or trees, there is a closed CO_2 circuit.

Traditional energy sources

- Gas

Gas is the biggest energy source in the Netherlands. Almost half of the energy sources used in the Netherlands is gas, which is a lot. It is used a lot at power stations, mostly to absorb peaks and troughs in the power supply. Gas is also used a lot to warm up houses. However, to save the planet we need to reduce the use of gas. [3]

- Coal

Coal also is a big energy source in the Netherlands. This is because it is ridiculously cheap. Unfortunately, it is also one of the most harmful energy sources. Due to the toxic substances released, it's bad for the environment. Most of the substances are already taken out of the air in carbon power stations. CO_2 is not, that is too much work which would make carbon too expensive.

- Petroleum

Unlike coal and natural gas, petroleum is no longer used at power stations. It is more used to make plastics or used as petrol and diesel. This energy source also releases a lot of CO_2, which is why a lot of alternatives are being devised about how we can stop using petroleum. This is in the way of using electric cars and sustainable energy sources for planes.

How much and what type of energy is consumed?

In this chapter, we will search for what types of energy are produced and consumed in the Netherlands.

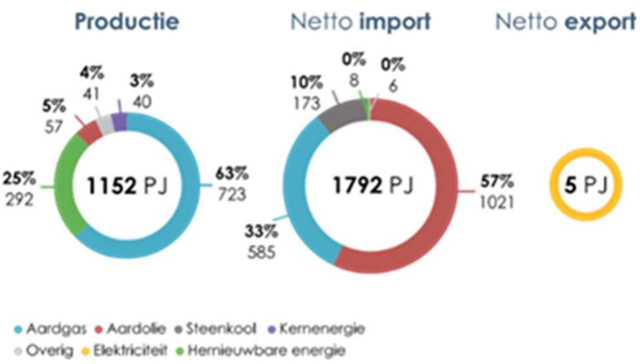

Image 1: graph of the used energy in the Netherlands by source, [3]

We can see in this graph what type of energy is produced and imported. We will now note and add up how much every type is in Petajoule (1 PJ is 277,78 million kWh)

Type of Energy	Produced: 1152 PJ	Imported: 1792 PJ	Total: 2944 PJ
Natural Gas	723 (63%)	585 (33%)	1308 (44.43%)
Petroleum	57 (5%)	1021 (57%)	1078 (36.6%)
Coal	0 (0%)	173 (10%)	173 (5.87%)
Nuclear Energy	40 (3%)	0 (0%)	40 (1,35%)
Renewable energy	292 (25%)	8 (0,44%)	300 (10,2%)
Other	41 (4%)	6 (0%)	47 (1.60%)

Table 1: used energy in the Netherlands, 2021

We found out how much energy is produced, but not how much is consumed.
In the same graph we found that only 5 PJ of energy got exported, only electricity.
We now know that the Netherlands consumed 2939 PJ in 2020.

What (if any) sources of energy are imported / exported?

The Netherlands is a rather small country for a population of 17,5 million people. We cannot produce enough energy to support so many people, so we import a lot of energy. In 2021 we imported 56% more energy than we produced.
Our latest reliable information is from 2021.
As you can see in figure 2, we imported 1792 PJ. 90% of this imported energy came from coal, petroleum, and natural gas. These fuels are polluting and have a lot of CO_2 emissions. They are bad for the environment and the climate. At a certain moment, these sources will be used up. By this time, the prices of energy will have increased. In 2021 our net export was 5 PJ, which is a small amount compared to our net import and production. How much of our exported energy is renewable or fossil is unknown. We do know that some of it comes from Natural gas. [3]

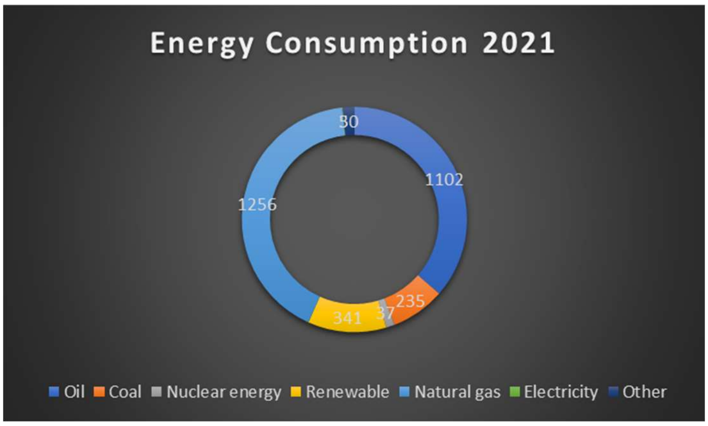

Image 2: Energy consumed in the Netherlands in 2021 [3]

Making an energy transition plan for the Netherlands.

We have interviewed Sam Lamboo from the TNO Delft, an applied research center, where he did research about the energy transition of the Netherlands, and who is currently working on research about energy production based on water. We have also interviewed Harm Jeeninga, who is the director Market at the Energy Transition and Materials unit at TNO. Both were useful for our research.

Our idea is to use multiple sources of renewable energy, and that when they work together, we do not need to use carbon-based energy sources.
We want to use multiple renewable energy sources because of the limitations of some and the downtime of others.

Tidal energy

Let's start with one of the first we would like to use; it all has to do with water. We will first build tidal energy systems in all places there can be. The research team from the TNO Delft, where Sam Lamboo was our contact person, already analyzed how much energy it could produce, it is between 1-3 TW of potential tidal energy, in the Netherlands. The development is already starting, and a company called Tocardo is already running a few test turbines [4]in the Oosterscheldekering, a dam in the Netherlands (image 3).

Image 3: the Oosterscheldekering in The Netherlands [5]

This project was already commercial, they built 5 turbines next to each other 10 years ago, but since then they have not built many more. The main idea behind tidal energy is the same as wind, but it uses the circulation of the water during the low and high tides instead of wind power.

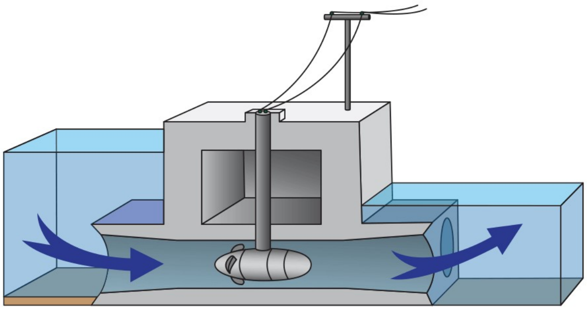

Image 4: How tidal turbines work[6]

Tidal Energy is captured with a turbine, it is a sort of dam built all the way to the height high tide usually is. You can see a sketch of it in image 4. There is an open tube at the bottom. In the tube is a turbine, that is connected to a generator. This generator is connected to the power grid or to a way to transform it into enough volts for the power grid. How tidal energy works is the following: Turbines are built, preferably in a small channel between two land masses. When the tide arrives, the water goes up in one part of the channel. All the water traverses the turbines, which makes electricity.

The main reason to use this system is what Ocean Energy Europe[7] says very well: "Tidal currents are not influenced by weather conditions, but only by the well-known cycles of the moon, sun, and earth. This long-term predictability makes tidal energy one of the most reliable sources of renewable energy available." Another reason for using tidal energy is that it will not block the view, because everything is underwater, unlike windmills that are above the ground.
For this reason, we would want to use tidal energy as a sort of solid base for our energy system.

Problems with tidal energy

Tidal energy, by itself, would not be able to generate enough energy for our country, but that problem we resolve by using other energy sources, that we will discuss later. Other problems and challenges we could encounter would be that not a lot of areas have a deep enough sea level to use the big turbines. Another challenge will be that the installation of the turbines is very risky. If it is built slightly wrong the turbine would break because of the amount of energy it would receive. The speed of the water is different everywhere, and you will need to configure it differently everywhere which is incredibly challenging. The last problem is that the tidal energy should be built close to where you need it, because transporting electricity can lead to losses, in the form of heat, in the transformers between the high voltage and low voltage cables.

Solutions for those problems

Researchers in this domain already thought about the fact that some places do not have a deep enough sea level, and they developed another smaller way, the Tidal Kite (see Image 5).

Image5: Tidal Kite, next to the Afsluitdijk, [8]

The kite is linked to a hydraulic cylinder, which is connected to a hydro motor and a generator that generates electricity from the movement. Next, there already are experts who know how to build the turbines. They have remarkably high success rates (only one failure since 2010, [9])and the more they practice, the better they become. Lastly, because we live in the Netherlands, the losing energy because of transport would not be a massive problem, because the country is small. Also, the energy cables are underground in the Netherlands, which makes it possible for them to be isolated better as the cables above ground. This is because you can fit more isolation per cable in the underground cables than in the above ground cables.

But with water as our only source of energy, our country wouldn't have enough. So, we've looked into some other carbon free energy sources. The two biggest sources would be wind and solar energy.

Wind energy

Wind energy would be generated by the use of windmills. You can place them almost anywhere and they cause very little harm to the environment. Also, the wind never runs out and is sustainable. But wind energy also has it's challenges. A lot of people don't want to live near windmills because they make noise, or they will ruin the view. And then there are animal activists that believe that windmills are super dangerous for birds. Researchers have already proven this to be a weak argument, because more birds die from windows than from windmills. But windmills are the most productive in an open field, where there are no buildings near to block the wind. So, you could just put all these windmills in the middle of nowhere and solve the problem? Easier said than done, the

Netherlands is already overpopulated, and a lot of meadows are already being turned into neighborhoods. Luckily, we live near the sea and we've already placed some windmills in the sea, where people can't hear the noises, they make. So, there aren't as many complaints. But placing windmills in the sea also has it's cons. Sea mammals, like seals, do suffer more intensely from the sound than we humans do. Because of the noise disturbance the area is no longer suitable for them as a rest and breeding place. This disturbance of the breeding process could lead to problems that will last for years for them and for their whole environment. Birds might start avoiding the windmills and their whole area, this could also affect their whole lifestyle and by that also their surroundings. Or it could be that they aren't scared of the windmills at all and they might just fly into them which could cause death. Either way there would probably be a reduction of the bird species in the area of the windmill park. The consequences for fish aren't quite clear yet, well is there research that has proven that younger fish that grew up near windmills are less developed than fish that did not. Whether this is because of the noise or other factors isn't clear yet. [10]

Solar energy

Then there's solar energy. Just like wind energy, it never runs out. You just need a lot of solar panels to gain energy, and solar panels take up space. Fortunately, a lot of people are willing to buy their own solar panels and put them on their rooftops. Solar energy doesn't have a lot of cons, but a big one is that it is an unreliable source. The same goes for wind energy. There will be days when there is a strong wind of a lot of sun, but there will also be days without any wind or sun. This means you have to store a lot of the energy generated by the wind and sun for days when you won't be able to generate enough for the day.

The biggest problem of the energy transition is storage. We could build big batteries, but to cite what Harm Jeeninga said to us in an interview: It would be better to use the electricity when we have it rather than store it for a long time in order to avoid substantial storage and conversion losses.

Storage in form of a battery

With the energy plan that we have, we will some days have a lot of electricity made, mainly solar in the summer and more wind in the winter than in the summer. Let us say hypothetically we have 1PJ too much in the summer, on 21 July. We want to store this energy to not lose it of course, so we will build a massive battery to be able to store it. There is already the first problem, the resources. The best material for the batteries would be lithium. Sadly, lithium mines are awfully bad for nature, and the resource is starting to be rarer and rarer. Next, the owner will also want to make the price back, so he will put a little tax on the electricity. The problem is that the next time that the battery is emptied, there will be a day where we do not have enough energy, maybe sometime in the winter. So, the battery will be full for many months, and only be emptied once or twice a year. This would mean that the price would never be gotten back from the tax, and it would also not be a worthwhile investment.

Storage by using it when we have it for personal use

A better way would be to use the energy when we have it, but we will have to split personal use and factory/industrial use. For personal use we cannot change a lot, people need their electricity every day, and we cannot just change that. We can make rules that they should use their high consumption machines (such as washing machine, dishwasher, boiler (to heat up water)) during the day, or during tides, when there is a lot of energy on the grid. We would of course have to make people cooperate, and making a law would not work. A better alternative would for example be making the price of electricity cheaper during those days, which would also already happen naturally. This is already happening in the Netherlands, they pay you a few cents when you use energy during surpluses, and make you pay more during the shortages. The reason behind this statement is purely economic. Let's say the demand for electricity is the same the entire day, but the supply varies over the day. At the time where energy supply would be higher, the cost would be cheaper, because else people wouldn't buy it. The problem behind this reasoning is that electricity is an essential product. The supply demand chart, when not taking into account the tidal energy, would look more like this (image 6).

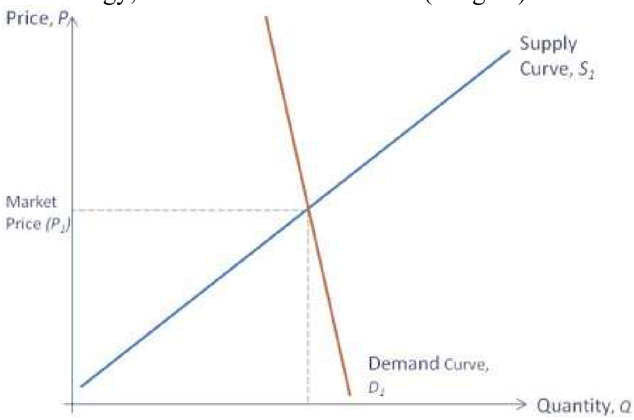

Image 6: Graph of demand and supply for primary goods, [11]

So, the supply would have to increase drastically for the price to get significantly lower. The best way for daily usage would be to try evening out the supply over the day, which could only work by storing it. But for long term usage this wouldn't work, as explained before.

Storage by using it when we have it for industrial use

For industrial use, we can plan it so that factories produce more when there is a lot of energy and produce less when there is less energy. Not all factories can be turned off/ made slower or faster that easily, but for the non-vital ones that also do not break when you turn it off it could be a clever idea. There even is a better alternative than shutting it down: we could only produce the parts that require a small amount of energy during shortages, and the parts that require a lot of energy during the overflow of energy. For the rest of the factories, the higher fluctuating price of electricity might already make them strive for a cheaper and more energy effective strategy. The price would maybe have to be influenced a little bit based on supply, but this would give the factories a choice. Vital factories should be supported, and shouldn't have to close down. There is a big ethical dilemma here with what is vital and what is not vital, but this would be a different subject, and doesn't fit in with our report.

Storing it by selling it to other countries

With the excess energy, we could also sell it to other countries that already have some way of storing energy. For example, in France there is a lake used as a battery, Le Pouget[12]. It uses the height difference between the lake and the river to generate electricity. It can also pump water back into the lake to store the energy. It is not 100 percent efficient, but is the most efficient big scale battery known at the moment. It is about 80 percent efficiency[13], but even battery's do not have 100 percent. This would of course have to be our last resort, but it is better than wasting it. L Pouget has a max capacity of 440 MW. Selling our electricity would allow us not to waste it and buy back the energy when needed.

What are some potential impacts of your country's transition on other countries?

As we wrote before, right now we still use a lot of carbon-based energy sources like gas and coal. Some of these sources are imported from other countries. If we would stop using these energy sources, the countries that sell these products to our country would lose some money.

It could also be possible that other countries would be able to buy energy from us, when there is too much energy made that day and the Netherlands would not be able to store the energy to use it later. It would also be possible to not use the energy and just lose the extra energy, but it would be better if other countries would buy it so we do not lose any energy that could be used somewhere else.

How can your country aid other countries in their transition to decarbonized energy systems?

We could give or loan them money, of course this isn't the most realistic option because we also need money ourselves. And with these kinds of projects, we are talking about billions. But maybe we could give them the materials to start their transition like turbines, solar panels, etc. We could always share our knowledge, so that other countries don't have to waste their money and time on repeating our research. Our expertise in building the contraption might also be handy for other countries. By being the first country to start this process, we could show and encourage other countries to do the same. Maybe we'll find some troubles in our transition and we can help other countries to prevent these.

Conclusion

The Netherlands uses a lot of diverse sources of energy. For example, they use a lot of windmills and solar panels, and the power of water and the heat of the soil and the air are already being used, but not yet a lot. Sadly, there is also a lot of carbon-based energy that is being used: these mainly consist of coal, natural gas, and petroleum. They make up about 90 percent of the energy used in the Netherlands, while renewable energy makes up the other 10 percent. In the Netherlands we produced 1152 PJ of energy last year, and we also had to import 1792 PJ of energy, while only exporting 5PJ. This means that we consumed 2939 PJ of energy. 1 PJ of energy is equivalent to 277.78 million KWH.
The energy transition plan we made for the Netherlands consist of a solid base energy, an energy that does not rely on the climate, which is tidal energy. We then want to use a lot more windmills and solar panels, which the windmills will be placed in the sea mostly and the solar panels on roofs. The main problem with windmills and solar panels is that they are inconsistent, so there will not be the same amount of energy every day. Our idea will be to try using the energy when we have it instead of storing it for later, because that would be better economically. We would make the non-vital factory's produce on days with more energy, and the excess would be sold to other countries that already have a way of storing it. When there is not enough energy one day, we would import it from the countries who we sold it to, or to countries with renewable energy sources.
Finally, the main influence this transition will have on other countries is that the countries where we now buy coal and other carbon-based energy sources from will get less money, and more countries will be able to buy energy from the Netherlands. We could also help other countries in their transition by sharing our knowledge and expertise on the subject, knowing how to build the turbines, and teaching it to them. Giving them money is not realistic, giving them the turbines/ solar panels/ windmills would be better.

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Energy Transition

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Keywords: OZE, coal, energy transition

Abstract

The Polish energy system is based mainly on coal. In addition to that, our energy sector also uses fossil fuels, imported mainly from US, Norway or Saudi Arabia, such as oil and gas. The share of gas in energy production in Poland is about 8%, and when it comes to oil >1%. In Poland in 2021 total emission of CO2 amounted to 192 mln tons - that's 11,5% more than in the previous year. Regrettably, the use of low-emission energy sources in Poland is still quite small. Renewable energy sources constitute only 17%. What's more, at the moment there is no nuclear power station in Poland. Fortunately, an increasing number of people are beginning to realize the seriousness of the matter. The current geopolitical situation, inflation and climate change is forcing Poles to find other ways to generate energy, move to low-emission energy sources that are safe and friendly for the environment.

In this research paper, the current state of energy in Poland and the possibilities of energy transformation will be discussed.

Introduction

Poland is a country lying on large deposits of hard coal and lignite (Fig1). In consequence our energy industry has always been mainly based on these raw materials.

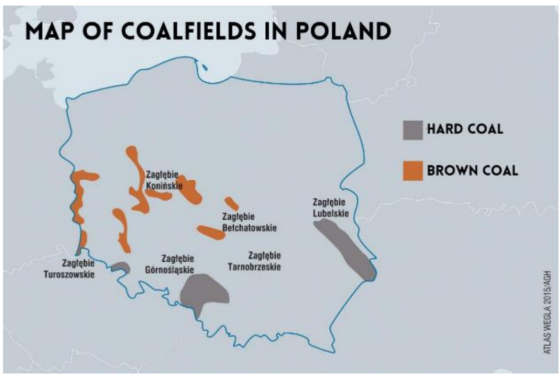

Fig. 1 Map of coalfields in Poland created by Forum Energii

It is also a factor contributing to the failure of carrying out the energy transformation, because it is a highly developed sector of our economy, therefore many people are employed in it and a lot of money is invested in mines (despite their frequent unprofitability). The departure from fossil fuels is associated with a major reform in the Polish energy sector, which the Polish government is constantly postponing. Rybnik is a city in Silesia, which currently has 2 hard coal mines (there are 2 more in neighboring towns). As a consequence, a large part of the Rybnik community has been employed in mines or mining-related companies for generations. Miners have many additional benefits to their dangerous work, such as early retirement or coal allowances, where they get coal from the employer free of charge. Thanks to these privileges working as a miner despite the danger, is tempting. Moreover many people are against the closure of mines and the implementation of the energy transition, because it is connected to loss of jobs, even for entire families. For the last few years despite some imperfections, this situation has been beneficial for many people. However in the current energy crisis and the problem with the demand for coal, the Silesian population as well as the entire Polish population, is aware of the need to switch to another source of energy. As for now, many households have switched to gas or heat pumps. There are also many campaigns promoting and supporting the transition from old furnaces to the new ones or switching to green energy. Our country is going in the right direction, but it is a time-consuming process and requires greater involvement on the part of residents and higher institutions.

1. What does the Polish energy system look like?

1.1.1 Hard Coal

In Poland, we mine thermal and coking or metallurgical coal. In 2021, hard coal mining in Poland amounted to about 55 million tons [1], and its share in electricity production in 2021 was more than 46% [2]. It is mined by using the deep mining method, currently from seams at depth of about one kilometer. The calorific value of thermal coal varies between 23 and 30 MJ/kg[3].

A significant part of hard coal production goes to electricity generators, so Polish mines are unable to meet the needs of private consumers, therefore the imported coal goes mainly to them. In 2021, 12.55 million tons of this carbon were imported into Poland [4]. Currently, imported coal comes from Colombia, Australia, the US, Kazakhstan and others, where it is mined by open-pit methods. Unfortunately, it is a low-grained coal, so after screening you get about 25% coarser coal, which is used for fuel [5]. That’s the reason why imported coal can give much less heat. In 2021, the Jastrzębie Coal Company alone exported 10 million tones of coking coal, mainly used in steel production [6].

Thermal coal is used in households, schools, company buildings, industrial plants, power plants, industrial power installations, in the production of plastics, fertilizers, plant protection products and others.

1.1.2 Brown coal

Poland is abundant in lignite deposits, which are very diverse in terms of species.

It is mined only by the opencast method so accordingly, only five operated opencast mines are currently opened in the country. As a result of their activity, around 30-40 mln tons[7] are mined every year. According to the Polish Geological Institute, Poland's geological balance resources amount to 23.14 billion tonnes (where almost all of it constitutes thermal coal) including developed resources of 1.04 billion tons (results from data in 2021)[8].

Lignite is used by Poles mainly to produce electricity, thermal energy and fuels. Besides that, it is also used in the chemical industry and in the production of fertilizers.

Polish residents are often eager to start using lignite mostly because it is much cheaper than hard coal and easily available. Unfortunately, they usually don't realize how destructive it actually is. Despite its practicality in many fields, it’s much more toxic considering emissions from its combustion. Its CO2 emission equals 1.22 Mg CO2/MWh (the highest of all sources)[9].

Lignite is characterized by high sulfur content (up to 6%), ash content and humidity.

Because of these features, which makes a fuel of much lower quality comparing to hard coal.

Significantly larger amount of ash, higher sulphation and the same amount of volatile substances as in hard coal, means that you need to buy 2-3 times more lignite than hard coal to get the same amount of heat. Due to its traits, brown coal must be completely burned close to where it is mined, as it loses its calorific value during transport, and in consequence loses its overall value. Another disadvantage regarding transport is the fact that lignite is soft in its raw state and due to the high affinity for water (it absorbs water more easily and is very moist itself) it begins to crumble in the drying process. The cracking of the coal causes such a big problem with unloading and in winter by freezing, that the delivery is completely pointless.

The damage caused by lignite in Poland was so intense, that in 2018 it was formally forbidden to use it in most voivodeships based on anti-smog resolutions

1.1.3 Natural gas

It’s a fossil fuel that is considered as transition fuel, because it causes lower CO2 emissions than other fossil fuels. Unfortunately it is not among the zero-emission fuels we are aiming for. There is not a lot of natural gas in Poland, which is why it is mainly imported. According to the Polish Geological Institute, in 2021, 4.86 billion m³[10] of natural gas was extracted in Poland, where the annual consumption of natural gas, according to Eurostat, amounted to 23.3 billion m³. In previous years, Poland imported natural gas mainly from Russia, in 2021 9.9 bcm of gas was imported to Poland in this way. Russia's attack on Ukraine caused a significant reduction in the transmission of natural gas from Russia, which was aimed at becoming independent from this country. Alternatives include the Terminal in Świnoujście, which receives LNG (liquefied natural gas) transported by sea. Its regasification capacity is 5 billion m³, but it’s planned to increase it to 10 billion m³. LNG is mainly purchased from the United States, Qatar and Norway. In October 2022, the Baltic Pipe was built. It transmits natural gas from Norway through Denmark to Poland. In 2022, its capacity is supposed to amount to 2 billion m³ per year, but in 2023 it is to be ultimately increased to 10 billion m³ per year. There are also connections between Poland and Germany, Ukraine, Slovakia or the Czech Republic, but the gas transmitted through them is Russian gas. There are also gas storage facilities in Poland with a capacity of approx. 3.2 billion m³. The construction of the FSRU unit - is a floating terminal for receiving LNG with a receiving capacity of up to 12 billion m³ is planned to be finished by 2027.[11]

1.1.4 Petroleum (Oil)

The oil sourced today is neither easy nor cheap to extract compared to previous years. As the world's oil reserves profitable for extraction are diminishing over the years, it is necessary to venture into hard-to-reach areas such as the Arctic, the Amazon, the Arctic Ocean. This entails greater expenses - the construction of a platform to enable its extraction in such places is estimated at about $3 billion[12]. Increasing expenses for oil extraction are associated with an increase in prices on the economic market.

Poland has very few oil deposits. Currently, 87 oil fields are documented in Poland, in which 57 fields are in production. The largest deposits are in the Polish Lowlands, as much as 66%, and the rest are in the Baltic Sea [13]. In 2021, we mined 733,000 tons by ourselves. About 64% was oil imported from Russia. Because of the war, the price of oil increased to $100 for a barrel, while in our country we consume 568,000 barrels of oil per day. Poland is trying to reduce oil imports from Russia, replacing them with imports from Saudi Arabia, Kazakhstan, Nigeria, Norway, the USA and the UK. This is made possible by having liquid fuel transshipment bases on the Baltic Sea.

Oil is the second largest source of primary energy right after coal, as it covers 25% of our country's needs. It is used to produce fuels, mainly gasoline and oil, as much as 50%, and the rest is lubricants, petroleum jelly, asphaltenes, paraffins, etc.[14]

1.2 Emission-free energy sources

Although in recent years Poles have been trying to switch to renewable energy by investing in photovoltaics or biomass, energy production from RES still totals around 15%. The economic possibilities of the society related to financial subsidies for both private individuals and enterprises cause more and more interest, which affects investments in emission-free energy sources. This can be seen on the graph showing how the share of RES in energy production has increased over the last decade.

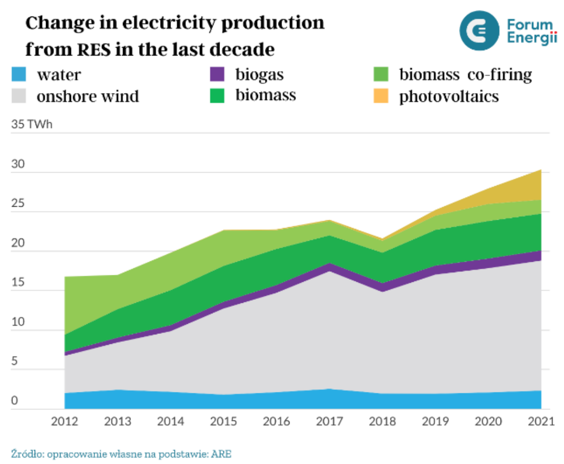

Fig. 2 Change in electricity production from RES in the last decade in Poland created by Forum Energii

1.2.1 Photovoltaics

Photovoltaics involves the conversion of energy from the sun's rays into electricity using photovoltaic panels. The amount of energy obtained depends on the solar radiation in a given area, which in Polish conditions gives a production of 1,000 kWh per year with 1 kWp of photovoltaic installation. The installed capacity of photovoltaics in Poland at the end of 2022 is more than 11 GW [15], or more than half of the installed capacity of RES, and the peak of energy production from photovoltaic panels, falls during the summer months. In 2021, photovoltaics alone produced 3.8 TWh that year, or about 13% of RES energy production [16]. In the Polish climate, it's very expensive to equip a building with a heating system and provide energy only from photovoltaics, because you need to use very large energy storage in winter, when there is low energy production from panels, and a large cost of energy consumption for heating. Therefore, photovoltaics is an additional source of energy production for the buildings in Poland.

1.2.2 Wind Energy

Wind energy is the cheapest energy from emission-free sources, which we can obtain for Poland on a large scale. Market share of wind farms in energy production in 2019 amounted 10%, in 2020 10,8%, and it has decreased to 9,4% in 2021. Wind farms construction in 2015 cost 1,9 mln euro, however in the last few years it has changed and today the cost equals 1,3 mln euro.

As for the disadvantages of the wind power plant, the most significant one is the cost of construction.

The problems that we have to deal with because of windmills are: a lot of energy needed to build a windmill, their lower efficiency in the summer, deaths of birds caused by them or the noise they make [17].

During the year we are not able to produce the same amount of energy every month, because of changing weather conditions.

The advantage is the access to the Baltic sea so we can develop the Polish offshore wind energy system. It has huge perspectives to evolve and a chance to play an important role in energy transition, because they do not apply to land distance limits and have minor effects on the environment.

1.2.3 Biomass

In Poland we have been burning biomass for around 12-15 years, so it is a relatively new way to generate energy. About 85% of biomass in Poland is imported, mostly from Russia, Belarus, Ukraine, Hungary, Bulgaria, and Latvia. According to the Polish Economic Institute biomass import from Russia and Belarus continued until June 2022, but after tightening EU sanctions on wood and wooden articles, pellet import from the United States, Canada, Ukraine and Turkey is growing. In comparison to other renewable energy sources, energy gain from biomass is minor (in Poland biomass provides only 7% primary energy). Biomass plants are one of the best methods to obtain biomass. They are using animal waste from farms and breeding's regardless of sun exposure or wind power. At the same time it has a good effect on cleanness of surface waters where animal waste often gets. Sewer system wastes also can be used in biomass plants, taking into account the fact that they are a burden to society with high costs of utilization (1000-2000 zloty per ton [18]). It is important to mention disadvantages of using biomass like for example high costs of getting and processing it. In Poland there are also energy crops - mostly plantations of various types of birches, because they do not need any special conditions.

They are characterized by high calorific value, low humidity and small amounts of ash residues. Their energy value totals 19,23MJ/kg [19].

1.3 Statistics

The graphs underneath show the actual impact of given raw materials in the Polish energy sector and Poland's current energy mix.

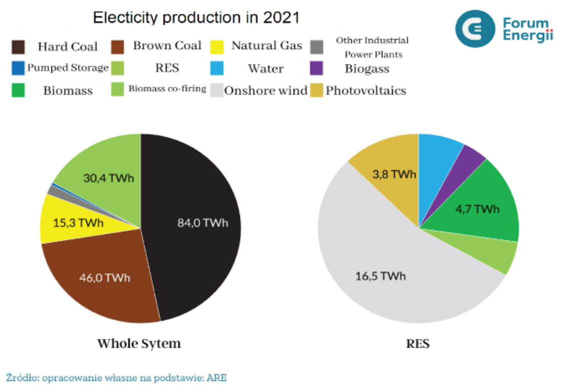

Fig. 3 Electricity production in 2021 in Poland created by Forum Energii

Hard coal has a big advantage over other energy sources, which shows how important it is to carry out the energy transformation as soon as possible in order to reduce the share of emission of raw materials.

To show how important it is to educate young people in the field of energy, our team conducted a survey on knowledge and awareness in this topic among Polish youth. The survey was completed by 400 people aged 15-19. The questions concerned knowledge about the energy mix in Poland, renewable energy sources and opinions on nuclear energy.

Based on the analysis of the feedback, we found out that despite the fact that all of the respondents indicated hard coal as the main source of energy, young people have limited knowledge about the energy mix in their own country.

Teenagers associate renewable energy mainly with photovoltaics, while other sources of green energy are little known to them.

Opinions on nuclear energy are very divided. Many people are afraid of the presence of a nuclear power plant in Poland and point to the failure of the Chernobyl nuclear power plant as the cause of fear.

After research, we realized that:

- young generations should be educated more about renewable energy sources and the need to use them

- the functioning of modern technologies in the field of nuclear energy should be explained to the people

- we should keep the public aware of the harmful impact of the use of fossil energy sources on health and the environment.

We are convinced that by raising our awareness and knowledge, we will be able to pass it on in our local environment and significantly contribute to positive changes in Poland.

1.4 Politics

The Polish government has always been convinced that coal will be the basis of our energy sector for the next few decades. They presume in the assumptions of the country's energy policy that by 2040 energy production will increase by 40%, which is why they try their hardest to stick to coal mining and the theory of increasing energy supply. At the same time, the European Union declares the reduction of energy consumption, therefore moving away from burning coal. Furthermore, through these desperate attempts to save the mining industry in the country, individual governments are driving Poles into the so-called political trap with consequences for the whole state. The trap consists that by promising to maintain the mines and continuing to draw energy from them, these particular governments are buying themselves time and votes of a very large group of electors, which includes miners, their families, companies gathered around mining, etc. therefore, most mining unions are not interested in the changes that would result from moving away from hard coal as the main energy source, in fear of losing their jobs and earnings, while ignoring the consequences it brings.

Another obstacle to the transition to renewable energy is the lack of vision and resources.

Poland can allocate 560PLN billion in the so-called national envelope for energy transformation in the long-term EU budget until 2027. Almost 190PLN billion has been assigned to the Polish energy transformation and climate protection so far and another 370PLN billion within a decade may come from emissions trading[20]. The government must assemble public and private entities to prepare good projects that will bring long-term effects, because without this, it will be impossible to use a significant sum of money. On the other hand, unwise and weak projects will consume considerable amounts of money, not contributing to the protection of Polish households and enterprises against price increases, which at the moment are already a problem for our country due to constantly increasing inflation.

The amounts related to Poland's energy transformation are so large that energy producing companies and the state will not be able to bear them, therefore they may affect our deficit.

Another barrier is the wind farm act brought to life in 2017[21]. Its purpose is to increase the distance between the windmills and residential buildings or valuable natural objects. As a result, there are few places in Poland where windmills can be built, in consequence the possibility of generating energy from them is automatically limited.

In fact, during our work on the report, several changes related to the act on wind farms were introduced. In December 2022, the Polish government established a self-amendment, which states that at least 10% of the energy produced should be transferred to the residents of the municipality where the farm is located. An additional requirement is the power of the wind turbine, which is to be within the scope of RES micro-installations i.e. up to 50 kW. Another modification was set in motion in February 2023, in which the parameters of the distance of the windmills from the buildings and the protected landscapes were altered. This change puts our country in a much more favorable situation, as the distance of the windmill from the facilities is to be 700 meters, which allows them to be built in larger quantities than before. Additionally, at the same time, the commission lifted the ban on the construction of residential buildings next to wind turbines.

2. How can we reduce the impact of fossil fuels on the Polish energy system?

2.1 Don't make the same mistakes

The Polish energy sector has always been based mainly on hard coal. This is due to geology, as there are many coal deposits in Poland, mainly in Silesia. During the times of the Polish People's Republic, a gigantic coal sector was created, where extraction in the best years amounted to as much as 200 million tons and the employment was then very large. The 1970s and 1980s were the best period for the Polish mining industry, but since then mining and employment have been declining. The Third Republic took over this sector, which at that time was the backbone of the country's economy. In the late 1990s, the then Prime Minister Jerzy Buzek wanted to reform the Polish mining industry. As part of this reform, employment was reduced and unprofitable mines began to be closed. The years 2002-2011 on the global market were a period of prosperity for coal, which the Polish authorities did not take advantage of in any way. At that time, despite high prices for coal, Polish mines were not profitable, because the money was not invested in any way in new technologies or innovations of the Polish mining industry. Failure to take advantage of these opportunities contributed to the lack of development of the Polish mining industry, in contrast to mining around the world. Over the next 4 years, Kompania Węglowa (Coal Company), which at that time was the largest mining company in Europe, almost went bankrupt. The Polish state government , wanting to save jobs, and at the same time being under the strong influence of trade unions operating in the mining industry, was forced to support the entire mining industry. In the following years, despite the change of the ruling party, which also planned an energy transformation in its electoral program, it failed to create a good energy mix based on fossil fuels and low-emission energy sources. The rulers, wanting to maintain the Polish mining industry, invested in the entire coal sector, instead of focusing on reforming the mining industry by closing unprofitable mines, restructuring and investing in new technologies. Over the last 3 decades, Polish taxpayers have invested 260 billion zloty in the Polish mining industry, which was poorly invested money, as it could have been spent on innovations in the Polish energy sector. Currently, most of the mines are unprofitable and survive only thanks to state support. Coal is currently mined at greater depths, and thus is of poorer quality. It is also very important that its extraction costs are high and methane is very dangerous. The existing mining plants are located in heavily urbanized areas, which means that possible mining damage poses a risk of mining related seismic events to the inhabitants of these areas. The actions presented above show the incompetence of the rulers in the 21st century. Investing in future-proof solutions led to the collapse of the Polish energy market, which we found out in 2022 [22].

2.2.1 Changes

To move away from non-renewable energy sources a clear and explicit action plan is needed. We must be aware that it will be a long and demanding process that will lead us to create a better world together. In order to start this process and encourage Poles to choose green energy sources, the inflation rate in Poland should first be stabilized and preferably reduced. According to the GUS (Central Statistical Office), in 2022 inflation ranged between 13% and 18%, and in 2023 the National Bank of Poland is forecast to increase prices by 10% to 15%. As believed by NBP, the worst case scenario for Poland is 27% inflation [23]. High inflation causes less interest in switching to green energy, because the cost of purchasing and installing a heat pump or photovoltaics is high, as well as adapting the building to a given energy source. An important issue is also the development of wind energy. The ongoing work on the wind farm act in the Sejm gives hope for the development of this industry through less stringent legal requirements for the construction of wind farms. It is worth noting that before 2017 it was the fastest growing branch of RES in Poland. We should therefore develop wind energy, while considering the possibility of short-term energy storage in the form of heat storage, which we can also use in photovoltaics. In a situation where we obtain a surplus of electricity from the sun or wind, we will be able to store it and then use it when we run out of it. However, it must be remembered that such warehouses are able to meet our needs for a few weeks. It is crucial to remember the essence of the energy mix and that we cannot focus on one energy source. At the moment, photovoltaics in Poland is developing strongly, but the big problem is the datedness and maladjustment of Polish power grids to obtain energy in this way. Polish energy concerns should carry out full modernization of the network on an ongoing basis, along with its adaptation to the needs of the use of modern energy sources. It is important to expand Poland's hydrogen potential through the increased development of the hydrogen economy through the cooperation of the Ministry of State Assets and private companies. At the moment, the Polish hydrogen potential, compared to highly developed countries, is small. Thanks to this cooperation, we are able to create a thriving way of obtaining energy. However, this is not a solution that we are able to implement quickly, but it is very profitable and the development of this sector of the economy can be seen on the domestic market. In the energy transformation, the most important is the departure from hard coal. The Polish government should ensure that the mining sector and the industries cooperating with it can smoothly change industries. The government should ensure that the process of liquidation of the mining industry is closely related to the development of energy transmission networks and energy storage facilities, because only such a solution will allow for the full use of green energy. The development of energy networks also determines the construction of nuclear power plants, the launch of which in Poland is planned for 2043. However, it is necessary to take into account the frequent extension of these investments. Therefore we should focus on the development of currently available low-emission sources of energy, while preparing the Polish energy system for nuclear energy. As you can see, the process of energy transformation is extremely expensive, while the Polish budget includes poorly managed money from CO_2 emissions. In 2021, Poland earned the most from the sale of CO_2 emissions in Europe, because this profit amounted to as much as PLN 25 billion, and less than 4% of this amount was allocated to the development of the energy sector [24], which is definitely not enough. These funds should be invested in the development of Polish energy or co-financing for citizens switching to renewable energy.

2.2.3 How ordinary people can help in energy transition

Many people think that only governments or other very influential public figures have an impact on the energy transformation. However, we are also able to help the energy transition by implementing new habits. One of the most important things is to save energy as it will be good for the environment and we can save money. Saving energy does not have to rely on constant sacrifices and we do not have to give up the comfortable life. The fact that we will start using electrical devices wisely, is enough.

It is best to start by checking all the devices in our home and see how much energy they use. There are many that we use for a short time, and then they remain in the standby mode, drawing energy in the process. There are devices whose energy consumption can be easily checked, but there are also those for which we will need a special tool, such as an electricity meter. Thanks to this gadget, we'll be able to check the energy consumed by home appliances. All we have to do is put it into the socket and connect the device to it to check the electricity consumption. Thanks to familiarization with the electricity consumption in our home, we can determine which one of the devices operating time should we limit, which turn off to avoid the energy-consuming standby mode and which to switch to energy-saving devices when replacing the device [25].

3. Global implications of the Polish energy system transition

3.1 Potential impacts of the Polish transition on other countries.

The Polish strategy expects that the demand for hard coal would be covered by the mines located in the country, and the raw material should be imported only in justified cases [26]. At the moment, Poland imports coal mainly from Australia, Colombia, the USA and others and in result affects the energy sector of these countries by driving their demand for coal mining. As a result, we're not simplifying the energy transition, constantly importing huge amounts of non-renewable raw materials like coal, instead, we should focus on investing in RES.

In the near future, the first nuclear power plant will be built in Poland. Polish company "Polish Nuclear Power Plants" has signed a cooperation agreement with Westinghouse Electric Company - an American corporation specializing in the production of equipment using nuclear energy. According to energynews:

"The signing of today's [...] contributes to further strengthening our strong partnership with the US. It's also an important signal for the domestic industry, enabling its development in the construction and use of a nuclear power plant. The implementation of the program to build new nuclear capacity means generous benefits for the economy, but also ensures predicted prices of energy for consumers, which is especially important for energy-intensive companies affected by the current crisis and high energy prices" said Anna Moscow, Minister of Climate and Environment.

Considering all these facts, we came to the conclusion that Poland needs cooperation and partnership from abroad, which would result in a gradual transition to green energy sources and investments in foreign companies.

3.2 How can we help other countries in their transition to decarbonized energy systems?

We need to start making progress, beginning with showing that Poland is already changing in terms of energy and that we are advancing the energy transition in our country.

Setting a good example for other countries may prompt them to take action and cooperate to create a better future together.

Additionally we can continue to export various types of electric vehicles to other countries seeing as it is possible thanks to the factory of electric delivery vehicles operating in our country, as well as the plants producing electric microcars and one-track vehicles. By the end of 2024, Polish brand "Izera" is planning to launch the production of zero-emission cars that will also be exportable.

It's worth mentioning that Poland is a European leader in the production of car batteries used in electric and hybrid cars. Their export already reaches about 2 percent of all our exports, and by continuing it, we will also support and push the development of the energy transformation of other countries.

4. Summary

Concluding all of the points mentioned above, we can see that the path chosen by the government is the right one in concept, but some modifications are definitely needed.

The ongoing measures do not entirely allow us to fully use the current potential. Accordingly, in our opinion, broadly understood social education, full modernization and expansion of energy networks in Poland will enable full and effective use of our dormant potential in low-emission energy sources.

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Unlocking the Potential of Solar Energy in Thailand: Overcoming Efficiency and Temperature Challenges for a Net-Zero Future

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Abstract

The world strives to restore the deteriorating environment. Many countries are reducing their reliance on fossil fuel, which is a significant contributor to pollution. Thailand also needs to transition its energy sector towards clean energy to ensure sustainable development in the long run. Among the various sources of clean energy, solar energy is expected to hold immense potential in Thailand due to its location near the equator. Although Thailand has abundant sunlight exposure, solar energy remains a small fraction of its overall energy production. In order to encourage its utilization, there is a need to address recurring issues related to photovoltaic (PV) cells, particularly their efficiency and temperature dependence, which pose significant challenges. This article reviews the solar energy utilization and production potentials in Thailand, covering the on-going solar technology development, financial incentives, and approaches to addressing temperature-related challenges. Should these challenges be overcome, there is reason to believe that the target of achieving net-zero emissions and carbon neutrality by 2065, as outlined in the Paris Agreement's worldwide climate objective, can be achieved as planned. Additionally, the success of Thailand's global efforts towards energy transition could potentially stimulate greater awareness and consciousness regarding this issue.

Keywords : Solar energy, Thailand, Photovoltaic cell, Net-zero emission, Carbon neutrality

Contents

1 Introduction

Thailand's energy sector is primarily dominated by fossil fuels. But in the recent years, Thailand has been transitioning its energy towards renewable sources. The goal is to reach 29,411 MW of installed renewable energy capacity by 2037. Of all the possible renewable sources, solar energy proves to be an interesting alternative for Thailand. Because of its location in South East Asia, near the equator, Thailand receives high levels of sunlight throughout the year, with an average of 9 hours of sunlight per day. This makes Thailand an ideal location for solar energy production, as solar panels are able to generate a significant amount of electricity from the abundant sunlight.

Photovoltaic technology converts light into electricity. Solar photovoltaic has seen rapid development due to the increasing demand for renewable and clean energy in the market. Numerous technologies are being continually applied to improve its efficiency and maintenance. The efficiency of Photovoltaic (PV) energy generation is greatly affected by weather conditions and temperature. Rising temperatures of PV cells can significantly reduce their efficiency, and lack of sunlight and unpredictable weather can also pose challenges. Therefore, in order to address these issues, it is necessary to develop PV cells that are more environmentally friendly and sustainable, and to incorporate active cooling systems that can transfer heat using special devices or take advantage of the surrounding environment, such as placing the cells on water.

As proposed by the Intergovernmental Panel on Climate Change (IPCC) special report, it is clear that in the absence of a significant increase in efforts to reduce greenhouse gas emissions by 2030, there is a high likelihood that global warming will exceed the 1.5°C limit in the coming decades [1]. This could result in permanent damage to fragile ecosystems and a series of crises for societies and individuals who are most at risk. Thailand is cognizant of this issue and has enacted the Nationally Determined Contribution Roadmap on Mitigation 2021-2030, with the goal of cutting down greenhouse gas emissions by 20-25% [2]. In addition, our dedication to the Paris Agreement has led us to implement a revised strategy aimed at achieving Net-Zero Emission, the balance between the emission and removal of greenhouse gases, by 2050. The main objective of the current plan is to reduce emissions directly from their source, which is the fossil fuel industry, by gradually eliminating coal-fired power plants. This approach is preferred over expensive and impractical measures such as Carbon Capture and Storage (CCS) and other negative emissions techniques. This effort to lessen fossil fuel-based energy can not be achieved without implementing another substitute, renewable energy. National Environmental Strategic plan, 2018-2037, stated that renewable energy should contribute to at least 40% of Thailand's final energy consumption. However, the Thailand profile in Decarbonising South and South East Asia report has established that with the current implementation, renewable energy will only be produced for about 60% of total energy production which will make the final consumption lower than the initial goal.

In this report, we will address these respective essential topics to fully understand and recognize the importance of the transition to clean solar energy: basic concepts of PV cells, situation in Thailand, solution to eliminate limitations and obstacles, official policy and purposed roadmap and the importance and impact of this process.

2 Principle of Solar cell

A solar cell is a device composed of semiconductor materials like Silicon and Gallium. By utilizing these semiconductors, the photovoltaic effect is triggered, leading to the production of electricity from electrons generated through the absorption of light, in other word energy transit from light energy into electrical energy.

2.1 The Photovoltaic Effect

First discovered by Edmond Becquerel in 1839 [3], photovoltaic effect is a phenomenon in which photovoltaic cells produce an electric current from the incoming light. Solar cells consist of two kinds of semiconductors p-type and n-type that are doped to function effectively, the occurrence of doping is dependent on the type of doping used. In the case of p-type doping, holes are generated, which means that electrons become connected to atoms, leaving them with positively charged atoms and vice versa. This process generates holes and electrons in the p-type and n-type doping, respectively. When bonded together creates a p-n junction, and the excess electrons will flow to the p-side (containing holes or more positive charge), forming a depletion region that has no free electrons and holes. Due to the migration process, electric fields are formed between the depletion region, creating a driving force.

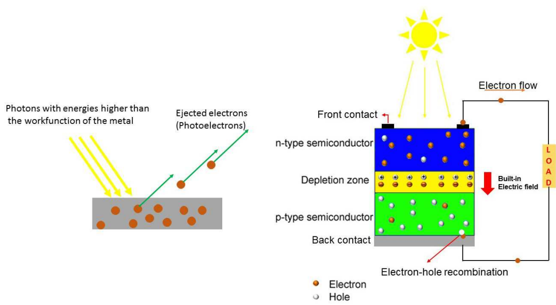

Figure 1: Right : Photovoltaic effect overview, Left : Electron path way in solar cell [4]

As the solar cell is exposed to incident light, it enters the depletion region where it generates pairs of electrons and holes. These pairs are then separated by a driving force, resulting in a higher voltage being produced across the cell. In practice solar cells, the p-type material is typically lightly doped and thicker than the n-type material, which is highly doped, leading to the creation of a larger depletion region that would result in more electric current generation in the PV cell. When the depletion region/zone experiences excitation, both electrons and holes are generated. Subsequently, the excited electrons begin to flow through the circuit and recombine with holes present in the p region. This complete cycle allows for a continuous generation of electric current.

Figure 1 shows the solar cell inner working process and inspect crucial features like the depletion region. This allows us to understand the mechanics behind the Photovoltaic Effect.PV cells include various components, each differing in type and characteristics which would lead to different efficiencies across each cell. These include mono-crystalline solar panels, known for their Optimum efficiency, as well as poly-crystalline and amorphous thin-film solar panels.

2.2 Efficiency

The efficiency of PV cells varies based on the materials and types chosen. One well-known type is Silicon solar cell others such as, Bifacial modules and Perovskite cell

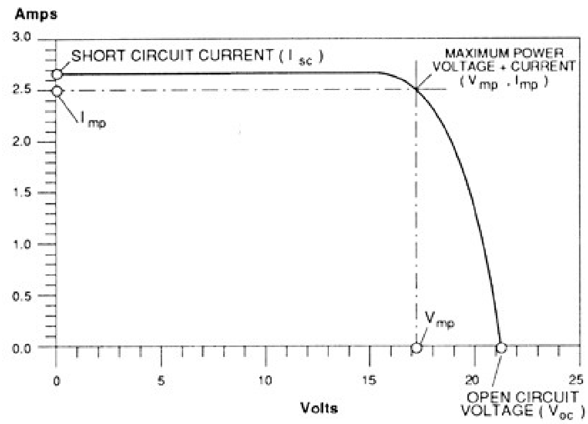

Figure 2: IV-curve indicate from I_{sc} and V_{oc} [5]

The rapid progress, intensive research projects, and strong contributions in the field of Perovskite cells have ushered in a new era for solar cell technology.; their high efficiency and low-cost materials have out stood others organic and inorganic solar cells or even silicon solar cells, reaching up to 25.2% [6] using a mixed cation and/or mixed anion composition. Their characteristic features in materials would easily achieve higher efficiency with further technologies such as coating and composition engineering.Nevertheless, Bifacial modules (BF), can generate energy both from the front and rear sides, which would provided more incident radiation for the solar cells. The problems with BF is that they relied much from the irradiance incident which would become more specific to the installation site of the solar cells, specific property of the site including albedo, tilt angle and reflective surface size [7].Compared to the initial reported efficiency of less than 1% in 1941, significant advancements and the application of quantum knowledge have led to substantial improvements in silicon solar cell technology. Over time, the energy conversion efficiency of silicon solar cells has increased to 25% [8].

From figure 2, the power conversion efficiency (PCE) of solar cells given by

$$\eta = P_{max}/P_{input}*$$

where P_{input} is the incident radiation power.Another useful factor we can extract from the IV-curve is the Fill Factor (FF) which is given by

$$FF = P_{max}/V_{oc} * I_{sc}$$

where I_{sc} is short-circuit current and V_{oc} is open-circuit voltage. We could also write

$$P_{max} = I_{max} * V_{max}$$

in other words the Fill Factor is essentially a measure of the efficiency for PV cells.

to be more precise, solar cells are generally categorized into three types: amorphous (non-crystalline), poly-crystalline, and mono-crystalline. From figure 3, mono-crystalline cells exhibit higher efficiency compared to multi-crystalline cells or poly-crystalline due to production disparities. However, it is worth noting that mono-crystalline cells also incur significantly higher costs.

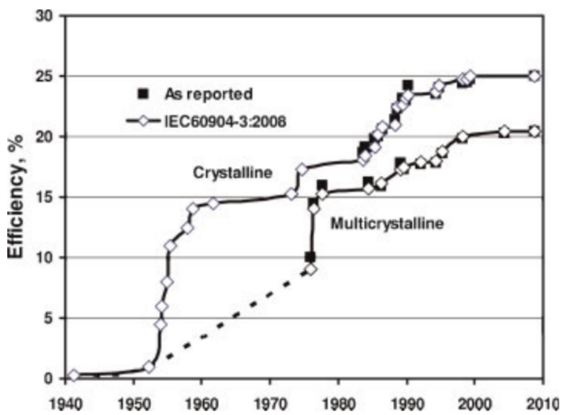

Figure 3: Energy conversation for crystalline and multi crystalline silicon solar cell are represented [8]

2.3 Photovoltaic Technologies

Conventionally, the production of photovoltaic (PV) energy has primarily relied on crystalline silicon and thin-film technologies, such as Cadmium telluride (CdTe) and Copper Indium Gallium Selenide (CIGS). However, in recent times, researchers have been exploring numerous emerging PV technologies with the aim of developing more efficient, recyclable, energy-conserving, and environmentally friendly options. These include dye-sensitizers, carbon nanotubes, organic polymers, inorganic materials like Cu2ZnSnS4 (CZTS), and inorganic-organic hybrid materials such as perovskites [9]. Despite the promising potential of these emerging technologies, their current efficiency levels, as indicated in [10], are significantly lower than those of crystalline and thin-film technologies. Consequently, their market share is currently less than 1% [11]. However, due to their faster rate of scalability compared to crystalline PV technologies, it is anticipated that these emerging technologies will eventually dominate the market share in the future.

Multi-junction cells

The concept of multi-junction devices was introduced to enhance the conversion efficiency of photovoltaic (PV) cells by matching the wavelength of photons with the band-gap of specific materials. This is achieved by stacking and connecting materials with different band-gaps in series or parallel configurations to capture a wider range of solar spectrum. The solar radiation is divided into different wavelengths that align with the band-gap energies of the absorbing materials. This can be done using bandpass filters or by arranging materials with different band-gaps in a specific order, placing material will the highest band-gap on top of the stack. To form the stack, a highly recombinative layer, such as tunnel junctions, is utilized for inter junction series connections, allowing for high current density and minimal voltage drop. Furthermore, as will be discussed in the next section, Metal halide perovskite semiconductors offer rapid, low cost deposition of solar cell active layers with a wide range of bandgaps, making them ideal candidates for multi-junction solar cells [12].

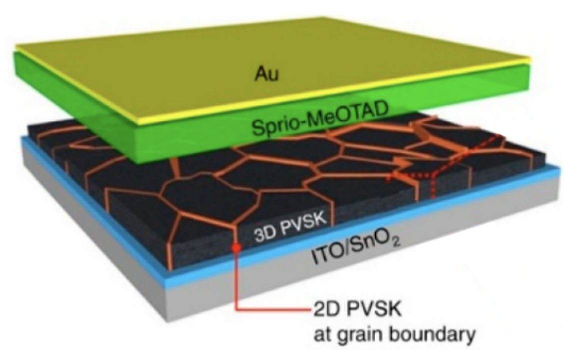

Figure 4: Schematic of perovskite solar cells [13]

Bifacial cells

Since the 1960s, researchers have been actively developing bifacial technology, which utilizes both direct radiation and reflected radiation (albedo) from the ground. The earliest documented literature on this technology dates back to 1980 [14], focusing on single crystalline silicon (s-Si) cells. In addition to s-Si silicon, bifacial technology has now matured using multi-crystalline silicon (m-Si), glass, transparent conductive oxides (TCO), silicon thin film, CIGS, GaAs thin film, dye-sensitized solar cells, and CdTe [11]. At present, bifacial PV panels have the potential to generate up to 50% more power output compared to monofacial panels of the respective technology [15]. Recognizing this potential, numerous leading manufacturers worldwide have increased their production capacity to meet the anticipated high demand for bifacial modules. It is expected that the market share of bifacial technology will reach as high as 40% by 2028 [16], reflecting the global inclination towards its adoption. However, it is important to consider the cumulative effects of mutual shading (panel-to-panel) and self-shading (panel-to-ground) in a PV power plant, since shading effects can diminish the perceived advantages of bifacial technology in conventional array designs.

2.4 Effect of temperature on efficiency

The energy conversion of PV cells is affected by multiple factors. More exposure from sunlight does not always indicate more energy output. This is because heat hinders its efficiency, as PV cells perform best at an optimum temperature of 25 °C [17]. Therefore, one dilemma that prevents solar energy from becoming a reliable source for countries that are around the equator is the fact that PV cell efficiency decreases as the temperature rises.

The power output of a PV cell is determined by the difference between the energy of excited electrons and the low energy ones. The bigger the energy difference or the voltage, the more power a PV cell can produce. When the PV cells are heated up, the energy of bound electrons is increased, reducing the voltage and the power output.

Various factors contribute to the increase in PV cell temperature. Unfortunately, many are external factors that cannot be controlled because PV cells are directly exposed to the environment when in use. These factors may include wind speed, radiation rate, ambient temperature and dust accumulation [18]. Therefore, internal factors are adjusted to maximize PV cell potential, one being the surface temperature of PV cells.

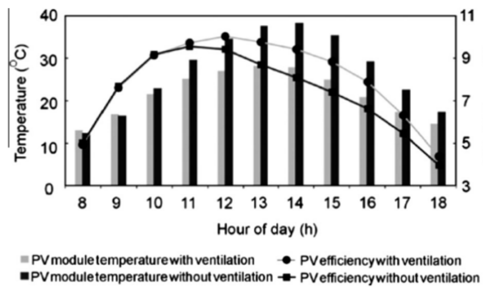

Figure 5: PV efficiency and module temperature during the day [19]

In figure 5, a graph depicts the relationship between temperature and efficiency throughout the day, both with and without ventilation. The data reveals that temperature and efficiency are not directly proportional. In fact, elevated temperatures can lead to a reduction in PV cell efficiency. However, the introduction of ventilation can help lower the temperature of the PV module, compensating for the heat loss caused by higher temperatures and subsequently improving efficiency.

3 Situation in Thailand

3.1 Thailand uses a mix of energy sources

Thailand uses and produces many different types and sources of energy, which can be grouped into general categories such as primary and secondary, renewable and nonrenewable, and fossil fuels.

As can be seen in the chart above, primary energy sources include fossil fuels (petroleum, natural gas, and coal), and renewable sources of energy. Electricity is a secondary energy source that is imported from international markets and can also be generated (produced) from primary energy sources. Energy sources are measured in different physical units: liquid fuels in barrels or gallons, natural gas in cubic feet, coal in short tons, and electricity in kilowatts and kilowatthours. In Thailand, thousand ton of oil equivalent (ktoe), a measure of quantity of energy compared to a ton of crude oil, is commonly used for comparing different types of energy to each other. In the first quarter of 2022, Thailand 's total final energy consumption was equal to about 76,637 ktoe.

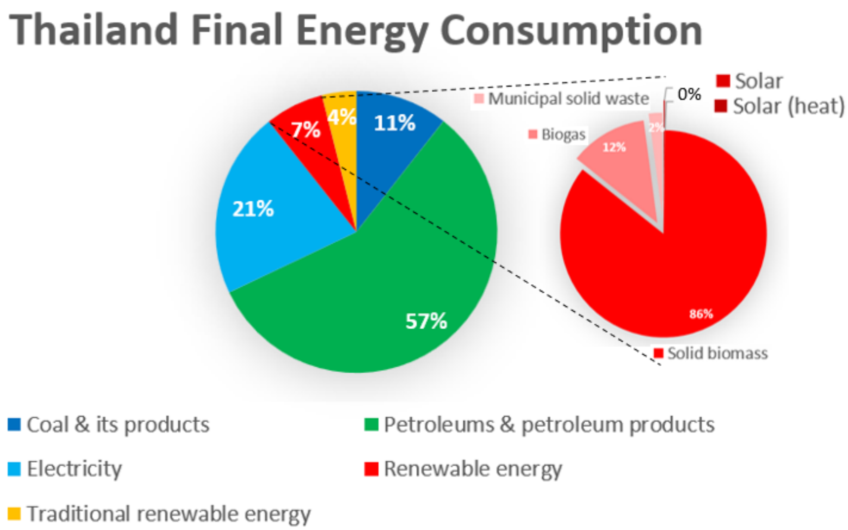

Figure 6: Thailand final energy consumption (first quarter/2022) [20]

Even though renewable energy contributes to about 7% of the total consumption, solar energy shockingly does not have a part in it because of the entire loss through the final transformation process. Thus more actions need to be taken towards this serious lack of awareness in Thailand's current energy transitioning plan. Additionally, the proposed scheme can also play a vital role in coal and petroleum phasing, which contributes to greater reduction in greenhouse gasses emission.

3.2 Use of Solar Energy in Thailand

Thailand's location near the equator gives it access to high solar irradiance. This allows PV cells to harvest a constant amount of light, and gives it potential to be Thailand's alternative source of energy. But despite that, majority of Thailand's energy is still from fossil fuel. This is because solar energy may not prove to be as reliable as it is right now due to these following factors:

3.2.1 Periods with Low Irradiance

Thailand's average solar irradiance may be high, but the ever fluctuating weather makes solar energy production unreliable at times. Thailand's has its peak exposure to sunlight in summer, especially in April. But the trend of exposure gradually decreases as winter approaches. Moreover, along the way, in rainy season, the sky will be covered with clouds which blocks off sunlight.

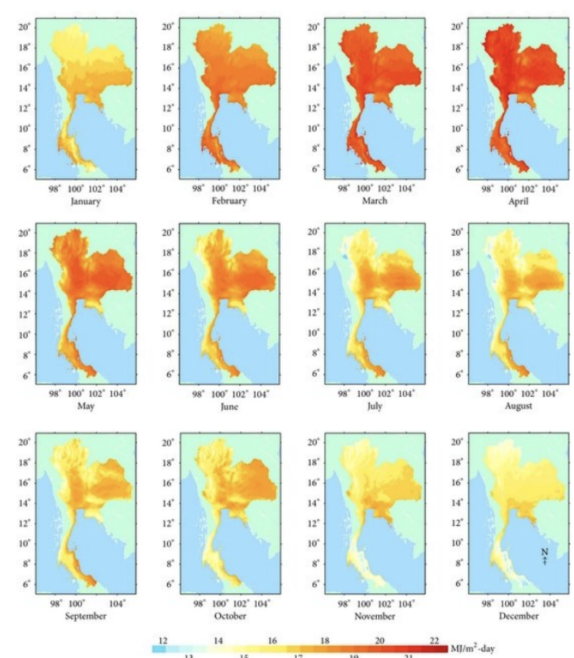

Figure 7: Sunlight exposure (MJ/m2-day) of each month depicted with color gradient) [21]

3.2.2 Excess Heat

PV cells operate better at low temperature. Although the average temperature of Thailand lingers

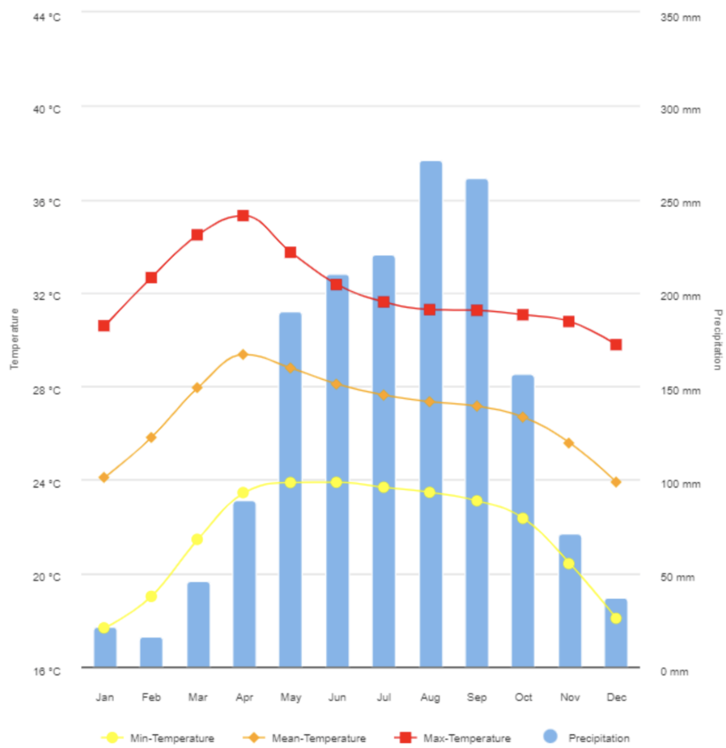

Figure 8: Max/Min/Mean Temperature and precipitation of Thailand (1991-2020)) [22]

at around 26-27 °C, the temperature at day time is usually much higher than 25 °C.

As shown in the figure, the maximum temperature, which usually occurs during day time when sunlight is available, rises as high as 35 °C, yet the time when temperatures drop is without sunlight, at night. This causes the efficiency of PV cells to decrease significantly.

4 Solution approaches for PV cells sustainable employment

4.1 Future technologies of PV cells

Photovoltaic (PV) technology refers to the direct conversion of sunlight into electricity using semiconducting materials. For the adoption of PV to be widespread,it depend on factors such as cost, lifetime, and conversion efficiency. The fulfillment of these criteria has led to the global deployment of PV technology to meet energy demands. However, there is a constant demand to further reduce costs while maintaining performance and lifespan. Extensive research and development efforts have been undertaken worldwide to achieve this objective. As a result, there has been a significant reduction in the levelized cost of energy, reaching approximately 4 cents per kilowatt-hour. This value is ten times lower than what it was ten years ago. The cost reduction is not solely due to performance enhancements but also driven by advancements in fabrication processes and the implementation of lab-scale and module-level improvements. The economics of scale have also played a crucial role in overall cost reduction.

Currently, crystalline silicon (c-Si) dominates the PV market with a market share of over 90% [23]. However, the performance of c-Si solar cells has reached a plateau with a record efficiency of 26.7% (Fig. 1), which is close to the theoretical Auger limit of 29.4% for silicon solar cells. Achieving further cost reduction requires a pathway to increase conversion efficiency. However, this objective seems challenging due to inherent losses, such as thermalization and transparent Eg, associated with single-junction devices. Moreover, considering the current market density for Si PV, it is not feasible to deplete or replace the existing production lines with other materials and technologies to enhance conversion efficiency in the near future.

To pave way for further advancements, researchers have combined silicon-based PV technology with other promising semiconducting materials to create tandem solar cells. This approach aims to improve the utilization of the electromagnetic spectrum emitted by the sun. Tandem solar cell designs simultaneously address thermalization and transparent Eg losses associated with the bottom and top subcells, respectively. Furthermore, c-Si tandem solar cells have the potential to surpass the Auger limit of 29.4% for silicon solar cells and the SQ limit of 33% for single-junction solar cells.

Initially, this semiconductors, III-V compound, were introduced for silicon-based tandem solar cells. However, the high manufacturing costs associated with III-V compound-based PV technology hindered its further development. In order to achieve better performance at a lower price, researchers turned to hybrid organic-inorganic halide-based perovskite materials for application as the top subcell in silicon tandem solar cells. Standalone perovskite solar cells have achieved impressive research results, with a recent record conversion efficiency of 25.6% (Fig. 9). The improved standalone performance has led to the development of perovskite-silicon (PVK-Si) tandem solar cells, which have garnered significant attention from researchers. The PVK-Si combination has performed well and has shown a substantial increase in conversion efficiency since its inception. While the record conversion efficiency for silicon solar cells has remained at 26.7% (Fig. 9) for over three years, PVK-Si tandem solar cells surpassed that value in 2018 and recently achieved a record conversion efficiency of 29.5% (Fig. 9), surpassing the previous record of 29.15% obtained in early 2020. Key contributors to the development of PVK-Si tandem solar cells with record efficiencies. The theoretical efficiency limit for series-connected PVK-Si tandem solar cells is 45.1%, and Oxford PV researchers have experimentally achieved an efficient PVK-Si tandem solar cell with 29.5% conversion efficiency (Fig. 9). Moreover, the trend in previous research in this domain also showed the possibilities to unlock the efficiency potential of PVK–Si tandem solar cells close to theoretical limits [23].

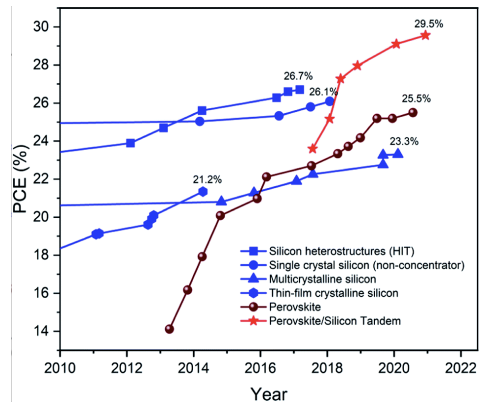

Figure 9: Efficiency chart for silicon, perovskite, and perovskite–silicon tandem devices in the last decade.[23]

4.2 Thermal Regulation of PV Cells

As previously indicated, the effectiveness of the PV modules is temperature-dependent [24]. [25] conducted a literature review and suggested various connections that can be used to calculate the PV efficiency in relation to temperature. They determined that there is a significant relationship between the reduction in efficiency and the increase in temperature, and that this relationship is linear. These findings underscore the importance of cooling the PV modules in order to improve their efficiency. In addition to boosting the electrical efficiency of the PV panels, the heat energy generated can also be utilized for other purposes, like heating, which can result in an overall increase in the system's efficiency. Various systems that can implement the extracted thermal energy of the solar cells are known as PV/T, which have been widely developed in recent years [26].

Every method used for managing the temperature of energy systems has its own set of benefits and drawbacks. Active methods have the advantage of being able to remove more heat, but they also tend to have a more complex structure because they require extra equipment. In contrast, passive methods have simpler structures, do not need additional equipment or devices, and are generally less expensive to maintain. According to recent comparisons [27, 28] of different cooling techniques in photovoltaic (PV) panels. The cooling techniques are ranked in terms of their ability to increase PV efficiency, from highest to lowest, as phase change cooling, liquid cooling, passive cooling, and air cooling.

Air cooling methods can utilize both forced and free convection to manage temperature. Passive methods employ mediums such as heat spreaders and heat pipes. Liquid cooling methods can use various coolants, but water is particularly useful for solar systems as the heated water can be repurposed for heating. When dealing with high levels of heat, a phase change heat transfer mechanism is preferred. This includes evaporative cooling and two-phase cooling with boiling for high temperature conditions, while phase change materials are used for lower temperature conditions. In PV modules, two-phase heat transfer is limited to evaporative cooling using water spraying and solid phase change materials.

Figure 10: Cooling methods employed for PV cells [29]

4.2.1 Best-performed and Promising PV Cooling Methods

Overall methods for reducing PV temperature can be divided into two main groups, ones that reduce surface temperature, mainly from environmental factors, and others that primarily focus on reducing heat loss within the system. Currently, there have been many results pointing that passive cooling methods for environmental factors, namely spraying water cooling method, are superior in dealing with thermal regulation especially in tropical climate, as in Thailand. Nevertheless, recent studies also suggested that the integrative system of both approaches is possible and is currently in the developing process as will be discussed in detail later.

4.2.2 Spraying Water Cooling System

One of the major challenges in renewable energy, particularly in hot regions like Thailand, is how temperature affects the performance and efficiency of photovoltaic (PV) panels. High temperatures in hot weather can cause a decrease in the open circuit voltage and overall efficiency of the PV module.

Recent research from Iraq [28] compares two main methods of cooling for photovoltaic (PV) modules, namely water cooling and air cooling. The first method was air cooling, with the cooling system positioned at the back of the PV module. The water cooling method has two techniques: the first technique employs two aluminum blocks for cooling (known as water cooling blocks), which are placed at the back of the PV module, while the second technique uses a perforated copper tube for spraying water and is placed at the front of the PV module. Experimental results indicate that the technique involving spraying water for cooling is the most effective in enhancing efficiency compared to the other techniques (water cooling blocks and DC fan), especially at high PV temperatures.

Figure 11 illustrates the outcomes of utilizing the spraying water cooling method compared to the control setup without any cooling system. This technique withdraws heat from the front surface of the PV module, resulting in the cooling of the PV and an increase in energy productivity. The efficiency of the module increases considerably with colder water and longer spraying periods, which led to a recorded increase of 11.89%. The measurements also indicate a reduction of 21% and 34.43% in the PV temperature and temperature percentage, respectively.

The utilization of cooling technologies results in an increase in the electrical energy produced, leading to an improvement in the efficiency of the PV module, which is dependent on the level of solar radiation. They summarized that in the case of an air-cooled method utilizing a DC fan, the temperature of the module dropped by over 16°C, and the efficiency increased by 9.34%. On the other hand, for water-cooling methods, the PV temperature decreased by 9.3°C and 21°C for both cooling techniques (blocks and spraying), respectively, resulting in an average percentage efficiency increase of 5.65% and 11.89% for the same sequences of water-cooling processes. It can be concluded that the spraying water technique is the most suitable method for enhancing the efficiency and the best cooling technique for hot climates.

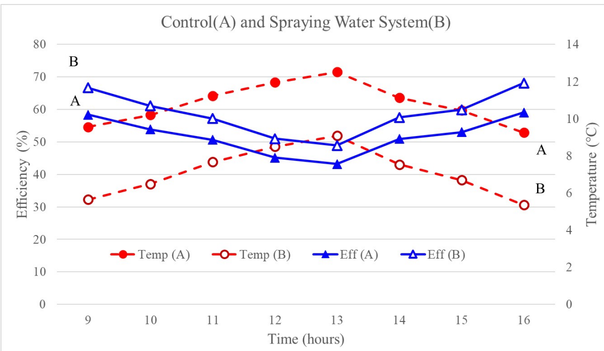

Figure 11: Daily average efficiency and temperature of simple PV and PV with water spraying cooling system [28]

4.2.3 Integrative Passive and Active Cooling System

A combined passive and active cooling system has been developed and modeled to regulate the temperature of a concentrated photovoltaic (CPV) solar system. Fig. 12 shows the proposed schematic design incorporates a heat storage battery with phase change material (PCM) and a closed loop water cooling system[30]. A two-dimensional model was developed to simulate the CPV layers along with the integrated cooling system. The results of the investigation assess the thermal and electrical performance of the system components as well as the overall system.

The use of nanofluid as a heat transfer fluid (HTF) to enhance system performance was also evaluated. The findings indicate that the proposed system reduces the average CPV temperature by 60% compared to conventional direct PCM-PV and water-cooling systems used individually. At a concentration ratio (CR) of 10 and HTF velocity of 0.01 m/s, the cell temperature remains below 78°C. Additionally, the PCM's maximum temperature stays below the limit at which degradation occurs. Introducing nanofluid as an HTF enhancer improves CPV efficiency by 2.7% and decreases the maximum temperature of the PV panels and the PCM melting time by 4°C and 12%, respectively.

4.3 Proposed Policy for PV Cells Employment

Thailand heavily relies on fossil fuels for its electricity generation, but it has made commitments to reduce greenhouse gas emissions through its nationally determined contribution (NDC) and NDC roadmap. To support these efforts, Thailand is developing its first Climate Change Act. Implementing a carbon price could expedite the transition to low-carbon energy, especially in the power sector. By internalizing the cost of carbon, incentives can be created to move away from fossil fuel-based electricity. This report examines the potential role of carbon pricing in Thailand's power sector, assessing its impact on reducing CO_2 emissions and promoting cleaner energy sources. It also explores the implications of carbon pricing on operating costs and electricity prices. The report is part of the International Energy Agency's (IEA) support to the Thailand Greenhouse Gas Management Organization (TGO) in designing policies for clean energy transition and climate change mitigation in Thailand.

The modeling conducted in the report indicates that carbon pricing can encourage CO_2 emission reduction in Thailand's power sector by shifting generation from carbon-intensive plants to those with lower emission intensity. The carbon price increases operating costs for carbon-intensive plants, making them less economically viable and pushing them further down in the merit order under economic dispatch decisions.

By combining a moderate carbon price of USD 30 per ton of CO_2 or more with increased variable renewable energy (VRE) capacity and system flexibility, a successful transition from coal to VRE can be achieved. This transition would lead to further emission reductions and a significant transformation of Thailand's power sector. In a scenario called Flex, which represents a progressive vision for Thailand's power sector in 2030 with higher renewable penetration and enhanced technical and contractual flexibility, the modeling results show that without a carbon price, having more VRE capacity and system flexibility could reduce power sector emissions by 11 million

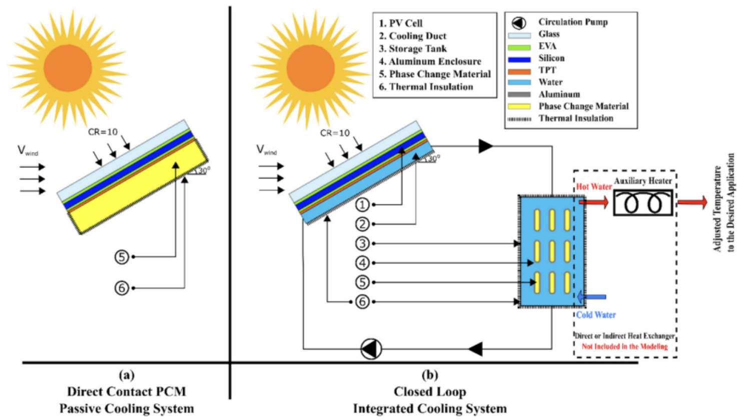

Figure 12: Physical Model for a) Direct contact PCM and b) Indirect PCM-water loop integrated system [30]

tons of CO_2 in 2030. However, due to the higher operating costs of natural gas, primarily in the form of combined cycle gas turbine plants (CCGT), the addition of VRE capacity without a carbon price would result in a shift from natural gas to VRE with limited impact on coal.

Introducing carbon pricing alongside VRE capacity additions could bridge the cost gap between natural gas and coal, facilitating a shift from coal to VRE and reducing emissions from coal power generation. With a carbon price of USD 40 per ton of CO_2, an additional 15 GW of VRE capacity, and a more flexible power system, total emissions from the power sector could be reduced by 26 million tons of CO_2 in 2030 compared to a scenario without a carbon price. Moreover, compared to the same carbon price in a scenario following the Power Development Plan (PDP), a more flexible power system with additional VRE capacity would achieve greater emission reductions due to a larger decline in fossil fuel generation.

Considering the structure of Thailand's power sector, another policy option could involve the Electricity Generating Authority of Thailand (EGAT) applying an implicit shadow carbon price for dispatch decisions, in parallel with an explicit carbon price set at a limited level. A shadow carbon price is a hypothetical cost used during the planning process to internalize the carbon cost without actually incurring the liability. Implementing a shadow carbon price could minimize the potential economic impact of a sudden high carbon price liability and give businesses time to transition and prepare for a clean energy shift. However, one disadvantage of the shadow carbon price is

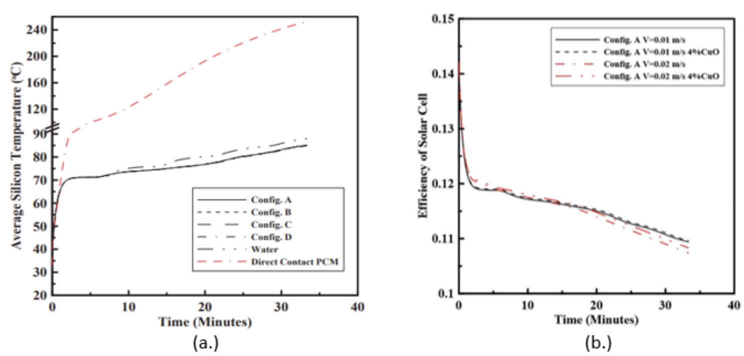

Figure 13: (a.) Variation of the average silicon temperature with time. (b.) Effects of HTF velocity and using nanofluid on the solar cell efficiency. [30]

that it does not generate additional revenue for the government to address climate-related issues.

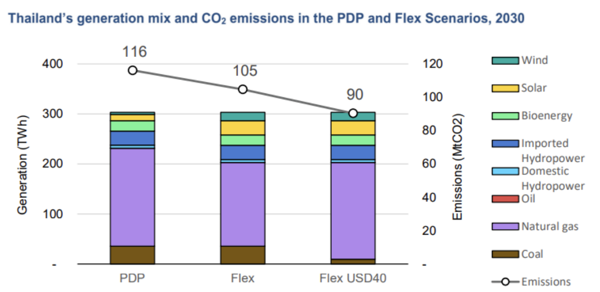

Figure 14: Thailand's generation mix and carbon dioxide emission in the PDP and Flex scenarios, 2030 [31]

5 Policy and Roadmap

5.1 Official Policy about Energy

In an effort to reduce carbon emmissions and secure a sustainable future, the government aims to improve Thailand's energy production potential. According to the AEDP2018 from the Ministry of Energy, Thailand is promised the energy production potential of 18,696 MW [32]. 12,015 MW of which is expected to be solar energy, which contributes to over 64% as represented in the figure below.

5.2 Proposed Roadmap

The following is our proposed roadmap in order to achieve an effective energy transition with the help of improved solar technologies.

5.2.1 Adjustment on policy and regulations

Topics	Short term	Long term
• Supporting the production of solar power energy	1. The government buys solar energy at a satisfying price for all parties. 2. Encourage entrepreneurs that are interested in solar power production by setting up a one stop service center to be used when requesting the production permit. 3. Encourage civilians to use solar energy by simplifying the process of permit request as mentioned above.	1. Adjust other regulations to allow solar power sites to produce energy efficiently. 2. Adaptation of available public land to become solar power sites. 3. Set up regulations for the proper discardment of PV cells and other equipment used in power production that are out of order.

5.2.2 Development of technology and knowledge

Topics	Short term	Long term
• Training personnel to be adept in the field of solar technology	1. Train personnel to be adept in the designing and installation of PV cells and its related system.	1. Encourage researchers and developers to construct Thailand's own equipment in solar power plants.
• Stimulate cooperation in communities	1. Develop a system where civilians can have a say in the energy production of solar power plants.	1. Encourage civilians to transition their household's main power source to solar energy.
• Development of solar technologies	1. Fund research about PV cell cooling systems. 2. Consider effects of cooling systems on the environment 3. Develop the storage system that can make solar power reliable even without sunlight	1. Analyze and make adjustments to PV cells in all power plants to increase overall efficiency. 2. Utilize and install an efficient storage system in communities.
• Increasing the potential of other clean power	1. Fund research on other clean energy to make them more reliable.	1. Use more clean energy and less fossil fuel.

5.2.3 Raising awareness about the importance of sustainability

Topics	Short term	Long term
• Increase cooperation of communities	1. Educate people about sustainability and environmental problems.	1. Make a norm out of a sustainable lifestyle for Thai people.

6 Importance and Impact

Should the road map be successfully implemented, desirable changes in many fields are to be expected. While the plan involves the improvement of the system and the development of technologies, it also promotes the idea and awareness to the common people to make the concept widely known and successfully implemented by the public. The impact should be noticeable in these following aspects:

6.1 Impact on the environment

Transitioning Thailand's energy sector to solar energy will greatly reduce the reliance on fossil fuels. Without excessive use of fossil fuels like nowadays, there will be less carbon emission, which is the root cause of various environmental problems, such as acid rain and climate change caused by greenhouse gasses. If successfully adapted, Thailand should be able to reach net-zero emission and carbon neutrality. This roadmap is one small step we need to take to ensure our future generations a sustainable environment.

6.2 Impact on Technology

The improvement of solar technology can persuade companies to invest in further development. If more researches are given enough fund, advancement will surely be made to improve PV cells and increase its efficiency to make it an even more attractive source of clean energy for the public to choose over unsustainable ones.

6.3 Impact on the Economy

With the increase in solar power production potential, Thailand can cut down the cost of energy purchase and rely more on its own energy sector. The budget that has been used to pay for energy can be used in other sectors and to boost the economy. Other projects can also be more thoroughly funded to improve the quality of life of citizens and support the overall development.

6.4 Impact on Energy Dependency

Currently, Thailand depends on other countries in terms of energy to be able to keep the economic running. If Thailand can produce sufficient renewable energy, its development potential will greatly increase. Cutting down Thailand's reliance on others can also benefit us in terms of negotiation and trade.

7 Conclusion

Thailand has great potential to be a site for solar energy production, but there are also obstacles and limiting factors, an important one being excess heat. Therefore, if our purposed roadmap is applied to eliminate the limitations and increase the efficiency of solar power production, solar power will be able to become a more reliable energy alternative for Thailand, for it to successfully transition its energy sector to sustainable ones, and become a model for other countries as well.

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AN INVESTIGATION OF THE ENERGY SYSTEM AND POTENTIAL TRANSITION PLANS AWAY FROM CARBON-BASED ENERGY SOURCES IN SINGAPORE

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Content

Summary

Singapore's energy system relies heavily on imported natural gas and crude oil, with 58.5% of its energy from crude oil and around 95% of its electricity supply from natural gas. With most of its energy and electricity supply from natural gas, Singapore ranks 27th out of 142 countries in terms of CO2 emissions per capita. With new technologies and digitalisation, energy consumption in Singapore has increased. Between 2009 and 2020, Singapore's electricity system demand increased from about 42 terawatt-hours (TWh) to 53 TWh. It is projected that energy consumption in Singapore will increase in the future. Despite this, renewable energy in Singapore has lagged behind, with less than 1% of its energy supply from renewable sources such as solar. With rising energy prices and increasing demand for energy, Singapore must find a reliable source of renewable or, at the very least, low-emission energy. This report will discuss the specifics of Singapore's heavily carbon-based energy system, possible plans for transitioning to cleaner energy sources such as nuclear, hydrogen and regional energy networks and expected challenges in implementation on a national and global level at an economic and societal level such as land use, available technology and social unrest as well as possible methods to overcome said challenges.

Keywords

Energy, Nuclear and Hydrogen, Fossil fuels, Natural gas, Renewables

1 Singapore's Current Energy System

1.1 Sources of energy currently available

1.1.1 Sources of energy currently available in the world

The research data below shows the type of energy usage across the world for the year ending 2022.

The primary energy sources currently available are fossil fuels and cleaner energy, renewables being a subtype. The following table overviews each type of energy and respective sources.

Table 1.1.1.1: Overview of energy sources [57] [56] [25] [3] [50] [37] [34] [33] [32] [36] [35] [43] [58] [26] [1] [17] [13] [14] [19] [18] [20] [16] [21] [23] [15] [22] [12]

Type of energy	Source of Energy	Uses	Advantages	Disadvantages
Fossil Fuel	Oil	Electricity generation Waxes Transportation	Mature Efficient Easy to transport and store Can be refined	Environmental impacts of extraction Releases pollutants Finite reserves
	Coal	Electricity Generation Metal work Coal oil production Heating Water-filtration	Abundant Reliable	
	Natural gas	Electricity generation Natural Gas Vehicles (NGV) Heating	Cleanest fossil fuel Abundant Efficient Reliable	
Renewable	Hydropower	Electricity generation	Zero direct emissions Reliable Efficient Energy storage Water management Flood control	Environmental and societal impacts of construction Dependence on seasonal water flow Limited availability
	Wind		Zero direct emissions Abundant Installed on existing infrastructure Coexist with other land uses	Impacts on wildlife Energy storage systems required Limited availability
	Bioenergy		Carbon Neutral Reduces waste Versatile	Releases pollutants Competition with food production Impact on biodiversity
	Marine		Zero direct emissions	Under research and development

	Hydrogen		Zero direct emissions (based on type) Versatile Abundant	Under research and development Energy storage systems required
	Solar	Electricity generation Heating	Zero direct emissions Abundant Installed on existing infrastructure	Energy storage systems required Manufacturing and disposal environmental impacts
	Geothermal		Zero direct emissions Reliable Efficient	Limited availability Can cause earthquakes.
Other	Nuclear	Electricity generation	Zero direct emissions	Potential of high risk disaster Radioactive waste Politicised

1.1.2 Sources of energy currently available in the region (Southeast Asia)

In Southeast Asia, coal has been the main source of energy since 2000 with the region relying on coal power for rapid economic growth in the last 2 decades, increasing the greenhouse emissions in the region. This is also similar to countries in the wider Asia Pacific region, namely India and China which experienced unprecedented economic growth alongside Southeast Asia [30].

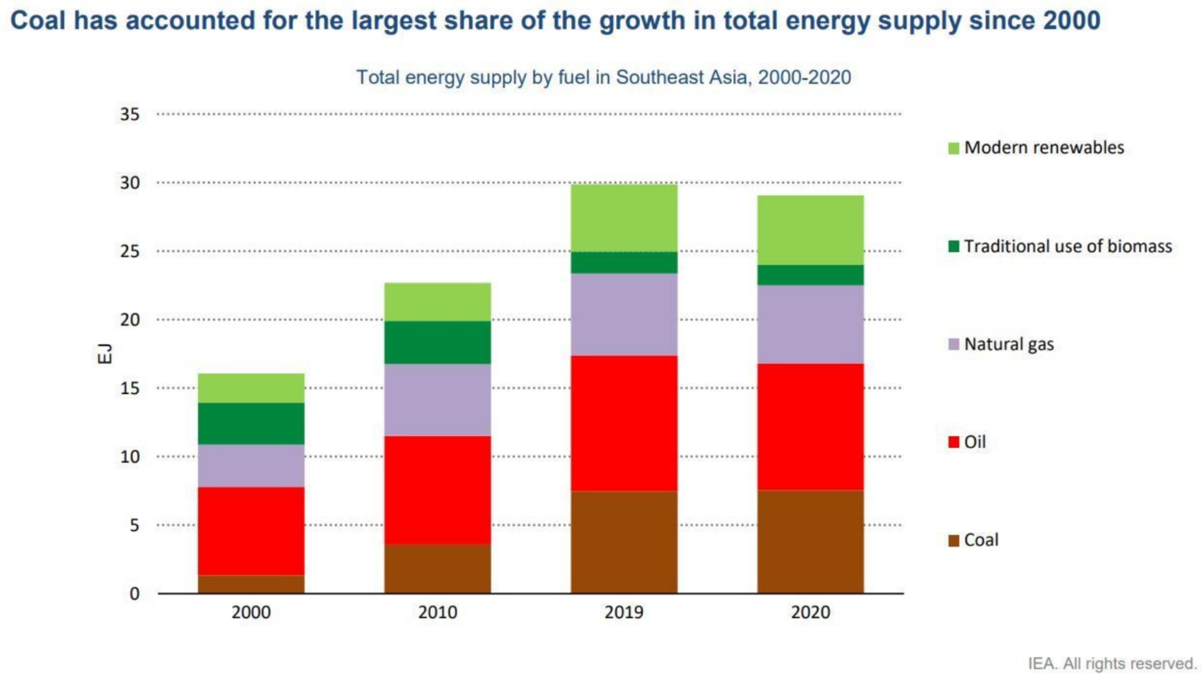

Figure 1.1.2.1: Total energy supply by fuel in Southeast Asia, 2000-2020

However the sources of energy vary widely from country to country. This is mainly due to the different resources available. The Mekong river runs through Laos, Myanmar, Thailand and Cambodia enabling them to harass hydropower. Natural oil and gas reserves are present in Malaysia, Indonesia and Brunei, making up a large portion of their energy supply.

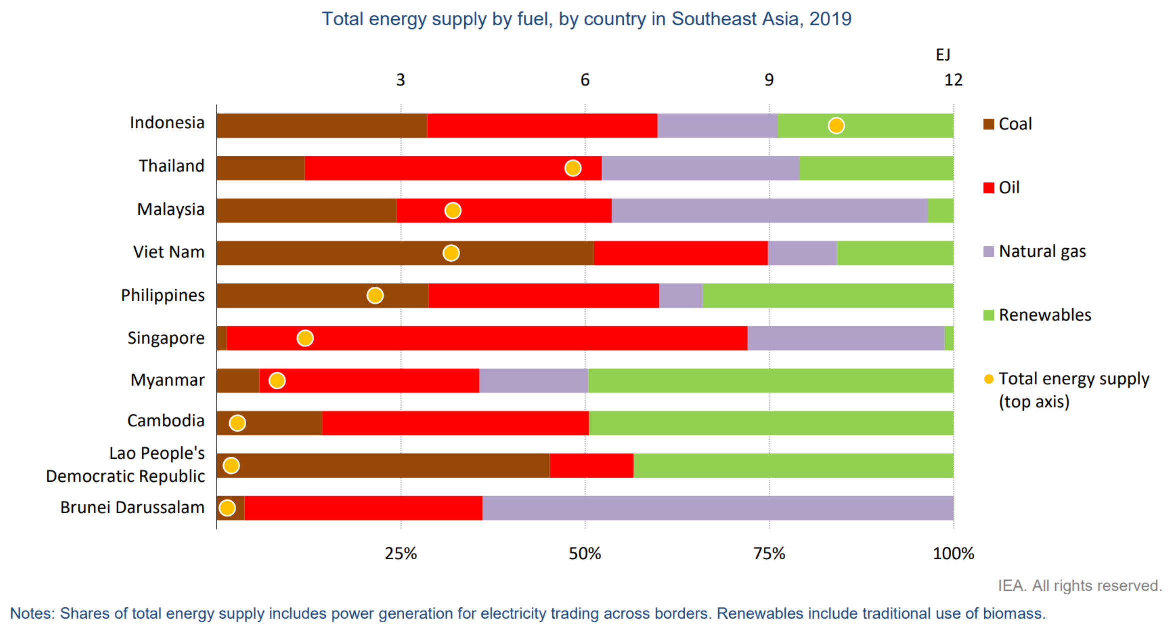

Figure 1.1.2.2: Total energy supply by country in Southeast Asia, 2019

1.1.3 Sources of energy currently available in Singapore

To carry out our analysis of Singapore's energy system, we sought the assistance of the Energy Market Authority (EMA) who provided us with valuable data presented in our report.

In Singapore, there is a lack of natural fossil fuel resources, leading to the reliance on fossil fuel imports from other countries. Many renewable sources of energy are also limited due to the geological location of Singapore. There are no hydro resources, our wind speeds and mean tidal ranges are low, and geothermal energy is not economically viable. Solar energy remains the most viable source of renewable energy. Being in the tropical sun belt, Singapore enjoys an average annual solar irradiance of 1,580 kWh/m2/year. This makes solar energy the only viable energy source. However, challenges are faced in regards to the space constraints on the island nation, making it hard for large scale solar deployment.

Sources of energy currently available in Singapore are as follows (Figure 1.1.3.1.):

- Coal
- Petroleum Products
- Natural Gas
- Electricity

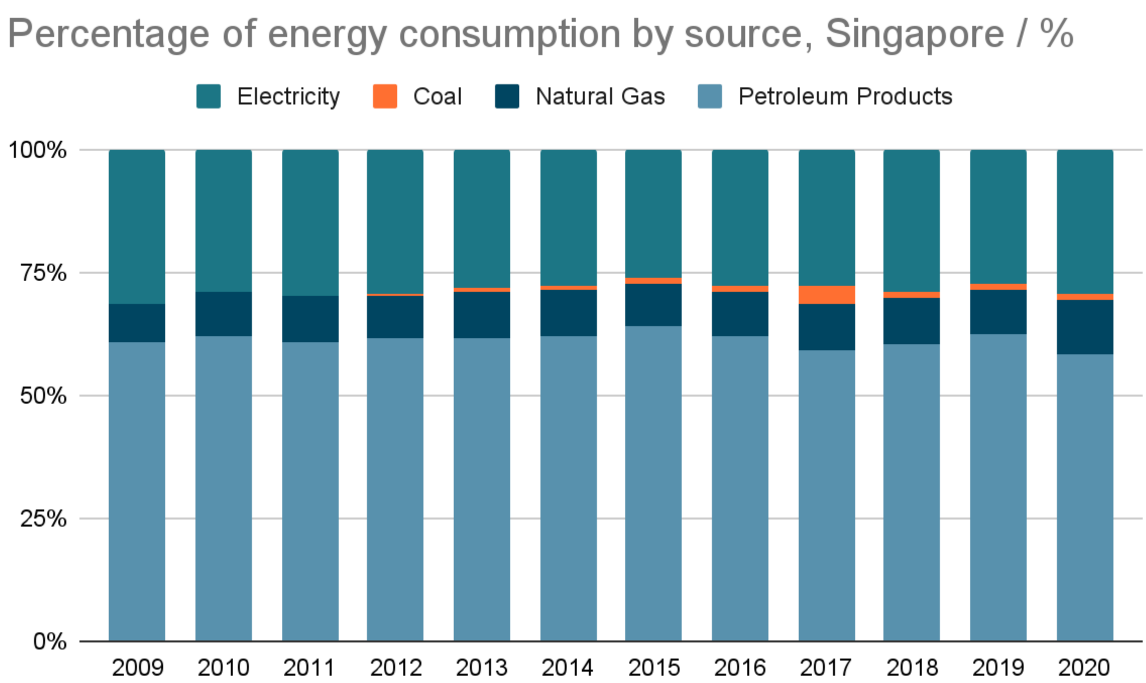

Figure 1.1.3.1: Percentage energy consumption by source, Singapore

As Singapore is a small country with limited natural resources, 95% of our electricity is produced from natural gas in our 18 power plants [44], followed by 1.2% from coal, 1% from solar and the remaining from other sources [42]. (Figure 1.1.3.2.) As of today, Singapore has installed 5455 solar PV systems at residential buildings, grassroots organisations and industries which have a capacity of 670 MWp. It is estimated that solar power could account for up to 10% of Singapore's electricity needs [27].

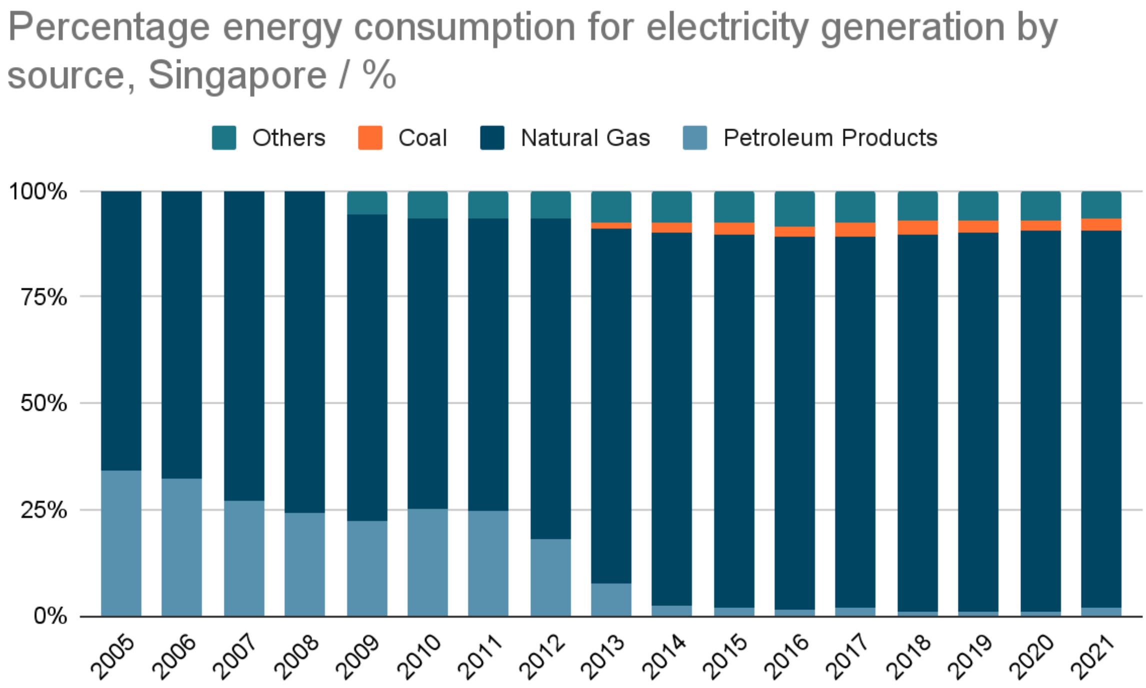

Figure 1.1.3.2: Percentage energy consumption for electricity generation by source, Singapore

Apart from the sources of energy consumed, Singapore also processes crude oil as feedstock in its 3 refineries. ExxonMobil's 605,000-bbl/d refinery at Pulau Ayer Chawan, Royal Dutch/Shell's 500,000-bbl/d refinery on Pulau Bukom and the Singapore Refining Company's 290,000-bbl/d refinery on Pulau Merlimau [38]. Singapore has a crude oil refining capacity of 1.3 million barrels per day [55], as the fifth largest refinery and export hub in the world.

Table 1.2.2.1: Energy flow in Singapore

Source of energy	Coal and Peat	Crude Oil & Natural Gas Liquids	Petroleum Products	Natural gas	Electricity	Others	Total In	Total Out
Flow								
Electricity Generators / ktoe	250.4 (in)	-	92.4 (in)	8596.9 (in)	4,564.1 (out)	653.4 (in)	9,593.1	4,564.1
Oil Refineries / ktoe	-	34,905.5 (in)	41,422.8 (out)	-	-	7,403.7 (in)	42,309.3	41,422.8

*Others: Bioenergy and Solar

* All data as of 2020

Therefore, Singapore mainly relies on fossil fuels to satisfy its energy demands. It imports fossil fuels in the form of coal, petroleum products and natural gas for energy generation. Singapore is also a major refinery hub importing crude oil for refining into petroleum products which are either used locally or exported.

Residential forms of energy in Singapore can be categorised into the following:

- Gas (town gas)
- Electricity

Gas is a key electricity source for Singapore, with natural gas making up 94.9% of our electricity mix in 2021 [6]. To foster competition, the Singapore gas market has been structured so that the gas transportation business is managed solely by PowerGas while the more competitive businesses of gas import, shipping and retail are managed separately by individual competitors. Singapore has two gas pipeline networks for Town Gas and Natural Gas. Town gas is produced by City Energy Pte Ltd and is mainly used for cooking and heating by residential and commercial customers. Natural gas has been imported via pipelines from Indonesia and Malaysia and in the form of LNG since May 2013. It is mainly used for electricity generation and industrial feedstock [8].

The electricity market of Singapore has been structured around the regulatory framework of the Electricity Act 2001, which aims to create a competitive market framework for the electricity industry and provide for the safety, technical and economic regulation of the generation, transmission, supply and use of electricity [4]. Notable developments are the Open Electricity Market [5] and regular reviews with industry players to enhance emergency preparedness of the power sector. This results in an average interruption time of less than 1 minute per customer per year [10] [9].

1.2 Energy Consumption

1.2.1 Energy Consumption in the world

The energy consumption of all types of energy sources has increased from 123,821TWh in 2001 to 176,431TWh in 2021, due to development (Figure 1.2.1.1). Over the past decade, the consumption of fossil fuels has reduced and that of low-carbon and renewable sources has increased. (Figure 1.2.1.2). Hydropower consumption is the largest, with newer technologies like solar growing at a faster rate (0.01% to 5.12%) (Figure 1.2.1.4).

Nuclear energy generation has remained stagnant for the past 2 decades. This is mainly due to the political scrutiny and the decommissioning of nuclear power plants.

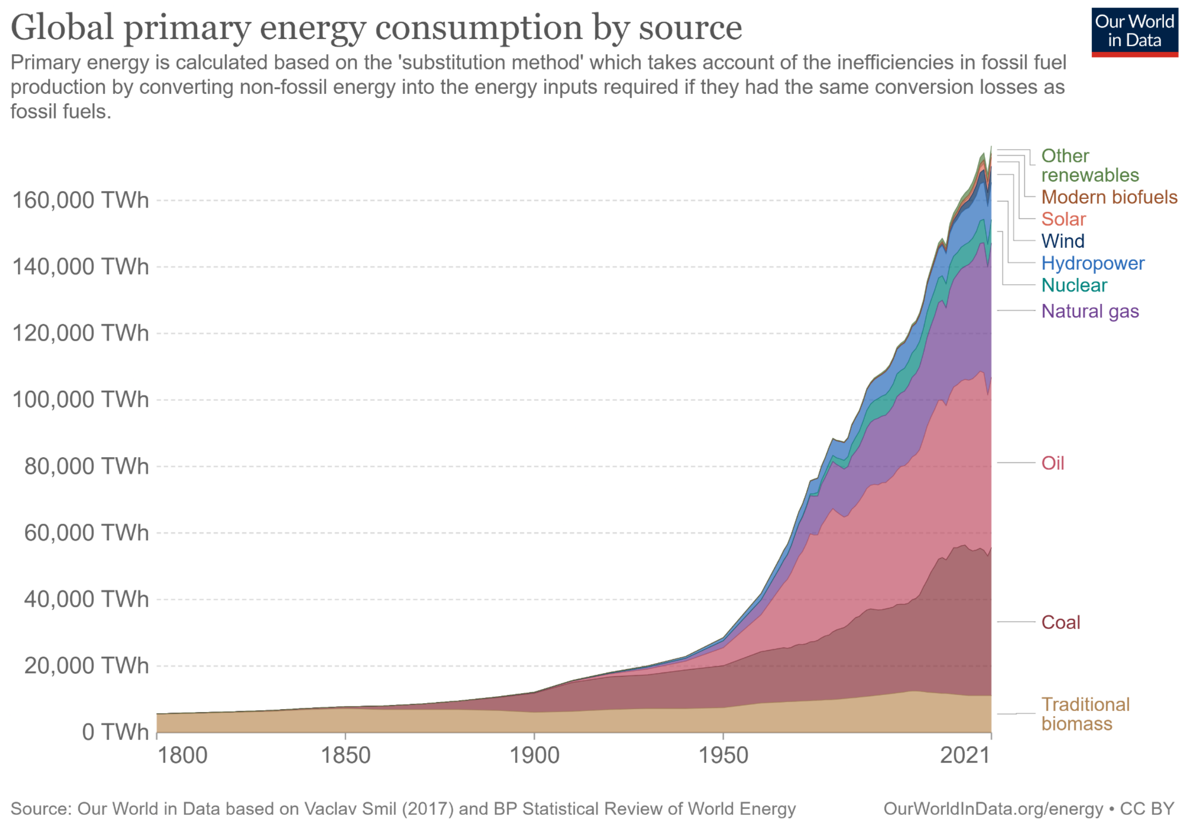

Figure 1.2.1.1: Primary energy consumption by source, World [45]

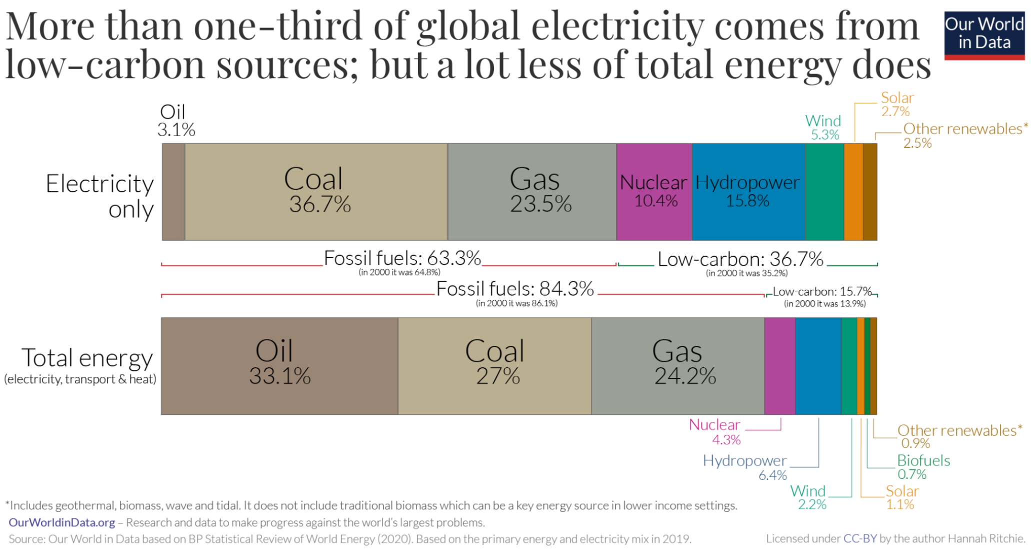

Figure 1.2.1.2: Global electricity and energy consumption by source [48]

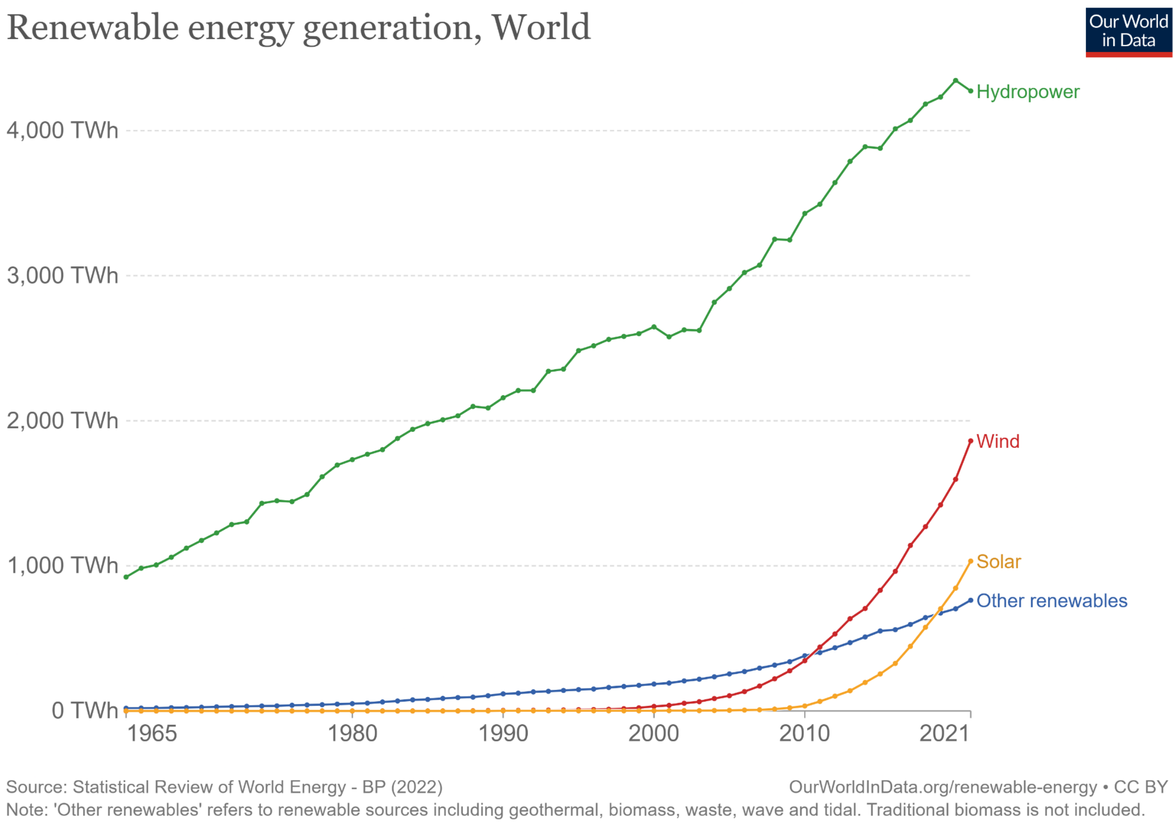

Figure 1.2.1.3: Renewable energy generation by source, World [46]

1.2.2 Energy Consumption in Singapore

Singapore's energy consumption is largely made up of oil (58.5%) and gas (11.0%) as of 2021. About 1.2% is made up by coal with the remaining 29.3% being made up of electricity (Figure 1.2.2.3). A total of 14,900.6 ktoe of energy was consumed in 2020.

The industry accounted for more than 66% of energy consumption in 2020 (Figure 1.2.2.1). Petroleum products were extensively used in the transportation sector. Electricity usage in the commerce and services sectors and households is shown in Table 1.2.2.1.

The proportion of renewable energy has been increasing since 1985, with the commissioning of waste-to-energy plants generating bioenergy. From 2008, solar power generation also increased (Figure 1.2.2.4)

The proportion of oil energy has decreased in the recent decade due to the transition to gas in the electricity generation sector (Figure 1.2.2.5).

In 2021, Natural Gas accounted for 94.9% of the electricity generation fuel mix. Other energy products accounted for 2.9%, while the rest were contributed by Coal (1.2%) and Petroleum Products, mainly in the form of Diesel and Fuel Oil (1.0%) [6] (Figure 1.2.2.6). 4,366.3 ktoe of electricity was consumed in 2020.

Singapore is highly dependent on fossil fuels for energy. 49,749.1 gigagrams (Gg) of greenhouse gas emissions were released in 2020, ranking 27 out of 142 countries in terms of carbon emissions per capita in 2018 (Figure 1.2.2.7). Singapore's carbon emissions are mainly made up of carbon dioxide emissions (99%). Carbon emissions have been steadily rising, however, in the past 5 years, emissions have started to decrease with the adoption of renewable energy (Figure 1.2.2.8).

Table 1.2.2.1: Energy consumption in Singapore for 2020

Source of energy	Coal and Peat	Crude Oil	Petroleum Products	Natural gas	Electricity	Total
Consumption						
Industry / ktoe	182.7	-	6,406.7	1,479.5	1,803.9	9,872.8
Commerce and Services / ktoe	-	-	69.3	77.5	1,592.2	1,739.0
Transport / ktoe	-	-	2,214.3	2.0	241.5	2,457.8
Households / ktoe	-	-	23.1	76.2	708.9	808.2
Others / ktoe	-	-	-	3.0	19.7	22.8
Total Consumption / ktoe	182.7	-	8,713.3	1,638.3	4,366.3	14,900.6

* All data as of 2020

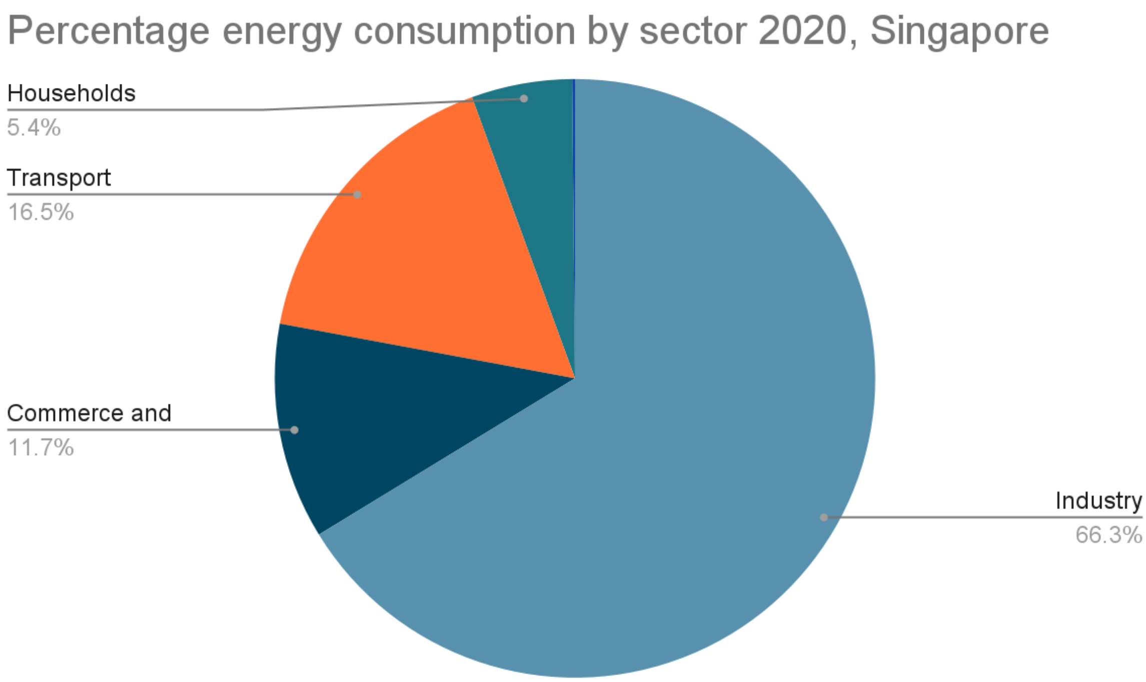

Figure 1.2.2.1: Percentage energy consumption by sector 2020, Singapore

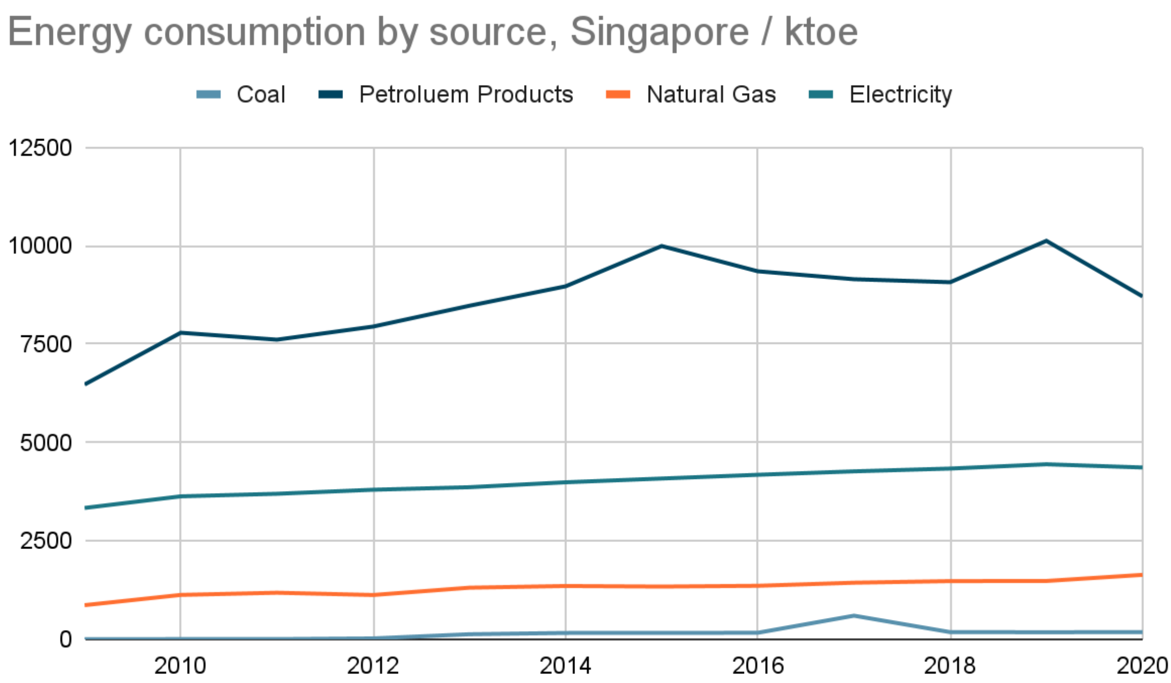

Figure 1.2.2.2: Energy consumption by source, Singapore

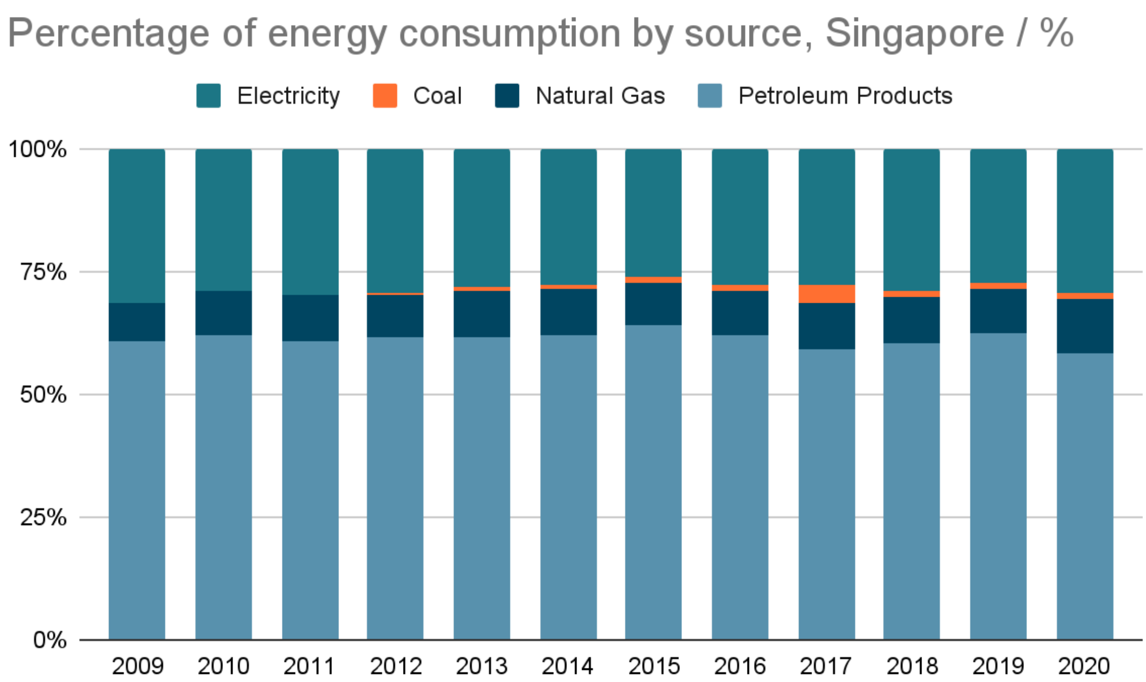

Figure 1.2.2.3: Percentage energy consumption by source, Singapore

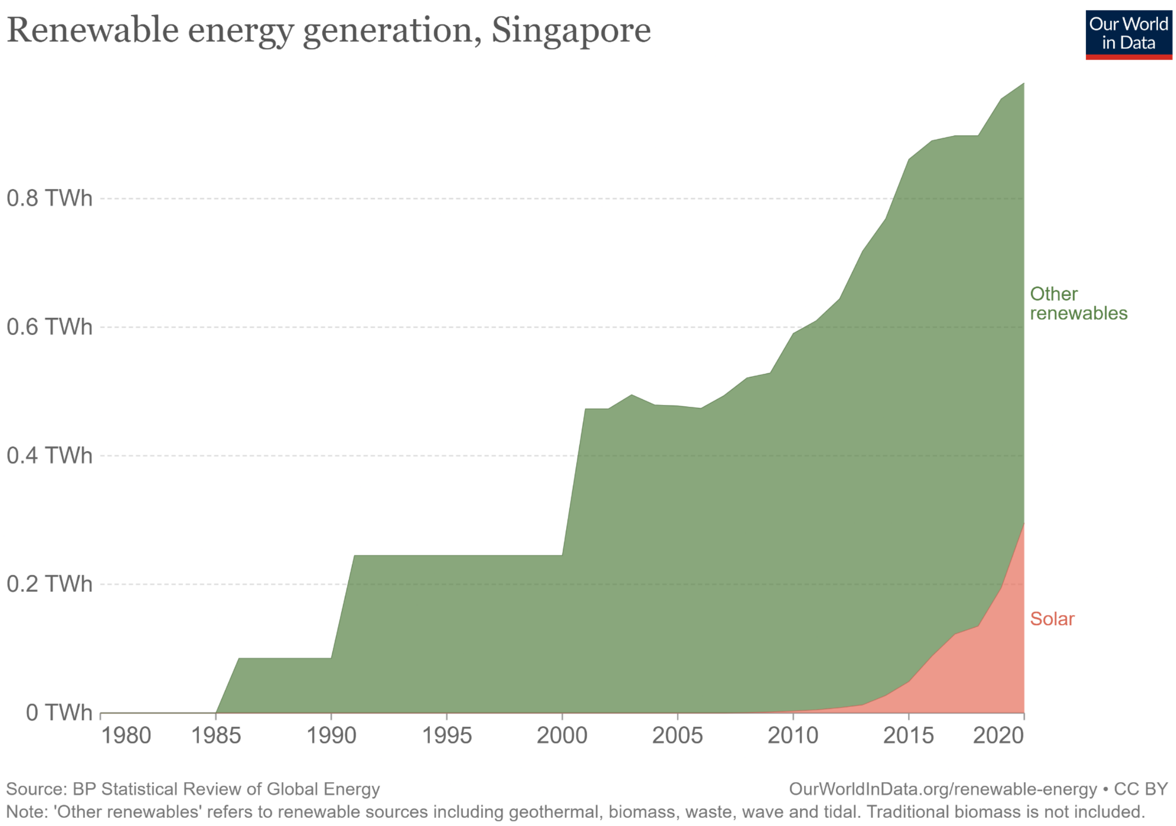

Figure 1.2.2.4: Renewable energy generation by source, Singapore

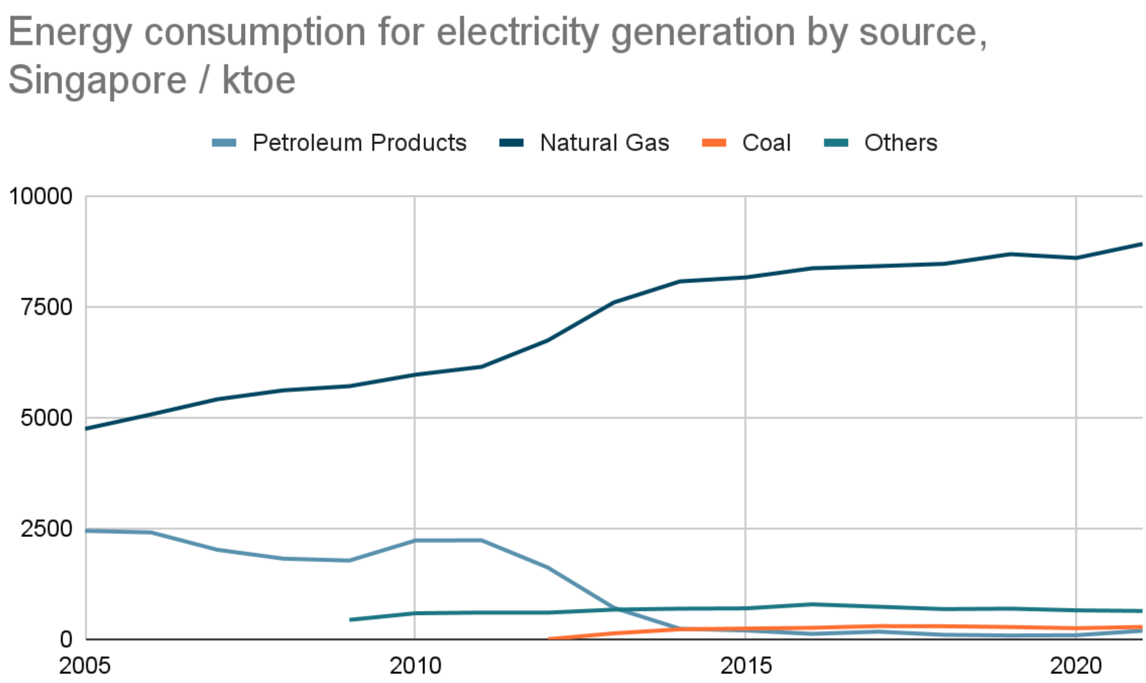

Figure 1.2.2.5: Energy consumption for electricity generation by source, Singapore

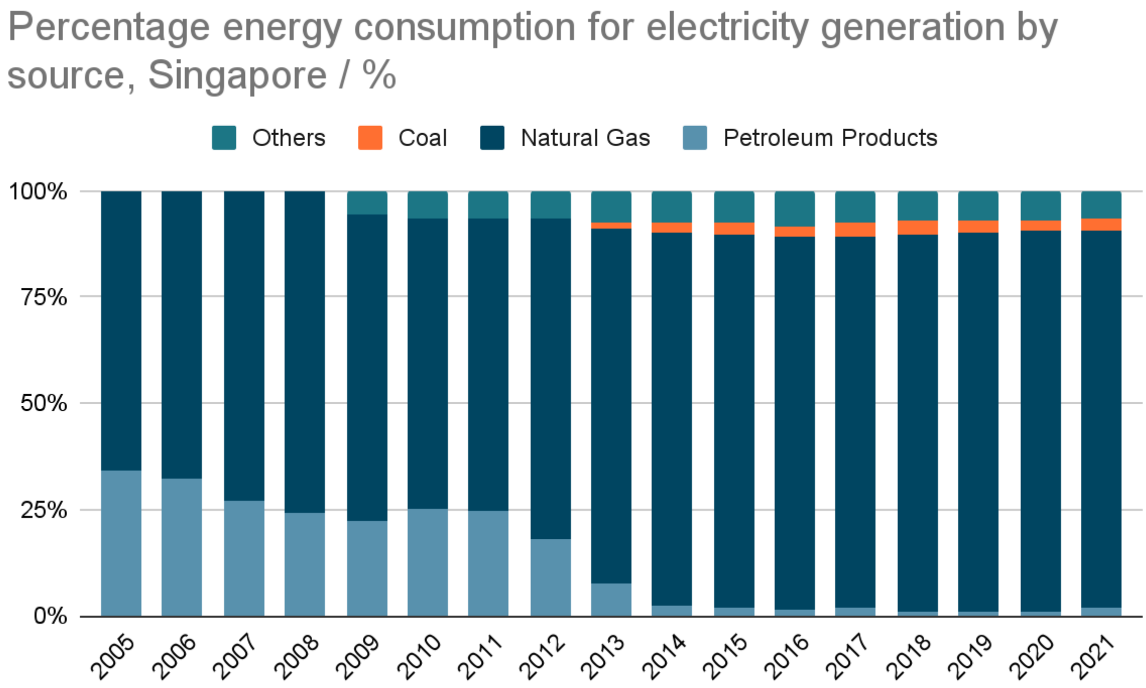

Figure 1.2.2.6: Percentage energy consumption for electricity generation by source, Singapore

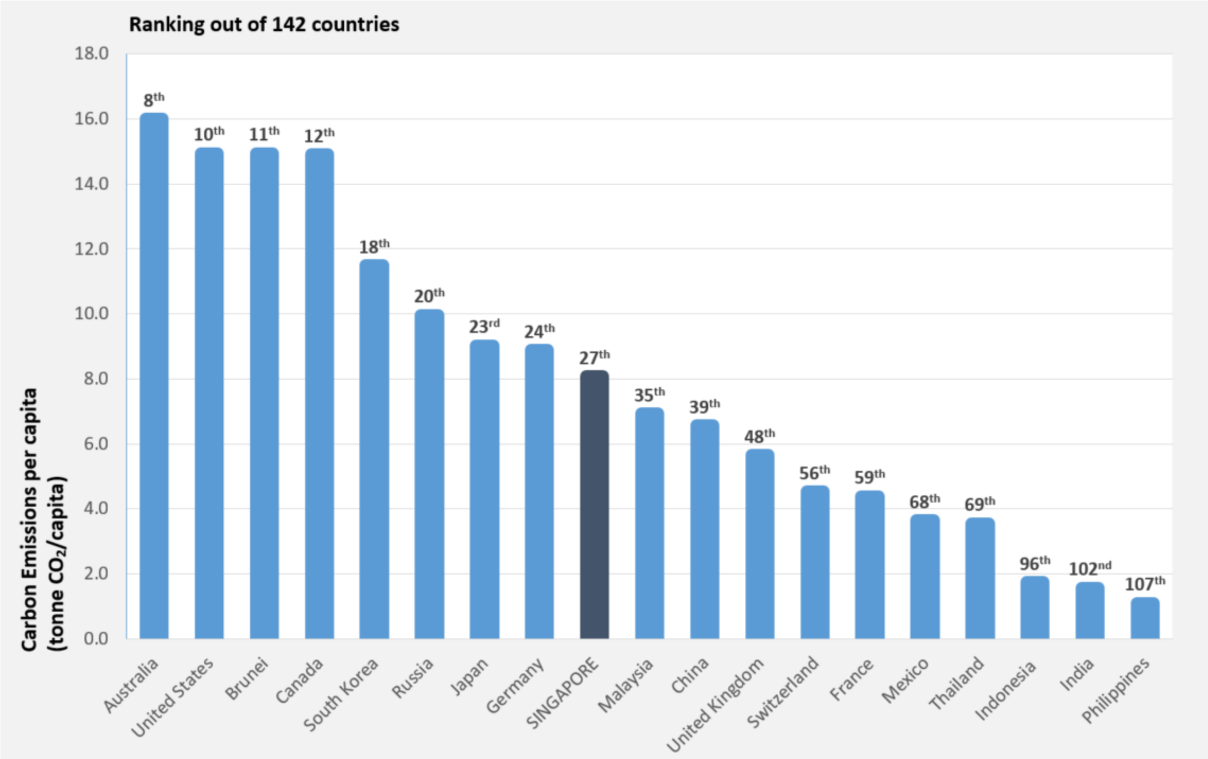

Figure 1.2.2.7: Carbon emissions per capita 2018 (IEA) [40]

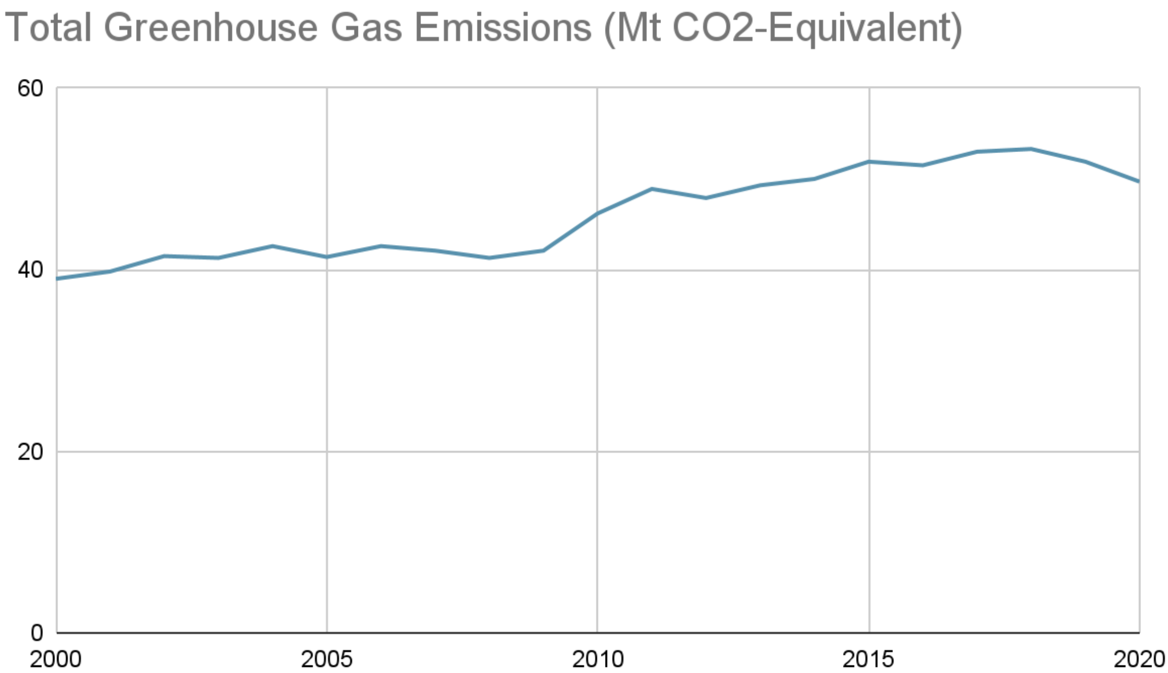

Figure 1.2.2.8: Total Greenhouse Emissions, Singapore

1.3 Energy Imports and Exports

Singapore has no naturally occurring hydrocarbon resources, importing most energy as fossil fuels. Being an key energy trading and refining hub in Asia, petroleum is refined for local consumption and export making Singapore the world's largest bunkering port [55]. Figure 1.3.1 compares the amounts of the various imports and exports. The individual locations and uses are detailed in this section.

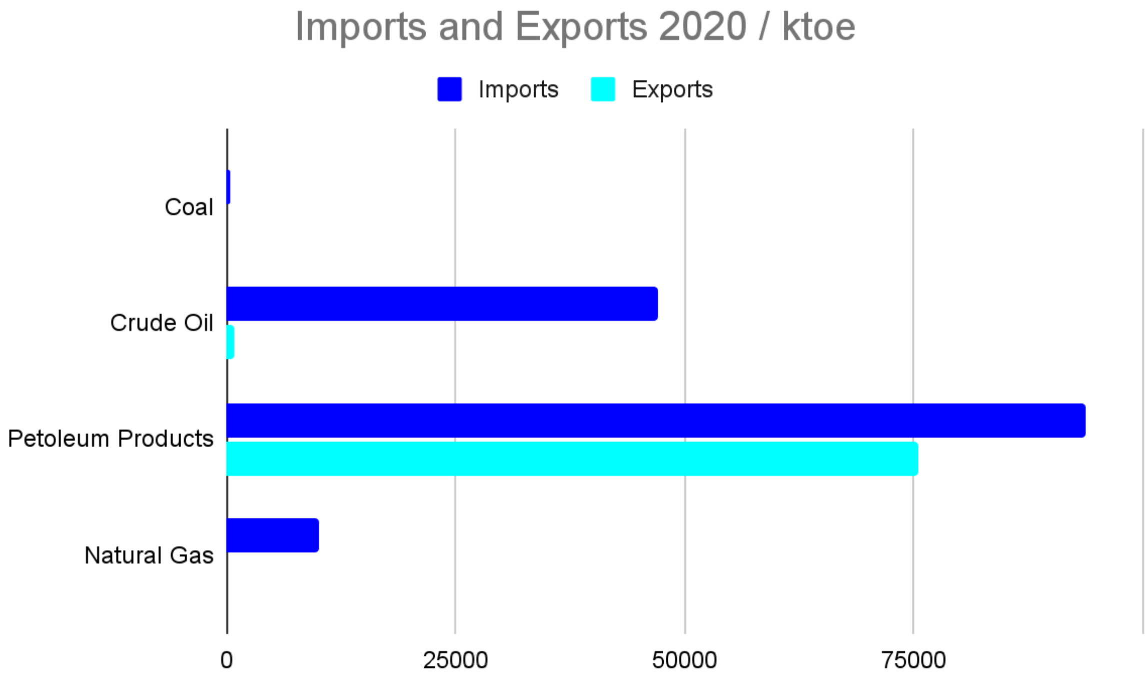

Figure 1.3.1: Imports and Exports of energy 2020, Singapore

Crude oil

Crude oil is imported for refining. Singapore has a crude oil refining capacity of 1.3 million barrels per day [55], as the fifth largest refinery and export hub in the world. Crude oil is imported mainly from Arab countries - United Arab Emirates, Qatar, Saudi Arabia and Kuwait (Figure 1.3.2). The crude oil exported is almost exclusively to Australia.

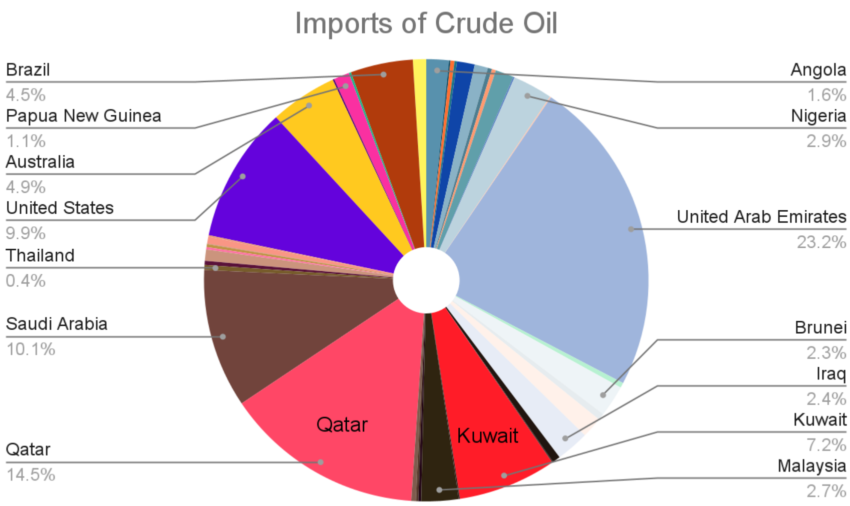

Figure 1.3.2: Imports of Crude Oil by country 2020, Singapore

Petroleum Products

Petroleum products are imported for domestic petrochemical industries. They are mainly imported from countries in Asia, such as China, Malaysia and India (Figure 1.3.3). Petroleum products produced from refining crude oil are exported to countries in the South China Sea, with China, Indonesia, India, Malaysia, Thailand, and Vietnam being the top destinations for petrochemical exports and Malaysia, Indonesia, Australia and China making up 60% of the petroleum product exports [55] (Figure 1.3.4).

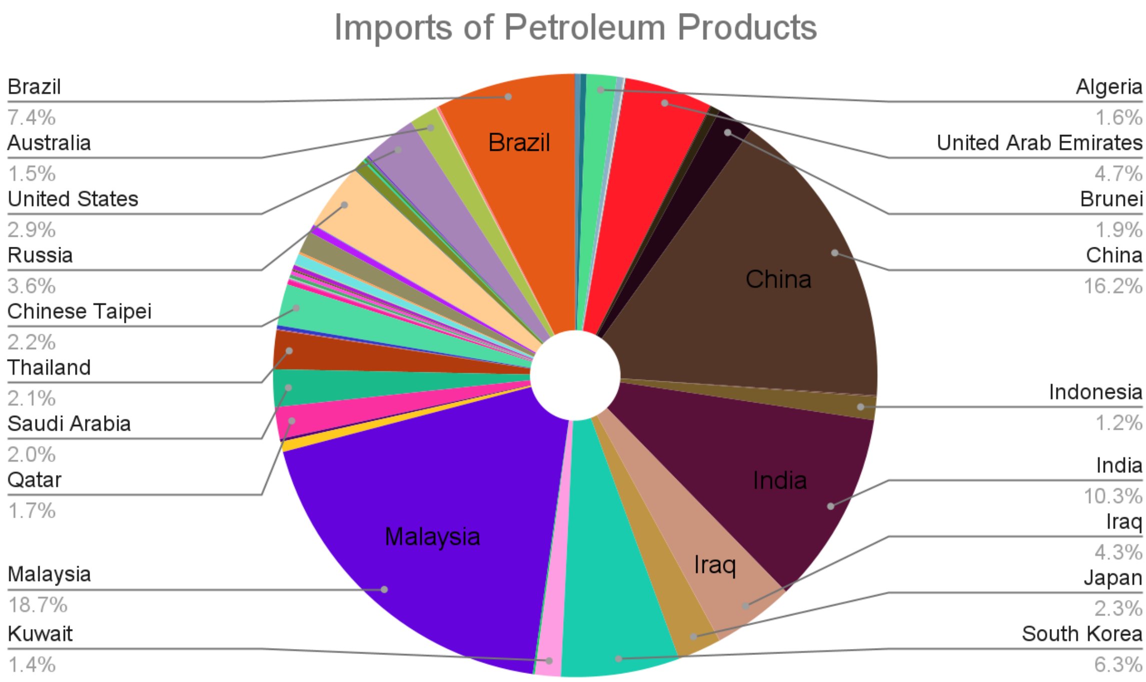

Figure 1.3.3: Imports of Petroleum Products by country 2020, Singapore

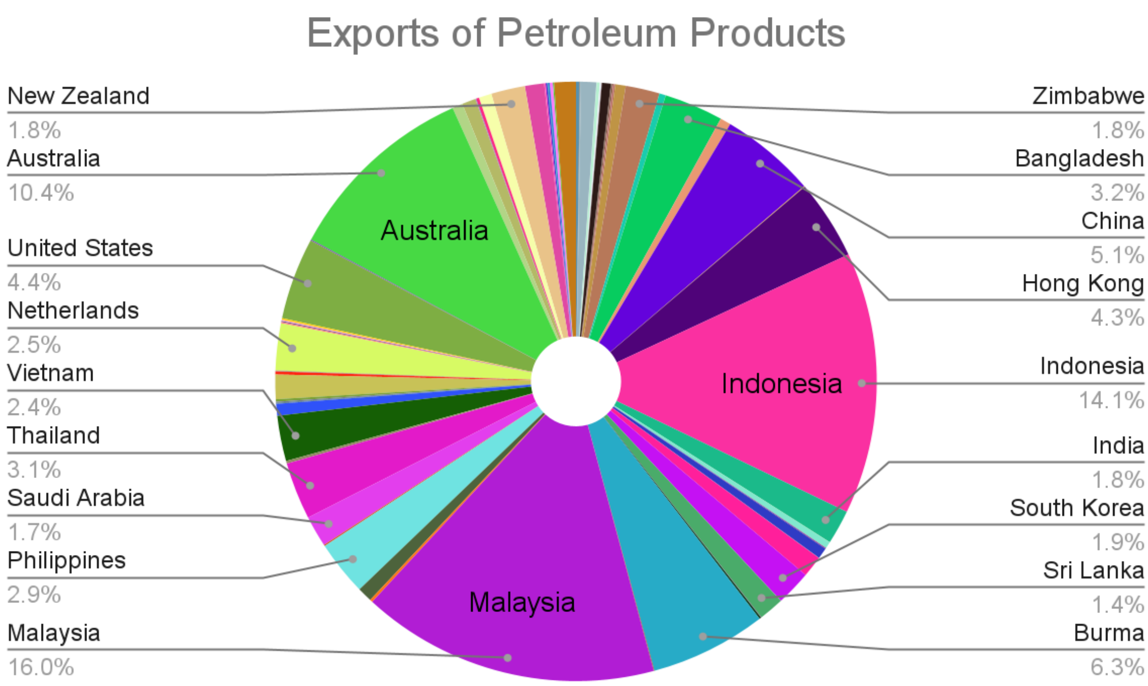

Figure 1.3.4: Exports of Petroleum Products by country 2020, Singapore

Natural Gas

Natural Gas is imported for use in electricity generation, with over 90% of electricity from natural gas. Singapore imports natural gas through 2 main methods; pipelines and liquified natural gas (LNG). The main import sources through pipelines are Malaysia and Indonesia, while 70% of LNG imports are from Australia and the United States, with the remaining from Qatar and Angola, among other countries [55] (Figure 1.3.5).

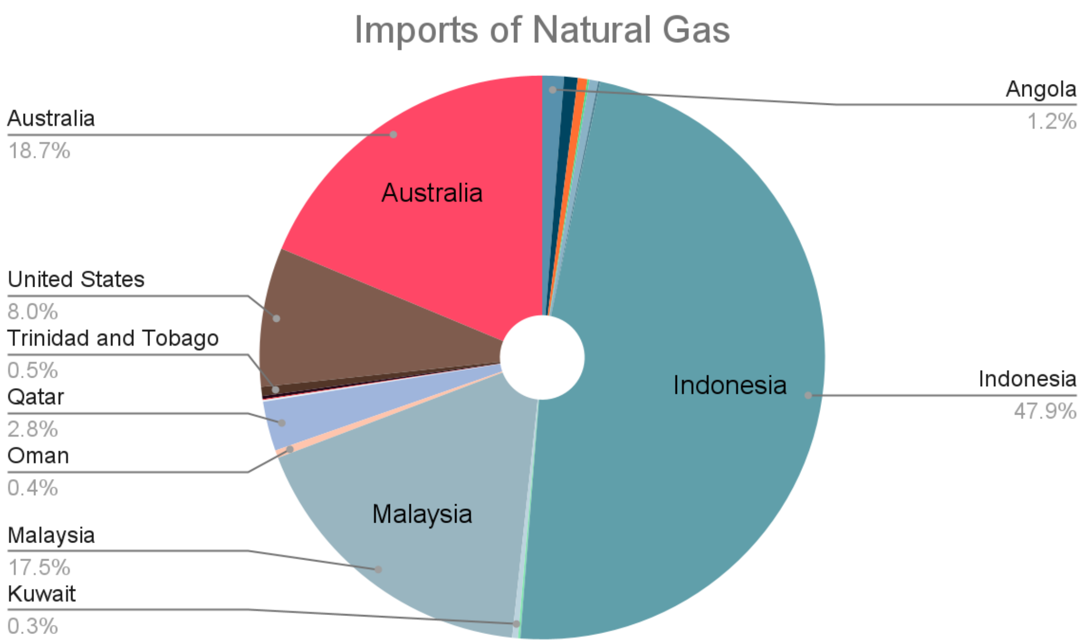

Figure 1.3.5: Imports Natural Gas by country 2020, Singapore

2 Energy Transition Plan

2.1 Energy Sources Used, Development and Acquirement

The levelized cost of electricity (LCOE) represents the cost of generating electricity for various technologies, showing the economic viability of the technology in the market. In general, the LCOE of fossil fuels is becoming less competitive compared to renewable energy, as they improve and costs decline (Figure 2.1.1). Within the last decade, the LCOE of solar photovoltaics has fallen 90% from $359 to $36, making it one of the most economically viable options for energy generation [39] (Figure 2.1.2). Therefore, transitioning to renewable energy sources now would be an economically viable option.

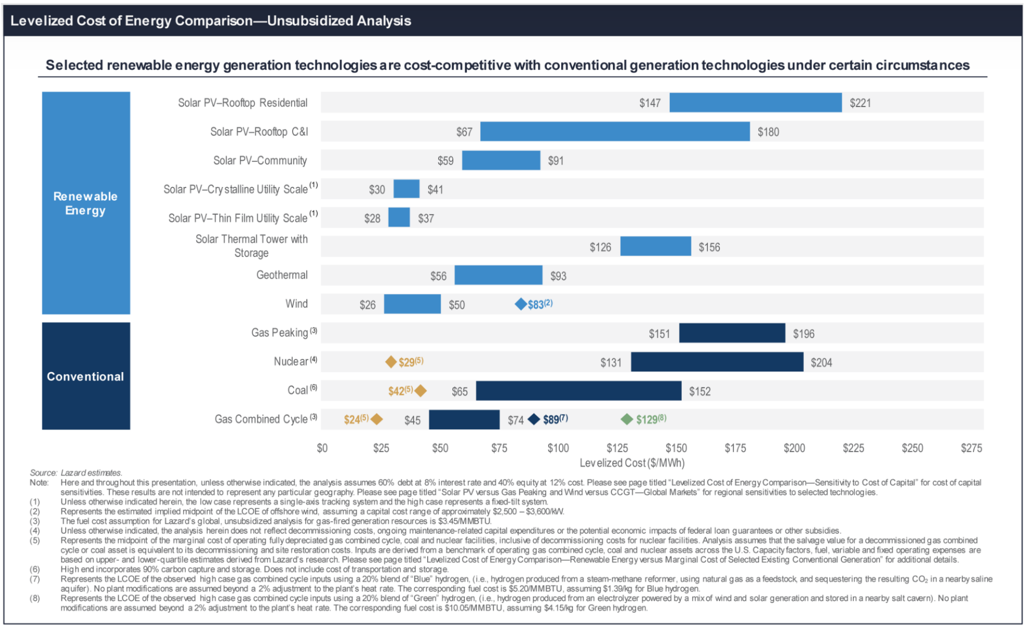

Figure 2.1.1: Levelized Cost of Electricity (LCOE) comparison of different technologies 2021 [53]

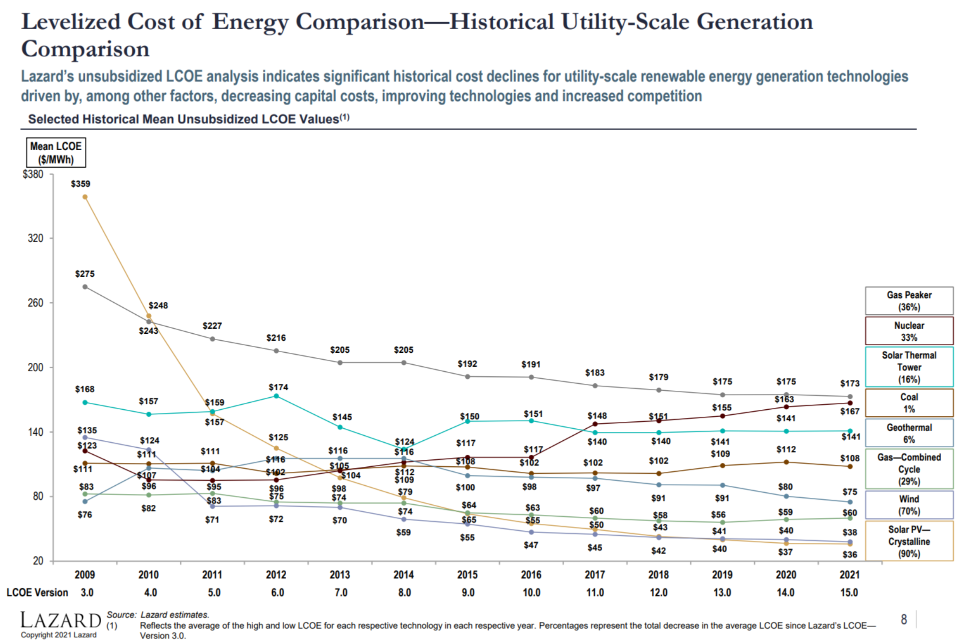

Figure 2.1.2: Historical Levelised Cost of Electricity (LCOE) comparison of different technologies 2021 [53]

2.1.1 Singapore's Proposed Energy Strategy

Singapore's energy strategy as developed by EMA is as shown in Figure 2.1.1.3.

According to the EMA, Singapore plans to achieve net zero emissions for the power sector by 2050 through 3 strategies [7].

1. Embark on economy-wide energy conservation and energy efficiency efforts to manage total and peak electricity demand

2. Leverage a variety of low-carbon supply options while aiming to ensure security and affordability

3. Transform the grid using new technologies and storage capabilities to support the decarbonisation of the power sector.

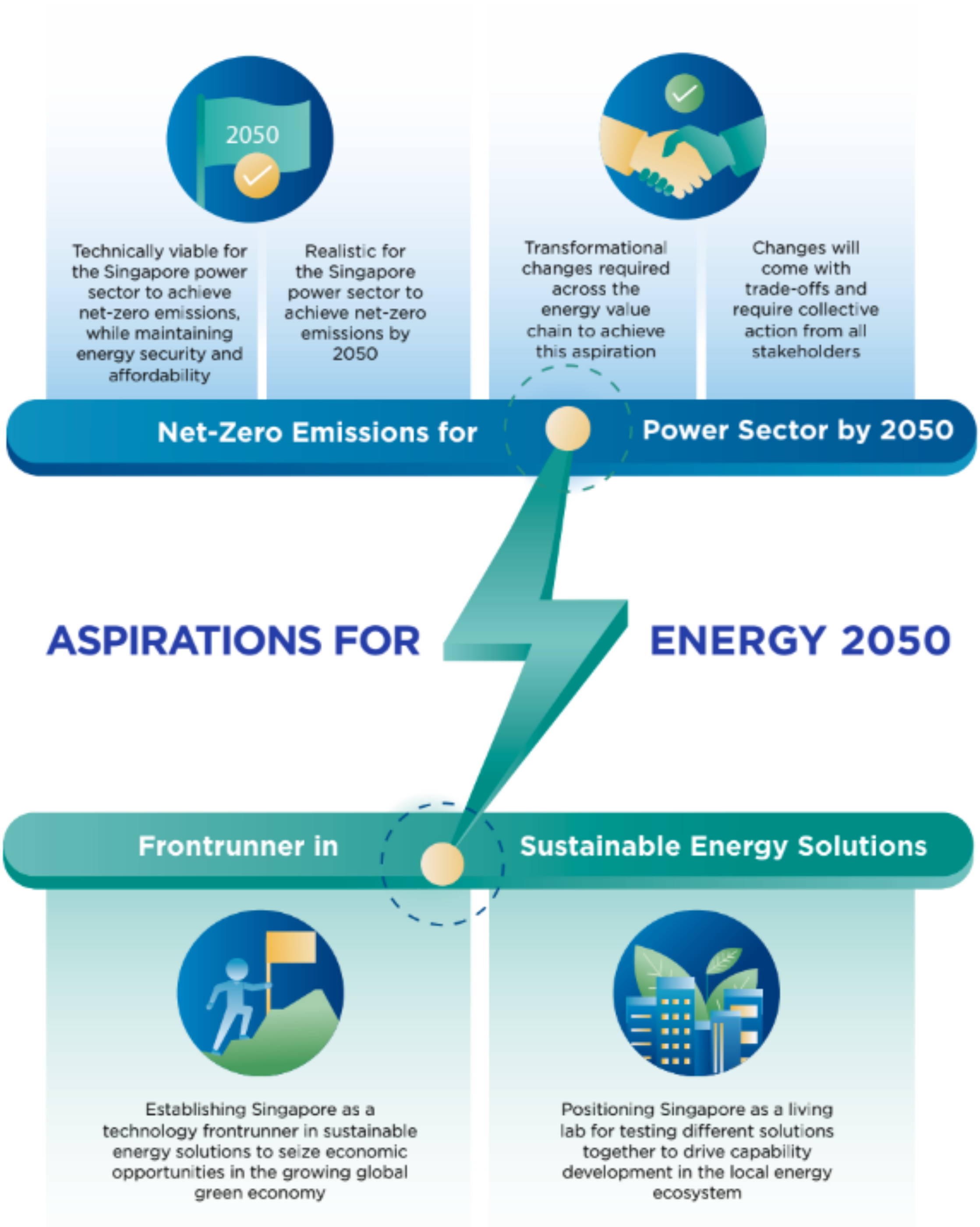

Figure 2.1.1.3: Singapore's aspirations for energy by 2050

Trends and possible pathways to net zero

Between 2009 and 2020, Singapore's electricity demand increased from 42 terawatt-hours (TWh) to 53 TWh. The peak demand grew from 6,041 megawatts (MW) to 7,376 MW. The annual electricity demand and peak demand are projected to grow at a compounded annual growth rate of between 2.8% and 3.2% from 2022 to 2032.

The main energy consumers in Singapore are economically important sectors like advanced manufacturing and chemical engineering. Increasing digitisation trends like Internet of Things (IoT) and 5G would likely increase energy consumption. The electrification of land transport and the industrial sector will also contribute to increased demand. While electrification would reduce carbon emissions and increase energy efficiency, it will cause an increased demand. With ever-evolving technologies, the demand, and hence energy consumption will inevitably increase. The best way to counteract this is with more energy-efficient technologies and carbon-free energy sources.

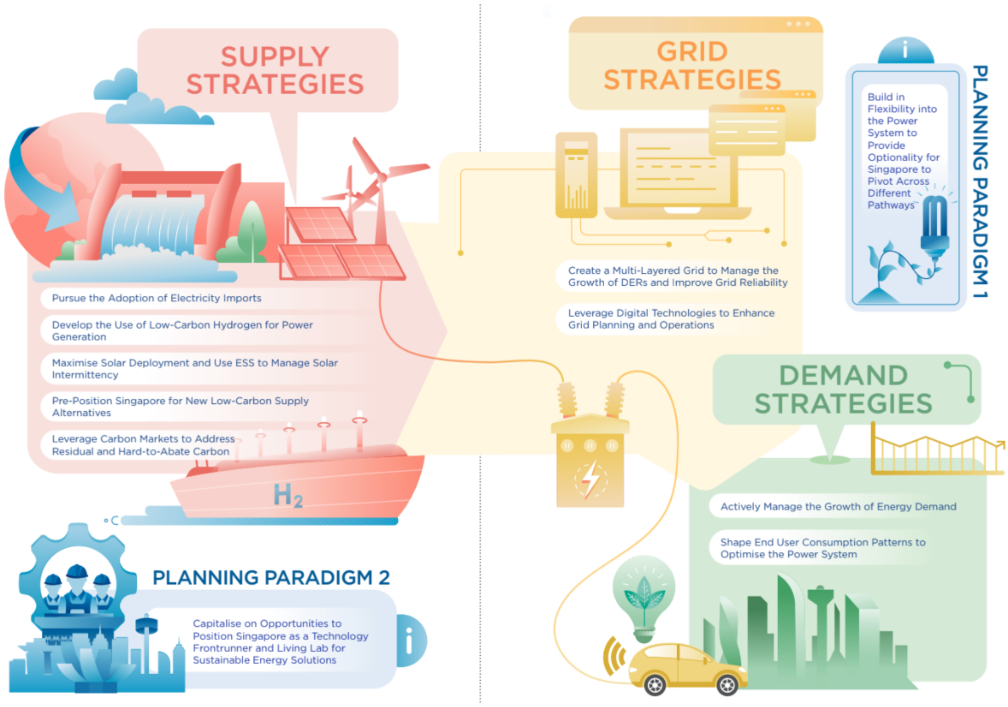

Figure 2.1.1.4: Singapore's energy strategies

We thus propose a future energy mix for Singapore as shown in Figure 2.1.1.5. This will mainly consist of Hydrogen Fuel cells and Electricity imports from other countries through regional power grids as proposed by EMA as well as Nuclear energy. These three methods will be discussed in detail in sections 2.1.2 to 2.1.4.

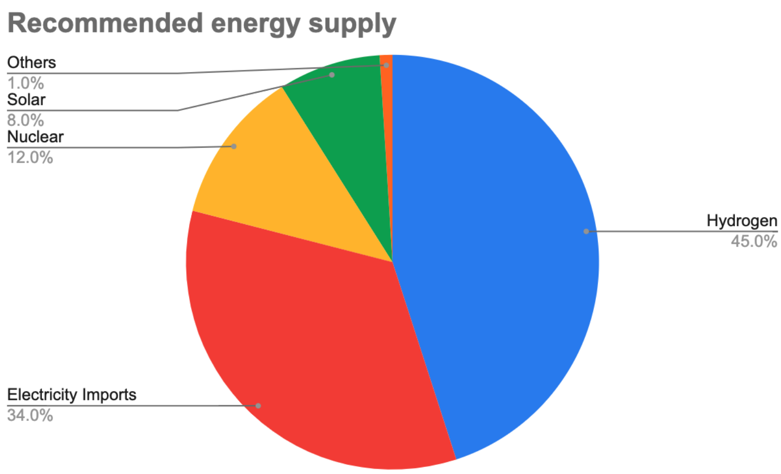

Figure 2.1.1.5: Proposed post-transition energy mix for Singapore.

2.1.2 Hydrogen

The four main types of hydrogen energy that can be generated carbon-free for Singapore are Green, Blue, Pink and Turquoise. Blue hydrogen should be phased out as soon as possible as carbon dioxide, a greenhouse gas, is a byproduct. Green hydrogen would be the simplest to implement as existing renewable energy sources could be used to generate energy for electrolysis. Unfortunately, Singapore has limited renewable energy sources (Section 1.1). As such, green energy must be imported from overseas. Both Pink and Turquoise hydrogen require new technologies to be used efficiently. As nuclear power may take time to implement, Turquoise hydrogen is thus the most feasible and carbon-free type that can be used in Singapore and is an excellent alternative to current energy sources. Existing natural gas supplies can be used to provide methane for Turquoise hydrogen. Pink hydrogen is discussed further below.

Table 2.1.2.1: Overview of types of hydrogen and production [41]

Type of Hydrogen	Production	Carbon-free	Suitable for Singapore
Green	Green hydrogen is produced with no carbon emissions using clean electricity from renewable energy sources to electrolyse water. Green hydrogen is expensive and dependent on renewable energy sources.	✓	✓
Blue	Blue hydrogen is produced mainly from natural gas through steam reforming, which brings together natural gas and heated water in the form of steam. The output is hydrogen and carbon dioxide as a by-product. Carbon capture and storage is essential to trap and store this.	✓(To an extent)	✓
Grey	Grey hydrogen is created from natural gas or methane, using steam methane reformation but without capturing the greenhouse gases produced.		
Black/Brown	Black/Brown hydrogen uses black coal or lignite to produce hydrogen, releasing fossil fuels		
Pink	Pink hydrogen uses nuclear energy to power electrolysis, the heat from nuclear reactors can also be used to produce steam for electrolysis and steam reforming methane reactions	✓	✓
Turquoise	Turquoise hydrogen uses methane pyrolysis to produce hydrogen and solid carbon. $CH_4(g) \rightleftarrows C(s) + 2H_2(g)$ Using high temperatures and different catalysts (nickel, carbon, noble metal, iron) hydrogen and carbon are separated from methane. The solid carbon produced can be stored and later used for other industrial processes. This process could be further improved by being heated by nuclear reactors. This would also provide a use for methane which would go out of favour with the introduction of large-scale renewable energy sources.	✓	✓
Yellow	Yellow hydrogen uses solar power to power electrolysis reactions	✓	
White	White hydrogen is hydrogen naturally found underground, however, there are no methods to extract hydrogen from them at the moment		

2.1.3 Regional Power Grids

Regional power grids buy and transport renewable energy from foreign countries, which may be able to produce renewable energy such as wind and hydropower more easily than Singapore. Compared to Singapore's current importing of LNG and coal via ships, which produces carbon emissions, are expensive and may not be reliable, Regional Power Grids rely on nearby countries to transfer renewable energy through underwater pipelines to Singapore, making them cost effective and reliable. Another benefit of regional power grids is the diversification of energy sources. More countries with different energy sources can supply them to countries needing energy. If one of these suppliers has difficulty supplying energy to another country, other suppliers would be available, ensuring energy security for countries part of these regional power grids.

ASEAN Regional power grids, Lao PDR Thailand-Malaysia-Singapore Power Integration Project (LTMS-PIP)

From 23rd June 2022, Singapore has been importing renewable energy generated through hydropower in Laos via connections through Malaysia and Thailand to import 100MW of electricity, or 1.5% of Singapore's annual electricity demand [11]. There are plans to increase its electricity imports from low-carbon sources to meet the 2035 target of 4GW of energy utilising the ASEAN power grid. This regional power grid project is a key milestone in advancing multilateral power trade in Southeast Asia, assisting with the transition to renewable energy. It can help with the diversification and energy security of countries in Southeast Asia.

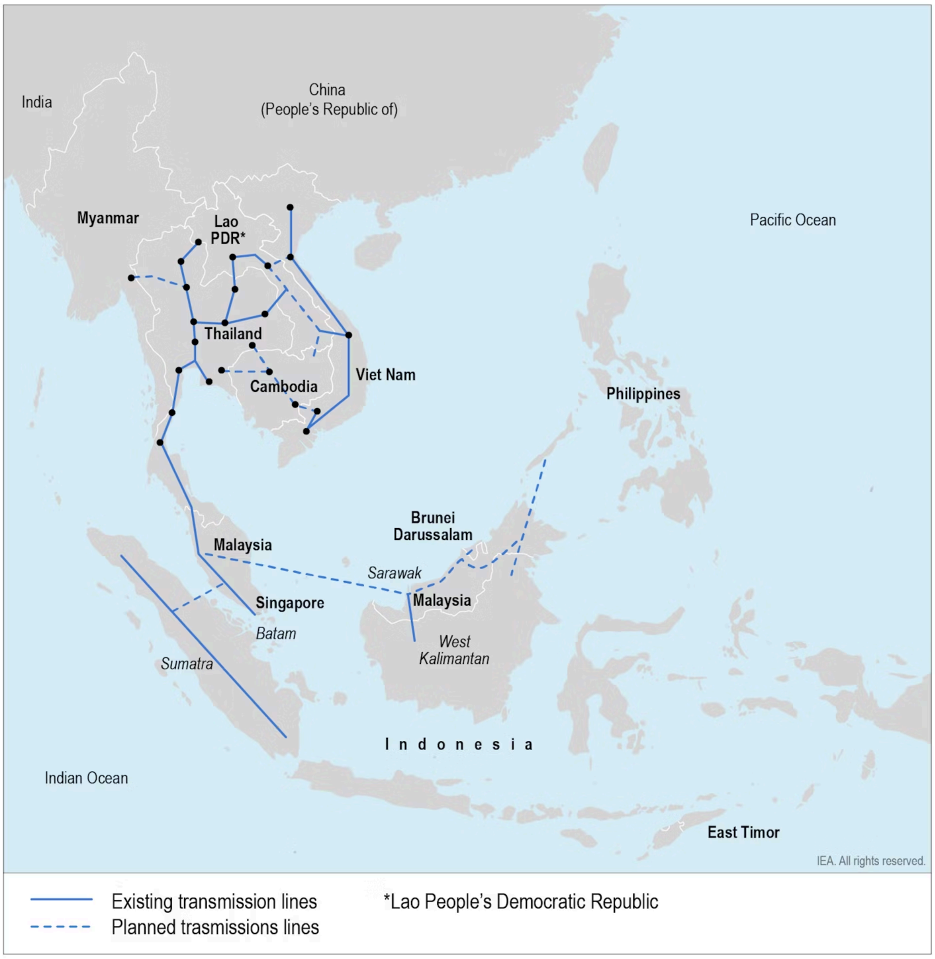

Figure 2.1.3.1: LTMS-PIP Plan [31]

Figure 2.1.3.1: Suncable energy plan [51]

Australia-Asia Power Link

Another regional power grid project was with Australia, where 3.2GW of power was to be transported over 5000 km from a solar farm in Elliot, NT, to Singapore and could provide 15% of Singapore's electricity supply. It was expected to be completed in 2027 but has since been stalled [24] following a dispute over funding. However, it may be re-instigated under new administration in the future.

2.1.4 Nuclear Energy

Apart from the usage of Hydrogen and Regional Power Grids as proposed by EMA, we also wish to propose the development and usage of nuclear energy sources in Singapore's energy mix. Nuclear energy, although conventionally considered unsafe, is sustainable, reliable and cost effective. The main 2 types of nuclear energy are fission and fusion. We will also be discussing thorium as a form of fission.

Nuclear Fission

Nuclear fission power plants generate power by using the thermal energy released by nuclear fission to drive a steam turbine, turning thermal energy to mechanical energy and then to electrical energy. Nuclear fission has been a carbon-free energy source for decades, however, due to many nuclear power plant disasters like Fukushima, Chernobyl and Three-Mile Island, many people believe that nuclear energy is dangerous although it has historically been the energy source that causes the least number of deaths. As fuel used for nuclear fission reactions could be refined into materials for nuclear weapons, it is difficult for nuclear energy to gain social acceptance.

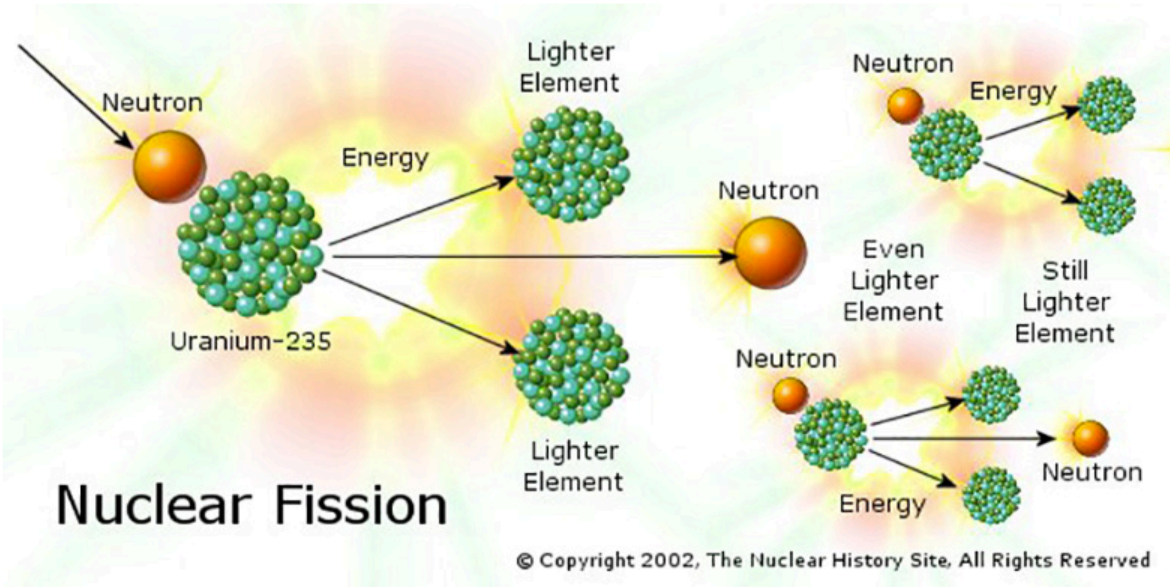

Figure 2.1.4.1: Nuclear fission reaction

Thorium Energy

Thorium is a naturally occurring slightly radioactive element that is more abundant in Earth's crust than Uranium. When Thorium-232 is converted into Uranium-233, the resulting Uranium can be used to fuel a nuclear fission reactor that does not produce large quantities of long-lived nuclear waste [59]. In the scenario of the most severe accident possible, the interaction of physical, chemical and nuclear processes would force the reactor to shut down without human intervention, making it a safe and viable option for Singapore [47].

Nuclear Fusion

Nuclear fusion uses extreme temperatures and pressures to fuse deuterium and tritium into helium. As the hydrogen's total mass is greater than helium's mass, the extra mass is converted into energy. This is the process stars use to generate energy. This process, however, is difficult to replicate on Earth, and it is currently impossible to sustain a net upbeat nuclear fusion on Earth. Technological leaps and bounds are still needed for nuclear fusion to be a reliable and cost-efficient energy source.

The Singapore Government has looked into the possibility of nuclear power in the past but shelved the idea after the Fukushima nuclear disaster in 2011. Nevertheless, A*STAR, a government-funded science research agency in Singapore, has been researching the topic, hinting that Singapore could have a future with nuclear energy.

As mentioned above, nuclear energy can be used to provide electricity and energy for industry, while pink hydrogen can be used for exports and as a fuel source.

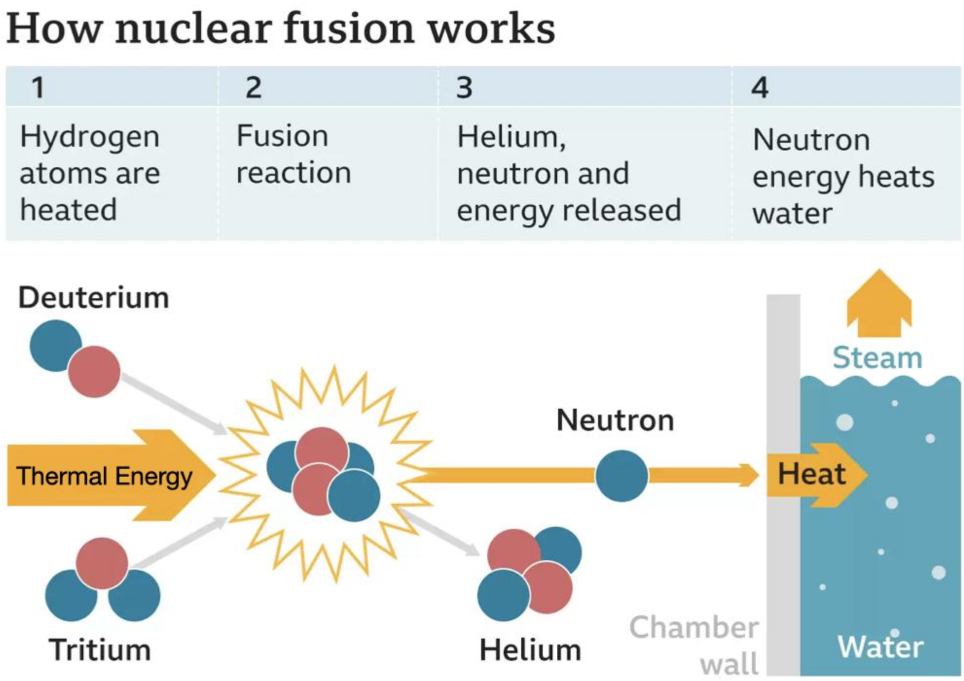

Figure 2.1.4.2: Nuclear fusion reaction

2.1.5 Transition timeline

Table 2.1.2.1: Overview of types of hydrogen and production

Year	**Milestone**
Before 2023	- Greater land use and space allocation for solar panels. More can be placed on rooftops and open spaces - Beginning of energy import agreements with Australia and ASEAN
2025	- Development and research on hydrogen energy, such as its possible sources, pricing, necessary infrastructure, reliability, legality.
2028	- Talks with countries globally about transition from fossil fuels to hydrogen. Ensure foreign countries are willing to adopt hydrogen to ensure Singapore will have sources to import from. Global investment in hydrogen will reduce prices and kickstart development
2030	- Commencement of increased electricity imports from Australia and ASEAN, possible to provide 10GW of power
2032	- Increase in foreign energy imports to around 15 - 20 GW
2035	- Small scale adoption of hydrogen power - Near maximum deployment of solar energy should be achieved at this stage
2037	- Planning and development of nuclear fusion technology
2040	- Around 25 - 30% of the energy mix should be imported from overseas and 15 - 20% should be hydrogen. The remainder is made up of solar and other minor energy sources
2045	- Global adoption of hydrogen is expected and various extents, hydrogen should steadily replace natural gas and fossil fuels, from 15 - 20% to 20 - 30%
2047	- Small scale deployment of experimental nuclear fusion power
2050	- Energy transition completed similar to Figure 2.1.1.5

While natural gas is still in use (between the years 2023 to 2045), carbon capture, utilisation and storage (CCUS) could be used as a transition technology, acting as cleaner alternative to the sole usage of natural gas.

2.2 Anticipated Challenges

By transitioning to the decarbonised sources, Singapore could face several challenges, as follows;

For Hydrogen energy adoption:

A. Singapore does not have well defined laws and regulations regarding the usage of hydrogen as an energy source [2]. The gap in legislation will cause legal uncertainty as the market evolves and if left unaddressed, Singapore could fall behind in the use of hydrogen. This will cause a slow start of hydrogen in Singapore and will not make an adequate impact on the transition to decarbonisation [29].

For Regional Power Grid adoption:

B. The variable nature of renewable energy makes it challenging to integrate these sources into a system that maintains a reliable supply of electricity. Since the traditional power grids are centralised and unidirectional, integrating renewable energy from different sources needs a more flexible and smart system [49].

For Nuclear Energy adoption:

C. The majority of the public have a strongly negative perception of conventionally dangerous nuclear power despite understanding its benefits and necessity [28]. Singapore being a relatively small nation adds to their fear as they feel the entire country may suffer setbacks. However, many grudgingly admit that nuclear power could be necessary and would be viable in Singapore if implemented with appropriate safety regulations.

For all energy sources:

D. As a small country with an area of only 728.6 km^2, Singapore has been facing severe problems with land usage. The current strategy is to allot certain areas for specific purposes, and it is improbable that these purpose-based allotments will change in the short term [54]. If Singapore were to build a new hydrogen or nuclear power plant, land would either have to be reclaimed or another plant would have to be replaced.

E. With its small population and relatively low taxes, Singapore could face monetary issues when transitioning. Switching to alternative energy sources could require large investments which will need to be procured by the government, likely from the citizens who may feel disgruntled at the prospect of paying more. Furthermore, citizens may feel that the financial investments in novel energy sources would be too costly if it fails or that Singapore would lose oil refineries like Shell, which have invested significantly in Singapore's economy [28].

F. A lack of technology development also poses a problem to this transition. In energy sectors, technology is being constantly developed and bettered. However this raises costs for countries that do not develop their own technologies. As a small city-state, Singapore has limited professionals in the energy sector and limited space and resources for large technological advancements. This could pose an impact on the speed at which we could transition. Dragging out the process will also increase costs, affecting the country and its citizens.

2.3 Methods to overcome challenges

The challenges Singapore could face cannot be avoided, but that does not mean that action to mitigate them must not be taken. Instead, the government should strive to lessen their impacts by taking the following steps.

For Hydrogen energy adoption:

A. The Singapore government needs to work towards implementing adequate legislation regarding hydrogen power in Singapore while technology companies work towards safer and more efficient technologies. Singaporean fuel cell companies or organisations should also seek to set up small-scale hydrogen energy plants in neighbouring companies where legislation may have already been implemented so as to predict and test energy efficiency.

For Regional Power Grid adoption:

B. To ensure that Singapore continues to maintain a reliable grid system without power outages, we need to invest in transmission grid upgrades that can absorb the unreliability of renewable sources as well as transfer power to areas with high demand quickly and efficiently. In a regional grid system, costs should be divided adequately depending on the participating country's power demands and supplies so as to ensure equal access to the energy.

For Nuclear Energy adoption:

C. To lessen the negative perception towards nuclear energy sources, the Singapore government and local media need to make increased efforts to portray nuclear energy sources in a positive or objective light rather than a negative one. Although flaws or concerns need to be discussed openly, the agency's efforts to mitigate potential problems must be well-developed and clearly highlighted to the public. However, educating adults who typically follow the media is insufficient. To achieve a truly all rounded approach, schools in Singapore should also teach students about nuclear energy sources and their benefits, perhaps during the character and citizenship education lessons that typically happen once a week in all schools or exposing them better to advances in the energy sector through learning journeys or conferences. By participating in in-school or inter-school panel discussions, debates and more revolving around the nuclear energy sector, students are sure to gain an interest in and a better understanding of the field.

For all energy sources:

D. As mentioned above, to solve the problem of lack of land, existing power plants may have to be broken and replaced with renewable energy plants. However, as these plants are owned by individual companies, choosing to reallocate the land to other companies may cause dissatisfaction with the government. On the other hand, reclaiming land would be expensive and affect surrounding marine life negatively by disrupting their habitats and polluting the water. In such a scenario, the two options must be weighed and considered before an appropriate decision is made.

E. To finance the huge energy facility, raising taxes is a clear solution. However, this cannot be the sole solution as it will cause unrest among the citizens. Instead, the government and individual companies should apply for grants or collaborations with other countries so costs could be split. This also allows for better sharing of ideas. Having applied for grants, it should be clear to citizens that the government is trying to mitigate costs before taxes are slowly raised over a few years. The reasons for and benefits of the raised taxes should be highlighted.

F. Multiple organisations in Singapore such as the Agency for Science, Technology and Research (A*STAR) and the Hydrogen Fuel Cell Association Singapore (HFCAS) are currently innovating and ideating consistently for a cleaner future. Furthermore, about SGD 35 billion of green bonds will be issued by 2023 to fund public sector green infrastructure projects as discussed in Budget 2022 [52]. Although these are good efforts, more can be done to increase collaboration with other countries. By hosting conferences or extending offers for connectivity, Singapore companies and the government can better harness ideas from around the world.

3 Global Implications

3.1 Potential impacts of Singapore's transition on other countries

Singapore's energy transition could have both positive and negative impacts on other countries. They can be categorised into economic and societal impacts, of which Tables 3.1.1 and 3.1.2 offer an overview.

Table 3.1.1: Positive impacts of Singapore's energy transition on other countries

Economic	**New market for green energy technologies** Singapore will become a new buyer and consumer of hydrogen technologies, allowing countries that are currently suppliers of said technologies to raise prices due to the increased demand, causing them to profit.
	Decline in global oil/gas prices Singapore will reduce consumption of fossil fuels such as oil and gas, causing the demand to decrease. This will in turn cause suppliers to decrease oil and gas prices as per the supply and demand curve, making oil and gas more affordable for other countries.
	Increased technological advancements in energy sectors With a larger market for alternative energy solutions, the industry would hasten to make advancements that would make transitioning to clean energy easier and more convenient, benefitting the world as a whole.
	Increased energy security and reliability With the increase in energy sources and access to regional power grids developed, countries can look forward to energy that is increasingly secure and reliable so as to cater better to theirs and their citizens' needs.
Social	**Positive influence on other countries** Singapore's transitions to alternative energy sources can act as encouragement to other countries to take the step towards cleaner energy sources.
	Collaboration opportunities By taking the first step towards decarbonisation, we can ensure we have a strong foothold in the industry before initiating collaborations with other countries in South-Ease Asia or around the globe to better the industry, technology and both countries' energy sources.
	Increased safety standards When utilising new or conventionally "dangerous" technologies such as nuclear fission, safety standards would definitely be a concern. As a small and still growing country, Singapore can not afford to lack stringent safety measures to ensure both citizens and industry specialists are not in danger. As we develop such measures, other countries could learn from our example or we could learn from theirs, allowing for safety standards to increase across the globe.
	Reduced carbon emissions By switching to decarbonised sources, we will be reducing the global carbon emissions, slowing climate change and giving Earth more time to respond to this disaster.

Table 3.1.2: Negative impacts of Singapore's energy transition on other countries

Economic	**Increased prices** Due to increased competition for energy resources, suppliers will raise prices, causing all countries to have to set aside more resources to fund their energy transitions.
	Negative impacts on countries that rely on Singapore's fossil fuel exports As a global oil refinery hub, if we were to reduce fossil fuel imports, and thus exports, countries that are reliant on us for a source of power would struggle and have to find alternative energy sources in a short period of time.
	Unequal access between developing and developed countries Singapore as a developed country has sufficient monetary resources to face any market fluctuations. However, other developing countries may struggle with this task and may fall behind in their transitions or

	choose not to transition at all as the task may seem too daunting.
Social	**Security concerns** If Singapore were to transition to newer energy sources, we may raise concerns about the safety of our power sources. As our neighbouring countries, Indonesia and Malaysia, are very close to our borders, they may worry about how safety hazards in Singapore would affect them. Other countries may also fear how safety hazards could lead to negative public perception of certain energy sources and how it would negatively affect their transitions. This could lead to Singapore having strained relations with other countries and impair trade and economy.
	Inter-country reliance If Singapore were to develop a stable alternative energy power source, establish regional power grids and make consistent technological advancements in the energy sector, other countries may start to develop a reliance on Singapore for advancements in alternative energy sources and/or power. This may in turn limit their ability to develop their own power sources, decreasing technological advancement of the world.

It is to be noted that the impacts of Singapore's energy transition may vary based on the scale and time frame of transition.

3.2 How Singapore can help with other countries' transitions

Singapore can aid other countries in their energy transitions both passively and actively. Some methods are as follows;

Passive

- Transition slowly, giving other countries time to adjust.
- Set clear and stringent safety standards so as to ensure there are absolutely no accidents by looking into historical accidents from similar transitions.
- Continue developing technologies in Singapore so as to minimise the hike in prices due to change in supply/demand. This will ensure developing countries could also switch to alternative energy sources.
- Promote green trade.

Active

- Extend offers for collaboration towards countries. Participating countries can share knowledge and resources and advance together.
- Share knowledge and expertise by initiating or hosting conferences regarding decarbonised energy sources.
- Provide grants or loans to help other countries transition.
- Invest in clean energy projects or technologies both within Singapore and in other countries

Acknowledgements

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The German Energy Transition via Emission Trading

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Abstract

This research report investigates the energy system of Germany, which is currently heavily reliant on carbon-based sources and depends on energy imports. The report proposes a plan to transition the country's energy system away from these sources and towards climate neutrality by 2045, the self-imposed goal of the German federal government. This plan involves reorganizing the power grid and energy consumption across multiple industrial branches while focusing on economic and regulatory opportunities available to the government. However, there are significant challenges associated with this transition, including the high cost of technology, the risk of losing wealth and increased cost of living, and division of society into those for whom change cannot come fast enough and those who do not see the need for climate protection. Furthermore, Germany's dependence on energy imports will probably remain for the near future, therefore areas outside Germany will have to be used for its energy supply, which may cause conflicts. The report emphasizes the need for European and international collaboration and highlights Germany's trailblazing role in paving the way for other countries to follow a sustainable energy path.

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Topic 1: The Current Energy System of Germany

Germany's Current Energy Generation

Today, about 3,500 petajoules (PJ) are generated domestically.[1] This corresponds to only about 29% of the total German primary energy consumption. The share of domestic production in primary energy consumption has fluctuated between 28 and 31% since 2008 which makes Germany rely heavily on imports. The reason for this relatively recent development is that Germany is not large in size[2] and therefore does not possess as many resources as other countries. It used up most of its prevalent resources and the price for imports is getting more lucrative in comparison to mining the remains of Germany's prevalent energy resources.[3]

Just looking at the energy sources Germany domestically produces, the most important energy sources are renewables such as wind energy, solar energy, and energy extracted from biomass. They account for more than half of the domestically produced energy sources. Some of the biomass extracted or consumed is traded with other countries. All other renewables are extracted in Germany and consumed in the same year.[4] Lignite accounted for 33% (1,153 PJ), Gas (natural gas, oil gas, and mine gas) for 9% (173 PJ), and most importantly, renewables for 55% (1,953 PJ) of domestically generated energy sources in 2021.[5] It has to be mentioned that since 1990, the generation of energy sources such as natural gas, coal, or renewable energies in Germany has decreased by about 45%.[6]

Hard coal production in Germany was discontinued in 2019. Germany is one of the few countries in the world that is making a binding commitment to phasing out both nuclear and coal energy. This transformation process entails not only significant changes in the energy sector but also in society and the economy.[7]

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[1] It has to be noted that apart from electricity there are other types of energy (e.g. heat, traffic,...). They add up to the total energy consumption in Germany.
[2] Additionally, Germany's population density is one of the highest in the world (232.7 inhabitants per km2). (Eglitis)
[3] ("Primärenergiegewinnung Und -Importe")
[4] ibid.
[5] The remaining energy generation share is covered by mineral oil, firewood, fuel lord, sewage sludge and waste.
[6] ibid.
[7] ("Kohleausstieg Und Strukturwandel")

Germany’s Energy Consumption

Germany’s gross energy consumption has an increasing percentage covered by renewable energy. The (German) government's goal is to increase this percentage to 30 % by 2030. The initial target of 18 % for the year 2020 was successfully met and even exceeded with a share of 19.1 %. In 2022, renewable energies made up 20.4% which is a significant increase, compared to 2021. This can be explained primarily by the significant increase in the percentage of renewable energies in electricity consumption.[8]

With this data, it must be taken into account that a "normalization" is carried out when calculating the renewable share following the EU Directive. This means that the influence of unusual weather in a year is corrected. Thus, in 2021, for example, the particularly low share of renewables in electricity consumption due to weak weather was less significant in the share of gross final energy consumption.[9]

The risks of this high import dependency became clear in the course of the war in Ukraine in 2022. Significantly reduced imports of natural gas from Russia led to sharply rising natural gas prices for consumers and consequently to considerable economic distortions.[10]

Imports

2021

If 29% of Germany’s energy consumption are covered by domestic sources, the rest has to originate from somewhere else. The remaining 71% are imported from other countries. The main energy sources imported are mineral oil, gas, hard coal, and uranium. Uranium for nuclear energy use is fully imported (see table below). After the cessation of hard coal mining in Germany in 2018, the supply[11] was provided mainly by Russia, which maintained its position as the largest supplier of hard coal to Germany with a share of around 45%.[12] The USA remained the second most important export country with a share of 18% - followed by Australia with 12%, Colombia with 6%, and Canada and Poland with around 4% each.[13]

In 2021, Germany imported 79 million tons of crude oil. The difference between crude oil and mineral oil is that mineral oil is understood to be the raw material stored on the earth’s surface. Once it has been extracted - albeit still in its unprocessed state - the energy source is referred to as crude oil. The main export nations are Russia,[14] USA, Kazakhstan, and Norway.[15]

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8 (“Primärenergiegewinnung Und -Importe”)
9 ibid.
10 ibid.
11 According to preliminary calculations, the share of hard coal needed was around 29.7 million tons.
12 Due to sanctions Germany (and most of the EU) prohibited importing coal from Russia.
13 ibid.
14 Germany radically stopped importing crude oil from Russia due to sanctioning measures during the war in Ukraine.
15 ibid.

Energy source	Import rate 2021	Share of energy source in primary consumption
Lignite	-2.30%	9.10%
Hard coal	100%	8.90%
Nuclear	100%	6.10%
Mineral oil	98.10%	32.50%
Natural gas	94.80%	26.70%
Renewables	-0.20%	15.70%

The table was translated from German[16]

Notable Changes since 2021

After the war in Ukraine had begun, Germany (among others) stopped importing natural gas from Russia. To compensate for the dependency on Russian energy resources, Germany started making fracking gas deals with the USA and importing natural gas from the Middle East (e.g. Qatar).[17]

Exports

Germany's energy export does not play a role as big as its energy import does. Still, Germany does export energy when needed. Most of the time it exports renewable energy. In the summer, the sun shines more frequently and thus Germany sometimes overproduces renewable energy, so it exports the remaining energy to close countries (e.g. electricity to France)[18].

[16] Original table courtesy of Source: ("Primärenergiegewinnung Und -Importe")
[17] ibid.
[18] (Sorge).

Topic 2: A Plan to Decarbonize Germany’s Energy System

Introduction

First of all, the goal of the researcher's plan should be described. With this plan, we want to transition the energy system of Germany away from carbon-based sources. The main goal is climate neutrality of the energy system. For this to be possible, the CO2 emissions need to be minimized. This process will hurt the economy in every scenario and thus also poses a threat to the people of Germany.

On the other hand, the urgency of climate change forces Germany to act and transition the country’s energy system nonetheless. As a consequence, we need to find a way to minimize this damage while still reducing emissions.

We propose emissions trading as a central means for the state to achieve this goal as efficiently as possible. We will address how emission trading works and why it is the best means for an economic transition.

Next, we will examine the Emission Trading System currently in place in the EU. After that, we will discuss why it is most logical to approach this transition on a European scale.

Since in our approach the market and innovation dictate the technologies and usage ratios used, a detailed consideration of these (as required in a) and b)) makes little sense. This is the reason we deviate from the given structure and instead cover important aspects of emission trading.

At the end of the 2nd part, we will deal with the problems of this plan:

More specifically, first the social issue and why the measures disproportionately burden the lives of people in lower income brackets and how we will solve this issue. Secondly, the problem with speculation on certificates, and lastly the competitive disadvantages that companies will suffer from, if the ETS is not combined with climate tariffs.

Emission Trading

Emission trading is the simple concept of the mandatory need for a CO2[19] certificate to emit CO2. This certificate is first created by a central body and then placed on the market.

This process happens in 2 steps: **“Cap and Trade”**.
By practicing "Cap" the total amount of CO2 that may be emitted is set centrally by a government or an international group. This results in strong means for the government to pursue climate policy and only means to meet climate targets with a correspondingly high cap.
By practicing "Trade" the certificates are then auctioned to the industry. Of course, they may later be sold to companies. This way, CO2 is saved where it is cheapest. Therefore, emissions trading minimizes the damage to the economy (and thus indirectly to the people, but more about this later in the social question).

Those who emit more CO2 than they possess certificates to legitimize it will be heavily sanctioned and will need to buy the certificates for the CO2 they evaded.

The idea is to create an economic incentive. Because the costs to emit CO2 are increasing, it can be worthwhile to save it instead. In this way, surplus certificates can be sold to compensate for a partition of the avoidance price. As already mentioned, this saving is most worthwhile where it is cheapest. The more sectors are involved, the more efficiently the savings mechanism works. In the best case, all relevant sectors would be included.

By internalizing the cost of greenhouse gases, the most personally selfish action is equivalent to the most socially altruistic action.

To reduce emissions over the long term, the cap is not fixed, but changes according to a predetermined pattern. For example, this pattern may be an annual reduction.
This allows companies to plan and thus makes climate-protecting investments profitable in the medium term.

The increased prices for CO2 also provide something desirable: since companies have to pass on the increased costs to customers so as not to make less profit, the products that emit less CO2 become more competitive.

[19] Mankind emits not only CO2 - which is harmful to the climate in excessive concentrations - but also many other greenhouse gasses. In order to include these greenhouse gasses in emissions trading, they are converted into CO2 equivalents. (“Der Europäische Emissionshandel”)

Why Emission Trading is Better than its Alternatives

In this section, we compare Emission Trading to other governmental methods.

"CO2 pricing in the form of an emissions trading system (ETS) has the following, fundamental ("theoretical") advantages: (1) As a market-based instrument, it offers the greatest possible flexibility with regard to the choice of abatement technologies and can stimulate investments and innovations in low-CO2 technologies in a cost-effective manner. The more comprehensive the ETS is (sectors, countries), the greater the cost-efficiency potential. The technologies with the currently most cost-effective abatement costs are implemented first. (2) If an ETS is implemented without maximum prices, the definition of the quantity target can basically guarantee the achievement of the target."[20]

The **CO2 price**, similar to emissions trading, requires a certificate for the emission of CO2. As another market-based instrument it also stimulates investments and innovation, but in contrast to emissions trading, the quantity of certificates is not limited: they are sold for a centrally determined price.
An advantage of emissions trading is the quantifiability of the emitted CO2 amount. This enables calculable climate policy. The market determines the emission price itself and thus the price-setting process becomes more efficient. Because of this fixed stock of certificates, emission trading safely meets our climate targets, which is why it is preferable to the CO2 price.
An advantage of the CO2 price is that it can be introduced quickly, and can therefore serve as a transition in sectors that have not yet been included in the emission trading to also add these to trading at a later date.

With **regulatory policy** (which involves bans, rationing, or mandates), the government intervenes heavily in the market, prohibiting, for example, an industry from emitting above a predetermined amount. It is centrally determined who is allowed to emit how much, which means that savings are not made where the costs are lowest. Thus, more emissions may be allowed in one place than is necessary and less in another, resulting in unnecessary emissions of greenhouse gases in one place and a shortage in production in another, since not as much can be produced as is needed. Overall, such a system is more inefficient but may meet with more acceptance among the population, since even the rich cannot buy their way out. In addition to inefficiency, another disadvantage is the uncertainty of the exact amount of CO2 a particular ban will save, and thus climate targets will not be met with certainty. Without the monetary incentive, innovation and investment in climate-friendly technologies will not be encouraged. A combination of regulatory policy and wide-ranging certificate trading does not make sense, since any additional CO2 that would be saved by the regulatory measures would be emitted elsewhere by the certificates that would not be used as a result. Thus, these measures would not benefit the goal to save CO2 and only increase the cost of saving it.

[20] Translated from (REGULATORISCHE HANDLUNGSOPTIONEN FÜR EIN KLIMANEUTRALES ENERGIESYSTEM)

Another strategy is **government subsidies**. There are two target areas: research and production. In production, subsidies are intended to make climate-friendly investments more profitable. For example, e-cars have been subsidized in Germany since May 2016.[21] Research is about efficient task allocation. A company that has been building and improving internal combustion engines for 50 years can then be paid to do more research on electric cars, for example. Subsidies almost always hurt the economy at first. This is because they interfere with the natural price-setting process. Subsidizing production has a weaker effect than making climate protection profitable (or more profitable) through emissions trading. In the case of research, subsidies make more sense. Companies innovate in areas where they have expertise, so subsidies are justified here.

As with all other climate protection measures, strict policies are needed for emissions trading. Climate change is the survival issue of our time and should not, as is often the case at present, give way to more important short-term issues. In terms of emissions trading, this means that during a crisis, no more certificates should be issued than previously planned, otherwise companies will rely on being helped if they do not transform in time, thus removing the incentive to do so. Nor must the state buckle before companies and grant them an excessively long transition period before they enter emissions trading, even if they threaten to leave or similar, as has happened in at least one case in Switzerland.[22]

[21] ("Wie Funktioniert Die Neue E-Auto-Prämie?")
[22] (Baumann et al.)

Emission Trading on a National and International Level

The EU has had an emissions trading scheme since 2005, which covers installations in the energy sector, energy-intensive industries, (aviation since 2012)[23]. These account for 36% of European emissions[24]. There is a rate of reduction in the cap of 2.2% per year from the historical 1990 level and an increase in this rate of reduction to 4.2% is planned under the "Fit-For-55" program (July 2021)[25]. From 2024, maritime transport is to be included in ETS 1. This would mean that ETS 1 would cover almost 50% of European emissions.[26]

In the future, about 85% will be covered by extending allowance trading to more sectors - especially transport and buildings. These will be traded in ETS 2 from 2027 with a cap decreasing annually by 5.1% and later by 5.38%.[27]

The question if individual countries like Germany should implement a national emissions trading system inevitably arises in the debate on emissions trading.
Germany has had an ETS in place since 2021[28], covering the transport and heating sectors.

Ultimately, however, it does not matter where greenhouse gases are emitted. What matters is that as few as possible are emitted and, in the best case, at the lowest possible cost. A national emissions trading system saves CO2 where it is cheapest in Germany, a European system where it is cheapest in Europe.

If we already have a European emissions trading scheme for one sector, a national one covering the same sectors is pointless, since the total amount for Europe is already fixed. If Germany saves more now, overall there is no more saving, and the CO2 is only emitted in other countries than Germany.

For sectors that are not yet covered (for example, transport and heat), national emissions trading may make sense for a transitional period if it cannot yet be implemented at the European level, for example, due to a lack of political majorities, although a European solution is always preferable because it is more efficient.

In this context, it is of course also true that the more countries participate, the more efficient (i.e., cost-effective) the CO2 savings become.

[23] ("Der Europäische Emissionshandel")
[24] ibid.
[25] ibid. and ("Europäisches Parlament Bestätigt Einigung Zur Reform Des EU-Emissionshandel")
[26] ibid.
[27] ibid.
[28] In fact, German emissions trading works on a transitional basis with the CO2 price. Thus, certificates are initially sold for a fixed price (rising from 25€ to 55€) for a certificate (= right to emit one ton of CO2) and are only auctioned from 2026 onwards, as is otherwise the case in the ETS. ("UBA-Erklärfilm Zum Deutschen Emissionshandel Für Brennstoffe")

Problems and Solutions of our Plan

Social Aspects

In emissions trading, there is an incentive to save CO2, because the emission cost exceeds the avoidance cost. By making it more expensive to emit CO2, all products that do so also become more expensive. Ultimately, of course, companies pass the increased production costs on to consumers.

Rich people tend to emit significantly more CO2 on average than others by buying products that emit a lot of CO2 in production, using more climate-damaging mobility options, and heating more due to larger living spaces.[29]

Due to the rising CO2 prices, they are also more burdened in absolute terms than poor people, who emit less CO2 on average. Relative to people's income, however, it can be seen that emissions trading burdens poorer people more than richer people, since it takes a larger share of the income of the poorer.

This creates a socially unevenly distributed burden of emissions trading that reduces acceptance among the population and calls into question its ethical viability.

The dilemma is clear: How to implement the sensible climate protection measure of emissions trading despite additional burdens on the lower classes?

Solutions

Possible solutions to this well-known and researched[30] problem are:

Option 1: A climate premium or climate money
Auctioning CO2 certificates generates revenue that could be (partially) distributed to citizens on a per capita basis by the state. Due to bureaucratic barriers in Germany, this would probably happen via tax relief or increased social benefits.[31]
With this approach, one would have money equal to the average CO2 budget (i.e., the average amount of additional costs incurred by the consumer as a result of emissions trading).
The lower-income strata emit less and thus receive a gain, while the higher-income strata emit more and pay more for it.
It is important to mention here that a higher certificate price does not influence this effect, as it also increases the climate money.

[29] (Oxfam) and (Kleinhückelkotten et al.)
[30] e.g. ("CO2-Bepreisung Sollte Und Kann Soziale Ungleichheit Vermeiden")
[31] (Junginger) and (Busch)

Option 2: Separation of social and climate policy
Even if climate policy can lead to social upheavals, these should not be solved by climate policy. Instead, the existing social systems need to be expanded or restructured.
The advantage of this approach lies in the separation of different policy areas. With such a separation, however, there is a danger that the costs incurred by the lower strata during the transformation will be forgotten or will be classified as secondary to the generally higher investment requirements, which would reduce the willingness for climate protection.

Conclusion

The main argument in favor of the first option is the high burden on all people, which means that the plan will most likely meet with a high level of s since no one suffers from it and the money is just no longer spent in any other way.
In this way, visible and tangible social cushions will be implemented in parallel with climate protection measures.
In the long run, however, it makes more sense for Germany to implement the second option. The first option only makes sense if CO2 is still emitted. With climate neutrality, the products for which CO2 emissions cannot be avoided no longer exist. Since no certificates are traded, this also means that climate money can no longer be financed. Nevertheless, there are high CO2 avoidance prices and the lower classes of the population are burdened more. Thus the climate money cannot function after climatic neutrality.

Speculations

In addition to companies, there are always speculators on the market. Thus, speculation can always lead to stronger price fluctuations.[32] This can lead to economic problems for a commodity as important for the economy as CO2 at the moment. Since the price will almost certainly rise in the next few years, it is an almost risk-free investment and many investors buy the certificates now to sell them later at a profit. Therefore, the price is already rising to a level that was not envisaged until 2045.[33] [34]

In addition, the same dangers of bubble formation and high volatility exist with certificates as with other financial products. To prevent these from costing trust in the reliability of certificate trading and losing the ability to plan, regulations are needed, as with any market, to prevent market failure. There is already a market stability reserve which, in the event of a surplus of certificates, buys them up in order to sell them again as soon as there is a shortage, thus having a price-stabilizing effect.[35] There are also possibilities to take action against speculators. However, the responsible authority sees no reason for this so far.[36] Furthermore, a rising certificate price, which could be generated by speculators, is in principle even good, as this creates greater incentives for companies to save CO2.

[32] (Börse Online Redaktion)
[33] (Bofinger)
[34] (Schultz)
[35] (“Wie Funktioniert Der Emissionshandel?”)
[36] (Nacu-Manole)

Competitive Disadvantages

Emissions trading would make the production of many goods in the EU more expensive. If it is now possible to produce outside Europe without this surcharge, this will mean a competitive disadvantage for European companies of varying magnitude depending on the sector. In the worst case, this would lead to the production of CO2-intensive products moving abroad and us importing them. The only effect that would come about would be an exodus of production from Europe; the climate would not be helped by this, as the CO2 would simply be emitted elsewhere. To compensate for this effect, we propose so-called climate tariffs, whereby a tariff would be levied on every product imported into Europe, corresponding to the cost of the certificates that would be required for the production of this product. Thus, there would be no competitive disadvantages for European corporations on the European market caused by certificate trading. This is another reason why certificate trading only makes sense on a European scale since Germany alone cannot impose tariffs. It will not be possible to prevent exports from being at a competitive disadvantage as a result of certificate trading. In the not-too-distant future, the entire global economy will have to be climate-neutral, so there is no way around climate protection in the long term, even for export-oriented companies.

Topic 3: Implications of the Transition

Germany's energy system transition holds global implications, both in terms of its potential impact on other countries and its role in aiding them in their transition to decarbonized energy systems. By focusing on European initiatives rather than solely national measures, Germany aims to foster a comprehensive approach to climate protection across Europe. We examine the potential impacts of Germany's energy system transition on other countries and explore how Germany can support their decarbonization efforts.

Europe is a pioneer in climate protection. Successful and efficient implementation of the energy transition in Germany could encourage other countries to adopt similar strategies and measures. But of course, this also means that inefficient and perceived unsuccessful implementation reduces the likelihood that other countries will follow our example, which is why it is so important to choose the most efficient means possible, which is emissions trading.

Our plan for a comprehensive and well-regulated emissions trading system ensures that climate goals are met not only within Germany but across the European Union. By promoting a robust and effective carbon market, Germany can help drive emissions reductions across the continent.

Many developing countries will continue to experience economic growth in the coming decades, which have to be climate neutral if climate goals are to be met. An innovative climate change program such as certificate trading, which harnesses the innovative power of the market, can promote the development and deployment of new technologies that these countries need to decarbonize their energy system. By sharing its know-how and collaborating with international partners, Germany can contribute to the global advancement of sustainable technologies.

In addition, climate tariffs, which are primarily intended to protect European industry, provide an incentive for non-European companies that want to import products into the European Union to produce in a more climate-friendly manner. Since Germany is an energy-poor country, we will continue to rely on imports in the future. Hydrogen exports, which Germany will be dependent on, could be a new source of income for many countries and already drive the construction of renewable energies in these countries.

Emissions trading is a climate protection instrument that is very compatible with the emissions trading systems of other countries, as can be seen from the cooperation with Swiss emissions trading.[37] Our goal would be a climate club with as many other countries as possible, with other Western industrialized countries probably being the main candidates at the beginning. Outside of this, Germany can actively collaborate with other countries by establishing partnerships and knowledge-sharing platforms. Through initiatives such as joint research projects, technology transfer programs, and financial support for climate protection measures, Germany can support other countries in their transition to decarbonized energy systems.

[37] (“Der Europäische Emissionshandel”)

Prospects

In this paper, we have mainly looked at measures that are not compatible with emissions trading. However, there are multiple measures that the state can implement and that seem beneficial in addition to emissions trading. For example, a reform of the tax and levy system seems to be a very sensible measure to smooth out already existing market distortions and thus make the savings more efficient.

Furthermore, little can be done in some places to protect the climate as long as the framework conditions remain the same. Assuming that individual transport no longer offers any major potential for savings, many motorists will have no choice but to either forego their destructive transportation choices or to pay more money as long as a more climate-friendly alternative such as public transport is available.

Also, many areas previously independent of electricity will become connected to it, so a more powerful grid is needed. The state can simplify the construction of wind turbines and new power lines, for example, by simplifying construction procedures and cutting red tape without having to subsidize. Additionally, a new and more flexible system of electricity payment could make a power system based on renewable energies more efficient.

Even if the path of transformation is less determined by the state in the emission trading, it is also important for companies to make forecasts of what a future climate-neutral economy and energy system could look like. Another way in which we could extend this work.

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Appendix

Declaration of Authenticity

We declare that we completed the research report "The German Energy Transition via Emission Trading" independently and used only these materials that are listed. All materials used, from published as well as unpublished sources, whether directly quoted or paraphrased, are duly reported.

Meißen, 2023-05-30

Place, Date

Signatures

EXPLORATION OF POTENTIAL CAMBODIAN LEAF WASTE *(PLUMERIA ACUMINATA)* EXTRACT AS BIOAVTUR

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SMAN 3 DENPASAR

2023

ABSTRACT

During the 2017-2019 period before the pandemic, consumption of fossil energy-based avtur in Indonesia ranged above 5 million kl per year. This is a serious problem because fossil-based fuels have a big impact on the environment. These problems can be overcome by developing avtur from plant-based ingredients that are renewable and environmentally friendly. In general, avtur fuel contains complex chemicals such as short and medium chain hydrocarbons such as hexane, heptane, octane and nonane, as well as aromatic compounds such as toluene, xylene and benzene. Frangipani leaf litter extract *(Plumeria acuminata)* also contains a lot of unsaturated fatty acids which are double bonds in hydrocarbon chains with derivatives of benzoic acid, benzofuran, x-hylene heptadecane, hexadecane, and octadecane. The purpose of this study was to determine the potential of frangipani leaf waste extract *(Plumeria acuminata)* as bio-avtur material and to measure the quality of bio-avtur from frangipani leaf waste *(Plumeria acuminata)* based on SNI standards (Indonesian national standards) aviation fuel. This research is a quantitative research with a descriptive approach.

The research method used is the experimental method. Experiments were carried out by extracting Cambodian leaf waste using n-hexana, then purified using a catalyst to extract the content of unsaturated fatty acids Benzofuran, benzoate, heptadecane, hexadecane, and octadecane, after that, the test is carried out according to the indicator. The indicators used in this study are, flash point, freezing point, copper blade corrosion, acid number, sulfur content, and avtur specific weight. The data analysis method used in this study is a quantitative descriptive analysis technique. In conclusion, (1) Cambodian plant leaf waste *(Plumeria acuminata)* has the potential to be used as an ingredient for making avtur, (2) Four of the six bioavtur research indicators from frangipani plant *(Plumeria acuminata)* leaf waste, namely flash point, corrosion of copper blades, sulfur content, and specific gravity are close to the SNI standard for conventional aviation fuel.

Keywords: Bioavtur, Frangipani leaves, Hydrocarbons, Fatty acids

CHAPTER I
INTRODUCTION

1.1. Background

Since long time ago Indonesia's avtur demand has been dominated by imports. Even Indonesia avtur imports in 2018 touched Rp. 12 Trillion. However, since 2019 Indonesia has stopped importing avtur and producing it independently by PT Pertamina (Persero). But, according to data from the Central Statistics Agency (BPS), Indonesia still import 15.26 million tonnes of crude oil in 2022.

In fact, the termination of avtur imports in 2019 did not change the market price of avtur. A number of airlines raised flight ticket prices following the soaring avtur prices due to high world oil prices. Avtur costs contribute to 40% of the ticket price composition. (Riyandanu, 2022). The Indonesian government, through Indonesian President Joko Widodo, expressed his wish that Indonesia could achieve self-sufficiency in avtur production and then open opportunities for exports to neighboring countries (kumparan.com , 2019). This is also supported by the refinery construction project planned by Pertamina. These refineries are targeted to meet fuel quality standards (CNBC Indonesia, 2021). This is part of the Indonesian government's commitment to carry out the energy transition process from fossil energy to Indonesia's renewable energy.

Based on data from the Ministry of Energy and Mineral Resources (ESDM), during the 2017-2019 period before the pandemic, consumption of fossil energy-based avtur in Indonesia ranges from over 5 million kl per year. This is a serious problem because fossil-based fuels have a major impact on the environment, such as increasing greenhouse gas emissions, depleting resource reserves, global warming, and acid rain (Sulistyono, 2012). These problems can be overcome by developing avtur from renewable and environmentally friendly vegetable materials, namely bioavtur (Amri dkk, 2017). This is in line with the priorities brought by the Government of Indonesia at the G20 Summit, one of which is related to a sustainable and environmentally friendly energy transition

In general, avtur fuel contains complex chemicals such as short and medium chain hydrocarbons such as hexane, heptane, octane and nonane, as well as aromatic compounds such as toluene, xylene and benzene. In addition, avtur fuel contains additives in order to improve engine performance and improve fuel quality. Some additives namely, antioxidants to prevent oxidation of the fuel which can cause the formation of scale or deposits in aircraft engines, anticorrosive to prevent corrosion on any part of the aircraft engine that is exposed to fuel, antistatic to prevent static charging which can cause sparks and fire, as well as anti-rot to prevent microbial growth in the fuel tank (Pertamina, 2023).

Based on research conducted by Megawati & Saputri (2012), frangipani extracts were found to contain compounds x-hylene heptadecane, hexadecane, octadecane which often dominate the components of gasoline and aircraft fuel. These compounds play a major role in increasing the octane number of gasoline and driving the increase in isobutene, according to one Chinese company Heze Sirloong Chemichal Co.Ltd. This isobutene makes a perfect fuel for jets and as a gasoline additive.

The frangipani plant leaf waste, which so far has rarely been used, was found scattered in the yards of Balinese people's houses. Quoting from (Sari, 2017) frangipani leaves *(Plumeria acuminata)* contain alkaloid compounds, saponins, flavonoids, triterpenoids, polyphenols, steroids, benzofuran, .alpha.-methyl-d-mann, opyranoside, 1,2,3,4,5 -pentamethox ybenzene, and essential oils. The benzofuran compounds contained in it have the potential to be used as fuel because they have flammable characteristics (Shi et al, 2020). Frangipani leaf waste also produces unsaturated weak acids which are double bonds in hydrocarbon chains with carboxylic acid derivatives, namely benzoic acid. High fatty acids are useful in making oil (Spianti et al, 2017). Also contained saponin compounds, flavonoids, polyphenols, and alkaloids have antioxidant activity that can prevent oxidation in fuel Utami & Cahyati (2017). In addition, Quoting from Anggoro et al (2022), frangipani leaves also contain phenolic compounds which work as anti-corrosive to prevent corrosion.

The availability of frangipani flowers is also very much. Apart from Indonesia, frangipani flowers grow a lot in Mexico, Central America and the Caribbean Islands. This flora is also spread in Brazil and Florida (Rochmawati, 2015). So it is very likely that frangipani leaf extract *(Plumeria acuminata)* has the potential as a raw material for bio-avtur and can be developed in several other developed countries.

Based on this description, the researcher is interested in researching "Exploration of the Potential of Cambodian Leaf Extract as Bioavtur."

1.2. Formulation of The Problem

Based on the background above, the formulation of the problem can be formulated as follows: "Bioavtur fuel contains complex chemicals such as short and medium chain hydrocarbons such as hexane, heptane, octane and nonane, as well as aromatic compounds such as toluene, xylene and benzene. Meanwhile, frangipani leaves produce unsaturated fatty acids which are classified as double bonds in the hydrocarbon chain which produce benzofuran, x-hylene heptadecane, hexadecane, and octadecane compounds. It's just not yet known the potential of frangipani leaf waste *(Plumeria acuminata)* as bioavtur," From the formulation of the problem, the following research questions arise:

1. Can frangipani leaf waste extract *(Plumeria acuminata)* be used as bioavtur material?
2. To what extent does the bioavtur from Cambodian leaf litter *(Plumeria acuminata)* match the SNI standard (Indonesian national standard) avtur

1.3. Research Purposes

The purpose of this research, namely:

1. To determine the potential of frangipani leaf waste extract *(Plumeria acuminata)* as bioavtur material

2. To measure the quality of bioavtur from frangipani leaf waste *(Plumeria acuminata)* based on SNI standards (Indonesian national standard) avtur

1.4. Benefits

The benefits of this research include:

1. Adding economic value to frangipani plant leaf waste by using it as a material for making bioavtur
2. As an alternative solution to replace fossil fuels by using renewable vegetable materials.

CHAPTER II
METHOD

2.1. Place and Time of Research

This research was conducted in the Student Research Center Room 'Pradnya Paramita' SMA Negeri 3 Denpasar in June 2023.

2.2. Types of research

This type of research is quantitative research with a descriptive approach. The data obtained in the form of pictures and statistics will be presented using a descriptive approach. The research object used is frangipani leaf extract *(Plumeria acuminata).*

2.3. Method of Collecting Data

The research method used is the experimental method. Experiments were carried out by extracting Cambodian leaf waste using n-hexane, then purifying it using a catalyst to extract the content of unsaturated fatty acids Benzofuran, benzoate, heptadecane, hexadecane, and octadecane, after which tests were carried out according to the indicators.

2.4. Research Indicators

1. Flash Point

Flash Point Indicator is an indicator that tests whether there is a flame in the current sample. The test is done by dripping the sample on a glass plate. Then the sample is given a spark. The minimum flash point on Avtur is 38°C. The unit is Celsius

2. **Freezing point**

The freezing point indicator is an indicator that measures the temperature in the sample at which a liquid changes to a solid. The test is carried out by placing the sample at a low temperature. In pure Avtur, the maximum freezing point is -47°C. The unit is Celsius.

3. **Copper Blade Corrosion**

Copper blade corrosion indicator is a test method that includes the determination of the corrosivity to copper of aviation gasoline. The principle of the test is that the sample is smeared on a copper plate and heated under certain conditions. The combustion results are observed and compared with the standard. The unit is class (Class 1, class 2, and class 3).

4. **Acid Number**

Acid number indicator is an indicator that measures the amount of free fatty acids contained in oil. The test is by reacting the fat/oil with KOH or NaOH base. In pure Avtur, the maximum acid in Avtur is 0.015 mg KOH/g. The units are mg KOH/g

5. **Sulfur Content**

Sulfur content indicator is an indicator that measures the sulfur content in fuel. The test is by pouring liquid fuel in the cup and then burning it immediately, wait until the combustion is complete and see the results of the combustion. If there is a lot of ash left, it shows a lot of sulfur or soot content. In pure Avtur, the maximum sulfur content is 0.30% m/m. The unit is % m/m

6. **Avtur Specific Weight**

Avtur specific gravity indicator is an indicator that measures the specific gravity of Bioavtur. The first test is that the measuring cup is weighed empty. Then the measuring cup is filled with 300 mL of water, then the measuring cup is filled with liquid.
Operation with the formula:

$$\rho_c = \frac{W_c}{Vol_c}$$

Pure avtur has a minimum specific gravity of 775 kg/m3 while a maximum specific gravity of 840 kg/m3 at 15°C. The unit is kg/m3

2.5. Materials and tools

The materials and tools used are measuring cups, beakers, hot plates, thermometers, 96% NaOH crystals, Methanol, Ethanol, aluminum foil, Tissue, Cambodian leaf waste, stirrers, Bottles, Scissors, n hexana, Avtur, Water, Analytical Balance , copper plates, and GC-MS (Gas Chromatography–Mass Spectrometry).

2.6. Research Stages

1. Preparation for Extraction from Cambodian Leaf Waste *(Plumeria acuminata)*

Fresh frangipani *(Plumeria acuminata*) leaf waste is collected and washed clean and cut into small pieces. Then dry it under the hot sun for ± 3 days. Save the dried Cambodian leaf waste for the next processing step.

2. Preparation of Sodium Methoxide Solution

Prepare the first catalyst, namely, NaOH crystals at a rate of 3 grams per 1000 mL of Cambodian Leaf Extract. Once measured, put the NaOH into a 100 mL beaker and pour the second catalyst of methanol at the rate of 5: 1 or 200 mL of methanol per 1000 mL of Frangipani Leaf Extract. Then stir the two catalysts until the NaOH crystals are completely dissolved in the methanol solution. Save the two catalysts for use at a later stage.

3. Production of Bioavtur from Cambodian Leaf Waste *(Plumeria acuminata)*

Prepare 4 liters of n-hexane solution. Prepare 4 beakers with a size of 1000 mL. Place frangipani leaves that have been cut into small pieces into a beaker glass, then add n hexane. Then cover with aluminum foil and let stand for 24 hours. After 24 hours, drain the frangipani leaves from the n-hexane solution. The former soaking is set aside and then the solution is heated using a hot plate by measuring the temperature of the solution using a thermometer, so that the temperature of the solution does not exceed 60^0C. Let the extraction process last for ± 8 hours. Once thoroughly mixed, separate (filtration) the liquid oil with the residue. The residue can be removed.

4. Cambodia Leaf Waste Bioavtur Refining

Frangipani Leaf Oil *(Plumeria acuminata*) needs to be added with methanol to separate pure Frangipani Leaf Extract and glycerol. Heat the oil at 50°C. After that, mix the heated oil with the sodium methoxide solution. Stir for 10-15 minutes to mix well. Next, put the mixed extract into a plastic bottle and pour it slowly. Close the bottle and shake gently so that the solution is evenly mixed in the oil. Let the separation process occur for ± 1 day until two layers are visible. The bottom layer is glycerol and the top layer is pure extract. Separate the glycerol to get pure Cambodian Leaf extract which will be tested according to indicators.

5. Bioavtur Sample Testing

Testing the research sample was carried out according to the research

2.7. Data Analysis Technique

The data analysis method used in this study is a quantitative descriptive analysis technique.

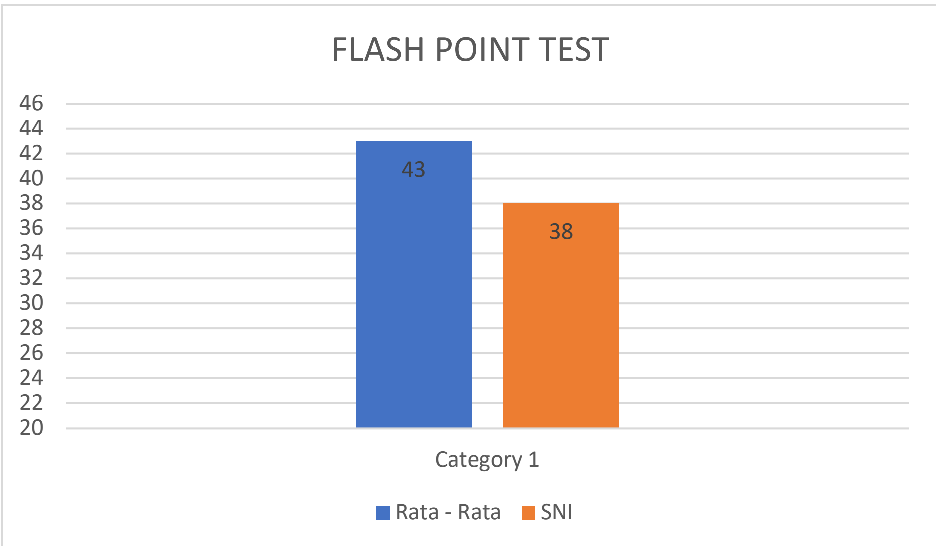
CHAPTER III
RESULTS AND DISCUSSION

Based on the results of the tests that have been carried out, the following results are obtained:

No	Indicator	Avtur Indonesian International Standard	Average Point
1	Flash Point	38^0 C	43^0 C
2	Freezing point	-47^0 C	0^0 C
3	Copper blade corrosion	Class 1	Class 1
4	Angka asam	0 - 0,015 mg KOH/g	4,6 mg KOH/g
5	Sulfur Point	0 - 0,30%	Tidak ada
6	Specific Weight Test	775.0 kg/m^3	690.0 kg/m

Table 1. Bioavtur Test Results

Based on this table, there are four indicators close to the Indonesian National Standard for avtur fuel. That is the flash point, copper blade corrosion, sulfur content, and specific weight test. The average flash point obtained is at a temperature of 430C, which means that it is close to the SNI flash point, which is 380C. Quoting from the journal Wibowo et al, (2017). states that in the solution extracted from frangipani leaf waste there are benzofuran compounds which are flammable and at the lowest temperature of 380C, the bioavtur solution can burn. A higher flash point could be better as long as it's not too far from the standard value of Avtur.

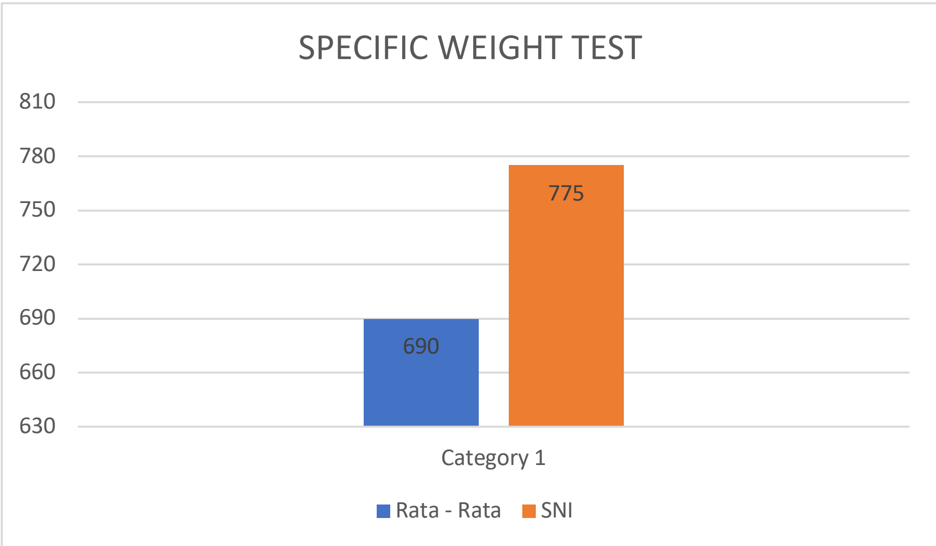


graph 1. Flash Point Test

Whereas in the corrosion of copper blades, when conducting experiments on heated copper with bioavtur from frangipani leaf trash extracts, they did not show signs of corrosion. The results look the same as before, which means that the copper blade corrosion test is in class 1. According to Anggoro et al, (2022), this is because the oil from the frangipani leaf waste extract has phenolic compounds in the form of phenolic acids which work as anti-corrosives which prevent corrosion.

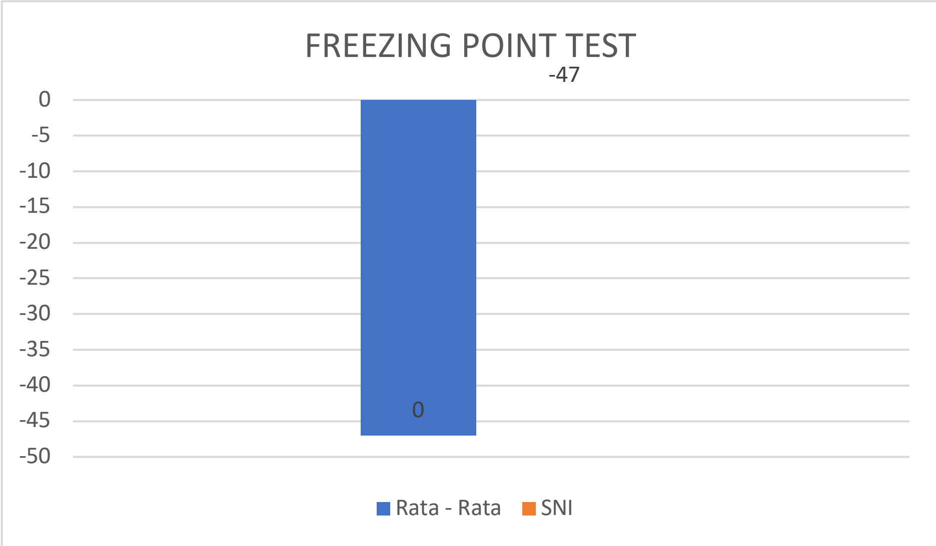
Bioavtur from frangipani leaf waste extract which was tested for sulfur content, showed no sulfur generated due to combustion. This happens because of a purification process called hydrodesulfurization and the low sulfur content of frangipani leaf waste extract. The low sulfur content in bio-avtur can help maintain vehicle engines to last longer (Speight et al, 2015).

In the specific gravity test the results obtained are close to SNI on aviation fuel, which is 690.0 kg/m^3. Quoted from the Speight Journal entitled "Handbook of Petroleum Analysis", (2015), the specific gravity of bioavtur is caused by its chemical composition and chemical properties contained therein



graph 2. Uji Specific Weight Test

For the freezing point test, the results obtained are far from the Indonesian National Standard (SNI) for avtur. This is caused by differences in the production methods of bio-avtur and conventional avtur. Conventional avtur has more complex production stages, while bioavtur from frangipani leaf waste extract in this study uses production stages that are not as complex as avtur in general.



graph 3. Freezing Point Test

In the acid number test, the results obtained are not at all close to the SNI on avtur. The table shows the acid number of the bioavtur is 4.6 mg KOH/g while the SNI for aviation fuel in the acid number test is 0.015 mg KOH/g. This is caused by the source of biomass from bioavtur from frangipani leaf waste extract. Bioavtur is produced from biomass sources, such as vegetable oil. The chemical properties of biomass are very different from petroleum. the higher the acid number, the lower the corrosive level (Lutfhi & Taufik, 2020).

So that frangipani leaf waste extract has the potential to be used as bioavtur material. It's just that of the six indicators tested, there were four indicators whose results were close to the SNI standard for conventional aviation fuel. While the other two indicators do not meet the standards of SNI for conventional avtur. So further research is needed on these two indicators to approach the conventional avtur SNI standard.

CHAPTER IV

CONCLUSIONS AND RECOMMENDATIONS

4.1. Conclusions

Based on the results and discussion, it can be concluded as follows:

1. Frangipani leaf waste (Plumeria acuminata) has the potential to be used as an ingredient in avtur production.
2. Four of the six bioavtur research indicators from frangipani leaf waste (Plumeria acuminata) namely flash point, copper blade corrosion, sulfur content, and specific gravity are close to the SNI standard for conventional aviation fuel.

4.2. Recommendations

Suggestions that can be recommended by the author include:

1. Further research is very needed to improve the quality of frangipani plant leaf waste (Plumeria acuminata) as an alternative source of bioavtur so that it meets SNI avtur
2. GC-MS test is very needed to determine the content of the compounds in the leaf extract of the frangipani plant (Plumeria acuminata) which are in accordance with the ingredients needed to make bioavtur.

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GALES "TiltShift Challenge 2003"

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By Yetta, CiCi, Bella and Lydia

Chinas energy transition prospects.

Introduction

As both the world's largest energy consumer and carbon emitter, China has a diverse energy system and complex energy trade situation which have profound implications for global energy security and climate change. The major sources of energy in China include coal, petroleum, natural gas, hydroelectric power, nuclear energy, wind energy and solar energy. However, coal remains China's primary energy source, accounting for about 60% of total energy consumption according to the latest statistics from National Bureau of Statistics. The high dependence on coal leads to severe environmental issues like air pollution, making energy transition an urgent task for China.

Since China is currently the world's largest CO_2 emitter and accounted for 28% of global emissions in 2019 and surpassed the USA as early as 2007 [(fig1),] it therefore has a key role in mitigating the problems of CO_2 emissions and their relationship to climate change. We believe that China has made an excellent start to this mitigation through diversification in power generation which we will look at through the rest of this essay. We will attempt to show how China is meeting its commitments to decarbonization and how it can continue to make significant improvements in the future with further diversification to a range of different sources of electricity generation.

Fig. 1: China's carbon emission trend.

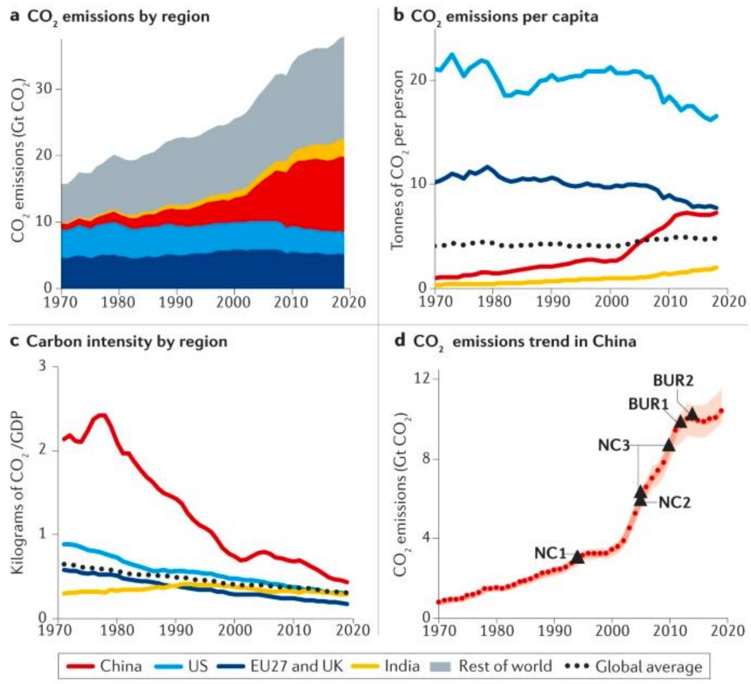

Fig1. Source 1

Through the implementation of various “five-year plans” China managed to reduce CO_2 emissions by 48% between 2005 and 2020[1], however China is committed to reach peak emissions by 2030 and to be carbon neutral by 2060. These targets pose significant challenges, and our research indicates that by diversifying to the generation systems that we will examine these targets can be hit and even improved upon.

The current situation and the coal issue!

In 2021, China's total energy consumption reached 550 million tons of standard coal. Specifically, the consumption of raw coal was 320 million tons, accounting for 58.2% of total energy consumption; petroleum consumption was 67 million tons, accounting for 12.2%; natural gas consumption was 36 million tons, accounting for 6.5%; hydroelectric power consumption was 12 million tons, accounting for 2.2%; nuclear energy consumption was 1 million tons, accounting for 0.2%; the consumption of wind energy and solar energy were 3 million tons and 0.2 million tons respectively, indicating China still relies heavily on fossil fuels despite increasing use of renewable energy. The characteristics and trends of China’s energy consumption structure exhibit diversified sources and a coal-dominated pattern, posing a major challenge for energy transition and environmental protection.

Fig 2 source 2

From the perspective of energy trade, China imports a large amount of coal and coal products, indicating the complexity and diversity of China’s energy market. In 2019, China imported 299.67 million tons of coal and coal products, increased by 6.3% year-on-year, with a total value of 160.5 billion RMB, decreased by 1.1% year-on-year. Exports of coal and coal products were 6.03 million tons, increased by 22.1% year-on-year, with a total value of 6.41526 billion RMB, increased by 24.7% year-on-year. There are considerable fluctuations in coal import and export, reflecting the tight supply-demand situation and uneven distribution of energy resources in China's domestic market. Reliance on imported fossil fuels may pose threats to China's energy security.

年份	煤（万吨）		原油（万吨）		天然气（亿立方米）		电力（亿千瓦时）	
	进口	出口	进口	出口	进口	出口	进口	出口
2010	16310	1910	23768	303	165	40	56	191
2011	22220	1466	25378	252	312	32	66	193
2012	28841	928	27103	243	421	29	69	177
2013	32702	751	28174	162	525	27	75	187
2014	29120	574	30837	60	591	26	68	182
2015	20406	533	33550	287	611	33	62	187
2016	25543	879	38101	294	753	34	61.9	189.1
2017	27090	817	41957	486	956	35.4	83.8	194.7
2018	28189	493	46189	263	1260	34	56.88	209
2019	29967	603	50572	81	1333	36		

Fig 3 Source 3

In the future, China's energy system is expected to undergo significant changes driven by new energy technologies, increasing environmental awareness and the goal of achieving carbon peak and neutrality. As alternatives to fossil fuels, "non-fossil energy" (NFE): hydrogen energy and nuclear energy are regarded as promising options that can reduce carbon emissions and the dependence on chemical materials. As are a range of renewables such as wind solar and hydro, of which China as a large country with a diverse climate has the largest amount of resources in the world.

In the remainder of this essay, we will explore the various prospects of NFE and look at the benefits and challenges related to using each of them to replace fossil fuels.

The prospects for hydrogen?

Hydrogen energy is a secondary form of energy produced from fossil fuels, industrial by-products or renewable energy sources like solar and wind power through water electrolysis. According to the latest research, China's annual hydrogen production is around 3500,104T currently, with coal accounting for 57%, natural gas 22% and industrial byproduct 19%. The hydrogen from renewable-based water electrolysis only accounts for 1%. [5]Indicating the technology of green hydrogen production is still immature in China, leading to the high cost which hinders large-scale application. Hydrogen energy is highly efficient and cost-effective. In transportation, hydrogen fuel cells are suitable for most vehicles. The International Hydrogen Energy Commission predicts that there will be at least 25 million hydrogen fuel cell vehicles in the world by 2050.[5] If technology can be further improved to produce green hydrogen at a lower cost. Therefore, improving technology and reducing the cost are keys to expanding the use of green hydrogen and reducing emissions in China. Strong policy support, increased investment in R&D and rapid advancement of renewable energy are required to achieve this goal. [6]

It seems for the moment that the cost of producing hydrogen both environmental costs, in terms of the carbon emissions, and economical costs are too high for hydrogen burning to become a realistic option for electricity generation, but its future might lie in an alternative fuel for transport.

A nuclear family?

Nuclear power comes from the energy that is released in the process of nuclear fission. Most nuclear power plants use enriched uranium as their fuel to produce electricity. This fuel contains greater amounts of a certain kind (or isotope) of uranium known as U-235. Its atoms are more easily split apart in nuclear reactors.[7]

In 2020, China will generate 366.25 billion KWH of nuclear power, equivalent to a reduction of 105 million tons of standard coal and 274 million tons of carbon dioxide.[8]

The Global Energy Internet Development Cooperation Organization points out in its energy transformation plan that before 2030, the proportion of clean energy will increase from 15.3% to 31%. During the period from 2030 to 2050, China will enter the stage of fastest growth in clean development, reaching 75 percent by 2050. China will maintain a high level of clean energy development between 2050 and 2060, with 90 percent of its energy demand met by clean energy by 2060, and a comprehensive transformation of the energy production system will be realized.[9]

In early 2022, the National Development and Reform Commission and the National Energy Administration formulated the 14th Five-Year Plan for a Modern Energy System. By 2025, about 70 gigawatts of nuclear power will be installed in operation[10].

According to a projection by the OECD the average investment cost of a 2nd generation nuclear reactor in China is more than double that of a large-scale thermal plant.[11]

China has given the go-ahead for two new nuclear power projects in the south of the country costing about CNY80 billion (USD11.5 billion) to add energy capacity and promote green[12]

However, nuclear energy also faces significant challenges like location selection of power plants, safety regulation, nuclear waste disposal and high investment cost which may hinder future development. Selecting sites in remote areas, improving technology, expanding production with policy support, and establishing a comprehensive monitoring system and emergency response mechanism can help address these challenges while minimizing environmental impact, making nuclear energy a bigger part of China's energy mix and contributing to carbon peak and neutrality.

The answer my friend is blowing in the wind? Here comes the Sun?

In addition, wind energy and solar energy are also promising renewable sources for China's energy transition. Wind energy production reached 414.6 billion kWh in 2020, accounting for 6% of total electricity generation. 【13】 The average cost of wind power in China is the lowest in the world, providing cost competitiveness. However, instability, low energy density and a high proportion of curtailment are challenges, increasing the cost of wind power and reducing economic efficiency. Updating technology of wind turbine components, using intelligent software to forecast output and match demand, increasing efficiency of each wind farm and interconnecting grids across regions are key strategies to overcome the challenges, allowing wind energy to reach a higher proportion in the future.

Solar energy production occupied 2.7% of total electricity generation in 2020, according to the National Energy Administration. [14] The cost of solar power has decreased to 0.3 CNY per kWh and is expected to further decrease to below 0.25 CNY per kWh during the 14th Five Year Plan period, lower than most coal power. With abundant solar resources, especially in western China, only 1-2% of land area needs to be developed to supply most of China's future primary energy demand under the "double carbon" goal. [15] However, instability and expensiveness also pose challenges for large-scale application of solar energy. Energy storage, intelligent inverters, increasing efficiency of panels and reducing waste can help address these challenges, facilitating greater use of solar power.

The shape of water

Hydropower is also a promising source for clean energy in China given abundant water resources. The installed capacity of hydropower has exceeded 341 GW, accounting for about 18% of national electricity. [16] The Three Gorges Dam is the largest hydropower project, with an installed capacity of 18.2 million kW and an annual output of 84.7 billion kWh which equals 40 million tons of coal. [17] Although hydropower is renewable and environmentally friendly, it still faces challenges like resettlement, environmental impact, unstable power supply and decrease in thermal efficiency. Developing hydropower equipment manufacturing, choosing better locations, reducing environmental damage and updating technology are strategies to improve efficiency and facilitate expansion.

Tidal energy is a largely untapped resource in China with reserves of 110 million kW along the coastal area. The installed capacity is currently only 21.79 MW, accounting for a tiny proportion. [18] Although renewable and sustainable, tidal energy faces significant challenges including high cost, low conversion efficiency of devices, complicated technology, lack of professionals and conflicts with other projects like navigation routes and fishery. Strengthening technology innovation, providing policy and financial support, building virtual tidal power plant models to assist site selection, improving devices, cultivating talent and developing a tidal power industry chain are key strategies for China to tap into this enormous potential to achieve the goal of energy transition.

Its hot down there!

China is the largest country in energy consumption and the second largest economy in the world. In the “Five Year Plan” (2016-2020) China aimed to use more than 15% of renewable energy sources by 2020 and reduce CO_2 emissions simultaneously by 18%. At the moment China has made remarkable achievements in the development of renewable energy such as wind power and solar power, but has just started in the development of geothermal energy. China is one of the leading countries in direct geothermal utilization, reaching 25.2% of the global total, but only 27.78Mwe of electricity is directly generated by geothermal, accounting for 0.2% globally making it 18th in the world. The geothermal resources shallower than 5 km in the world are about 4900 trillion tons of standard coal. China's geothermal resources account for about one-sixth of global resources, which means that the geothermal energy sector has a great potential for development. Under the background of energy saving and emission reduction, the exploitation and utilization of geothermal resources can realize the green development of China's energy industry. And the geothermal energy could replace fossil fuels to provide the basic load for China's future energy. [19]

At the moment the vast majority of geothermal energy in China is used for non-electricity generating purposes such as heat in greenhouses for agriculture, recreation, and domestic heating using heat pumps.[20]Geographically China’s highest electricity demands are in the east of the country but the majority of the renewable resources such as wind and solar are in the west. Geothermal energy however is more available in the east where the vast majority of China’s electricity generation is needed both domestically and industrially. It therefore seems that the exploitation of geothermal energy in the east should be at least investigated.

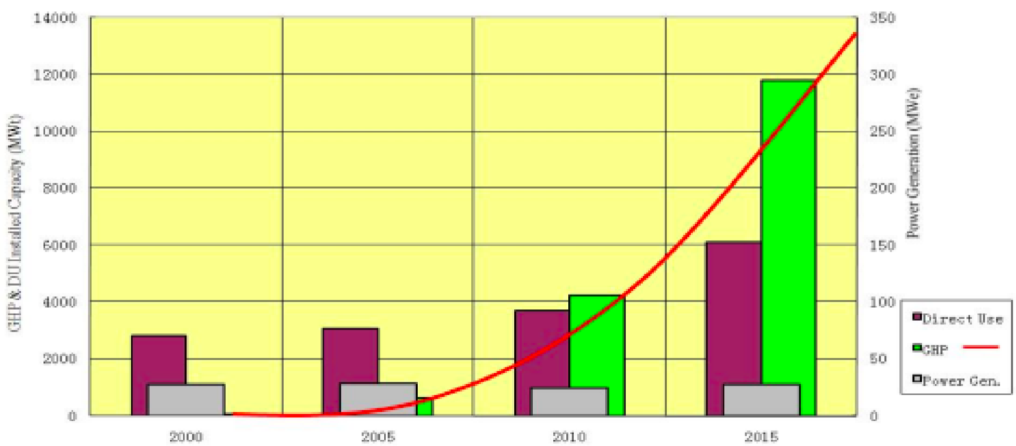

Fig. 1. Comparison of growth of GSHP, geothermal direct use and power generation in China

Fig4 Source 20

The above graph shows a significant growth in direct use of geothermal energy and ground heat pumps since the year 2000 but virtually no growth in geothermal power generation.

The reasons for this are mixed but are partly due to the fact that China has concentrated on other renewables for electricity generation and generating electricity using nuclear power. Additionally, there is often poor matching of the geothermal fluid to the available technology, poor energy endowment of some of the resources and a slow growth in the technology needed to produce GPG safely and with little environmental inpact.[21]

Conclusion

Although China is currently the largest producer of carbon dioxide globally this fact is mitigated due to it currently having the world's largest population and as a proportion of per capita production China is a long way down the list of global polluters with the USA being comfortably at the top. Nonetheless China is well aware of its responsibility to reduce anthropogenic global warming and it is taking its commitments to this very seriously setting itself very challenging targets, making a global commitments and local commitments within its five-year plans. The five-year plans always contain Nationally Appropriate Mitigation Actions (NAMAs) and Intended Nationally Determined Contributions (INDCs).

Although China produces greenhouse gases from a range of sources the vast majority of carbon dioxide is produced in electricity generation and the vast majority of this electricity is generated to drive China's manufacturing base. Power generation accounts for 44% of the CO_2 produced and 38% of this is used in manufacturing.[1]. We believe a two-pronged strategy should be developed where through investment, research, and politico/economic strategies the country moves away from using fossil fuels in energy generation, and secondly to create energy efficiency improvements in both electricity transportation and consumption both domestically and industrially. Both of these things could be driven by NAMAs and NAMAs incorporated into the Five-Year Strategic Plans.

1) Moving towards NFE

Being a very large country with a very diverse climate and appropriate geological features China possibly has unique opportunities to generate NFE. As we have seen in the bulk of this essay China is already producing large amounts of energy from renewables, hydro, nuclear and a small amount of geothermal. We believe that since China is blessed with these abundant resources the best strategy is to diversify its NFE generation and continue to use the full range of available resources including nuclear.

One the challenges here is that the vast majority of energy is used in the east of the country which is the heartland of manufacturing but the majority of renewable energy sources particularly wind and solar are in the west. Amoung the things we would recommend is that a large amount of investment should be placed into distribution and storage technologies which are currently underdeveloped. This would make it more viable to export renewable electricity generated in the west of the country to the industrial heartlands in the east. A possible reversal of this strategy would be to invest in infrastructure to enable to move some of the manufacturing to the west this would help the west to economically develop and increase employment in these areas.

It was reported recently by an NGO in the US that China should hit it's 2030 target in the production of wind and solar energy by 2025 [22]. This would be a remarkable success in this area and leads us to believe that wind and solar should be the focus of NFE investment. However, since climate and weather are notoriously unpredictable it would be unwise, as it were, to "put all of one's eggs in one basket", therefore our belief that diversity in NFE as the key is crucial. For example, recent droughts have caused large HEP generating plants to close resulting in factory closures in certain regions.

2) Increasing efficiency in electricity consumption.

It seems to have been established that the best way to create increases in efficiency in energy consumption is through imposing quotas and targets on various industries to reduce consumption by increasing efficiency in industry and on local authorities to increase efficiency domestically. Central government through its five-year plans and local authorities should set emission reduction targets in provinces and cities which would force increases in efficiency. Such targets have already increased efficiency in our home city of Wuxi which peaked emissions in 2019.[1] . This success was part of a pilot scheme, but it is our belief that they should be rolled out across all cities in China requiring them to produce emissions peak paths and establish systems for monitoring and controlling emissions.

The further development of carbon trading schemes within industry sectors and within local authorities in cities (players) could incentivize and enhance this process. Overall caps should be set and then the trading scheme would allow players below their caps to benefit by trading with other players. Overtime the caps could be reduced this would lead to increases an efficiency.

China's industrial economy is largely based on manufacturing and extraction and many of these industries are not particularly efficient. Incentives should be given by government to encourage transition to more efficient industries such as service industries and high-tech manufacturing this could come in the form of tax breaks or beneficial carbon trading opportunities for companies in more efficient industries.

Oppotinities.

We have already discussed China's advantaged position in terms of its geography and climate in the generation of NFE. However, we believe the Chinese political system may give it another advantage. China's economy is at least part driven by the central government rather than simply relying on market forces. The traditional way the government has used to drive the economy has been through investment in infrastructure, industry, and an enormous building programs, all of which have the potential to increase CO_2 production. This couples economic successes with carbon production to some extent. It is our belief that China should move away from this model and instead try to drive the economy through investment in green technologies particularly storage and transport of electricity.

Like many countries in the world China has a compulsory state funded free education program for its young people. Education is the key driver in most development. This gives the government of China and opportunity in it's compulsory national curriculum to educate the entire future generation on the need for diversification and reduction and CO_2 emissions.

Mitigations

China is still an economically developing country and lags behind in certain technologies that are available in countries that are more developed. These technologies would of course be vital in developing diversification in NFE. China therefore needs invest very heavily in new technologies and develop global strategies for better relationships with countries it can share and develop technology with. The current US technology embargo on China could prove to be a major problem going forward. Recently some of these tension seems to be thawing and China should make every effort to continue openness and cooperation with other countries in the world.

China has developed a significant trade with other countries in the global south often referred to as south-south trade [1] where China imports raw materials and low-end manufactured goods from less developed countries and exports higher end manufactured goods. Since the things China imports and more carbon intensive than the things that exports, this could lead to an imbalance where less developed countries in the global south actually increase the emissions as China reduces its. This problem could be mitigated by fairer carbon trading schemes.

In conclusion, China's energy system exhibits diversified sources but relies heavily on fossil fuels, especially coal, leading to a complex import and export trade situation and severe environmental problems. The promising alternatives like hydrogen, nuclear, wind and solar energy as well as strong motivation for achieving "double carbon" goal are expected to significantly reshape China's energy landscape. By improving technology, reducing cost, providing policy support, interconnecting grids, increasing efficiency and reducing waste, the challenges to energy transition can be properly addressed. With the joint efforts from government, enterprises and individuals, China has the potential to become a leading country in clean energy and sustainable development. Achieving a greener and carbon-neutral energy system is vital for China to peak emissions before 2030 and realize carbon neutrality before 2060.

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GALESS Tiltshift Challenge, Energy Transition

Assessing Indonesia's Renewable Energy Landscape:

A Study of Energy Transition Pathways

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August 15, 2023

Word Count: ~5000

Abstract

The research paper intends to explore three main topics connected to the country's energy sector in depth. To begin, it intends to examine the present energy landscape by identifying accessible energy sources, measuring energy consumption patterns, and assessing energy import and export dynamics. Second, the document will present a strategic plan for shifting the country's energy system away from carbon-based sources. This plan will define the utilisation and development of alternative energy sources, as well as examine and propose potential solutions to the issues connected with this transformation. Finally, the study dives into the worldwide ramifications of the country's energy system transition, examining the potential consequences for other countries and identifying ways in which the country might contribute to other countries' decarbonization efforts. Using these three interconnected themes, the research paper aims to offer valuable insights into the current conditions of the energy system in Indonesia and its future potential.

This study concludes the various available energy sources in Indonesia: fossil fuels, hydroelectricity, geothermal, solar power, wind power, nuclear power, and biofuels. For each energy source, data was compiled regarding its compatibility with Indonesia’s plan to transition to renewable energy. Furthermore, the study outlines a plan to ensure Indonesia’s smooth transition, along with the problems the country may face and their solutions. Finally, with data backing up the claims, the study predicts possible impacts on other countries due to this change.

Introduction

In 2017, President Joko Widodo launched the 35 GW acceleration power supply programme, targeting the 'addition of 4.68 gigawatts of solar power capacity by 2030, aiming to source 51.6% of its added power capacity from renewable sources under a new master plan'. (Bagaskara et al., 2023). All this was conducted under the knowledge that the country was a major coal producer and exporter, and yet the government pursued its plan to shift away from fossil fuels and reach net zero carbon emissions by 2060 (Executive *Summary – An Energy Sector Roadmap to Net Zero Emissions in Indonesia – Analysis*, n.d.).

However, Indonesia is still facing multiple difficulties—from both economic and technological viewpoints (Center, 2020). The main problem is the country's high dependency and reliance on fossil fuels, with approximately 96% (48% fuel, 30% coal, and 18% gas) of its energy being supplied and only 4% using renewable energy sources (Hasan et al., 2012). In this introduction, we will explain the main energy sources in Indonesia and their potential for the future.

Available Energy Sources

1. Fossil fuels (Oil, Coal, and Gas)

As one of the major exporters of fossil fuels, Indonesia has deep reserves of fossil fuels such as oil, coal, and natural gas. It acts as the fourth-largest producer of coal and Southeast Asia's biggest gas supplier. Due to its cheap market price, a large majority of the Indonesian population heavily relies on this ‘easily accessible’ energy source. For example, in 2009, the country exported 198 million tonnes, which represented 77% of total coal production, to Japan, Taiwan, China, India, South Korea, Hong Kong, Malaysia, Thailand, and the Philippines (Hasan et al., 2012). This has ultimately led to fossil fuels continuously dominating the share of energy consumption.

Due to their large-scale use, fossil fuels have had a large impact on the environment. Whether it be the excavation technologies, transportation, and storage, or the main problem—the combustion of fossil fuels, creating greenhouse gases. These factors have resulted in problems such as air pollution, acid rain, floods and landslides, livestock losses, and much more. In 1990, the damage had been estimated to be around $2360 billion per year, let alone in this modern age where its usage is only rising despite continued efforts (Barbir et al., 1990).

Furthermore, fossil fuels remain a non-renewable energy source, meaning that they are limited in supply and will ultimately run out. With the high and constant demand, there is a large probability of a decrease in the availability of this energy source. This further highlights the importance of transitioning to renewable energy (PUSHEP, 2020).

However, Indonesia has become so reliant on fossil fuels that it's built the entire energy infrastructure around them, with them accounting for 86% of the country’s energy source. According to the IESR (Institute for Essential Services Reform), changing this course of action would require approximately 1.4 billion dollars in funding, including renewable energy and energy infrastructure upgrades.

2. Hydroelectricity

Hydroelectric energy, otherwise known as hydroelectric power or hydroelectricity, is an example of energy that uses the natural flow of moving water to generate electricity (*Hydropower Basics*, n.d.).

Hydroelectric dams have several general advantages. Firstly, hydroelectric dams are multipurpose. Hydroelectric dams can also be used as a source of domestic drinking water, irrigation source, and to help control floods (Bartle, 2002). Indonesia is already utilising this highly efficient source, with Sulawesi having the 'largest hydropower potential and being expected to have the most extensive system for developing hydropower plants' (Novitasari et al., 2023).

However, hydroelectric dams are not without flaws. There are global environmental impacts of hydroelectric dams with regard to site selection and evaluating the terrestrial, aquatic, and overall biodiversity impacts caused by electric dams (Dorber et al., 2020). Daniel Estrin stated that dams disturb rivers and cause harm to aquatic animals (*Dam Accounting: Taking Stock of Methane Emissions From Reservoirs • The Revelator*, n.d.).

3. Geothermal

Geothermal energy refers to heat energy from the earth—Geo (earth) + thermal (heat) (*Geothermal Basics*, n.d.). Indonesia, being a country situated in the Ring of Fire, has the significant advantage of its volcanic geology, with reports estimating that Indonesia has 40% of the world's potential geothermal resources, at 28,000 megawatts (MW) (*Medco Cahaya Geothermal – Medco Power Indonesia*, n.d.).

In 'Geothermal Basics' by the Office of Energy Efficiency And Renewable Energy, it is stated that Indonesia has significant potential for geothermal energy. The energy source has multiple benefits, including that it is renewable and domestic, meaning it does not require importing fuel; it has a small footprint, as 'They use less land per gigawatt-hour (404 m2) than comparable-capacity coal (3,642 m2), wind (1,335 m2), and solar photovoltaic (PV) power stations (3,237 m2)*); it is clean, as modern geothermal plants 'emit no greenhouse gases and have life cycle emissions four times lower than solar PV and six to 20 times lower than natural gas'; and it is baseload, meaning that it can consistently and continuously produce electricity.

However, only 1.9% (2356 megawatts) of Indonesia's energy supply. This untapped potential, however, will soon be utilised as 'the government plans to build 44 more geothermal plants by 2025, increasing its geothermal capacity to 4000 megawatts. And aims to produce more than 9000 megawatts in the future. Unfortunately, this would only reach 5% of Indonesia's energy needs' (*Geothermal Basics*, n.d.).

The main issue with geothermal is its risky nature. Investors have to pay potentially hundreds of thousands of dollars to drill into the crust of the earth, and there is only a possibility that there are water pockets. This risky investment deters us from using geothermal, especially because we are a developing country and the money could be better spent on infrastructure or other potential sources of energy (*Medco Cahaya Geothermal – Medco Power Indonesia*, n.d.).

4. <u>Solar Power</u>

Indonesia is located at the equator, making it a prime location for solar power. With a maximum potential of around 4.8-5.1kWh/m2/day, this means that for every square metre of solar panels, up to 4.8 kW/h can be produced (Ventures, 2023).

In a perfect world, this would mean that with an area of around 100,000 km2, you could power the entirety of Indonesia with clean energy with only around 5% of Indonesia's total land area. Furthermore, the price of solar energy is much cheaper than fossil fuel energy, which is the cheapest form of energy (*Solar Energy vs. Fossil Fuels | ConsumerAffairs®*, 2023).

However, this is overly optimistic as it does not take into account factors such as batteries, the cost of installing and maintaining these solar panels, or the cost of exporting electricity to other parts of Indonesia. But with innovations in batteries such as sodium ion batteries and plummeting battery costs in general, the cost of operating these solar farms will be much lower (CNBC, 2023).

Innovations in solar farms have also been made in recent years, especially in agriculture. These farms utilise the land typically used to farm crops for the country. Building solar panels above and around these crops, provides several benefits for plants and farmers (*Solar Panels Plus Farming? Agrivoltaics Explained - YouTube*, n.d.). For example, solar panels that are built above plants are known to protect plants from heavy rains and winds, preventing them from dying. Furthermore, some of these plants grow better in darker, cooler conditions, such as tomatoes and peppers. And these solar panels let enough sunlight through to allow most crops to grow.

As an added benefit, the electricity produced by the solar panels can be used to power the houses of the farmers. This is advantageous since farmers in Indonesia are usually very poor and have little access to electricity. These solar farms can benefit them since they can allow them to have lights, running water, and electricity (*The Potential of Agrivoltaics for the U.S. Solar Industry, Farmers, and Communities*, n.d.).

In addition to all this, solar panels that give shade also reduce water waste, as when irrigating the soil, the soil stays moist for longer periods since the Sun cannot evaporate the water in it. There are even more benefits to installing solar panels on farms, like the cooling effect that plants have. As plants transpire, they have a cooling effect that cools the solar panels above them, allowing the solar panels to work more efficiently and produce more electricity (*Agronomy | Free Full-Text | Agrivoltaic Systems Enhance Farmers Profits through Broccoli Visual Quality and Electricity Production without Dramatic Changes in Yield, Antioxidant Capacity, and Glucosinolates*, n.d.).

5. Wind power

Indonesia's wind power potential is subpar compared to other sources of renewable energy. In most areas, Indonesia lacks strong wing power to support windmills, rendering them useless (Hidayat, 2022). So far, the net potential of Indonesia's wind power is around 150 GW (Sikumbang, n.d.). In addition to that, Indonesia's wind farms, to be affected by the wind, must be built offshore. However, offshore wind farms' construction is inefficient due to their high monetary cost. Still, there is potential for Indonesia's wind power; 'Although our on-land potential is 60 GW, we are only utilising 154 MW, which is only around 0.25% of the total potential energy.' Unfortunately, this wind power is effectively available in mainly East Nusa Tenggara, South Kalimantan, West Java, South Sulawesi, Aceh, and Papua. However, considering our capital is going to be built in Kalimantan, this wind farm can potentially power the new capital of Indonesia.

6. Bio Fuels

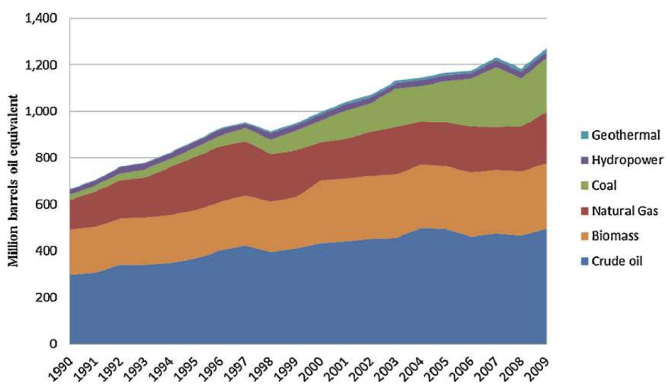

Fig. 1. Primary energy supply by fuel type in Indonesia.

As seen in Fig. 1, the primary energy supply by fuel type in Indonesia ranks biomass as one of the main fuel types. It is an extremely popular energy source in Indonesia, with much infrastructure already built.

Advanced Biofuel

Biofuels can also be made from human waste such as manure, cooking oil, food scraps, and unused fat. This fat can be further refined into oils that can fuel cars and planes. Furthermore, the byproduct of this process is glycerin, which can be used in a variety of hair, skin, and oral hygiene products (Biodiesel Education, 2018).

Considering Indonesia is littered with many food vendors and small restaurants and food joints, it can be extremely easy to collect oil from these stores at a very cheap price, especially if they are subsidised or compensated by the government (*Critical Review on the Biofuel Development Policy in Indonesia – IESR*, n.d.). Manure can also be converted into biofuel. This process is very simple and requires very little investment. This is because we already have a huge, interconnected sewage system that collects all of our excrement. However, other sources of manure can also be exploited, such as cow or lamb dung (Indonesia (GAPKI), 2017).

Algae

Algae cultivation, especially in Indonesia, can be extremely cheap and easy. Since our country is a tropical land mass that is always warm, it has the perfect conditions for growing algae. All that is required to grow algae is sunlight, carbon dioxide, and some nutrients (from fertiliser).

Algae farms can also be easily scaled up to produce huge amounts of algae. The algae, after it finishes growing, is full of valuable protein, sugar, and oil. When refined, it can be used as biodiesel, jet fuel, and ethanol. Furthermore, the process is much cheaper than harvesting and refining crude oil (Arajo et al., 2021).

The most beneficial part of growing algae is that it even removes carbon dioxide from the atmosphere in the process. Theoretically, all the carbon emissions produced by biofuel were reabsorbed by cultivating algae, resulting in a net zero carbon emission.

Method

<u>Design and Procedure</u>

This research employed a systematic approach to gather and analyse data pertaining to renewable energy. The methodology utilised reputable sources, primarily Google Scholar, to access a comprehensive range of scholarly materials and research data related to renewable energy. These encompassed research papers, articles, and documentaries that focused on renewable energy on a global scale and further explored other sources of information from Google.

Subsequently, the collected data underwent a careful adaptation process to align with the distinct context of Indonesia, including its population, environmental considerations, economic landscape, and unique energy requirements. To ensure the credibility and reliability of the data sources, a stringent set of criteria were employed to assess and evaluate the quality of the selected materials, including various data innovations and advancements in the realm of renewable energies, such as agrivoltics and floating solar farms.

The following criteria were applied to ascertain the suitability of the chosen sources: relevance to Indonesia and the different forms of renewable energy (hydroelectricity, solar power, fuel cells, and geothermal); the currency of information published after 2016; a comprehensive analysis of Indonesia’s climate and its alignment with the different forms of renewable energy; and a targeted focus of the results that were specifically targeted at Indonesia or certain areas of the country.

By adhering to this set of criteria, the research ensured the exclusion of sources that would limit the substantiation and understanding of Indonesia's renewable energy landscape, such as the economic viability of the energy source, the risk of investment in the energy source, the efficiency of the energy source, the capability and potential of the energy source, and the reputation of the energy source.

Results and Discussion

As the global population rises, energy supply is a crucial problem that all nations are starting to address. The demand for non-renewable sources of energy, such as coal and natural gas, is increasing, with fuel consumption almost doubling from 1980 to 2006 (6630 million tonnes to 11.163 million tonnes in 2006). Indonesia, as one of the major exporters of crude oil and natural gas, has limited reserves estimated to last for 23 years and 52 years, respectively (Hasan et al., 2012). The rapid depletion of these stores further emphasises the importance of transitioning to renewable sources of energy for this developing country. We propose a plan combining multiple sources of energy and utilising them at their highest efficiency throughout the day to maximise energy input.

As the main energy source in Indonesia, the first step would be to reduce the country's reliance on it. Various sources of funding have already been forged between the Indonesian government, and the Multi Development Bank, the Energy Transition Partnership (ETP), which focuses on clean energy deployment, and the Clean Investment Fund-Accelerated Coal Transition (CIF-ACT) (Bagaskara et al., 2023). These finances are crucial in the development and implementation of renewable energy sources and technologies, used for funding the building and maintenance of these sources.

By developing the country's technology infrastructure for renewable energy, Indonesia can slowly introduce larger percentages of renewable energy into its energy usage, shifting the population's reliance away from fossil fuels.

Stage One—Development of Energy Transportation:

Renewable energy farms are usually located far from metropolitan areas. They can sometimes be hundreds or thousands of kilometres away from any major city. These major cities are the most power-hungry parts of Indonesia. Thus, before building any renewable sources of energy, Indonesia must first construct a new electrical grid. Since wind, solar, and hydroelectric farms are usually built far from towns and cities, we need an electrical grid capable of sending this electricity hundreds or thousands of kilometres. This can be accomplished through high-voltage DC current, also known as HVDC. This type of current allows us to transport electricity over long distances without losing much of the power. This is unlike the traditional AC current that is currently used for our power grids.

Stage Two—Decrease in Fuel Reliance:

Biofuels

Biofuels have slowly integrated themselves into Indonesia's energy sources. In this current period, there is a mandate of 30% for all gasoline sources as a way to cut down on the use of oils. As one of the most suitable and efficient alternatives to fossil fuels, biofuels have slowly but surely shown their promise.

Biofuels made up of palm oils are already a large industry in Indonesia. However, we believe that we can further enhance its efficiency with the addition of advanced biofuels and algae biofuels.

a) Advanced Biofuels:

Biofuels can actually be made from not only organic material but also from grease and waste products like grease and cooking oil. Indonesian street food is notorious for being deep frying and oily. These kitchens and food vendors can be endorsed into donating their leftover grease to the government for processing. Tax and fining policies can be enforced for illegal or improper dumping of grease. This grease is valuable because leftover cooking oil and grease can be refined into diesel that can actually be used by vehicles.

As a matter of fact, Indonesia is already using this process to turn palm oil into biofuel. We can take advantage of the already existing infrastructure to produce more biofuels from waste cooking oils or grease. Manure of any type can actually be turned into biofuel. This can range from cow dung all the way to human waste. Human waste would be the easiest to collect since there are already vast, interconnected sewage systems.

b) Algae biofuels

Indonesia consists of 18,110 islands and over 8,300,000 km2 of land. A large proportion of this land can be used as a plot for algae farms. Since algae farms do not require complicated infrastructure, they can be built in rural areas where it is easy to deconstruct and maintain.

Algae, as one of the fastest-growing biofuel crops, reduces the need for complicated crop farms. Their spatial attributes are a significant advantage, as this makes them more productive and efficient than other biofuel farms. Some strains are even able to produce 80 times more oil than typical fossil fuels ("17 Advantages and Disadvantages of Algae Biofuel," 2016).

Usage of Biofuels

By combining algae biofuels and advanced biofuels with the already existing palm biofuels, we aim to increase the amount of biofuel generated per month. From the 30% usage of biofuels in petroleum, Indonesia can slowly raise the percentage to 50% within ten years. This estimation has taken into account the time required to build such infrastructure and to increase the popularity of the fuel source.

Stage Three—Shift to Renewable Energy:

Solar Energy

Being a country located on the equator, Indonesia has a constant stream of steady sunlight throughout the year, making it highly suitable for solar power plants. The small size of the solar panels enables them to be installed in houses for a limited cost, allowing them to be used in households as a hybrid system between fossil fuels and solar energy. However, we aim to greatly increase Indonesia's reliance on solar energy.

As an energy source currently being developed by the Indonesian government, solar energy has been proven to have the potential to ultimately power the country's energy consumption. Clean energy that does not pollute the environment is what Indonesia is aiming for, and solar energy ticks all the boxes. In the current capital, Jakarta (Java), the sun typically rises at 6 a.m. and sets at 5 p.m. every day. This means the area receives 11 hours of sunlight per day.

a) Photovoltaic Solar Energy Technology

A photovoltaic system is defined as an energy-generating system that utilises solar energy and uses a photovoltaic system (Hardianto, 2019). They are the most widely used source of solar energy, with up to 15 years of experience in Indonesia. By increasing the usage of these sources, such as by installing them on roofs and around large areas of land, such as crop farms, we can greatly increase the amount of solar energy produced per year.

This is particularly applicable in densely populated areas since solar panels can be constructed anywhere. For example, Indonesia is slowly implementing solar-powered street lamps. Using this idea, we are able to install solar panels in houses, starting small, such as heating up water, and slowly moving to rely on them for day-to-day electrical usage.

This set-up can also be combined with agrivolatics—the co-location of solar energy installations and agriculture beneath or between rows of photovoltaic panels (*The Potential of Agrivoltaics for the U.S. Solar Industry, Farmers, and Communities*, n.d.).

Wind Energy

Wind energy can be constructed in only a few places. Fortunately, these few spots are also hubs for Indonesian mining projects. Specifically in Papua, Sulawesi, Maluku, and Kalimantan. All these are very power-hungry locations in Indonesia that require a lot of energy to mine and harvest ores and minerals from the crust of the Earth. In most regions, nickel is being mined, which is essential for lithium-ion batteries. Providing clean energy to these facilities can help us further green transportation.

Goal

Anticipated Challenges

Indonesia's geography is highly uneven, usually covered by forests and hilly terrain. This increases the difficulty of developing land and building solar and wind farms. Therefore, large amounts of funding are required for excavating and conditioning the land for proper use. At the same time, many of our rainforests house various endangered species of animals which have to be protected. This limits the amount of available land.

Of all the problems Indonesia will face, the most concerning factor will be volcanic eruptions. This natural disaster has the potential to destroy all the infrastructure around it. Thus, energy farms have to be built far away from them, especially solar farms.

At the same time, volcanic dust from the eruptions is released into the atmosphere, blocking the majority of sunlight from reaching solar panels. This dust will fall, settling onto the surface of the solar panels, rendering them useless for long periods of time, depending on how long it takes to clean them. Apart from that, solar farms have to be maintained to ensure no trees or vegetation obstruct the sunlight.

Batteries are an essential part of renewable energy, and that is undeniable. Solar energy and wind power can produce a lot of energy, and there can be a surplus of energy. This means that a lot of energy could be wasted during peak hours of energy production.

Resistance by fossil fuel companies will come naturally throughout this transition. As we transition away from fossil fuels, these companies will make less money. And since fossil fuel companies are very rich and powerful, especially in Indonesia. What makes it worse is that Indonesia's government is very corrupt. These rich corporations can bribe cabinet members to vote against the transition to renewable energies.

Solutions to Challenges

Although Indonesia's terrain may be uneven, by effectively utilising available space, the country can minimise its losses and increase efficiency. Using agrivoltaic sources of energy, as mentioned above, we can utilise land originally used for crop farms, installing solar panels around the area to minimise the space required. Furthermore, this solution not only decreases the amount of land needed.

In the case of volcanic dust, it is an inevitable phenomenon. Indonesia, being located in the Ring of Fire, experiences higher frequencies of volcanic eruptions. This, ultimately, will result in damage to infrastructure.

Using Japan as an example, it is one of the most earthquake-prone countries in the world. Throughout the years, they have developed various ways to decrease the impacts of earthquakes on their infrastructure. Pendulums in the core or on the roof of buildings, dampers installed between the levels of the building, and mesh structures to help fortify the building (*Construction Expertise from Japan: Earthquake Proof Buildings - PlanRadar*, n.d.). By utilising these characteristics in its infrastructure, Indonesia can reduce the impact of earthquakes by strengthening its infrastructure and maintaining the efficiency of its energy sources.

There are constant technological advances in the field of batteries. For example, one way to save the excess energy produced is by using lithium-ion batteries. Due to advantages such as having the highest energy density of any battery technology today, low maintenance, and no memory effect. Lithium-ion batteries are already being used to power electrical systems for some aerospace applications, further proving their potential in the renewable energy field. Sodium ion batteries can also be considered for use. Sodium ion batteries can store more energy per dollar than lithium ion batteries while using cheaper and more accessible materials. These materials also cause less pollution and destruction in the world than lithium ion batteries. Furthermore, sodium ion batteries are safer to deal with and are less volatile than lithium ion batteries. The downside to sodium ion batteries is their size. However, since the idea is that Indonesia will only use the sodium ion batteries to store surplus energy, size will not be a huge factor (CNBC, 2023).

Although fossil fuel companies will lose some revenue from the sale of fossil fuels, they will certainly find other business opportunities in green energy. This has already been showcased in Indonesia since fossil fuel companies have already invested in green energy. Especially because it not only improves the image of their company for investing in green energies but also gives them a wider portfolio and makes them less vulnerable to the price changes of oil in the future (Center, 2019).

Global Implications

Potential impacts on other countries

On one hand, Indonesia is one of the major exporters of coal, with 450 million tonnes of coal exported in 2022. Whether it be within the country or in countries it exports to, there is an extremely high reliance on fossil fuels within the country. If, or when Indonesia transitions to renewable energy, there will be a predicted drop in demand locally for fossil fuels. In this scenario, Indonesia's fossil fuel producers will lose a large amount of their export revenues. Completely stopping the export of fossil fuels will be devastating to the country, especially because it makes up a huge amount of our profits every year. A lot of funding will be cut for many of Indonesia's programmes. However, Indonesia becoming an economic powerhouse in other industries could offset this loss in revenue.

Limiting the scenario to Asian countries, not all may be able to afford to transition. Due to the drop in local consumers, Indonesia's fossil fuel producers will most likely decrease their prices to attract more consumers—especially from countries they export to. These countries still relying on fossil fuels may take this chance and purchase the excess fossil fuels. While this will decrease Indonesia's carbon footprint, it may have an adverse effect on other, less developed countries.

On the other hand, by announcing its desire to shift to renewable energy, Indonesia may attract the attention of other, more developed countries such as Singapore or China. These countries may initiate a partnership with Indonesia, possibly providing capital such as machinery and infrastructure to spur Indonesia's development.

Aid to other countries

Indonesia is widely regarded as an emerging economy. Its desire to shift to renewable energy is likely to have a broad impact on its economy. To put it into figures, the gross domestic product (GDP) of Indonesia from crude petroleum, natural gas, and geothermal sources is expected to be roughly 587.6 trillion Indonesian rupiah in 2022 (*Indonesia*, n.d.). In spite of the far-reaching impact on its economy, the effort to shift its energy source may create opportunities for innovation and growth that were never considered before. Transitioning may promote opportunities for ASEAN countries to work together. This collaboration could include the exchange of valuable knowledge and resources about renewable energy technologies and machinery. Furthermore, the participation of more developed countries with more advanced skills and capital in renewable energy can result in collaborative initiatives. These countries might send experts and participate in renewable energy projects in Indonesia, accelerating the country's energy transformation while also facilitating international investment and knowledge transfer. At the same time, Indonesia may send local people to more developed nations like Singapore and other countries in Europe and North America for further education and training in renewable energy technology to contribute to the expansion of its own renewable energy sector.

Furthermore, Indonesia’s actions in shifting towards renewable energy sources may serve as a blueprint for other Asian countries. These countries may be facing similar difficulties— high reliance on fossil fuels, etc. Countries facing similar energy issues can learn from Indonesia's accomplishments and missteps, allowing them to more effectively negotiate their own changes.

Conclusions

The research in this paper emphasises the critical need for Indonesia to address its expanding energy demands (PUSHEP, 2020) and the rapid acceleration of climate change (*Climate Change: Global Temperature | NOAA Climate.Gov*, n.d.). Combined with the rising population (0.7%) (*Indonesia - Place Explorer - Data Commons*, n.d.), there is an urgent need to shift to more sustainable energy sources (*State of the Climate in Asia 2022 | World Meteorological Organization*, n.d.). Ultimately, the purpose of this paper is not to totally decarbonize Indonesia but instead to reduce its carbon emissions to a sustainable level.

The proposed plan focuses on three main energy sources: biofuels, solar energy, and wind energy. Biofuels stand out as they are highly efficient and a practical alternative to fossil fuels that can be quickly increased in their percentage of our energy mix. Solar and wind energy, while equally effective, face location and climate challenges. Therefore, our decision to merge the two sources of energy provides the fullest potential for its utilisation (*Hybrid Wind and Solar Electric Systems*, n.d.).

During Indonesia's shift to these three energy sources, it will confront a number of challenges, such as a fear of infrastructure destruction from earthquakes (Pribadi et al., 2021). Indonesia may overcome these challenges and establish a robust and resilient electricity infrastructure by drawing inspiration from innovative solutions used in earthquake-prone locations, such as Japan, and exploiting technological advancements in battery storage.

Indonesia will also be cooperating with fossil fuel companies to push the development of new green energies. They have even signed an agreement with some fossil fuel companies, so they do not resist the transition to green energy sources.

The economic and environmental consequences are expected to be significant, providing chances for innovation, growth, and international collaboration. The possibility for more industrialised countries to contribute and impart knowledge could speed Indonesia's energy revolution while also strengthening ASEAN collaboration.

In conclusion, the comprehensive strategy presented in this study aims to address Indonesia's energy needs while promoting environmental sustainability and economic growth. The suggested strategy, which is backed up by rigorous evaluation of difficulties, potential repercussions, and collaboration opportunities, provides a road map for Indonesia's transition to a cleaner, more resilient energy future.

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Is the growth of solar farms in Brazil really sustainable?

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Abstract

Brazil's energy matrix is very different from the world's. The country uses more renewable sources than other countries. Adding firewood and vegetable charcoal, hydraulics, sugarcane derivatives, and other renewables, renewables encompass 44.8%, almost half of our energy matrix. However, many renewables cannot accomplish total sustainability. This makes the country look for new technologies to generate energy with less environmental impact. The Brazilian electrical matrix is even more renewable than the energy matrix because much of the electricity generated in Brazil comes from hydroelectric plants. Wind and solar energy have also been growing significantly, contributing to the electricity matrix continuing to be, for the most part, renewable. Nevertheless, hydroelectric plants, despite being renewable sources can produce undesirable environmental impacts, and wind energy is not available in all parts of Brazil, as it is a country with continental dimensions. Thus, solar energy appears as an alternative. It is a clean and non-polluting energy source, because it converts sunlight, an inexhaustible resource, into electrical energy. This conversion can be done in two main ways: photovoltaics (PV) and concentrating solar-thermal power (CSP). Solar farms are huge areas with photovoltaic panels that transform the sun's rays into electrical energy. In 2021, solar energy in Brazil represented 1.7% of the entire energy matrix; and 2.5% of the electric matrix. According to a survey by the National Electric Energy Agency, there are about 2469 solar farms in Brazil (2019). Due to the importance of this type of energy in Brazil, this work aimed to get the geographical coordinates of at least three solar farms in the south of Minas Gerais state, located at Varginha and Três Corações cities and study by Google Earth available data and the places where the solar farms were installed. Despite the growth of solar energy this research aims to understand the impacts that solar farms have on biodiversity and natural areas where they were built, study the implantation laws, and suggest strategies to avoid social and environmental impacts.

1. Introduction

Brazil is a country with continental dimensions and produce energy for different sources. Many people get confused by the difference between the energy matrix and the electrical matrix, and even think that they are the same, but actually, they are different. While the energy matrix represents the set of energy resources used to move cars, prepare food in the oven, and create energy, the electrical matrix is formed by the group of resources only used to generate electrical energy. So, we can conclude that the electrical matrix is part of the energy matrix. The world has an energy matrix composed, mainly, of non-renewable resources, like coal, petroleum, and natural gas (Fig. 1A and 1C) whereas coal, natural gas, and petroleum are the primary sources. Brazil's energy matrix is very different from the world's. Brazil uses more renewable sources. Adding firewood and charcoal, hydraulics, sugarcane derivatives, and other renewables, Brazil's renewables encompass a total of 44.8%, almost half of its energy matrix (Fig. C). This feature of the Brazil matrix is very important. Non-renewable energy sources are the main responsible for the emission of greenhouse gases (GHG). As Brazil consumes more energy from renewable sources than other countries, dividing the emission of greenhouse gases by the total number of inhabitants in Brazil, we will see that Brazil emits less GHG per inhabitant than most other countries, considering the energy matrix. However, Brazil contributes to undesirable emissions without direct contribution by the energy matrix. It comes from enteric fermentation (animal flatulence), landfills (decay of organic matter), manure management, deforestation and others [2].

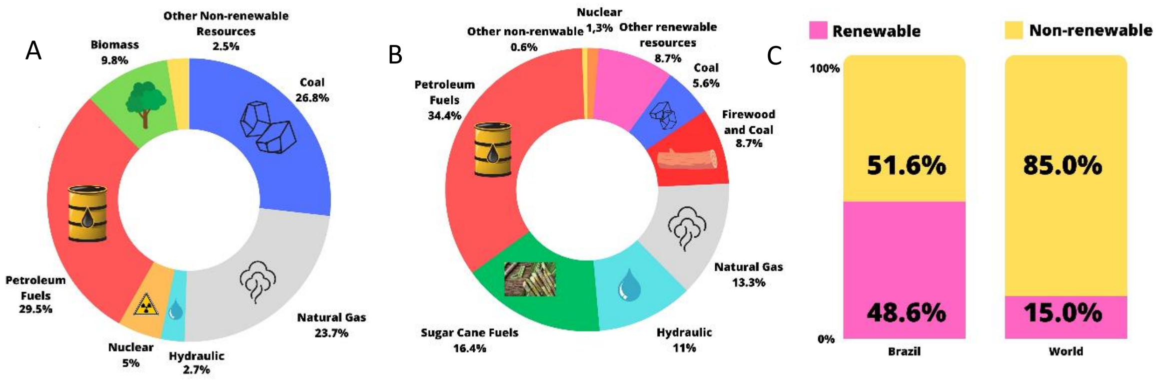

Figure 1: World (A) and Brazil (B) energy matrix and comparison of use of renewable and non-renewable energy sources (C). Adapted from [1].

The electric matrix is formed by a set of available resources just for the generation of electric energy. Electric energy is used, for example, to watch television, listen to music and charge our phones. The generation of electric energy in the world is based, mainly, on fossil fuels like coal, oil, and natural gas (Fig. 2A). The Brazilian electrical matrix is even more renewable than the energy matrix because much of the electricity generated in Brazil comes from hydroelectric plants. Wind and photovoltaics energy have been growing significantly, contributing to Brazil's electricity matrix continuing to be, for the most part, renewable (Fig. 2B).

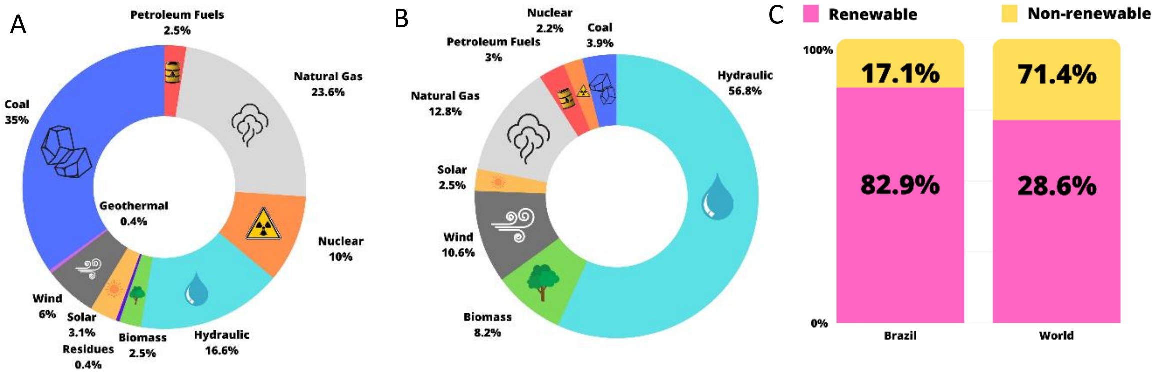

Figure 2: World (A) and Brazil (B) electric matrix and comparison of use of renewable and non-renewable energy sources (C). Adapted from [1].

The unit of electrical energy currently used by Brazilian National Electrical Energy Agency (ANEEL - Agência Nacional de Energia Elétrica) is the kWh (kilowatt/hour) or the MWh (megawatt/hour). They are units used to indicate the "power per unit time" that a power generation plant can produce in a specified time. This production of electricity can occur through several generation sources, including [2]:

- Hydroelectric Power Plants: are those with a hydraulic potential of power greater than 1,000 kW and equal to or less than 50,000 kW, in an independent production or self-production regime, without the characteristics of a small hydroelectric power plant

- Small Hydroelectric Power Plants: are those undertakings intended for self-production or independent production of electricity, whose power is greater than 3,000 kW and equal to or less than 30,000 kW and with a reservoir area of up to 13 km², excluding the regular bed gutter from the river. Hydroelectric use with a reservoir area greater than 13 km², excluding the regular riverbed channel, will be classified in this category if the reservoir is regularized at least weekly or whose sizing was proven to be based on objectives other than the of electricity generation (definition will be provided by Normative Resolution No. 673 of 8/4/2015 by ANEEL);
- Hydroelectric Generating Centers with Reduced Capacity: are hydroelectric uses with power equal to or less than 3,000 KW (definition will be provided by Normative Resolution No. 673 of 4/8/2015 of ANEEL);
- Thermoelectric Power Plant: these are undertakings that use the energy released by any product that can generate heat to generate electricity, such as bagasse from various types of plants, wood waste, fuel oil, diesel oil, natural gas, enriched uranium and natural charcoal;
- Thermonuclear Plants: these are thermoelectric plants that use the energy released by the nuclear fission of uranium as a source. The National Nuclear Energy Commission (CNEN), a Brazilian federal agency linked to the Ministry of Science, Technology and Innovation (MCTI), is responsible for regulating the use of nuclear energy in Brazil;
- Wind Generator Center: these are projects that transform the kinetic energy of the wind into electrical energy;
- Photovoltaic Solar Generator Center: these are projects that transform the sun's energy into electrical energy through the photovoltaic effect. The photovoltaic effect is the creation of electric voltage or a corresponding electric current in a material, after its exposure to light.

Hydroelectric generation is the main source of energy in Brazil. Hydroelectric plants, despite being renewable sources can produce undesirable environmental impacts. Basically, there are three types of hydropower facilities: impoundment, diversion, and pumped storage. Some hydropower plants use dams and some do not [4]. Ten of the largest hydroelectric plants on the planet, are Brazilians: Itaipu Binacional, Belo Monte and Tucuruí. According to Aneel, the country has 219 large hydroelectric power plants in operation, in addition to 425 small hydroelectric power plants and 739 hydroelectric generating centers. In all, there are 739 hydroelectric power plants, which, in 2021, accounted for 62.48% of the country's installed power and 67% of all electricity generated [5].

The largest hydroelectric plant in the country, Itaipu, with its 14 GW of capacity, was for a long time the largest on the planet, now supplanted by the Three Gorges plant, in China, which adds up to 22 GW. Iconic, Itaipu has a unique history and has produced more than 2.8 million gigawatt hours (GWh) since the beginning of its operation in 1984. Even with a smaller installed capacity, there are years when Itaipu produces more energy than Three Gorges since the priority of the Chinese hydroelectric plant is not to produce energy but to regulate the Yangtze River and make river transport possible [5].

Belo Monte is the largest all-Brazilian hydroelectric dam. The Belo Monte Hydroelectric Plant is installed on the Xingu River. It is also one of the largest hydroelectric plants in the world and contributes to Brazil maintaining one of the cleanest energy matrices on the planet. With an installed capacity of 11.2 GW and an average amount of energy generation of 4,571 MW, Belo Monte establishes itself as the largest fully Brazilian hydroelectric plant. The engineering also included the question of the sustainability of the enterprise and, to reduce the environmental impact, the main reservoir of the enterprise, formed in the channel of the Xingu River, was designed with a run of water, a modern and preservationist technology that meets the strict principles of sustainability, respecting the environment and surrounding communities. Together with the Intermediate reservoir, the project's flooded area totals 478 square kilometers, which is considered small when compared to the area flooded by other hydroelectric projects in view of their power generation capacity [5].

In Varginha there is a small hydroelectric power plant, PCH Boa Vista II with a power capacity of 26,5 MW. It was built on Rio Verde River. The Rio Verde basin encompasses the following cities Aiuruoca; Alagoa; Baependi; Cambuquira; Campanha; Carmo da Cachoeira; Carmo de Minas; Caxambu; Conceição do Rio Verde; Cristina; Cruzília; Dom Viçoso; Elói Mendes; Itamonte; Itanhandu; Jesuânia; Lambari; Monsenhor Paulo; Olímpio Noronha; Passa Quatro; Pedralva; Pouso Alto; São Gonçalo do Sapucaí; São Lourenço; São Sebastião do Rio Verde; São Tomé das Letras; Soledade de Minas; Três Corações; Três Pontas; Varginha; Virgínia [6]. The Rio Verde River receives a great load of untreated wastewater from some of these cities (Table 1). Associated with the environmental impacts caused by the hydroelectric dam and the power plant itself the maintenance of the river health is a great challenge due to the water quality of the tributaries and the sewage released upstream off the dam. Most of them do not have efficient wastewater treatment and many still release raw sewage directly to the river [7]. Therefore, PBH Boa Vista II dam concentrates a high load of organic matter and face several environmental problems as intensive growth of aquatic macrophytes, fish death and illegal fishing, lack of riparian forest and poor environmental enforcement and surveillance.

Table 1: Percentage of swage treatment in the cities upstream Small Hydroelectric power plant Boa Vista II dam.

	City	Percentage of sewage treatment
1	Itanhandu	22%
2	Passa Quatro	60%
3	Campanha	0%
4	Baependi	0%
5	São Lourenço	0%
6	Caxambú	90%
7	Três Corações	77%
8	Varginha	91%
9	Conceição do Rio Verde	0%
10	Carmo da Cachoeira	0%
11	Carmo da Cachoeira	0%
	Passa Quatro	60%

Adapted from reference [7]

Concerning to the growth of electricity generation and energy transition in Brazil, July (2023) was the month of winds according to data monitored by the National Electric Energy Agency. Of the 525.5 megawatts (MW) added to the

country's installed capacity this month, 421.2 MW came from 18 new wind farms, seven of them in Rio Grande do Norte state. Two photovoltaic solar units (93.6 MW), two thermoelectric plants (10.0 MW), and two small hydroelectric plants (0.7 MW) also started operating in the period [8].
The Brazilian electrical matrix reached this year, until the end of July, an expansion of 5,673.9 MW. ANEEL recorded the entry into commercial operation of 176 plants, 79 wind (2,713.8 MW), 61 photovoltaic solar (2,295.1 MW), 25 thermoelectric plants (531.4 MW), eight small hydroelectric plants (122.2 MW) and three hydroelectric power plants (11.4 MW). Solar and wind plants represent, together, 88.3% of the installed capacity in the year. The plants that started operating this year are located in 18 states across all Brazilian regions. In descending order, the states of Bahia (1684.7 MW), Minas Gerais (1315.7 MW), Rio Grande do Norte (1160.3 MW), and Piauí (460.9 MW) present the best results so far [8].
The above data shows the transition of the electrical energy matrix in Brazil, highlighting the wind power and photovoltaic energy generation systems. As wind power plants are located in the north of the country, it was decided to study the implementation of a photovoltaics generation center in the south of the Minas Gerais state, specifically in Varginha and Três Corações cities. It is also important to mention that Brazilians have now the choice to purchase part of their electric energy from the photovoltaic generation center reducing the consumption of energy from hydroelectrical power plants, this has a positive impact not only in sustainability but also on their electric invoices, with savings of up to 15%. Independently from household photovoltaic systems that can be purchased by all Brazilian residents, this work aimed to study the sites where big photovoltaic generation centers were installed to check if the expansion of solar farms was not linked to deforestation or biodiversity losses. For that five photovoltaic generation centers were investigated three in Varginha city and two in Três Corações city, Minas Gerais state.

2. Methodology

The group visited the sites where photovoltaic generation plants were installed and got their coordinates using the application “My GPS Coordinates”. The application was downloaded from the play store on cell phones. After that, historical data of satellite images available on Google Earth were investigated. Images from five years intervals were obtained (2003, 2008, 2013, 2018, 2023), and when this period was not available images from other intervals were acquired and are specified in the results sections.
Interviews were performed with professionals involved in the construction and maintenance of the photovoltaic generation center. The types of solar panels of these photovoltaic power plants were studied and some aspects of vegetation covers and drainage systems were investigated. Five photovoltaic generation centers were investigated, three located in Varginha city and two in Três Corações city, all in South of Minas Gerais state, Brazil. Unfortunately, this report lacks very important accurate data such as power capacity and kinds of solar plates for proper evaluation of enterprises. The reported power capacity mentioned was based on personal communication. As this work is based on freely internet information, probably confidential data are not available to citizens. The solar power plants located in Varginha seems to use single-axis solar tracking systems that follow the solar by moving in a single axis (vertical or horizontal). Generally, the inclination angle is adjusted and automatic movement is provided in the east–west direction. The power stations located in Três Corações seems to have a fixed racking system. All of them have uncovered soil and drainage systems to avoid the erosion process.

3. Results

Five photovoltaic generation centers were investigated, three located in Varginha city and two in Três Corações city, all located South of Minas Gerais state, Brazil. Their coordinates are shown in Table 1.

Table 1: Photovoltaic power plants location and coordinates.

Photovoltaic Power Plant	Coordinates	Cities of Minas Gerais State, Brazil
A	21°31’185” S 45°29’551” W	Varginha
B	21°31’112’’ S 45°29’469” W	Varginha
C	21°38'108" S 45°25'042"W	Varginha
D	21°40'031" S 45°18'067"W	Três Corações
E	21°42’323’’ S 45°17’410” W	Três Corações

The photovoltaic power plants, A, B, and E were located in a rural area. Photovoltaic power plants C and D were located in industrial areas. A, B, D, and E started to be built in 2022-2023 and probability will start to operate in September 2023. The two power plants A and B are installed close to each other. Figure 3, shows an overview of them. Figures 3 to 7 show historical data collected from satellite images using Google Earth for each site where power plants were installed.

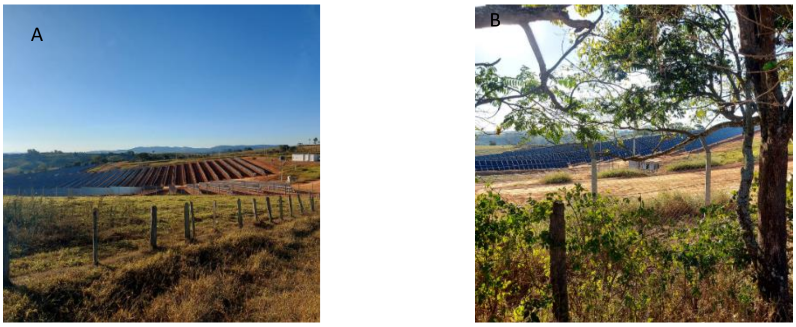

Figure 3. Overview of two powerplant, A and B, located in rural area of Varginha city, Minas Gerais state, Brazil.

Figure 4 shows the satellite images from photovoltaic power plant A, it is noticed fragments of forest were preserved until 2023 (red arrows). However, since 2003, most of the area was covered by pasture and coffee crops. It is important to mention, there is evidence of water body formation in the area (blue arrow) since 2003. Extra work should be performed to verify the nature of this water body and if it would be a spring, an area considered as permanent preservation, that must have at least 50 meters of radio of riparian forest [9]. It is important to mention, that images of Google Earth are not real-time images. Despite the images of 2023 for photovoltaic power plants A and B are not shown they are ready (Figure 3).

Timeline: 2003	2008	2013	2018	2023

Figure 4. Satellite images acquired using Google Earth form the site where Photovoltaic Power A is built.

Images of the area were photovoltaic power plant B (Fig. 5) was built shows native forest was presented until 2003, it was size decreased in 2007 and it was almost fully replaced by pasture in 2013.

Timeline: 2003 2008 2013 2018 2023

Figure 5. Satellite images acquired using Google Earth form the site where Photovoltaic Power Plant B is built.

Imagens of the area where photovoltaic power plant C was built show native forest was preserved until 2018 and it was size decreased in 2023. More studies must be performed to understand if there would be any negative effect of solar plates and electric systems on the native vegetation.

Timeline: 2003 2008 2013 2018 2023

Figure 6. Satellite images acquired using Google Earth form the site where Photovoltaic Power Plant Varginha V is built.

Images for the area where photovoltaic power plant D (Fig. 7) was built show a small fragment of native forest is preserved until 2023. As the construction of the photovoltaic plant is still in progress, in the future we will be able to assess whether there will be a reduction in this area after the plant starts operating. At this moment as shown in Fig. 8 no intervention was made.

Timeline: 2005 2007 2014 2020 2023

Figure 7. Satellite images acquired using Google Earth form the site where Photovoltaic Power Plant D is built.

Figure 8. Overview of power plant D located in industrial area of Três Corações city, Minas Gerais state, Brazil.

Images for the area where photovoltaic power plant E was built show a small fragment of native forest preserved until 2023. As the construction of the photovoltaic plant is finished, in the future we will be able to assess whether there will be a reduction in this area after the plant starts operating.

Timeline: 2007 2014 2017 2020 2023

Figure 9. Satellite images acquired using Google Earth form the site where Photovoltaic Power Plant E is built.

Consulting free available government database, at http://sistemas.meioambiente.mg.gov.br/consulta-intervencao and satellite images, it was found that there were losses of fragments of Atlantic Forest associated with the implementation of some solar system power plants and grid. Data of correspondent area was filtered by each city and power plant locations and the sum of approved intervention was calculated (data not shown). However, more studies should be performed to understand the pros and cons of these energy production systems. In agreement with Brazilian and Minas Gerais state environmental regulations in such cases environmental compensation is required.

In case of intervention entrepreneurs must perform the environmental compensation for the cutting or influence on vegetation in medium or advanced stage of in the Atlantic Forest Biome. When it applies: Federal Law nº 11.428/2006, it is characterized by the cutting or exclusion of a forest fragment or massif of primary or secondary vegetation in a medium or advanced stage of distribution in the Atlantic Forest Biome, as well as existing disjunctions.

The compensation area will be in the proportion of twice the suppressed area (2x1), in the form of art. 49 of Decree No. 47,749/2019, and must be located in the State of Minas Gerais. The following measures are allowed, the entrepreneur can choose:

I – Allocation of an area for conservation with the same ecological characteristics, located in the same hydrographic basin and, whenever possible, in the same hydrographic micro basin and, for the cases provided for in art. 30 and 31 of Law nº 11.428/2006, in areas located in the same municipality or in a metropolitan region;

II - Allocation, through a donation to the Government, of an area located inside a Conservation Unit in the public domain, pending land regularization, located in the same hydrographic basin, in the same State and, whenever possible, in the same watershed;

III – Recovery of the area through the planting of native species similar to the suppressed phytophysiognomy in an area located in the same hydrographic basin and, whenever possible, in the same micro basin.

4. Conclusion:

This research raises awareness and argue if there are any kind of energy production systems where only positive gains for nature are observed without any losses. Is it possible? Therefore, from now we are going to investigate the strategies of the environmental compensation systems applied because implementations of solar power energy production systems are not the future in Brazil, they are already a reality and maybe the environmental compensation strategies can help preserve contiguous areas replacing highly fragmented native areas that are very vulnerable. Therefore, economic and environmental gains can be united. Unfortunately, we did not have accurate data on the installed capacity of photovoltaic power plants to compare with the small hydroelectric power plant present in the city and evaluate economic and environmental gains as a whole.

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A Mathematical Modeling for Thailand's Investment in Renewable Energy

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Abstract

Thailand has been grasping annual temperature hovering caused by high levels of greenhouse gas emissions. To resolve this national and global crisis, Thailand must obey the Paris Agreement, "All countries must aim for net-zero emissions by 2050". In this article, we proposed the AIM/EndUse Model, a mathematical model to simulate the most cost-effective investment to increase the ratio of renewable electricity production with minimal effects on consumers. AIM/EndUse Model can project options for investment plans based on the database of current energy consumption, the predicted energy demands from the economic growth, and the available renewable energy resources, including the energy trade with neighboring countries. "Transition of Thailand's Power Sector toward Carbon Neutrality 2050" is the article we selected most suitable for creating a roadmap towards carbon neutrality. The policy is then constructed following the plan of the generated article model: three policies on investment in renewable energy resources were implemented following Solar village, Wind power, and combined-cycle power plant. Finally, our plan can guide and contribute to mapping Thailand's transition toward a net zero future.

Keywords: AIM-Enduse, SSPs, Monocrystalline panels, Combined-cycle powerplant, Distributed wind

Contents

1 Introduction

Thailand, like many countries worldwide, is grappling with the urgent need to address its significant greenhouse gas (GHG) emissions. Thailand's Population produces more than 3.69 tons per person [4]. These emissions have had far-reaching consequences, affecting its citizens' well-being and quality of life of its citizens. Critical contributors to Thailand's emissions include the loss of carbon sink from deforestation, emissions from agriculture and farming, and using fossil fuels for energy generation and transportation. Recognizing the gravity of the situation, the 21st session of the Conference of the Parties (COP21) established the Paris Agreement - an international treaty aiming to combat climate change. The Paris Agreement calls for global efforts to limit the rise in global temperatures to well below 2 C, preferably targeting 1.5 C compared to pre-industrial levels. This agreement directs countries like Thailand to take ambitious actions toward decarbonization and reducing their carbon footprints.

The AIM-Enduse model provides valuable insights into the current energy landscape, facilitating the evaluation of various transition strategies and their potential impacts. Policymakers and researchers can utilize this model to simulate and analyze different scenarios, ensuring that policy interventions are evidence-based and aligned with Thailand's decarbonization goals. This article aims to inspire and inform Thailand's energy transition journey by examining successful case studies from other countries and best practices. It will also address the challenges and obstacles during the process. Technical, financial, and regulatory barriers will be explored, along with potential solutions to overcome them. Additionally, this article will highlight the opportunities of transitioning to renewable energy, including enhanced energy security and improved air quality.

2 Country Background

2.1 Geographical and Natural Resources

Thailand is located at the Latitudes N 5°37' to N 20°27' and longitudes E 7°22' to E 105°37' [9] (Figure 1). The country has six distinct regions: the mountain range in the north and the west, the Khorat Plateau in the northeast, the Chao Phraya River basin in the central, and the long coastline in the south. Thailand has a total land area of approximately 513,115 km2. About 46% of the land (238,791 km2) is used for agriculture (Figure 1). According to the Royal Forest Department's estimation, there are 164,000 km2 to 16.40 million hectares of forest area under the protection of the government agency. Agriculture relies on the annual precipitation during the monsoon season and the irrigation systems from the major rivers. At present, renewable energy in Thailand comes from hydropower, solar, and wind. The major dams serve as hydropower plants in addition to being water reservoirs. For example, the hydroelectric capacity of Bhumibhol Dam and Srinagarind Dam are 790 and 720 MW, respectively. Due to the proximity to the equator, the region of Thailand gets 8 – 11 hrs of sunlight annually. The capacity of the largest solar farm in Lampang and Phitsanulok province in the northern region is about 90 MW. The wind farms, however, are limited to capacity of 12 MW.

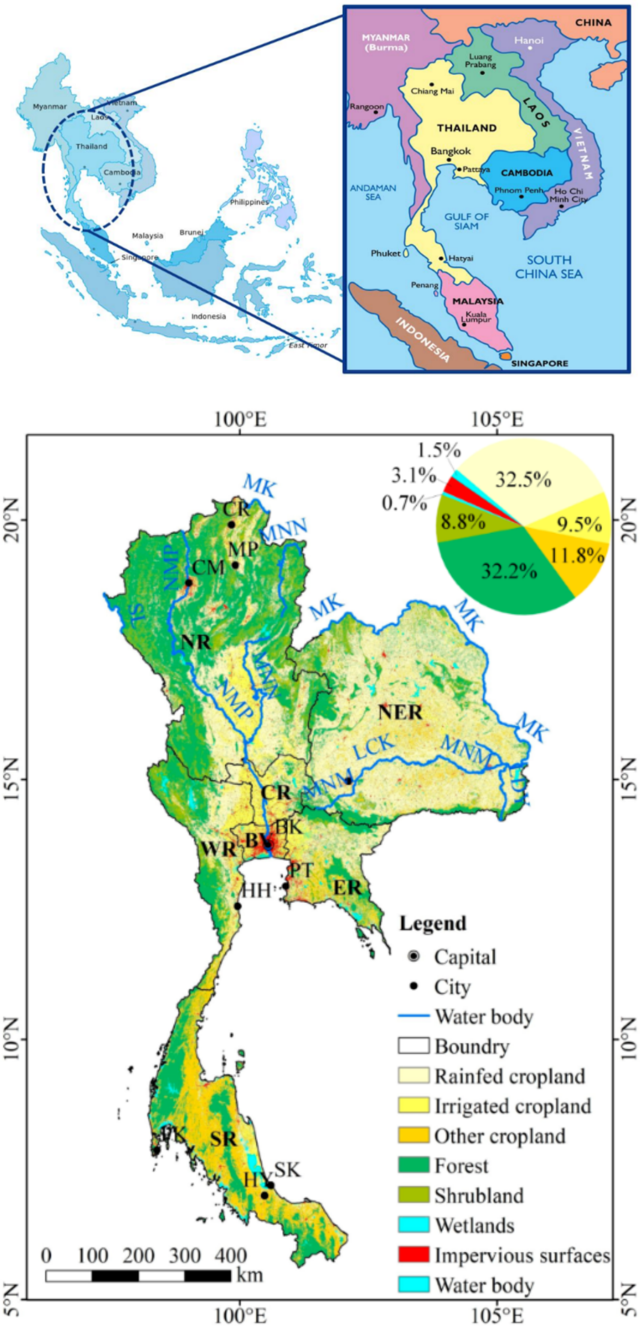


Figure 1: Thailand's Location and Thailand's Land Use Land Cover

2.2 Population, Economy, and Energy Consumption

As of 2023, Thailand has a population of 71.8 million. Due to the declining birthrate, the population was forecast to decrease to 65.37 million in 2050. On average, the population density is about 141 per km2 [17], with the highest density in Bangkok and other provinces in the central region. In the past decade, GDP growth was about 2 – 4%, with industry and services sectors as the main contributors. The energy consumption of Thailand is 190 billion kWh of electricity per year. Currently, the energy sector relies heavily on carbon-based fuel, accounting for 66%of the overall energy production. Since the discovery of a large reservoir of natural gas in the Gulf of Thailand in late 1980, Natural gas has become a crucial part of Thailand's energy and chemical industry. However, Thailand's natural gas reserve is depleting rapidly, leading to a higher energy cost as there is a need to import more natural gas from Myanmar and Malaysia. Thailand does not have crude oil resources. Therefore, crude oil from the middle east accounted for almost half of the imported energy in 2022 (Table 1). Overall, Thailand has an energy balance deficit of 60 Mtoe in 2022. Although Thailand has abundant natural resources for renewable energy, they are not utilized to their full potential. Renewable energy contributes to only 25.4% of energy production, with the highest output from hydroelectric

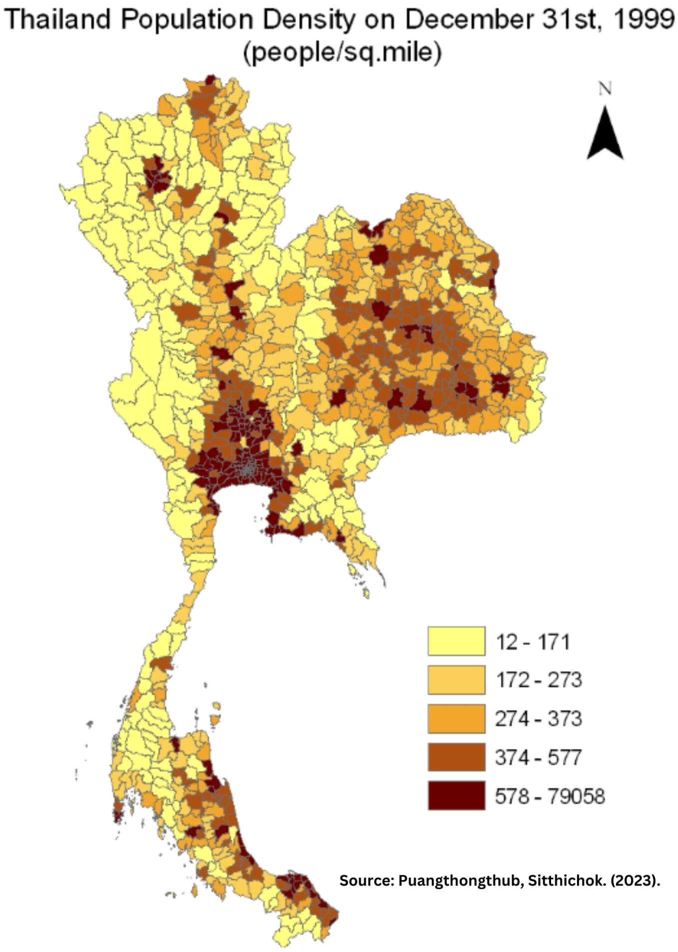


Figure 2: Population Heatmap in Thailand

Followed by the 12th National Economic and Social Development Plan (2017-2021), extended to 2022, which adhered to National Strategy (2018-2037). In the past decade, GDP growth has grown only in single digits (Industrial and service sectors were the main drivers). Thailand is the Second largest economy in Southeast Asia. However, The GDP ranked 4th. The country's weakness was that it relies heavily on exports, accounting for one-third of the GDP, and the Coronavirus Pandemic caused Thailand's Economy to shrink by 6.1%. Despite that, Thailand's economic growth is expected to rise after the pandemic.

Indicators	2020
Growth in Real GDP	-6.1
Investment	-4.8
• Private	-8.4
• Public	5.7
Private Consumption	-1.0
Government Consumption	0.8
Export of Goods	-6.6
• Volume	-5.9
Import of Goods	-13.5
• Volume	-11.8
Current Account to GDP (%)	3.3
Inflation (%)	-0.8

Table 1: Growth in GDP

2.3 Current Energy Situation

2.3.1 Energy Production

Thailand's Energy production heavily relies on commercial energy(66.39%), and to be more specific; Natural gas played a crucial part in Thailand's energy productivity as in 69% of overall production in Thailand. For Renewable energy, 25.4% of Thailand's energy production was from this section.

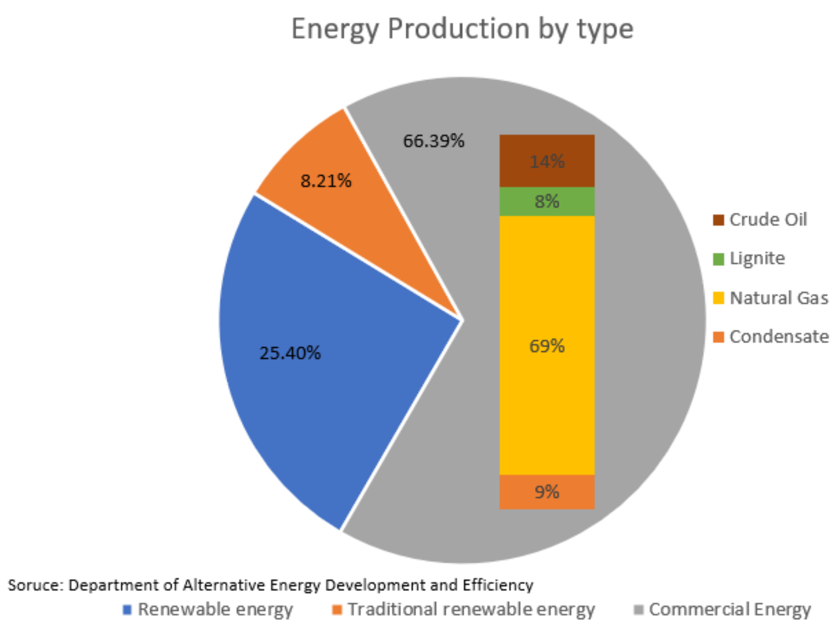


Figure 3: Energy Consumption by Type

2.3.2 Energy Import and Export

Overall, Thailand's net energy imports (Imports - Exports) rate is higher in 2022 than in 2021 at 14.6% because of more imports and fewer exports too. Thailand mainly imported crude oil and partially imported coal and natural gas for 17.8%. Crude oil imports came from the United Arab Emirates ($5.94B), Saudi Arabia ($3.88B), Indonesia ($1.31B), Angola ($1.17B), and Malaysia ($1.07B). Natural gas came from Malaysia, and electricity came from both Malaysia and Laos. Overall, Thailand's export rate has decreased every year. Thailand mainly exported finished oil for 89.5% and crude oil for 7.3%. The main destinations of crude oil exports from Thailand are: China ($253M), Singapore ($68.6M), Malaysia ($48.8M), Australia ($22M), and South Korea ($20.8M). Thailand is mainly more of an importing than an exporting country.

Types of Energy	Import in 2022 (Ktoe)	Export in 2022 (Ktoe)
Total	13486	97
Coal	13663	22
Natural gas	38580	723
Crude Oil	1205	-
Condensate	1252	9310
Petroleum Products	2633	154
Electricity	35	11
Conventional Renewable Energy	70854	10317

Table 2: Energy Import and Export in 2022

Currently, Thailand's hydroelectric power comes mostly from Bhumibhol and Srinagarind Dam, both located in the westside of Thailand, with 749 and 720 MW of capacity. Moving on to solar power, Lampang and Phitsanulok Solar Farms account for 90 MW each. In terms of wind power, most of the power is from the east side of Thailand, and the Korat and Laem Chabang wind farms are the most notable sites at about 200 MW each. Lastly, Thailand's biomass shares a very small capacity compared to the others. The site which contributes the most is Saraff Energies in Krabi, with 12 MW.

Figure 4: Most important power plants in Thailand.

3 The AIM/Enduse model

The AIM/End-use model is a part of the AIM/emission model for the estimation of greenhouse gases emission and absorption in the Asian-Pacific region[6]. The greenhouse gas emission modes generally can be classified as top-down or bottom-up models. The long-term forecast generally prefers the bottom-up model that focuses on the final energy consumption with a more detailed description of the energy technology and the performance of each energy service. The AIM/End-use is a bottom-up technology selection model within a country's energy-economy-environment system. The cost is optimized under various constraints such as resource availability, operation cost of technology, and service demand satisfaction.

4 Transition of Thailand's Power Sector toward Carbon Neutrality 2050

Chaichaloempreecha and Limmeechokchai applied the AIM/End-use model to create investment options for Thailand's power sector. In their study, population and GDP were assumed to set up the model condition. Based on the average -0.5% population growth rate, Thailand's population and GDP projection in 2050 were 66.1 million people and 668 billion USD, respectively. The scenarios were formulated based on the expected outcome of socioeconomic challenges for mitigation and adaptation. The business as usual (BAU) is the scenario based on the current energy supply and demand pattern. In the BAU scenario, the net CO2 emission from the energy sector will increase from 142 Mt in 2030 to 223 Mt in 2050 due to almost three folds increase in energy demand if Thailand continues to rely on carbon-based fuel. The net-zero trajectory required measures in both mitigation and adaptation in the Shared Socioeconomic Pathways (SSP). Mitigation is the attempt to prevent or reduce the emission of GHG, such as the use of cleaner automobiles or the storage of GHG. Adaptation involves anticipating the adverse effect of climate change and making the most of climate change, for example, the investment in facilities suitable for the rising temperature.

Each SSP is based on lists of assumptions (Table 3). The AIM/End-use Model prediction for the transition of Thailand toward 2050 carbon neutrality gave three scenarios of SSP1, SSP2, and SSP4. The SSP1 is the future where biomass and fossil fuel use is greatly minimized. On the contrary, the SSP4 will keep a portion of energy production from carbon-based fuel in coordination with other measures to offset the emission, such as carbon capture technology. The SSP2 is the middle way where renewable technology is gradually replacing the fossil-fuel power plant. Considering the availability of biomass from the agricultural sector, the future of Thailand's energy sector is likely to follow the SSP2 and SSP4. The difference between SSP2 and SSP4 is that SSP4 requires a rapid improvement in carbon capture facility and regulates the amount and the efficiency of energy usage, for example, the rapid transition to electric vehicles. By 2050, the SSP4 will have an energy consumption of 6,000 ktoe lower than SSP2; at the same time, the energy generation in SSP4 will also be lower than SSP2 by 3,000 ktoe. The SSP4 is sometimes called the inequality pathway because this strict regulation will limit mobility, trade, and household consumption in this scenario.

Element	SSP1	SSP2	SSP3	SSP4	SSP5
Renewable energy cost decrease speed	H	M	L	H	L
Social acceptance of modern biomass use	L	M	H	H	L
Renewable energy preference	H	M	M	H	L
Nuclear technology progress speed	M	M	L	H	M
Social acceptance of nuclear energy	L	M	H	M	M
Preference for fossil fuel-fired power plants	L	M	H	M	H
Autonomous energy efficiency improvement	H	M	L	H/L	M
Energy use coal preference	L	M	H	L	H
Energy use electricity preference or electrification speed	H	M	M	H	M
Speed of moving away from traditional biomass use	H	M	L	L	H
Service demand for transport	L	M	M	L	M
Coal mining cost	M	M	L	M	L
Oil and gas extraction cost	M	M	H	M	M
Intermediate input of material decrease rate	H	M	L	H	L
Carbon capture and storage (CCS) cost	M	M	M	L	L
Household preference for manufacturing goods	L	M	H	L	M
Air pollution control level	H	M	L	L	H
Non-energy-related emissions reduction measures cost	L	M	H	L	H
Yield growth assumption	H	M	L	H/L	H
Export tax and import tariff rate for agricultural goods	L	L	H	H	L
Export tax and import tariff rate for energy goods	L	L	H	L	L
Livestock-oriented food consumption preference	L	M	H	H	L

Table 3: Some elements of the shared socioeconomic pathways. L = low, M = medium, H = high

Therefore, in this study, the SSP2 is chosen as the pathway for Thailand's transition toward carbon neutral 2050 in the energy sector. The main reason for choosing SSP2 is the inclusiveness of people from all different socio-economic statuses. The SSP2 provides an intermediate challenge where the carbon-neutral policy can be implemented alongside social and economic development. According to SSP2, 2030 will be the pivotal year where the net CO2 emission will begin to decrease. Solar power should account for 15% and 50% by 2030 and 2050, respectively. In addition, SSP2 required an investment in wind energy; the power generation from wind energy is expected to grow from less than 5% in 2030 to 20% in 2050. In 2050, carbon-based fuel will account for 27% of the overall energy generation. However, the plant must be equipped with a more energy-sufficient system as well as a carbon capture unit.

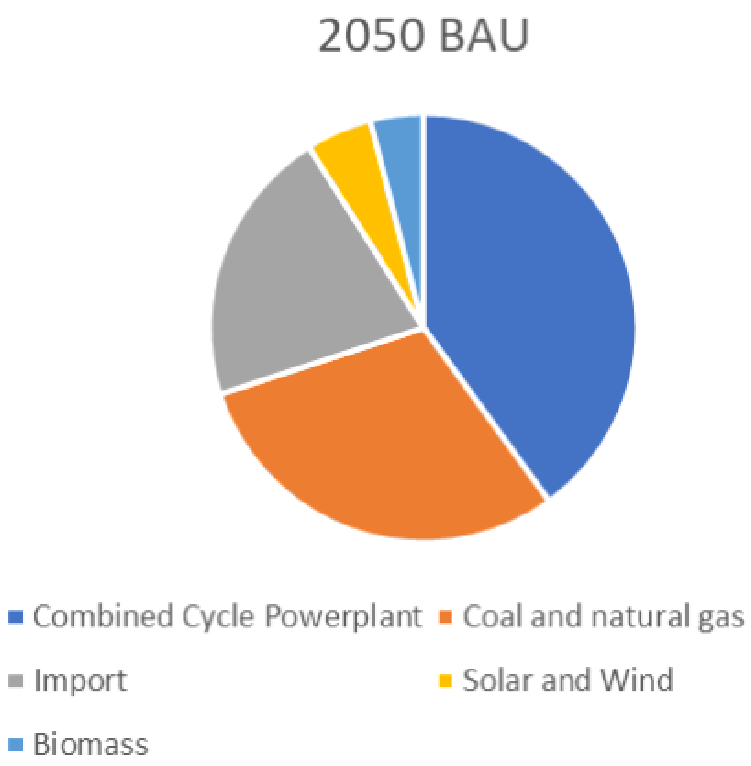


Figure 5: 2050 BAU scenario

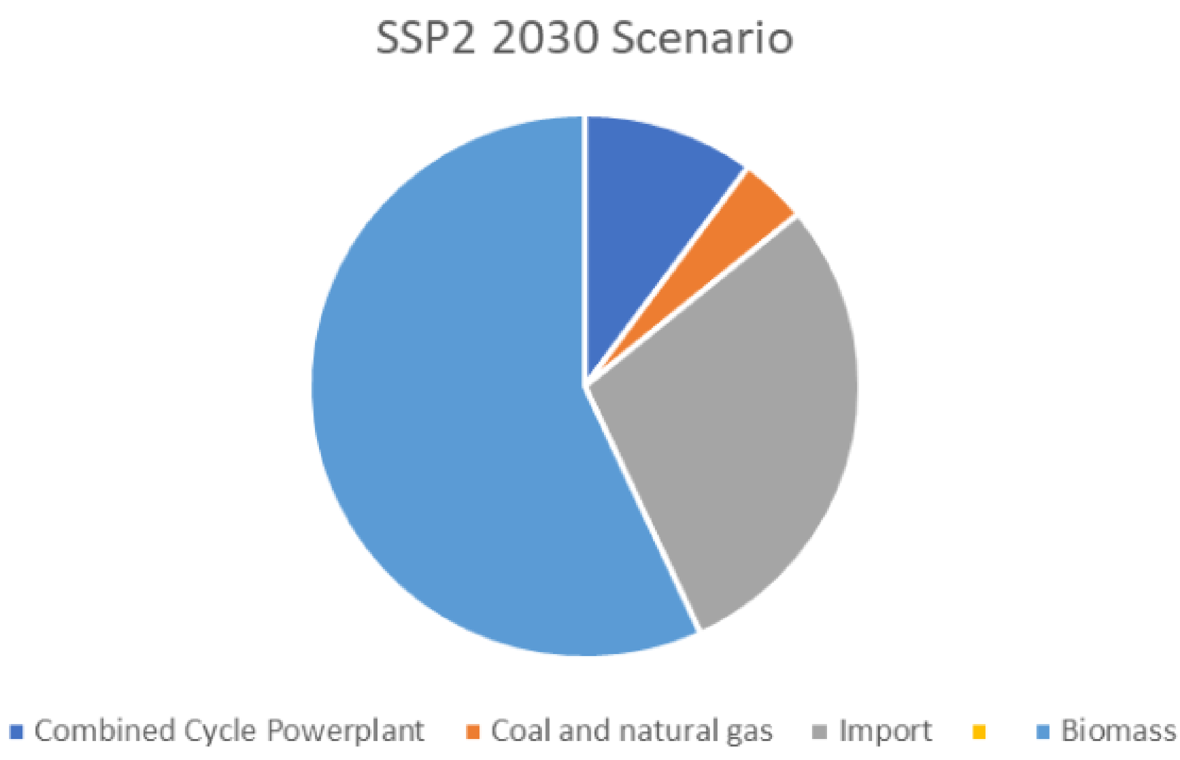


Figure 6: SSP2 2030 scenario

CN2050_SSP2	Goals	2030 and 2050
Solar	More electrical production	5% electricity Consumption
Wind	More electrical production	56.9% of electricity generation
Combined power plant	Help reducing CO_2 Emissions in 2050	Removes 46.4% (5.7 - 7MtCO_2) with 40 % of electricity generation

Table 4: Goals and result by 2030 and 2050

5 Solar Village

Solar Village is a project which needs to be done by using the power of the government. This project aims to set an example of a village using solar energy to run the overall cycle in just 2030. The plan starts with the government implanting solar panels on the roof of every house in the targeted village, which can be anywhere due to the all-over hot and sunny climate and will result in the usage of solar-based electricity in the residential sector of the village. The next process is to expand the solar-based utilities and facilities in the village to be the village that completely relies on solar energy and reaches the goal of net zero emissions. We think that 8,000,000 Baht as the annual fund is sufficient for the project.

5.1 Solar panel selection

There are three available types of solar panels, including monocrystalline panels, polycrystalline panels, and thin-film panels. The monocrystalline PV system has the highest efficiency rates, performance ratio at 80.5%, and specific yield per unit area. However, the monocrystalline panel is also the most expensive model, costing 7,500$ or 263,100 Baht for each 6 kW system. The 6kW system can generate up to 30 kWh a day, sufficient for 29 kWh, the average electricity usage per household a day. Therefore, the monocrystalline PV system built with monocrystalline solar panels is the one we will use as the model in the plan.

Figure 7: 6 kW solar system on a rooftop

5.2 Residential setup

Starting in January 2024, the process starts with setting the 6kW solar system on the house's rooftops in the village. After the usual electricity run throughout the year, the government will collect the excess electricity from the resident and sell it to increase the project fund. Each house will have 1kWh excess each day or approximately 365 kWh a year, converting into 1,803 Baht annually for each household. The used fund per month is approximately 526,200 Baht per month because the plan is to set up the solar system at the rate of two houses per month. This process can be finished in 2030 if the selected village has less than 168 houses, which is normal for Thailand's villages.

5.3 Expansion to other sectors

The goal of this expansion is to change the source of energy used in facilities and utilities of the village into solar energy, such as solar golf carts or solar rooftops on the village's gym, to revolutionize this village into net zero emission. In the financial part, the government can use the remaining annual fund amount to fulfill this expansion.

Figure 8: Solar power golf cart

5.4 Case study

A Case study of a solar-based village is the project called "Babcock Ranch". The project is about building and running a town mainly relying on solar energy. The town has its electric-producing stations, the 870-acre solar farm, solar tree charging stations, and a solar-plus-battery storage system, the country's largest one.

Figure 9: Babcock Ranch

5.5 Final remark on Solar power

The Solar Village project aims for a solar-powered village by 2030 to reach the goal, which is an example town presenting net zero emission. It starts with installing monocrystalline solar panels on houses, generating excess energy for funding. The plan begins in 2024, targeting two houses per month, totaling fewer than 168 houses. The expansion includes solar facilities like golf carts and gym rooftops. The project draws inspiration from "Babcock Ranch," a solar-powered town. Goal: net-zero emissions.
Overall, this project can be proposed to the government to reach the renewable energy plan of the AIM/Enduse model in 2050, which is the CN2050_SSP4, by taking the selected village as the example of the plan that has national scale all over Thailand's villages. Moreover, the fund for this type of project will gradually rise through the increasing amount of the project's committed households.

6 Wind power policy

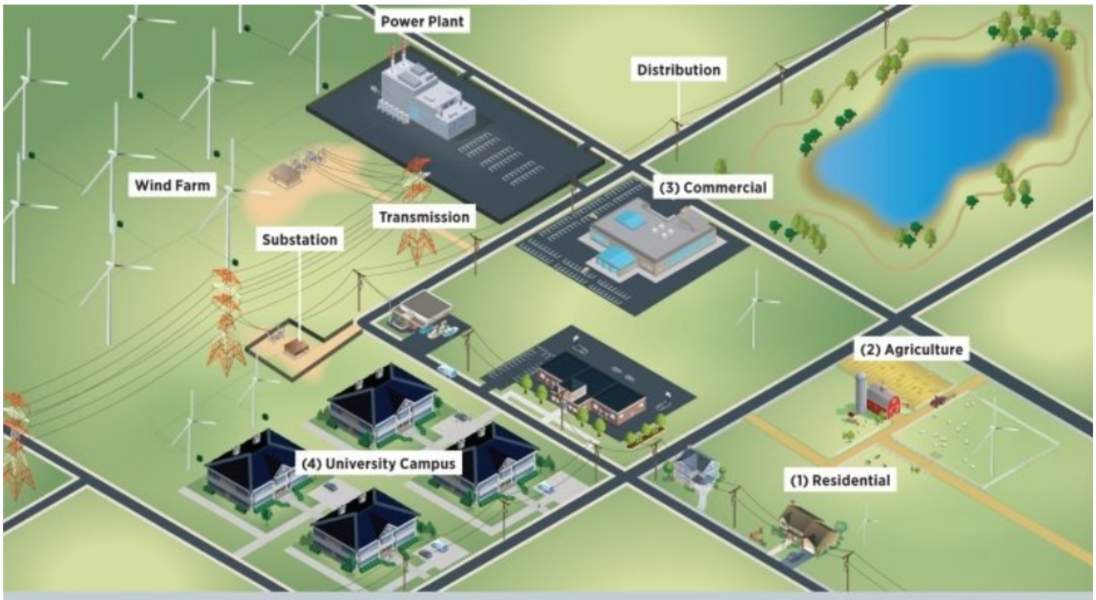
Thailand's wind power production is at 3220.0 GWh in 2020, which is about 1.7% of the total energy production, which is slightly lower compared to other renewable resources: namely, solar PV (2.8%), hydro (2.6%).

6.1 Thailand's wind power potential

The potential of wind power in Thailand is limited to its low average wind speed at 2.8-4 m/s (class 1-1.4 wind speed), which makes the produced energy lower and has a higher cost. To harvest wind energy, class 3 wind is the lowest requirement for a high-efficiency outcome. However, there are still several places with average more than class 3 wind speed thanks to the northeast and southwest monsoon affecting Thailand. The northeast monsoon produced a strong wind in the seaside area of southern Thailand and the Gulf of Thailand, while the southwest monsoon brought a strong wind to the mountain ranges in the west of Thailand. In conclusion, the sources of Thailand's high-efficiency wind energy are limited to the Southern and Western parts of Thailand.

6.2 Distributed wind energy

Distributed wind energy systems take advantage of the energy production from a smaller sector. It consists of conventional utility-scale and smaller-scale wind turbines connected to the grid. This makes the overall production of wind energy from the same area increase. To illustrate this, an example is depicted in the figure below. In the figure, wind farms, which consist of utility-scale wind turbines, contribute the most to energy production in this area. On the other hand, it can be seen that smaller wind turbines are installed in many other places, such as houses or schools.



In contrast to energy generated at large wind farms that is sent via transmission lines to distant end-users, distributed wind energy systems produce electricity that is consumed on site. Distributed wind projects can be (1) a 5-kW turbine at a residence, (2) a 50-kW turbine at a farm or (3) commercial user, or multi-megawatt turbines at (4) a university campus. *Image credits: NREL/David Schulz*

Figure 10: Distributed wind system

One way to increase the individual wind turbine is to apply a wind net metering policy, in which the electric bill price is reduced if the electric power produced by a private sector is sent to the power grid. This policy will make it more appealing to people to install wind turbines in their private areas. However, this policy will only work in the area with high-quality wind resources and high electricity bills.

6.3 Support wind energy investment

Lots of wind power plants are crucial to reach the potential of wind power. But regarding the high cost of production, it is hard for the government to pay for it on its own. Reducing taxes for industries contributing to wind energy production is way more effective. Tax incentives are adopted for this task. The industry would invest in wind energy and benefit from future profit and tax reduction. On the other hand, the government will get closer to the carbon neutrality goal and not have to pay for the turbine but pay for the energy. To achieve this, the government must carefully design policies to persuade as many industries as possible to participate in wind power production.

6.4 Increase offshore wind energy production

Offshore wind speed is faster than those on land, so wind farms located in an ocean will generate more electricity. Thailand has the potential for offshore wind. According to research from EGAT, it is expected that 10% of power production in Thailand can be generated by offshore wind power plants. As a result of this, plans for deploying offshore wind farms could play a crucial role in Thailand's energy transition. However, many obstacles need to be overcome. The most obvious one is that the upfront costs of an offshore wind power plant are much higher than those of regular windmills due to the need for specialized equipment such as underwater cables. There is also a concern about how those wind turbines located in the ocean will affect people who live near the coast regarding noise pollution or visual impact.

Figure 11: Floating platforms of shore turbine

6.5 Final remark on Wind energy

To conclude, Thailand must increase the contribution of wind power production from the private sector as well as increase the amount of private investment for a bigger project. Moreover, offshore wind has the potential to be an important source of energy for Thailand's energy transition.

7 CCPP(Combined-cycle power plant) policy

At present, natural gas is the major fuel source of Thailand's power plant. Although the natural gas reserves have dramatically decreased from over 12,000 billion cubic feet to around 4,000 billion cubic feet during the past 20 years (Figure 13), natural gas will still play a crucial role in Thailand's energy roadmap for 2050 carbon neutral.

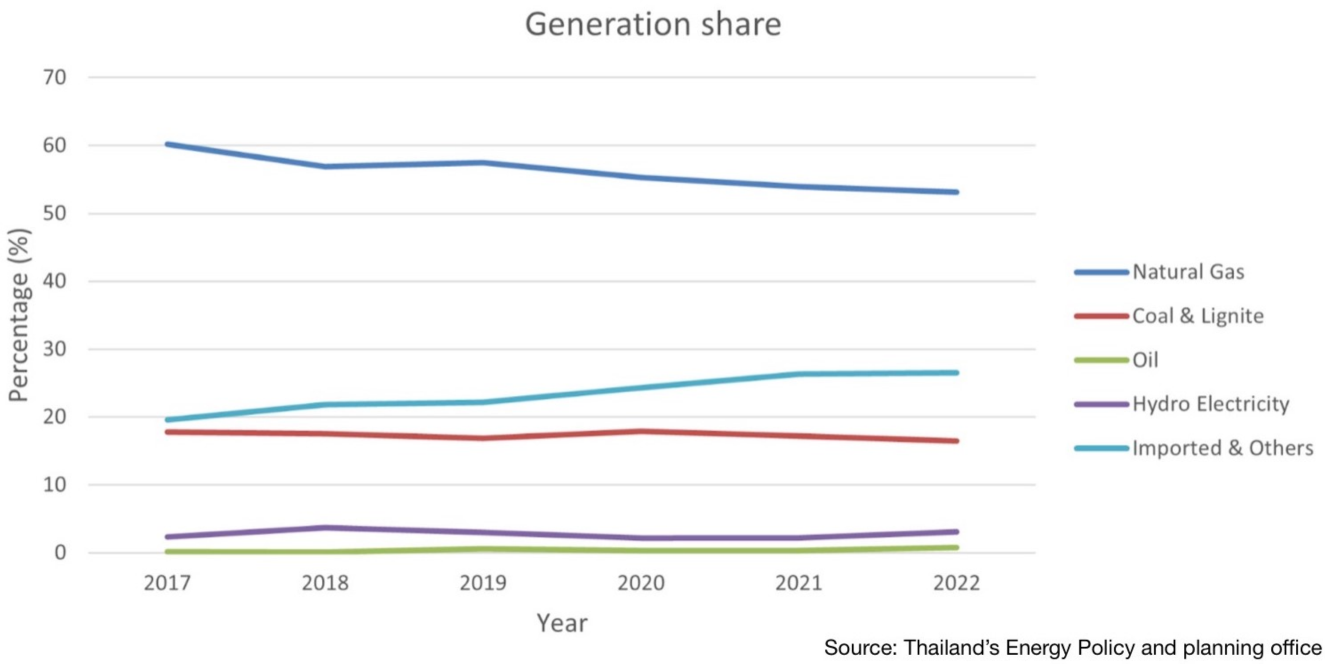


Figure 12: Power generation shares in recent years

The key improvement from the BAU model is to replace the conventional gas turbine with a more energy-efficient system of combined-cycle power plants. In addition, Thailand's government has already started "the Biomass Project" in 2022; the project plans to build 15 biomass and 75 biogas power plants, collectively increasing electricity capacity from biomass to 8.45 GW in 2030.

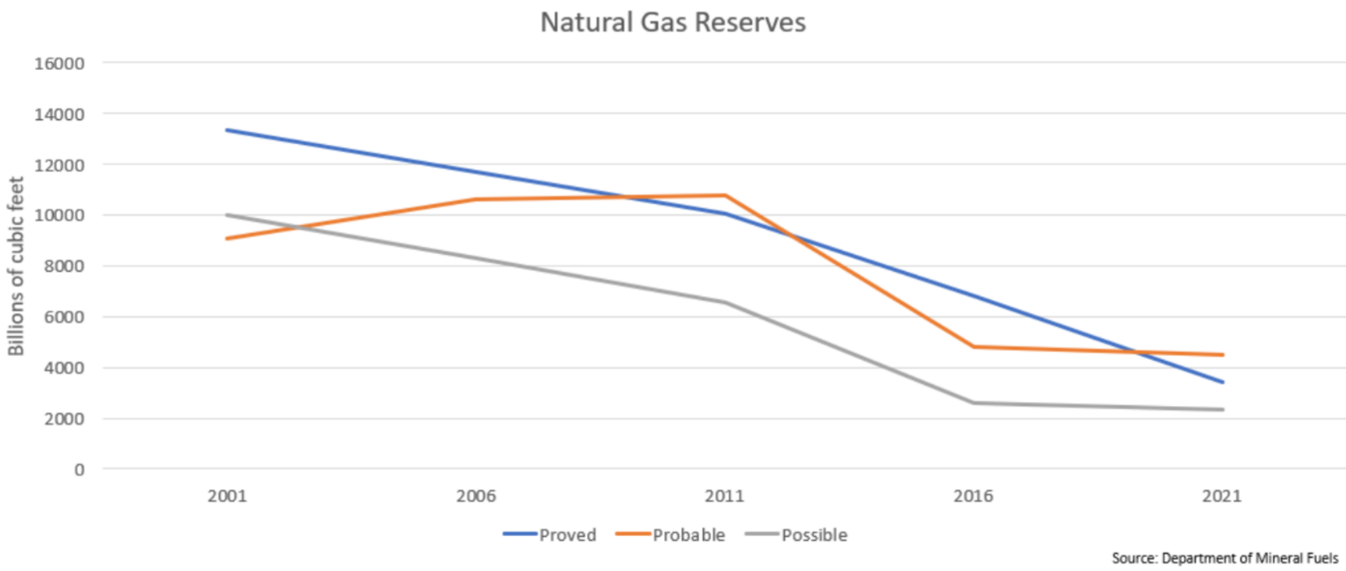


Figure 13: Natural gas reserve

7.1 Natural gas power generation

The power generation from natural gas in a gas turbine consists of three parts: a compressor, a combustion system, and a turbine (Figure 14). The compressor draws the feeding gas to the combustion chamber at high pressure. In the combustion chamber, the gas fuel is mixed with air; the ignition produces a high-temperature and high-pressure gas stream to spin the rotating blade of the turbine. Although the environmental impact of natural gas power plants is relatively low compared to other fossil fuels, the efficiency of the gas turbine system is only around 33 percent[11] due to the energy waste in hot air exhaust. The turbine system also requires a high cost of maintenance.

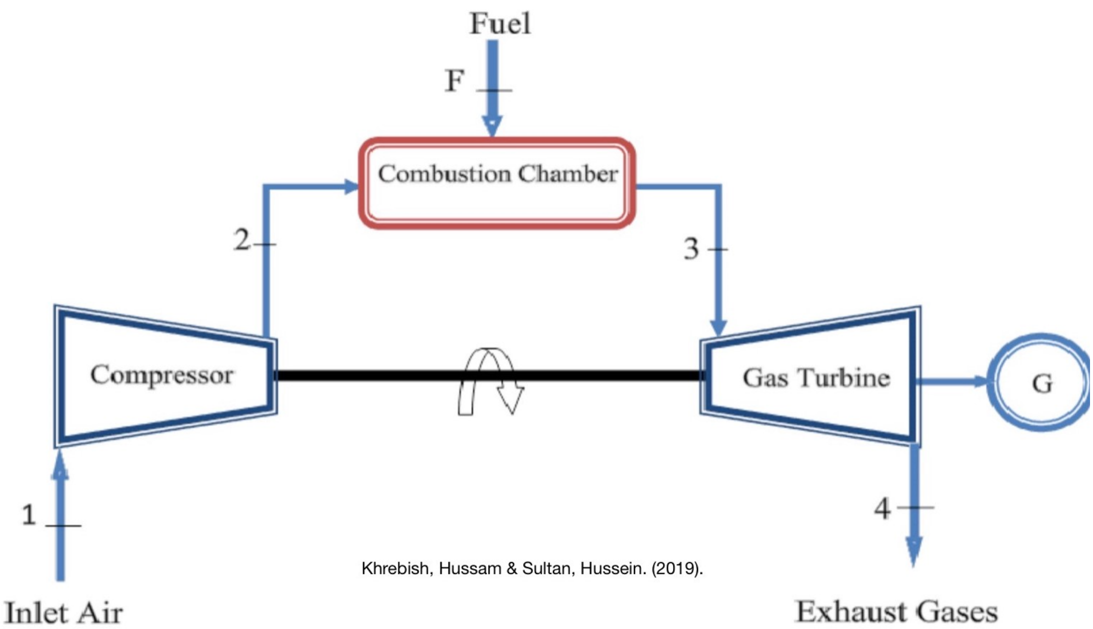


Figure 14: Simple cycle diagram

7.2 Combined-cycle power plant

The combined-cycle power plant is a game changer in natural gas power plant sustainability. In brief, this system will use the wasted heat from the exhaust gas to heat the water in the second-cycle water pipe (Figure 15), making water evaporate and rotating another turbine. Consequently, after the water vapor passes through the previous turbine, all of the vapor will condense and become liquid. Lastly, the condensed water will flow through the pipe and get heated repeatedly. As a result of these closed cycles, the wasted energy will be conserved, raising power generation efficiency.

To conclude, the CCPP system can raise the efficiency of natural gas power plants from around 33 percent to approximately 60 percent[11], making it the greatest developed and most utilized technology in various countries.

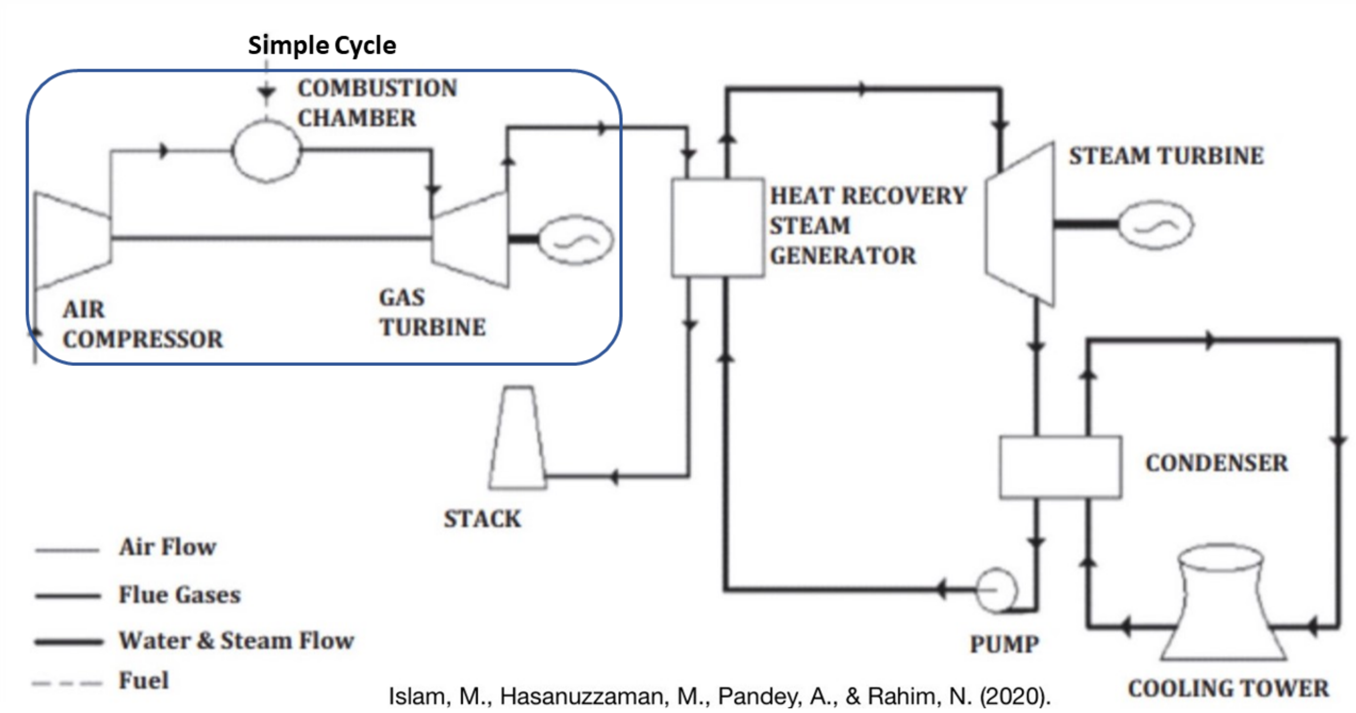


Figure 15: Combined cycle diagram

7.3 Transition Roadmap to CCPP

According to the model, by 2030, carbon-based power plants must reach 4,000 ktoe in electricity generation and approximately 12,000 ktoe by 2050. Although natural gas usage has to be decreased from the present, the energy produced by this fuel is always in need as an “Energy Security” of Thailand. Consequently, we propose a CCPP policy. It consists of 2 main points. The old natural gas power plant, which uses the simple-cycle gas turbine, will fade off due to its previously mentioned disadvantages. Second, the relatively new power plants with high capacity will be equipped with combined cycles.

There are currently seven combined-cycle power plants in Thailand. On the other hand, simple cycles are in all regions of Thailand with up to ten power plants. We will encourage the government to gradually suppress and eventually destroy these power plants with careful financial and environmental considerations, reducing ineffective natural gas usage. The power plants over 20 years will be stopped according to their average lifespan of 22 years[16], allowing the government to recycle their materials with other projects.

Second, converting a simple cycle to a combined cycle is the most sustainable way to unravel the unrenewable energy problems. Thailand has the majority of gas pipelines and gas separators in the Thai Gulf, indicating the proper location to build power plants. We will analyze the capacity of each gas separator and minimize the number of export pipelines in gas separators. Thus, the most suitable place for gas separators is around high-capacity power plants. Due to the low lifetime of power plants, we will propose a plan to convert only the high-capacity ones to a Combined cycle which will help us conserve non-renewable natural resources.

7.4 Final remark on CCPP

In conclusion, our policy is designed to address the predicted model, decreasing natural gas usage while strengthening the power plants by converting it to CCPP simultaneously. Thailand has enough potential to change and adapt; by using the projected main points, we will build sustainable natural gas sectors of Thailand in the future.

8 Conclusion

In this paper, concerning the AIM/Enduse model, three policies, namely, solar, wind, and combined cycle power plants, have been introduced to achieve carbon neutrality. Firstly, we propose a solar village project which aims to change the village's energy sources for facilities and utilities to solar energy. This plan started with installing solar panels with the government's help in targeted villages, then extended to a bigger scale. For wind energy, we suggested that the use of distributed wind systems should be increased to change the energy sources. Moreover, a plan to support private investment is also a purpose that expects more investment in both onshore and offshore wind farms. Lastly, we expected Thailand to change from single-cycle to combined-cycle power plants to increase the efficiency of conventional power plants and serve as a security in Thailand's energy.

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Research seeks to understand the source of Biomass for the generation of biogas in Vietnam

Highlighting the research location/region/country and your social/cultural setting of the thesis's in the challenge

Students: Minh Khoi Nguyen, Bao Nguyen Ngo, Minh Hoang Dang, Tuan Minh Nguyen
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Summary

In this day and age, the urgent issue is to find an alternative source of energy to replace fossil fuels. This report presents a type of energy that is green, efficient and practical, solving today's environmental problems: biomass energy. At present, an agro-agriculture like Vietnam possesses large amounts of agricultural waste every year. However, the traditional disposal methods have neither benefited the environment nor made the best use out of such waste including the sawdust, the bark, the cellars, the coffee grounds, etc. We see the potential at the right time, and our team wants to undertake an environmental project that serves our lives and needs. Now, we're doing a lot of research and testing on coffee grounds to create low-cost activated carbons. So after all of this testing, we obtain results that are creating large amounts of active carbons with very high productivity levels. Activated carbon can then potentially be used as an adsorbent in post-combustion CO_2 capture applications. Two methods of activation are compared: physical activation with CO_2, and chemical activation with KOH. The first method was considered less polluting; However, carbon has a lower structural development and therefore lower CO_2 adsorption capacity than it is gained by activating with KOH. On the other hand, multi-component adjunctive periodic experiments have shown that CO_2/N_2 selectivity of physically activated carbon is higher than that of chemically active charcoal.

Keywords

agricultural waste, coffee grounds, activated carbons, biomass energy

1. INTRODUCTION

1.1. Vietnam

Vietnam is a developing country with a fast-growing economy. For the last two decades, Vietnam's annual economic growth has reached approximately 6%[1] . At the same time, the energy demand has also greatly increased. To supply for the population's energy needs, Vietnam currently has 6 main energy sources that can be divided into 2 categories: fossil fuels and renewables.

Coal, accounting for 44.66% (569.25 TWh in 2022)[2], is the most used source for energy consumption in Vietnam. About 72% of Vietnam's coal is used for power generation[3], the remaining is used in other industries such as metallurgy, construction (cement and concrete), plastic production, pharmaceutical industry and even art[5]. Vietnam's annual coal production reaches 47.8 million tonnes in 2021, but this amount is not enough to supply for consumption, meaning Vietnam has to rely heavily on imports (55 million tonnes in 2021)[3].

Oil-based energy is consumed 286.49 TWh (22.47%) in Vietnam[2]. Crude oil is mainly used to produce fuel such as petrol, diesel…; while the rest are converted into other chemistry-production. "Vietnam is a big oil exporter, but even a bigger oil importer." In 2021, crude oil was exported 3.1 million tons but imported nearly 10 million tons. However, back in 2017, Vietnam was a crude oil exporter with 6.81million tons sold. After that, Vietnam has become an importer since the biggest refinery (Nghi Son) was in construction. Additionally, Vietnamese oil is more expensive than imported sources.[4]

Figure 1: Oil export and import in Vietnam from 2016 to 2021

At the lowest rank of fossil fuels, Vietnamese consume 77.97 TWh of gas (6.12%) in 2022[2]. The discovered reserves are like a sand in the sea of potential reserves. Therefore, the gas industry is being paid attention by the government and it can play an important role in the development of the economy. However, there are some drawbacks such as collections are separated, not completely discovered and some areas have high levels of CO_2. Nevertheless, gas can be a great long term project for Vietnam.[5]

The most populated renewable energy, hydropower, is consumed 250.17 TWh (accounting for 19.63%) in Vietnam. Hydropower in Vietnam all comes from power plants which are located at rivers headwaters (energy comes from tides that are not populated) and then converted into electricity. They expected that hydro-electricity is one of the most important exploitation, as the development is deeper and deeper. Projects with advantageous location and minimal cost are in constructing and exploiting. Some of the plants are being built to increase the quantity of electricity and to fit Vietnamese electronic structure.[6]

Solar power, which consumed 68.75 TWh in 2022 (5.39%), is the second popular source of energy in Vietnam[2]. From the middle part to the south of Vietnam, the sun's radiation is unchanged all through the year because of the equator area. Therefore, the amount of sunlight is huge so that it is one of the most suitable natural conditions to produce energy. Because the needs of energy of people are increasing day by day, rooftop panels are more and more popular among Vietnamese. However, low cost and climate change can be some of the most difficult challenges that Vietnam must face off.[7]

Wind, a source of energy that accounts for 1.65% (20.97 TWh) of Vietnam in 2022[2]. In southern Vietnam, with the advantage of natural terrains, is developing wind farms because of enormous wind resources from the sea. However, COVID-19 had delayed Vietnamese plans about developing wind power so that the future of these is unpredictable. Nevertheless, the Prime Minister is moving forward to develop wind power and other renewable energy. Also, investors can look at potentials in Vietnam so that wind energy can be expanded.[8]

Additionally, Vietnamese electricity was imported 3.32 TWh and exported 2.07TWh in 2021. [9]

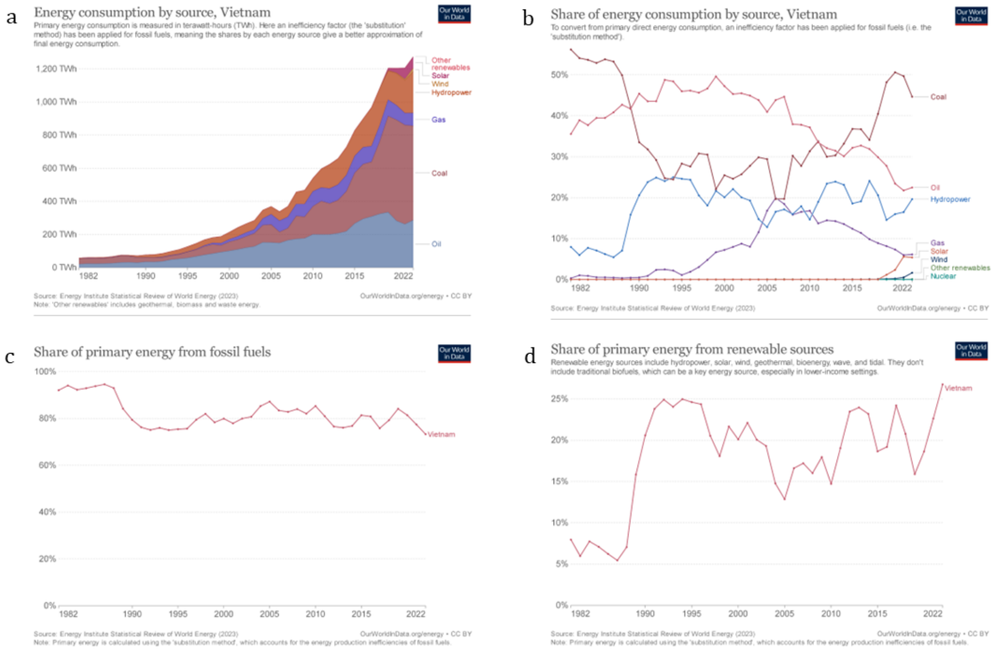
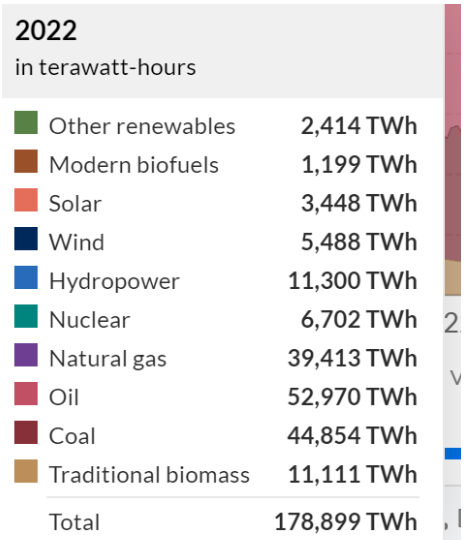


Figure 2: The situation regarding energy usage in Vietnam from 1982 to 2022 according to Our World in Data. a) Energy consumption by source; b) Share energy consumption by source; c) Share of primary energy from fossil fuels; d) Share of primary energy from renewable energy.

1.2. Global



2022 in terawatt-hours	
Other renewables	2,414 TWh
Modern biofuels	1,199 TWh
Solar	3,448 TWh
Wind	5,488 TWh
Hydropower	11,300 TWh
Nuclear	6,702 TWh
Natural gas	39,413 TWh
Oil	52,970 TWh
Coal	44,854 TWh
Traditional biomass	11,111 TWh
Total	178,899 TWh

Figure 3: The diverse number of energy sources consumed worldwide in 2022 (in terawatt-hours)

The diverse number of energy sources consumed worldwide is divided into fossil fuels and renewable energy. Fossil fuels consist of energy from nuclear, gas, oil and coal and the rest including solar, wind, hydro and biomass are renewable sources. So far, oil, coal, nuclear and gas still power the world.

Oil is the primary source of energy for transportation and also one of the biggest industries worldwide. In 2022, the total consumption of oil reached the highest figure overall with 52,970 TWh. In fact, the US and China alone account for over ⅓ of oil consumption. Energy from oil is created via the combustion of petroleum. In terms of oil's formation, crude oil was formed millions of years ago when bio remains are gradually mixed with salt, silt and calcium carbonate under heat and pressure. Nowadays, Per kWh produced, oil energy emits 970 grams of CO_2 on a life-cycle basis. The process of generating oil into energy begins with extracting the oil, erecting power plants to produce steam which turns a turbine and spins a generator for electricity. Besides providing electricity, petroleum products are also used to propel vehicles and heat buildings. However, oil is regarded as dirty energy because of its highest carbon footprint of all energy types, 970 grams of CO_2 for every kWh of electricity, contributing directly to greenhouse effect and climate change.

Coal has long been our planet's largest energy source for domestic electricity as well as overseas transport, being second most used energy in 2022 with 44,854 TWh. China plays the primary part in producing, importing and consuming ⅓ of global coal energy. Similar to oil, coal is combusted in coal-fueled power plants to produce steam that turns turbines and spins generators for electricity. Once the coal is mined, it will be transported to power plants by rail, river barge or truck. In general, coal is the world's most abundant and cheapest fossil fuel source, but also one of the most harmful sources. Every year, 14.5 bt of CO_2 is emitted from burning coal. Besides from global warming and climate change, other environmental drawbacks include air pollution from mercury, lead, sulfur dioxide that are released when burning coal and water pollution from leftover ash that can contaminate lakes and landfills.

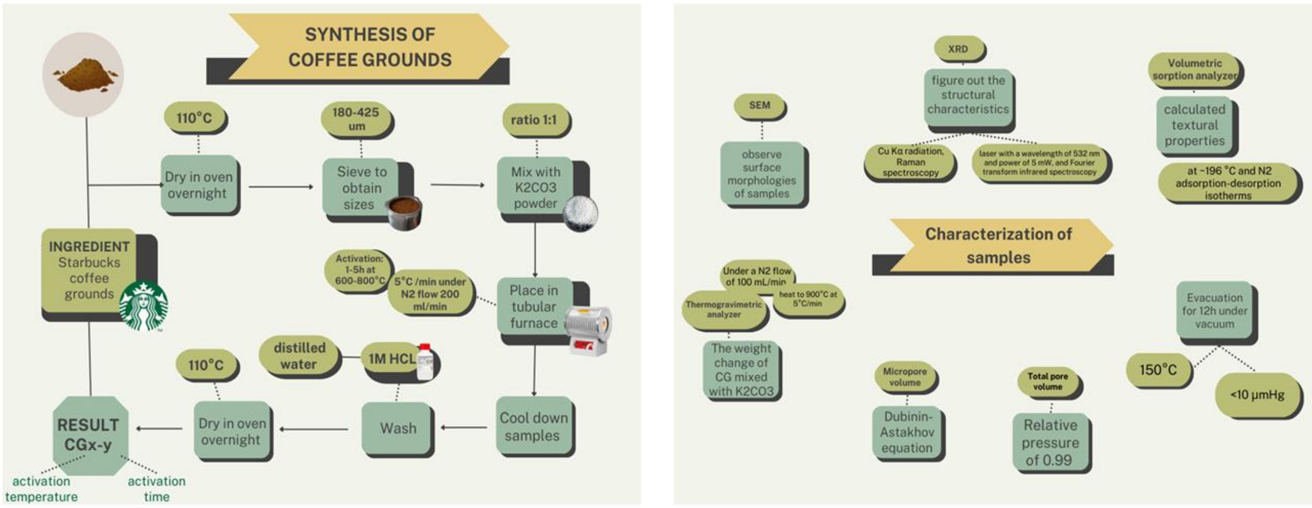
Natural gas (NG) is a flammable gas that occurs in large quantities naturally below the Earth. NG comes in 3rd in terms of most consumed energy. In 2022, 39,413 TWh of NG is consumed worldwide and the US appeared to be the largest consumer. This energy is extracted via different drilling and fracking methods to maximize the amount of NG extracted. After 4 steps of removal and separations, NG is transported to gas-fired power plants and goes through a similar process to the rest of fossil fuels. When it comes to effects on the environment, NG is considered to be the cleanest fossil fuel; however, its consumption still contributes to climate change in numerous ways. Apart from CO_2 release, the main concern with NG is CH4 leakage from well and NG combustion.

Many countries and territories have used solar power capacity into their electrical grids to supplement or provide an alternative to conventional energy sources. The worldwide growth of photovoltaics is extremely dynamic and varies strongly by country. In April 2022, the total global solar power capacity reached 1 TW. In 2022, the leading country for solar power was China, with about 390 GW accounting for nearly two-fifths of the total global installed solar capacity. As of 2022, there are more than 40 countries around the world with a cumulative PV capacity of more than one gigawatt. Solar energy is a renewable energy source, meaning you don't ever use it up. Solar energy is clean. It creates no carbon emissions or other heat-trapping "greenhouse" gasses. It avoids the environmental damage associated with mining or drilling for fossil fuels. Furthermore, solar energy also uses little to no water, unlike power plants that generate electricity using steam turbines. However, solar energy costs are initially high in installing panels or storing sources. The temporary decline in energy production during bad weather has been a major issue. Days with low solar energy, however, are having less of an effect due to advances in battery technology. It leads to stored solar energy by old technology, like lead acid batteries are being replaced by alternatives. Lithium ion batteries offer greater power at a lower cost.

Wind power is the use of wind energy to generate useful work. Today, wind power is generated almost completely with wind turbines, generally grouped into wind farms and connected to the electrical grid. n 2022, wind supplied over 2000 TWh of electricity, which was over 7% of world electricity: 58 and about 2% of world energy. With about 100 GW added during 2021, mostly in China and the United States, global installed wind power capacity exceeded 800 GW. To help meet the Paris Agreement goals to limit climate change, analysts say it should expand much faster - by over 1% of electricity generation per year. Wind power is considered a sustainable, renewable energy source, and has a much smaller impact on the environment compared to burning fossil fuels. Wind power is one of the lowest-cost electricity sources per unit of energy produced. In many locations, new onshore wind farms are cheaper than new coal or gas plants. Regions in the higher northern and southern latitudes have the highest potential for wind power. In most regions, wind power generation is higher in nighttime, and in winter when PV output is low. For this reason, wind power is suitable in many countries. However, Wind plants can impact local wildlife. Although wind projects rank lower than other energy developments in terms of wildlife impacts, research is still needed to minimize wind-wildlife interactions. Advancements in technologies, properly siting wind plants, and ongoing environmental research are working to reduce the impact of wind turbines on wildlife. Furthermore, wind projects may not be cost-competitive in some locations that are not windy enough. Next-generation technology, manufacturing improvements, and a better understanding of wind plant physics can help bring costs down even more.

Biomass, in the context of energy production, is matter from recently living (but now dead) organisms which is used for bioenergy production. Examples include wood, wood residues, energy crops, agricultural residues including straw, and organic waste from industry and households. The main waste feedstocks are wood waste, agricultural waste, municipal solid waste, and manufacturing waste. Upgrading raw biomass to higher grade fuels can be achieved by different methods, broadly classified as thermal, chemical, or biochemical. In 2020 biomass produced 58 EJ (exajoules) of energy, compared to 172 EJ from crude oil, 157 EJ from coal, 138 EJ from natural gas, 29 EJ from nuclear, 16 EJ from hydro and 15 EJ from wind, solar and geothermal combined. Approximately 86% of modern bioenergy is used for heating applications, with 9% used for transport and 5% for electricity. Most of the global bioenergy is produced from forest resources. Big problems are pollution of soil and water from fertilizer/pesticide use, and emission of ambient air pollutants, mainly from open field burning of residues. The traditional use of wood in cook stoves and open fires produces pollutants, which can lead to severe health and environmental consequences. However, a shift to modern bioenergy contributes to improved livelihoods and can reduce land degradation and impacts on ecosystem services. Otherwise, the climate impact of bioenergy varies considerably depending on where biomass feedstocks come from and how they are grown. For example, burning wood for energy releases carbon dioxide; those emissions can be significantly offset if the trees that were harvested are replaced by new trees in a well-managed forest, as the new trees will absorb carbon dioxide from the air as they grow.

2. METHODS AND MATERIALS OF EXTRACTING BIOMASS ENERGY

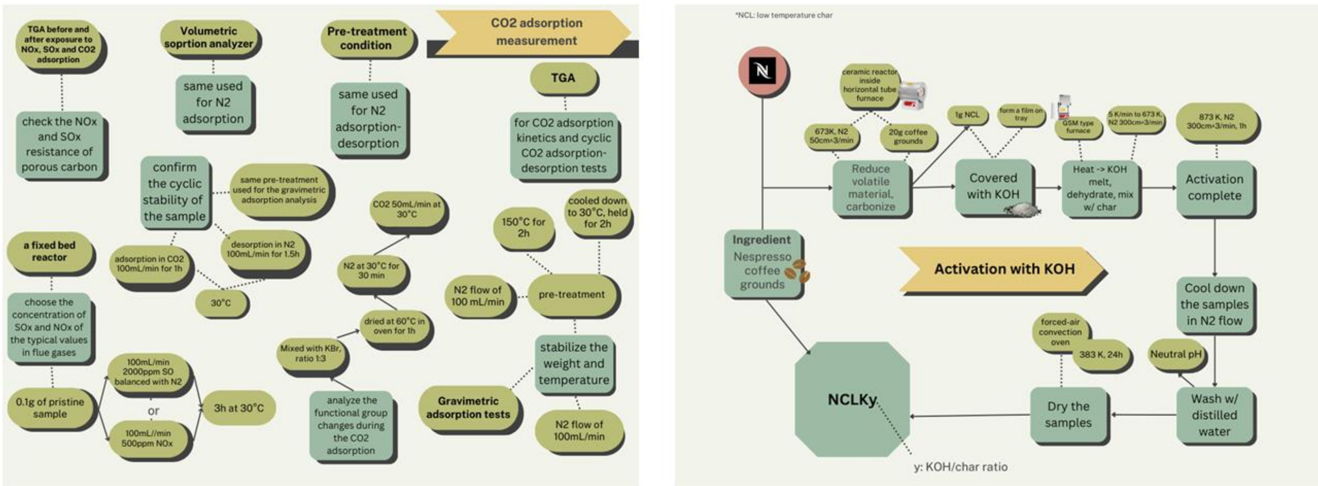


a

b

Figure 4: a) Process of synthesis of coffee grounds; b) Characterization of samples.

In Figure 4, we illustrate the process of synthesizing coffee grounds and the characterization of samples through measurement techniques such as SEM, XRD,....



a

b

Figure 5: a) CO_2 adsorption measurement and b) Activation with KOH.

Figure 5 depicts the process of measuring the CO_2 adsorption capacity of coffee grounds and the activation cycle of samples using KOH to enhance CO_2 adsorption capability.

3. BIOMASS ENERGY GENERATION

3.1. Report 1

3.1.1. Characteristics of CG

Looking at figure 6 - SEM pictures comparing CG and activated CGs, while CG is a bulky morphology with smooth surface and no pores activated. In contrast CGs are all observed with similar cheese-like shape with macropores despite different time and temperatures. These were formed through the release of pyrolysis gases during chemical activation with K_2CO_3.

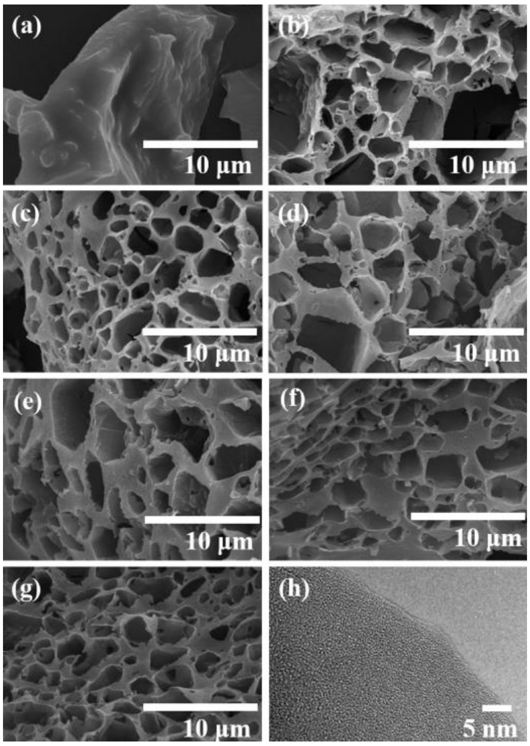


Figure 6: SEM images of (a) CG, (b) CG600-1, (c) CG600-5, (d) CG700-1, (e) CG700-5, (f) CG800-1, and (g) CG800-5. (h) TEM image of CG700-5.

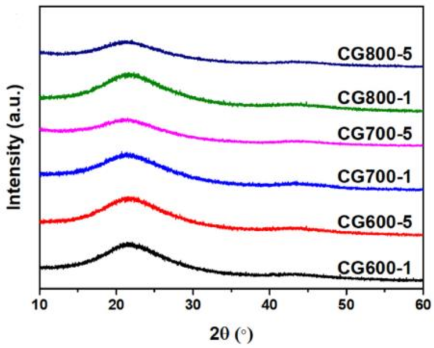


Figure 7: XRD spectra of activated CGs.

In terms of XRD spectra, all activated CGs go through the same amorphous carbon pattern, reaching a slight peak at around 26° - 43°. In addition, there were no K2-included products since they were removed through HCl washing.

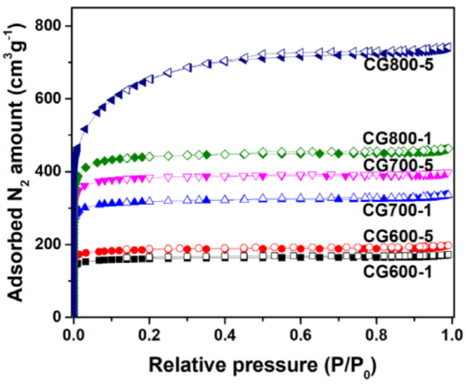


Figure 8: N_2 adsorption (solid symbols) and desorption (open symbols) isotherms at −196°C

N2 absorption at -196°C for activated CGs are illustrated in Figure 8. CG800-5 absorbed the largest amount of N2 while CG600-1 adsorbed the least. Not only that but each and every activated CGs showed respectively noticeable improvement. Specifically, CG800-5 happened to widen the micropore volume above 1.0mm. This means that the more severe conditions, the better N2 is absorbed; moreover, increases in activation temperature were more effective than time.

XRD spectra for the CG and K_2CO_3 mixture was put in comparison with those of CGx-1 samples before washing to measure the K_2CO_3 activation. No difference was discovered.

Chemistry reactions:

(1) Redox reaction between the carbon in spent coffee grounds and K_2CO_3 at above 600°C

$K_2CO_3 + 2C \rightarrow 2K + 3CO$

(2) Slow partial decomposition of K_2CO_3 at above 800°C

$K_2CO_3 \rightarrow K2O + CO_2$

(3) Partial carbon gasification at above 800°C

$C + CO_2 \rightarrow 2CO$

In addition, they measured the weight change of the mixture of coffee grounds and K_2CO_3 under 100 mL min-1 N2 flow from room temperature to 900°C at a heating rate of 5 °C min-1. The sample's weight decreased until 500°C because samples at 500°C showed poor textural properties. From there, the weight gradually went up but stopped and plummeted from 800°C. This means that the K_2CO_3 activation dominantly occurred at 800°C, resulting in the largest surface area and pore volume among the prepared samples.

- CO_2 adsorption performance of spent coffee ground-based porous carbons

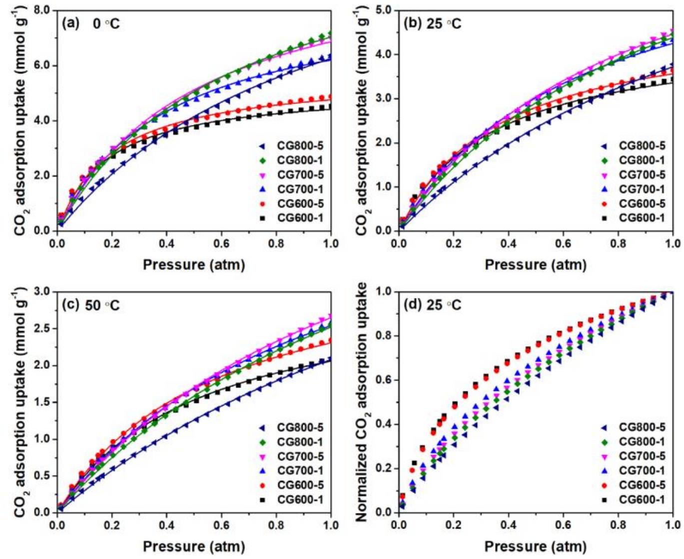


Figure 9: CO_2 adsorption isotherms at (a) 0, (b) 25, and (c) 50°C of activated CGs (symbols: experimental data, lines: Langmuir adsorption model fitting). (d) Normalized CO_2 adsorption isotherms at 25 °C.

For porous carbon made from used coffee grounds, the CO_2 adsorption isotherms were measured at 0, 25 and 50 °C and the results are presented in Figure 9a–c. All samples showed higher CO_2 absorption when adsorption was carried out at lower temperature, indicating exothermic CO_2 adsorption. The CO absorptions at 0.15 and 1 atm and three different temperatures are summarized in Table 1. These results imply that the porous carbons exhibiting the highest CO_2 absorption may vary depending on the temperature. adsorption pressure and temperature.

Table 1: CO_2 adsorption uptake of activated CGs at 0.15 and 1 atm and three different temperatures.

Sample	CO_2 adsorption uptake (mmol g^{-1})					
	0 °C		25 °C		50 °C	
	0.15 atm	1 atm	0.15 atm	1 atm	0.15 atm	1 atm
CG600-1	2.40	4.54	1.43	3.45	0.73	2.09
CG600-5	2.48	4.88	1.46	3.65	0.78	2.34
CG700-1	2.48	6.36	1.36	4.33	0.70	2.58
CG700-5	2.47	7.02	1.30	4.54	0.67	2.68
CG800-1	2.32	7.18	1.20	4.46	0.61	2.55
CG800-5	1.74	6.38	0.92	3.78	0.47	2.10

After exposure to SO2, the CO_2 absorption was slightly reduced by 6% compared to the original sample. The developed used coffee grounds-based porous carbon shows excellent NOx resistance and high SOx resistance, compared with other adsorbents such as silica and amine-functionalized zeolites.

3.2. Report 2

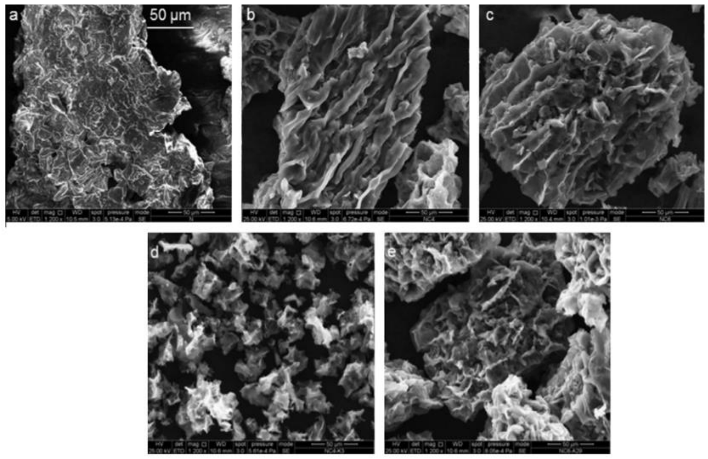


Figure 10: SEM images of: (a) dried spent coffee grounds (N), (b) char carbonised at 673 K (NCL), (c) char carbonised at 873 K (NCH), (d) carbon activated with KOH (NCLK3), and (e) carbon activated with CO_2 (NCHA29).

In the SEM images, it can be seen that physical activation preserves the morphology of the starting char whereas chemical activation causes substantial particle shrinkage. This effect has also been observed in the SEM images from other KOH biomass-based activated carbons. The SEM images of the samples are shown in Fig.10. The release of volatiles leads to a gradually less dense morphology, accompanied by a reduction in particle size.

Table 2: Carbon yield, point of zero charge and helium density of the samples.

Sample	Yield (g/ 100 g N)	Helium density (g cm^{-3})	pH_{PZC}
N	100	1.37	5.2
NCL	29	1.31	8.6
NCH	23	1.44	9.6
NCLK1	7	1.76	7.6
NCLK2	12	1.57	7.4
NCLK3	13	1.55	7.9
NCLK4	15	1.79	7.9
NCLK3b	9	2.10	8.4
NCHA29	16	1.89	9.9
NCHA36	15	1.72	10.1
NCHA41	14	1.83	10.0

Table 2 provides a summary of the materials' carbon production, helium density, and pHPZC. With the burn off achieved, that is, with the duration of the treatment, the carbon output of physical activation decreases. The yield of physical activation is comparable to or slightly higher than that of chemical activation for the burn off degrees taken into account, up to 41%. Due to the preferential removal of the disorganized carbon that obstructs the entrance of the chars' internal porosity, as well as the breaking of bonds and the removal of cross-links and carbon atoms that facilitate the atomic rearrangement and, consequently, the material's densification, activation increases the density of the carbons.

When comparing samples NCLK3 and NCLK3b, it can be shown that densification is encouraged by rising temperature. Chemical activation produces denser carbons (NCLK3b) for a given temperature of 973 K than physical activation (NCHA series). The higher particle shrinking brought on by chemical activation may be the cause of this. Table 2 further shows that samples activated with CO_2 slightly increase the basicity of the carbon surface, resulting in basic carbons, but samples activated with KOH are just marginally basic, with pHPZC that is close to neutral. The difference in pH between sample NCHA29 and char NCH can be explained to the activation temperature being 100 K higher than the carbonisation temperature. The creation of basic oxygen surface complexes during the activation phase is likely what causes the pH to rise with burn off . The production of acidic oxygen groups (R-COOH and R-OH) during KOH activation may be the cause of the lower pH found for the NCLK series compared to the NCH and NCL series .

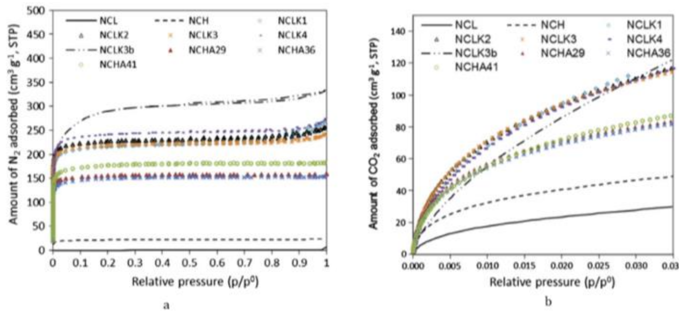


Figure 11: Adsorption isotherms of N_2 at a) 77 K and b) 273 K for the studied samples.

N_2 and CO_2 adsorption isotherms at 77 and 273 K are depicted in Figures 11a and 11b, respectively. All carbons are virtually microporous, as evidenced by the form of the N2 adsorption isotherms and the nearly complete absence of hysteresis loops. As the micropore volume is inextricably linked to the capacity for CO_2 adsorption at atmospheric pressure , this is particularly desired. From figure three, due to temperature-related diffusion limitations, NCl coal has essentially no N_2 adsorption; however, increasing the temperature to 273 K at a pressure ratio of 0.035, its growing microporous porosity makes CO_2 accessible. At 77 K, the porosity of char NCH, which was produced at a higher temperature, is already accessible to the N_2 molecule. The quantity of N_2 and CO_2 adsorbed reveals that the samples activated with CO_2 (NCHA series) exhibit an intermediate textural development between the NCH char and the samples activated with KOH (NCLK series). Carbon is gasified by CO_2 , which first removes the most reactive carbon deposits left over from carbonisation before causing the original char, NCH, to become more porous. The intercalation of potassium compounds in the carbon matrix, which results in the separation and distortion of the lamellae is thought to be the origin of the porosity that results after KOH activation . These substances are eliminated during the washing process, which results in permanent porosity. Through gasification using evolved gases and potassium reduction, carbon may also be burned in this process.

Table 3: Textural parameters of the samples obtained from the N_2 and CO_2 adsorption isotherms.

Sample	N_2 adsorption at 77 K				CO_2 adsorption at 273 K	
	S_{BET} ($m^2 g^{-1}$)	V_{DR} ($cm^3 g^{-1}$)	L_{DR} (nm)	V_p ($cm^3 g^{-1}$)	W_0 ($cm^3 g^{-1}$)	L_0 (nm)
NCL	–	–	–	0.01	0.09	0.6
NCH	84	0.03	2.1	0.04	0.14	0.5
NCLK1	831	0.34	1.1	0.41	0.41	0.6
NCLK2	876	0.36	1.0	0.40	0.36	0.6
NCLK3	840	0.34	1.0	0.37	0.36	0.6
NCLK4	925	0.38	1.1	0.42	0.33	0.6
NCLK3b	1082	0.44	3.0	0.51	0.22	0.6
NCHA29	593	0.24	0.8	0.24	0.25	0.5
NCHA36	568	0.24	1.0	0.24	0.25	0.5
NCHA41	590	0.24	1.3	0.28	0.27	0.6

S_{BET}: surface area calculated by the BET equation; V_{DR}: micropore volume determined by the DR equation from the N_2 adsorption isotherm at 77 K; L_{DR}: average micropore width calculated through the Stoeckli–Ballerini equation; V_p: total pore volume calculated from the amount of N_2 adsorbed at 77 K at a relative pressure of 0.99; W_0: narrow micropore volume determined by the DR equation applied to the CO_2 adsorption isotherm at 273 K; L_0: width of narrow micropores calculated through the Stoeckli–Ballerini equation.

The textural characteristics derived from the examination of the adsorption isotherms previously provided are summarized in Table 3. It can be shown that, with the exception of sample NCLK3b, the micropore volume (VDR) and total pore volume (Vp) are often extremely well matched. In addition, the majority of the produced porosity occurs inside the narrow microporosity domain. With the exception of samples NCH and NCLK3b, the typical micropore widths determined from the N2 adsorption isotherm (LDR) are close to 1 nm. As anticipated, the pore size increases with the level of physical activity (NCHA series) burn off. By altering the KOH/Char ratio at 873 K, no appreciable variations in pore volume or pore size were found. However, a rise in temperature during KOH activation from 873 to 973 K causes wider porosity, which results in higher BET surface area and total pore volume (see the sample NCLK3b's broader knee of the N2 adsorption isotherm in Fig. 11a and the linear shape of its CO_2 adsorption isotherm in Fig. 11b). This impact has already been discussed. Although activated carbons derived from coffee grounds treated with KOH at 1073 K have been reported to have greater BET surface areas, our study focuses on the creation of the narrow microporosity to maximize CO_2 adsorption. The chemically activated samples that were previously shown in this study (831–1082 m2g-1) had BET surface areas that compare favorably to those of activated carbons made from coffee grinds using H_3PO_4 and $ZnCl_2$ and H3PO4 combinations . Table 3 also includes the narrow micropore volume (W0) and narrow micropore width (L0) calculated using the DR approach from the CO_2 adsorption isotherms at 273 K. With the exception of NCLK3b, which exhibits a reduced volume of narrow micropores due to the collapse of pore walls at the higher temperature, which results in broader pores, both values are greater for the chemically activated samples.

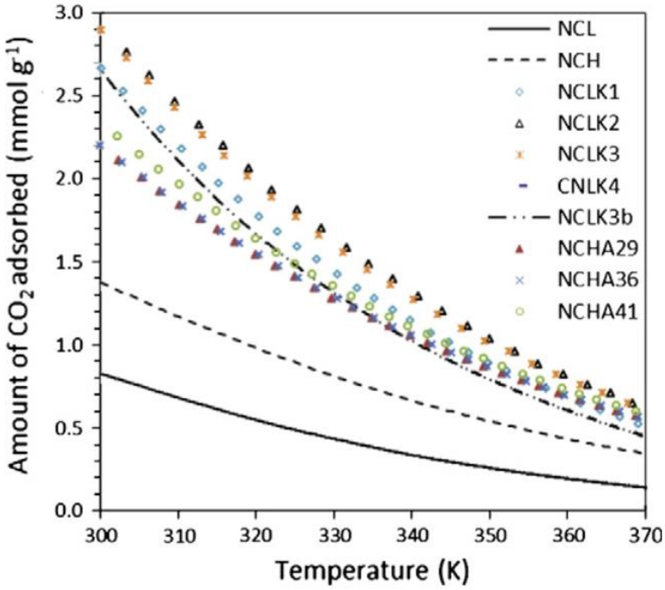


Figure 12: Amount of CO_2 that remains adsorbed over the studied samples in pure CO_2 flow under a heating rate of 0.5 K min^{-1}.

The results of the non-isothermal capture tests performed in the thermogravimetric analyzer are shown in Fig. 12. Due to the exothermic nature of the physisorption process, the amount of CO_2 that is still adsorbed on the various samples decreases from 2 to 3 mmolg-1 to a value close to 0.6 mmolg-1 as the temperature is gradually raised from 298 to 373 K in CO_2 flow. Be aware that series NCHA appears to be less sensitive to slow heating than series NCLK in terms of the amount of CO_2 adsorbed. This suggests that the samples activated with CO_2 had greater adsorbent-adsorbate interactions. This can be ascribed to their higher surface basicity and narrower porosity. At 323 K and atmospheric pressure, cyclic adsorption/desorption studies were performed on sample NCLK3. These circumstances might be regarded as typical of a postcombustion capture method.

The associated findings are summarized in Fig. 13: Keep in mind that the first adsorption phase (cycle 0) differs from the subsequent cycles since it starts from a different starting state following the conditioning stage at 373 K. After cycle 3, a cyclic stable state is gradually attained. The mass absorption is much lower (0.9 wt.%, or 0.3 mmolg-1 N_2) when the sample is subjected to pure N_2 flow. The ratio of the pure component adsorption capabilities at atmospheric pressure is typically used as an approximate indicator of selectivity. The resultant NCLK3 CO_2 /N_2 value is 5 (on a molecular basis). However, the principal diluent N_2 makes up the majority of the flue gas, with CO_2 typically comprising between 3% and 15% of the total volume. Therefore, two separate cyclic experiments were conducted: the first with a feed gas consisting of 10% CO_2 in helium, and the second with 10% CO_2 in nitrogen, in order to evaluate the adsorption behavior in a flow with lower partial pressure of CO_2 that is more indicative of the post combustion circumstances. Due to the decrease in partial pressure in both situations, it is obvious that the mass absorption experienced by the sample is significantly less than that experienced in a pure CO_2 flow. Helium, which is regarded as an inert diluting gas, results in a somewhat lower mass absorption (1.9 wt%) than nitrogen dilution (2.4 wt%). This demonstrates that N_2 and CO_2 are coadsorbed. The quantity of N_2 coadsorbed may be calculated using difference, assuming that the amount of CO_2 adsorbed is independent of the kind of diluting gas (just a function of the partial pressure of CO_2). The separation factor, which is the ratio of the molar fractions in the adsorbed phase to that of the gas phase , provides a more accurate estimate of selectivity. At cyclic steady state (cycles 3-5), sample NCLK3 has a CO_2/N_2 selectivity of 13.

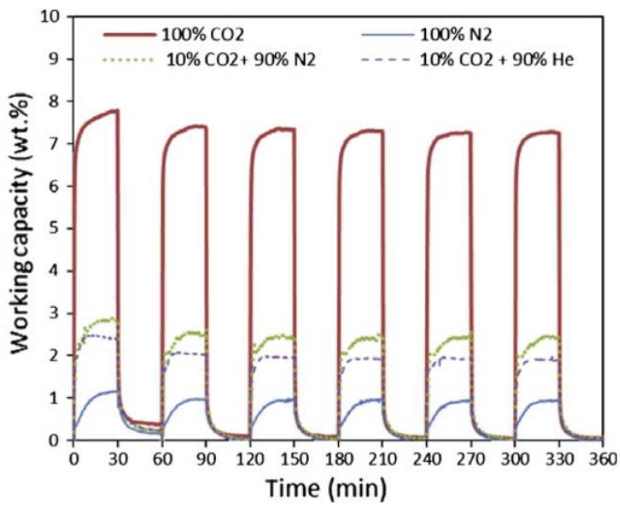


Figure 13: Adsorption/desorption cycles carried out at 323 K on NCLK3, using helium as purge gas during conditioning and desorption steps, and 100% CO_2 (red thick line), 100% N_2 (blue fine line), 10% CO_2 diluted in N_2 (green dots) or 10% CO_2 diluted in He (violet dashed line) as the feed gas during the adsorption step. (For interpretation of the references to colours in this figure legend, the reader is referred to the web version of this article.)

Table 4: CO_2 adsorption capacity of the samples at 298 K and 101 kPa.

Sample	CO_2 adsorption capacity (mmol g^{-1})	
	273 K	298 K
NCL	1.2	0.8
NCH	2.0	1.4
NCLK1	4.9	2.8
NCLK2	4.4	3.0
NCLK3	4.7	3.0
NCLK4	4.5	2.9
NCLK3b	3.2	2.7
NCHA29	3.5	2.2
NCHA36	3.4	2.3
NCHA41	3.6	2.4
R2030CO2	3.7	2.1

The materials' CO_2 adsorption capacities at 273 and 298 K in pure CO_2 at atmospheric pressure are summarized in Table 4. For reference, R2030CO2 from Norit, a commercial peat-based steam-activated carbon used for CO_2 adsorption, has also been added. The carbons made from Nespresso coffee grounds had higher CO_2 adsorption capabilities than the reference carbon, up to 4.8 mmolg-1 at 273 K and 3.0 mmolg-1 at 298 K. The samples that have been activated with KOH have the highest CO_2 adsorption capabilities, followed by samples that have been activated with CO_2 in the reference carbon order (slightly higher at 298 K). The chars' poor textural development results in poorer adsorption capabilities. It should be noted that whereas NCLK3b has the highest adsorption capacity at 273 K, this does not hold true at 298 K. Only the narrower holes are effective for the adsorption of CO_2 as temperature rises (and the kinetic energy of the gas molecules rises along with it).

4. CONCLUSION

The best energy sources to employ instead of fossil fuels are those that don't produce as much trash into the environment. The quantity of residential garbage that is discharged into the environment is constantly accessible, and it is ecologically favorable. Since coffee is consumed widely across the world, our team has effectively utilized the quantity of coffee grounds released into the environment to produce a significant amount of activated carbon with a high secondary CO_2 absorption capability. In this study, used Nespresso coffee grounds were physically and chemically activated to create low-cost microporous carbons. The produced carbons had CO_2 adsorption capabilities that were higher than a commercial activated carbon used as a benchmark, reaching up to 4.8 mmol g1 at 273 K and 3.0 mmol g1 at 298 K. Besides,we used K_2CO_3 in solid form as an activator. With increasing activation temperature and duration, CGs underwent changes in their textural characteristics and elemental makeup. Specific surface area and total pore volume increase with increasing activation temperature or time, and the degree of textural characteristic change was greater in activation temperature controlled samples than activation time controlled samples.

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APPLICATION OF SOLAR ENERGY IN WATER DISTILLATION SYSTEM

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Abstract:

An important factor in Vietnam's socio-economic development is the energy sector. The energy fuel resources in Vietnam are diversified, including coal, natural gas, petroleum, and renewable sources including hydropower, solar and wind energy. Recently, the nation has had success developing renewable energy sources, particularly solar power. On the one hand, Solar energy could reduce the carbon footprints in a short period of time. The energy transition goal is to limit global warming caused by greenhouse gasses, majorly emitted by fossil fuels. On the other hand, it is weather dependent and has a high cost of installation which can be unaffordable for the government to construct it at a large scale. Additionally, The solar energy panels would require huge areas leading to low capacity installations serving a small number of people. So we had an idea of creating a small and portable solar distillation with the water capacity of 1 L/day; Moreover, this system can also be used with solar energy, or a man-made light source with 4 incandescent light bulbs. In the future, the use of this system can be useful in the energy transition away from carbon-based energy and could filter all salty water into fresh water as it is affordable and convenient.

Keyword: Solar energy, mini solar distillation, energy transition, fresh water.

1. Introduction

The water shortage crisis is escalating all over the globe. On our planet, fresh water only makes up 3% of the total water supply, and only 0.5% is available for consumption. With the drastic progression of pollution and global warming, this microscopic number is bound to decline even more. To combat this adversity, we must utilize the other 97% of the water supply to manifest consumableuater[10]. That is why pioneering water distillation systems are so critical to human sustainability.

Current distillation systems are commonly unreliable in efficiency and usually not easy to be mass-produced. They are often too expensive and take too long to distill insignificant amounts of fresh water. With such methods like the simple traditional distillation, being the simplest method but also the most expensive to distill water in terms of energy consumption. In contrast with the simply traditional way, single stage distillation is an alternative method which is abundant, cheaper and energy sufficient but the quality of water that is distilled may contain significant impurities.

So we decided to use solar energy, which we believe is the most viable method currently. Solar energy is the most exploited in the renewable energy sector recently and the last decade has seen a lot of development in the field of tools and devices used in the generation of energy such as photovoltaic cells, the thermoelectric generators and solar concentrators.

2. Method

To guarantee a quality review of the literature on this technology, multiple different measures were utilized. Initially, we conducted extensive research on associated topics by analyzing research papers and books. We accomplished this by searching up crucial keywords on scholarly search engines and academic archives such as Google Scholar. Afterwards, we examined additional educational books and journals . The literature that we inspected is dated between the period of time from 2002 and 2023.

3. Literature review

3.1 Water shortage in Vietnam

Indeed, water plays a vital role in our daily life. Around 97 percent of the water on earth is found in the oceans, making it insufficient for most industrial applications, drinking, or even basic agriculture. Only 3% of the water on Earth is fresh, and more than 2% of that is locked up in polar ice caps, glaciers, or deep underground aquifers, making it inaccessible to meet human's requirements[14]. Moreover, there is just only .36% of the world's water in rivers, lakes, and swamps that is adequately accessible to be considered a freshwater resource. Transferring the scope to Vietnam which has 2360 rivers accounting for more than 10 km, thus it would seem that the country should have an abundant quantity of water[10]. However, due to a lack of physical infrastructure and financial capability, there is limited use of the supply, as well as an unequal distribution of ram for over decades, it is still reported that in many rural parts of the country have not seen infall, resulting in water shortages throughout the country. Despite tackling this probleany significant ameliorations in which only 39% of them are accessible to freshwater. Water resources are extremely important, particularly natural water sources in Vietnam's rural areas, since they serve as the foundation for economic, social, and cultural activities[10,14]. By putting these policies and initiatives into action, the Vietnamese government is addressing the country's problems with managing its water resources. Increasing access to clean water and sanitation for both urban and rural residents, enhancing public engagement and understanding, and bolstering river basin management are some of the issues that still need to be overcome.

3.2. Model description

3.2.1 How solar distillation works

Many countries are facing water shortages or their water sources are contaminated especially in tropical countries with islands. 2 Vietnamese islands Hoang Sa and Truong Sa are a typical example of water shortages. For several years, islands' citizens have suffered from soil salinity and they don't have enough freshwater for daily use. Apart from using common sources of energy, finding a different way to use the renewable resources would be an afflatus. Solar water distillation is the process using solar energy from sunlight to seperate salts and other contaminants from untreated water in order to create freshwater. The untreated water will absorb heat from sunlight then cautiously reach high temperatures. The water will be evaporated by the heat and left behind the contaminants and salts.

A solar still works on 2 scientific principles: evaporation and condensation. The salts and minerals do not evaporate with the water. For example, table salt does not turn into vapor until it gets to a temperature over 1400ºC. However, it still does take a certain amount of energy for water to turn into water vapor. While a certain amount of energy is needed to raise the temperature of a kilogram of water from 0ºC to 100ºC, it takes five and one-half times that much to change it from water at 100ºC to water vapor at 100ºC**.** Stills are mostly made by black bottomed vessels filled with water and the top was filled with clear glass or plastic. The black material speeds the evaporation rate of sunlight absorbtion. Normally, stills need to be six-squared in size to be able to provide enough clean water for 1 person to use in 1 day.

3.2.2. Advantages and Disadvantages of water distillation system

The solar water distillation system harnesses the power of sunlight to purify water, making it an environmentally friendly and sustainable solution. It does not require any external energy sources or fuel consumption, reducing both operational costs and carbon emissions. Additionally, solar water distillation systems are highly versatile and can be implemented in various locations with abundant sunlight. They are particularly beneficial in remote areas or regions with limited access to clean drinking water infrastructure. Moreover, these systems are relatively simple to operate and maintain, making them suitable for communities with limited technical expertise or resources. Overall, solar water distillation offers a reliable and cost-effective method for producing safe drinking water while minimizing environmental impact. On the other hand, this system also has some disadvantages, the efficiency heavily relies on sunlight availability and intensity. Cloudy or rainy days can significantly diminish their effectiveness, limiting their reliability as a consistent water purification solution. Moreover, solar water distillation systems typically have a lower production capacity compared to other water purification methods. The slow process of evaporation and condensation may not be suitable for scenarios where large quantities of purified water are required. Additionally, these systems often require ample space for installation, making them less practical for urban areas or locations with limited land availability. Lastly, the initial setup costs of solar water distillation systems can be relatively high, including expenses associated with solar panels and construction materials, which might hinder their widespread adoption, especially in resource-constrained regions.

4. Experiments and Results

4.1. Experiments

The high energy cost of the evaporation process accounts for the majority of the operational costs for the various distillation processes. Solar distillation appears to be highly appealing because it makes use of heat, an endless, free source of energy, the sun. Over a century ago, solar water distillation was first developed. A solar power plant with a capacity of around 4000 m2 was constructed in Chile in 1872 by a Swedish engineer, Carlos Wilson and effectively operated for many years.

In this method, the saline water is filled in a container which has a black plate in the lower part of the solar distiller. Being exposed to the heat from the sun, the saline water evaporates. Once being turned into gas, it reaches a surface made of plastic or glass where it condensed into purely distilled water droplets. Afterwards, when they are heavy enough, the formed water droplets slide down the surface into special channels located under the surface. Ultimately, the fresh water runs inside the channel to reach the tank for storage.

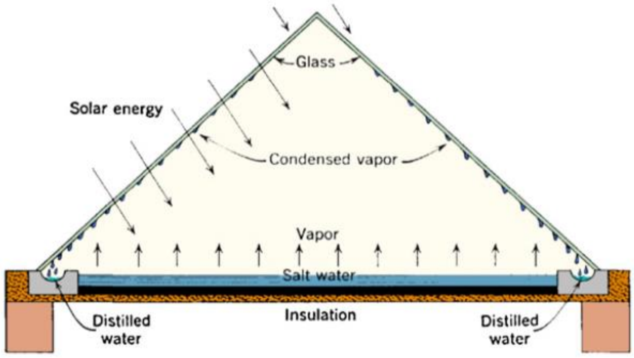

Fig. 1. Schematic diagram of the symmetrical greenhouse type solar still.

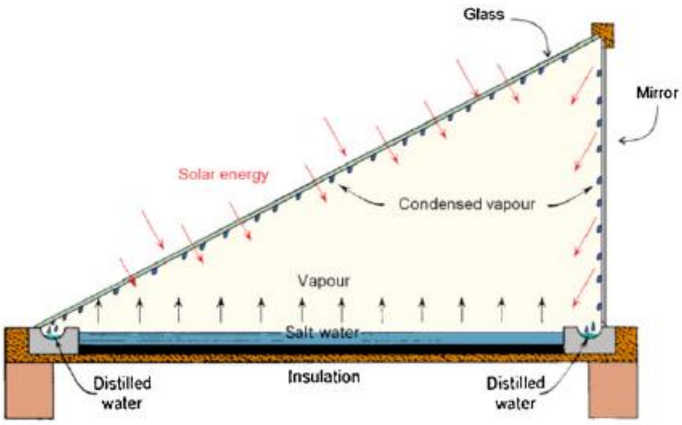

Fig. 2. Schematic diagram of the asymmetrical greenhouse type solar still.

There are two types of solar distillation systems that have been brought into further comparison in an experiment by two scientists Al-Hayeka and Badran namely: Symmetric greenhouse type (SGHT) (fig. 1.) **[12]** and Asymmetric greenhouse type (ASGHT) (fig. 2.) **[13]**. In this experiment, both systems have 1 m2 basin areas for comparison purposes, are made of 1.5 mm galvanized stainless-steel sheets, and covered with 4 mm transparent glass. To maximize solar radiation absorption, the inside surfaces of the stills' bases were blackened. To reduce heat loss into the surroundings, the bottom and sides of the two solar stills were insulated from the exterior with 100 mm rock wool and housed in a wooden box. With the aid of a siliconized acrylic sealer and a rubber gasket, the whole assemblies of both stills are rendered airtight. However, there is a noticeable difference is that the Asymmetric greenhouse type consists of an additional mirror while the Symmetric greenhouse type does not[11]. Will this element affect the efficiency of distilling fresh water of Asymmetric greenhouse type? The thermometers are placed in various positions to measure the temperature of inside and outside of the glass cover, solar basin water, ambient air, and water vapor. The principles of both systems are similar to the above-mentioned method by Carlos Wilson in 1872.

4.1. Results

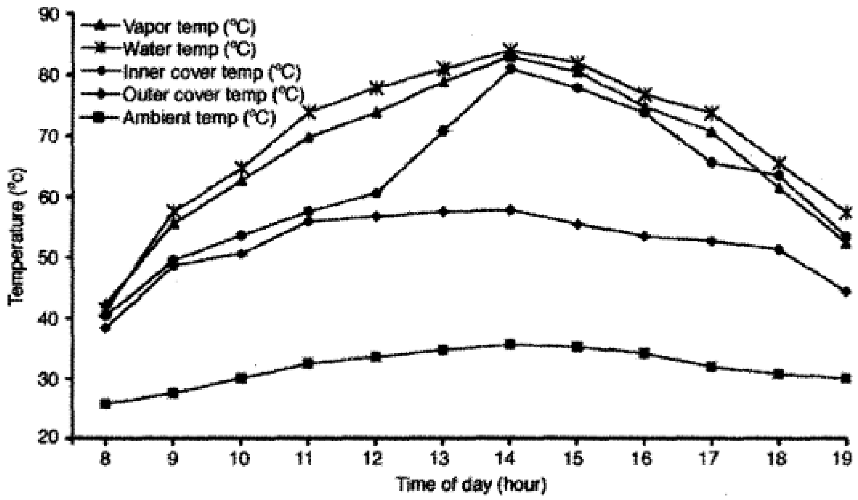

Fig. 3. Hourly variation of temperatures for the asymmetric greenhouse type solar still.

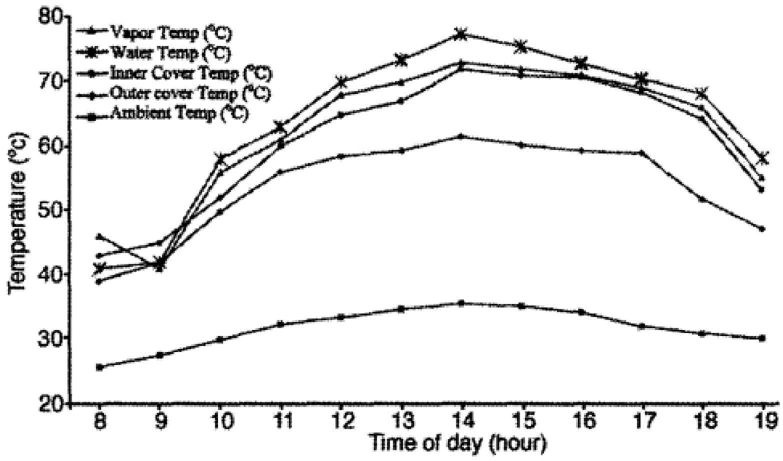

Fig. 4. Hourly variation of temperatures for the symmetric greenhouse type solar still.

Fig. 3. and fig. 4. illustrate variations of temperature of the vapor, basin water, inner and outer of the glass cover, and of the ambient over a period of time.. The two graphs display a similar trend where the temperature escalates gradually during the day, peaking at 14:00 PM when solar radiation is most intense, then declines as it reaches night. However, the ASGHT still operates at a greater temperature than the SGHT still, resulting from the mirrors lessening heat loss.[11]

Fig. 5a shows the dependence of the production rate on the ambient temperatures, solar radiation and hourly supply produced on the 6th of August for both the ASGHT and SGHT solar stills. From what we see from the line graph, the productivity at peak during the daytime as solar radiation intensity increases until it reaches the maximum value at 2 in the afternoon, after that the temperature slowly decreases;thus, gradually reduces the production rates.[11]

The differences of the productivity of freshwater between the two types of stills for a six-day period, and its clear that the production of the asymmetrical greenhouse type still is higher than that of the symmetrical greenhouse type still. And the overall trend of the production for both stills does not change with the daily collection

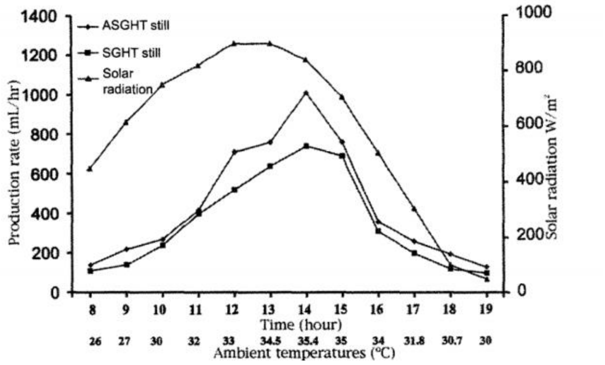

Fig. 5a. Fresh water accumulated and the solar radiation intensity during daytime on August 6.

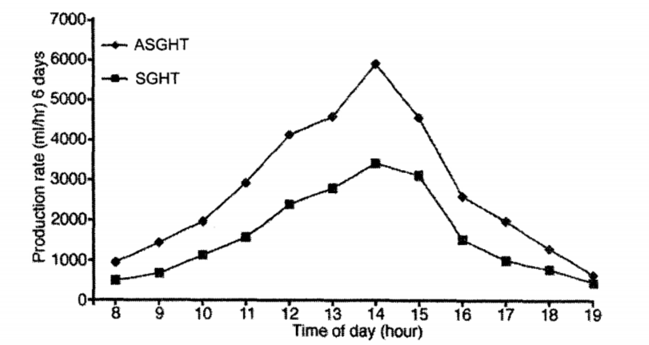

Fig. 5b. Fresh water accumulated for 6 days during the month of August.

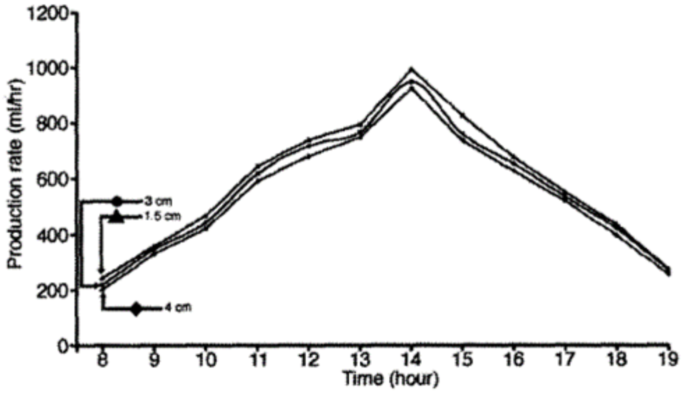

Fig. 6. The effect of water depth of the productivity of fresh water for the asymmetrical greenhouse type solar still.

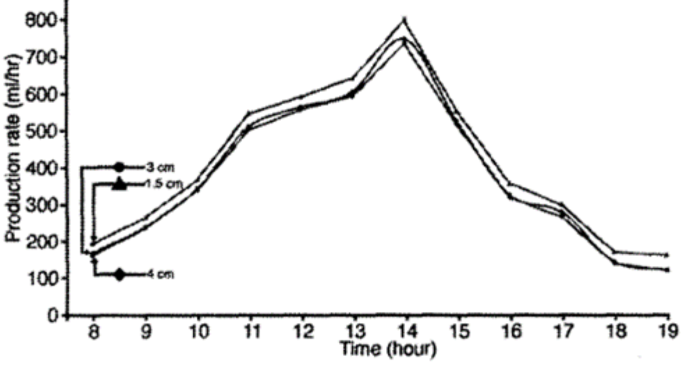

Fig. 7. The effect of water depth of the productivity of fresh water for the symmetrical greenhouse type solar still.

Fig 6. and Fig 7. Both show the production rate in a 19 hour time period in order to illustrate the effect of water depth on the productivity of freshwater for the symmetrical greenhouse type solar still.

Overall, it can be clearly seen that there is an uprising trend in the first 14 hours and then the production rates start to fall dramatically to the beginning level at 100ml/hr . In fig 6, the production rate peaks at nearly 1000 ml/hr at the 14th hour with 3 cm water depth level. On the same hand, the peak of production rate in fig 7. 800 ml/hr with 1.5cm of water depth.[11]

In both figures, in order to produce fresh water with the highest production rates, the water level should be at the lowest of 1,5 cm. Meanwhile, in both figures when the water level is 4 cm which is the highest, the production rate of fresh water seems to be the lowest when they nearly reached 800 ml/hr in fig 6 and just a little bit over 700ml/hr. With 3cm deep of water, the production rate will be at the average level between 1,5 cm and 4 cm, in fig 6 the production rate of fresh water is nearly 900 ml/hr while in fig 7 is only 700 ml/hr. --After peaking at the top production rate in 14 hours, the rate falls crucially to the beginning level of 100 ml/hr in the last 5 hours.[11]

5. Global implications

By developing its energy transition, Vietnam can foster nearby energy-deficit developing countries such as Laos, Cambodia, Myanmar, etc. Vietnam having a pioneering energy transition system will allow it to consume less natural resources, enabling the nation to share natural assets with other countries in need. This cooperation will ensure maximum efficiency of energy consumption, bringing economic benefits to all the nations.

6. Conclusion

The most suitable alternative source of energy for heating is solar energy. It is environmentally friendly, and limitless. Solar stills are a technology that is ready for much broader usage due to its inherent simplicity, capacity to provide fresh water to remote locations where freshwater is not adequately clean.

The results of this study showed that the addition of mirrors to the interior walls of the ASGHT still improved the production of distilled water more effectively than the SGHT by 20%. The output of both stills was also enhanced by the reduction in water depth and the addition of dye. The application of solar water distillation holds the promise of raising standards of living and health in remote areas in Vietnam, and also alienated parts around the Southeast Asian region.

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Michigan's Transition to Clean Energy

Yellow Jackets

Detroit Country Day School

United States of America

Jacob Hopkins and Solene DeGaynor

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Abstract:

Michigan generates the majority of its utility scale electricity from natural gas, coal, and nuclear energy. Our research will focus on the sufficient generation of renewable sources of energy as an alternative to carbon-based sources, and how this transition will be accomplished most easily. Energy providers such as DTE Energy and Consumers Energy have presented plans to move away from carbon-based sources. DTE aims to be coal free by 2036 and to have net zero carbon emissions by 2050. Consumers Energy released a proposal to go coal free by 2025 which involves a transition to 90% clean energy and the building of 8,000 megawatts of solar power by 2040. Additionally, Midcontinent Independent Systems Operator has made a $10.3 billion investment to build 2,000 miles of new transmission lines in the grid which will also be more high tech for efficiency in the transmission of energy. Considering these plans, our research will dive into Michigan's resources and how these can be used for a smooth shift to sustainable energy, as well as how trade between the United States and international companies can supplement the transition to clean energy in Michigan.

Keywords:

1. EV = Electric Vehicles
2. MISO = Midcontinent Independent Systems Operator
3. OECD = The Organization for Economic Cooperation and Development

Method of the investigation:

To garner a holistic overview of the topics at hand, our team gathered information from reliable online articles and governmental documents.

Our research centered on four guiding questions:

1. What is the distribution of energy sources that are used in Michigan?
2. What is Michigan currently doing in the energy arena to become more sustainable?
3. What is the best course of action to transition Michigan towards renewable energy, and what potential difficulties stand in the way?
4. What are the international implications of Michigan, and more broadly the United States, moving away from fossil fuels?

To supplement our research, we interviewed Tracy Wimmer from the media team in Consumers Energy and Paul Funk from the renewables group in DTE for solar and wind site planning and design to gain first-person insight on how energy companies are tackling sustainability.

Interview Questions

1. From our current knowledge, (We restated what we thought their current plan was from our research). Is this still the current plan that Consumers Energy/DTE has been following, or has something changed? Additionally, what is the current progress on this plan? What are some of the economic issues that have been faced, and how did the pandemic affect this plan in terms of customer views and satisfaction?
2. What are some of the plans to provide alternative forms of interstate energy exchanges knowing there are many interstate pipelines connecting Canada and Michigan to exchange Natural Gas and Petroleum? What are some of the other challenges in a shift in terms of national and international trade?
3. In the process of retiring coal and petroleum facilities, how has Consumers/DTE worked to offer employees alternative occupations?
4. What are some of the initiatives worldwide in the transition away from carbon-based sources of energy that Consumers/DTE is taking note of in what worked well and what didn't?
5. With the recent approval of the Midcontinent Independent System Operator (MISO) plan to build Tranche 1, a collection of 18 projects across the grid to build 2,000 new miles of transmission lines, what is Consumers Energy's/DTE's plan to improve local transmission systems and take advantage of the opportunities this project will offer in order to efficiently transmit new forms of energy to a greater amount of area?
6. What are some of the main sources of renewable energy that Consumers Energy/DTE is looking to use for a transition and what are their advantages or disadvantages? Why are other forms not as helpful?
7. What are the main areas of focus in terms of sectors of energy consumption where Consumers Energy/DTE is looking to make massive improvements and spread awareness? Knowing the residential sector consumption is much higher in Michigan than most states, what are some of the efforts that Consumers Energy/DTE has made in this area specifically?
8. With access to the largest underground natural gas storage capacity in the US, how will this be used to provide a steady energy output to sustain customer demand while transitioning towards renewable sources. Are there any other sources of energy with limited carbon emissions to provide a cushion in the transition?
9. What are some of the ways that Consumers Energy/DTE has worked with private energy owners in its area of distribution to reach common goals?
10. What are some of the challenges Consumers Energy/DTE has faced in the past in trying to install wind farms in west Michigan. What are some of the

ways Consumers/DTE has worked to sway customer opinion and maintain satisfaction in this area?

11. (Consumers Energy specific) With the recent installation of Assembly Solar, Michigan's largest solar farm, which was developed by Ranger Power, has Consumers Energy has planned on working with them to distribute this energy and to install more solar energy in Consumers' plan to build 8,000 megawatts of solar power by 2040. Where are some of the areas Consumers could work with to achieve this goal aside from this?
12. (Consumers Energy specific) If you are okay with sharing, can you explain some of the details from the recent lawsuit against Consumers Energy and how you are working to handle it?

These questions were made concerning the framework of our investigation—analyzing the situation from multiple angles. We combined this qualitative research with our previous knowledge to form conclusions about Michigan's future with sustainable energy.

Results of the investigation:

The United States heavily relies on fossil fuels and non-renewable energy sources. Using over 97 quadrillion BTUs in energy, the United States continually exploits various sources of petroleum, natural gas, and coal [1].

While this need for energy is distributed between electric power, transportation, industrial, residential, commercial, and then various smaller sources, electric power constitutes 96% of the U.S.' utility-scale electricity generation [1].

However, as the world has become increasingly aware of the dire need to transition away towards renewable energy, the United States has been at the forefront of implementing clean energy sources inside its borders. In 2021, the United States produced 97.78 quads [1]. Yet, while fossil fuels accounted for 79% of this, renewable energy and nuclear electric power made up 21% of the energy produced [1]. Renewable energy also reached a record high production in 2021, as energy sources such as biomass production, hydroelectric power, and geothermal energy have picked up steam significantly since the early-2010s [1].

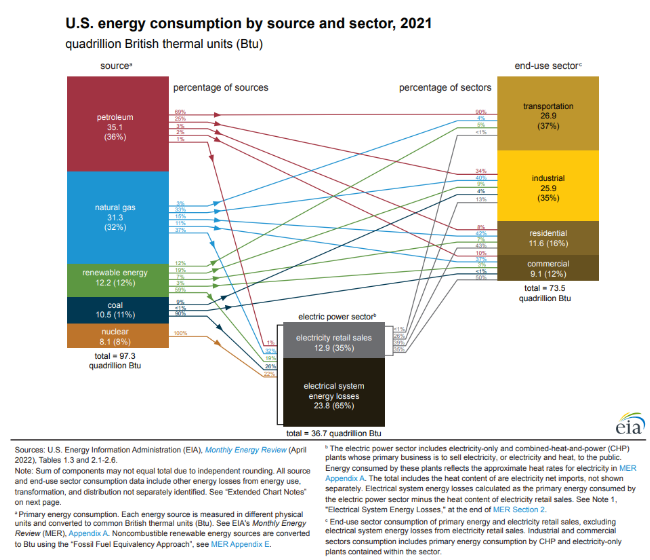

Figure 1: The chart above highlights the production and consumption of specific energy sources in the US in 2021, showing the distribution of these sources across energy sectors by percentages of abundances [2].

Currently, the Biden administration is taking an "all-of-government approach" toward the ambitious renewable energy goals that it has outlined. The executive order presented by Biden, "Tackling the Climate Crisis at Home and Abroad", includes goals to deploy 30 gigawatts of offshore wind by 2030 as well as creating new offshore wind leasing strategies. Additionally, on his first day in office, President Biden rejoined the Paris Climate Accord, a monumental step to reaffirm the United States' commitment to furthering the effort of net-zero emissions by 2050 [3].

In terms of how generated energy is distributed, three main interconnections manage distribution in the United States and the majority of Canada. The Eastern Interconnection runs from central Canada down to Florida and controls a majority of the power distribution in the eastern United States. The Western Interconnection covers most of the area west of the Eastern Interconnection, except for the Texas area which is managed by the Texas Interconnection [4].

The Eastern Interconnection is mainly managed by a collaboration of transmission companies called the Eastern Interconnection Planning Collaborative. It manages the planning and coordination of power distribution within the grid for maximum reliability [5]. The Midcontinent ISO (MISO), regulated by the Federal Energy Regulatory Commission, is part of this collaborative. Managing 15 states mainly in the midwest, it is responsible for "organizing wholesale power markets, ensuring regional reliability, and planning new transmission lines for the electric grid of the future" [6]. MISO does not own the energy production and transmission systems, yet it is given rights to manage them to benefit the grid. The operations of this system are difficult to smoothly pull off, yet through various efforts for efficiency the cooperative has been successful [6].

However, within the United States, each state faces its own challenges in transitioning towards clean energy. Our home state of Michigan, in particular, has built a reputation of poorly funded infrastructure with little hope to be a front runner in the race to reduce greenhouse gas emissions. Yet, under the governorship of Gretchen Whitmer, millions of dollars have been poured into sustainable energy. The "Michigan Healthy Climate Plan" aims to reduce the Michigan level of greenhouse gasses in 2005 by 52% in 2030 [7]. Furthermore, by the same year, the state is targeting to have 60% clean electricity, phase out coal fired power plants completely, and revitalize incentives for electric vehicles and charging stations [7].

Michigan is currently at a crossroads. The state powers 32% of its electricity net generation with coal [8]. Coal is closely followed in use by nuclear energy and natural gas-fired power, creating 30% and 27% of Michigan electricity net generation respectively [8]. Yet, while being in the top ten states for energy use and the top five for residential sector petroleum use, it is also in the top fifteen states for wind energy electricity [8].

The nature of Michigan's climate and population necessitates such an intense energy production. Cold weather and snow brings residential energy use per capita in the top fifteen states while transportation accounts for 25% of the state's energy use, much higher than other states [8]. The Industrial sector and the Commercial sector additionally make up 24% and 22% state energy use respectively [8].

The state also has bountiful natural gas reserves, totaling out to 1.1 trillion cubic feet of underground storage capacity, the largest in the US. The Atrium Field in the Lower Peninsula contains various reserves while interstate pipelines allow for Michigan production to be funneled to neighboring states as well as Canada. Canada's expectation for Michigan gas incentivizes the state to continue its production. The residential sector of Michigan also relies heavily on gas, with 75% of households using it for heating [8].

Michigan residents also consume the most propane nationally, largely through the use of gas. One in ten homes heat with petroleum products. Four-fifths of the consumption of petroleum is in the transportation sector for motor gasoline. However, there are disputes over the pipelines that run through Michigan in the present day. The Enbridge Pipeline, flowing petroleum from Wisconsin to Ontario, delivers oil to Michigan. Governor Whitmer revoked the pipeline's permit for operations in 2021 due to safety concerns, however Enbridge refuses to shut the pipe down, resulting in an ongoing legal dispute [8]. Aside from the pipelines, there hasn't been a large increase in Petroleum production since

1970 when it was found in reefs in Michigan's Great Lakes [8].

There are no longer active coal mines in Michigan, but Michigan ports still house a fair amount of coal shipments. Coal is also exported from the west from states like Wyoming and Montana [8].

Nuclear power plants supply 30% of instate electricity, yet this number is expected to decline [8].

Michigan has a lot of great access for renewable sources of energy; such as strong offshore wind from the Great Lakes, waste from forests and large cities to produce biomass, and multiple hydroelectric dams. Renewables made up 11% of Michigan's in-state electricity generation in 2021, 60% of which came from wind energy [8]. There are 32 wind farms in Michigan between Saginaw Bay and Lake Huron, with a generation capacity of 3,200 megawatts [8]. Biomass makes up 20% of the renewable energy generation, made up of three dozen biomass plants with a generation capacity of 550 megawatts. Michigan also has 50 hydroelectric dams, including the Ludington Pumped Storage Plant, which alone has a capacity of 2000 megawatts, making it one of the largest pumped storage facilities in the world [8]. Michigan has five fuel ethanol power plants that have a capacity of 390 million gallons per year [8]. Solar power makes up a small portion of the renewable energy generation, with around 450 megawatts of capacity, made up mostly of small customer-sited solar photovoltaic facilities. This number is expected to double by 2024, with the help of the addition of Michigan's largest solar farm, Assembly Solar, which opened in 2022 and will add 240 megawatts immediately [8]. Obviously, there is huge room for potential, yet Michigan's natural potential to house high amounts of renewable energy production has not fully been harnessed [8].

Figure 2: The map above shows the distribution of different sources of production as well as a diagram showing Michigan's transmission lines [9].

Organizations have already set goals to reduce the carbon footprint of fossil fuel production by working to increase the production and distribution of renewable energy. Energy providers such as DTE Energy and Consumers Energy, Michigan's two largest customer energy providers, are the key players in this effort.

On June 23, 2021; Consumers Energy released a proposal describing their plan for a decreased carbon footprint in future years. They wish to go coal free by 2025. Their plan also involves a transfer to 90% clean energy by 2040, in addition to the installation of 8,000 megawatts of solar energy by that year as well [10].

At the base of this plan, it called for the retirement of three coal fired units at Campbell Generation Complex, as well as Karn 3 and 4, plants that run on natural gas and fuel oil [10]. In an interview with Tracy Wimmer, a member of the electric and natural gas media contacts team, she says that workers in these plants are all being offered jobs in their field within 50 miles of the factories. These factories will most likely just be converted to green space [11]. She also says that issues such as this are not helped by growing inflation, and the actual costs of the decommissions are still being discussed. [11].

Additionally, Ms. Wimmer discusses the importance of political and local partnerships to this plan. Local nonprofits, such as the Pew Trust Organization are important to spread awareness and get the community involved [11]. County partnerships are more complicated when meeting customer satisfaction. This stems from trust building between politicians and Consumers Energy. Yet with the help of local nonprofits, those organizations can go out and gain community support for Consumers Energy. Also, property tax assessments have been used to sway opinions, as the property tax revenue increases from Consumers Energy partnerships due to using the land for energy installations [11]. Within Consumers Energy's region of distribution, multiple small energy companies function with privately owned businesses and facilities. Partnerships in these areas function by allowing Consumers Energy to manage these privately owned facilities to create energy that can be connected back to the grid [11].

Ms. Wimmer also went in depth about Consumers Energy's customer outreach programs. The Community Affairs Management Team is a branch of the company that focuses on developing relationships with elected officials and communities, involving customer interviews to manage priorities and attendance at town hall meetings and community events. Despite this, there has still been much customer resistance, sometimes in the form of financing worries or the desire to preserve the state's natural beauty in communities with a high amount of tourism [11].

In terms of what forms of renewable energy are most viable in Michigan, Ms. Wimmer says that Consumers energy has chosen to focus mainly on wind and solar energy [11]. Furthermore, with access to huge underground natural gas storage facilities, Consumers Energy buys this energy during the summer when it is cheapest and stores it for the winter. The grid is huge and extends to the warmer states in the south. However, these states are not as prepared for the cold spells that northern states experience, so they take energy from other regions in the grid, affecting Michigan as a result [11].

Consumers has multiple programs to make the grid smarter and more efficient, such as offering to talk with homeowners about how to be more efficient and save money [11]. Consumers has had some great success with their plan, and these are not the only efforts circulating in Michigan

DTE Energy announced that they plan to have net zero carbon emissions by 2050. This plan would require an addition of a total of 10,000 megawatts in renewables. Through this plan DTE has mentioned building additional wind and solar parks, and the retirement and conversions of power plants such as the Belle river power plant and the Monroe power plant [12].

Through an interview with Paul G Funk, a member of the renewables group in site planning and design for wind and solar development for DTE, a lot of great information was gathered about this plan. Currently, about 15% of DTE's electricity generation is from renewable sources, obtained through various ways including 33 solar parks and 18 wind farms [13]. Their plan is to increase these resources so there will be enough to power over 1 million homes in 2025, being able to power about 700,000 currently on renewable energy [13]. Additionally, DTE still has access to high tech facilities for generation across all areas of generation, yet some of these facilities are in the process of being retired to transform the grid. Fermi 2, located in Monroe County, is a nuclear power plant that has a capacity of 1,142 MW accounting for 20% of the electricity generated by DTE. The Blue Water Energy Center in East China Township is a natural gas combined-cycle plant that has a capacity of 1,127 MW. This plant has been very helpful in cushioning the retirement of other power plants [13]. Huge lithium-ion batteries are used in storage systems to store energy for the grid. Coal used to make up 77% of DTE's generation in 2005, yet they are planning to move to 15% by 2029 and 0% by 2035, which is proposed to be cost effective in the end [13].

To try to encourage a switch to renewable energy among households, DTE recently created a program called MIGreenPower. This program allows customers to connect a portion of their energy use to renewable energy sources. With about 80,000 customers in the program, there are still around 500 residential customers joining every week. In terms of long term effects, 4 million megawatt hours of clean energy have been used in the program, and 3 million tons of carbon dioxide emissions have been avoided [13]. Overall, DTE has taken some great steps in the right direction with its plentiful resources [13].

Organizations such as MISO have also made investments to try to help in a transition for the grid itself. MISO recently announced plans to make a 10.3 billion dollar investment to build 2,000 miles of new transmission lines within the grid to help cushion the stress that the transition to renewable energy is putting on the grid [14]. These lines are additionally being developed to move energy in both directions, which will allow for greater efficiency for the transmission of energy from clean sources [15]. Projects may not be completed until 2030s, however, as state permissions are still being discussed. Such developments allow for the United States to internalize their clean energy sources even further. Other projects that are waiting to be worked on would result in 56 gigawatts of generation - enough for 40 million homes [14]. However, the progression of these projects is held back by massive costs. The potential is there, though, which is promising for future endeavors [14].

The United States has the immense opportunity and responsibility to be a leader in transition away from non-renewable energy. Currently, China is at the forefront of supporting developing nations with the energy they need to progress them to second or first world countries. China is investing heavily in fossil fuels and then loaning this energy to support developing nations. China has financed over 196.7 billion dollars in overseas energy sectors between 2007 and 2016. Unfortunately, as long as China is able to maintain complete control over investment in developing countries, it will be difficult for the world as a whole to move away from fossil fuels [16].

The United States, however, has the opportunity to act as a counterweight to China's energy investments by financing more clean energy projects. This would help low-income countries move towards renewable energy, further advancing the goals of the 2015 Paris Agreement on Climate Change [16]. Recently, the United States spent about 2 billion dollars on climate finance to support low-carbon development in third world countries. It created a loan system with low interest allowing emerging nations to have the finances to support clean energy infrastructure [16]. This is especially true in nations with growing energy needs such as Mongolia, Vietnam, and Burma [17].

Clean energy projects also can be cheaper at times for developing nations. Despite the connotation of clean energy and higher costs, the price of green energy is dramatically falling. In 2021, onshore wind costs fell by 15%, offshore wind by 13%, and solar energy by 13% compared to the year before [18]. Additionally, in 2021, 160 gigawatts of newly installed renewable power was proven to be a lower cost than the world's cheapest coal fired option. Furthermore, not only are initial costs lower, there is also a return on a country's development [18]. It was found that in non-OECD countries, 110 GW of renewable energy will reduce annual costs by 5.7 billion dollars over the next 30 years. This evidence supports the fact that with the United States' initial investment into low income countries will ultimately have tremendous payoffs. If the United States wants to be at the forefront of green energy, it is imperative that the country continues to act now in order to overcome China's investments in fossil fuels [18].

In order to reach the zero net emissions by 2050 goal, there simply needs to be further investment into clean energy related projects [19]. Unless this action is taken, carbon dioxide emissions from energy sources in developing economies from Asia, Africa, and Latin America will grow by 5 billion tons in the next 20 years [19]. These nations just do not have the funds to further invest in clean energy, and thus it is critically important that nations like the United States with massive GDPs invest in collaborative efforts with international agencies like the World Bank in order to funnel money into energy projects [19].

For the United States, policymakers can primarily work to adhere to the goals outlined in the Paris Climate Accord. Additionally, further investing in underdeveloped nations will allow for infrastructure to be built in third world countries that leads to a greener future [17].

From the information presented, the number of initiatives taken towards a common goal is clear. However, along the way these plans have met some roadblocks, and there are ways that these can be avoided for better efficiency. The relationship between the general public and big energy providers has been an area of improvement, but there have still been issues [20].

A specific instance of this is the Consumers Energy lawsuit on Tuscola County Michigan. This was a lawsuit on local businesses and services, in which Consumers Energy is demanding $8,000,000 in taxes paid be returned to them. Originally, Consumers Energy was given land on which to build wind farms in return for tax revenue, but the Michigan Tax Tribunal changed the tax depreciation schedule, causing Consumers Energy to demand that the county return overpaid taxes. The county has already used the money to make developments in schools, security, sanitation systems, and maintenance, so this lawsuit could really hurt the county [20].

In the interview with Tracy Wimmer, she presents a different view of this issue. She says that the State Tax Commission determined the tax tables for wind turbines a while ago, yet the Michigan Renewable Energy Collective did not agree with the state tax numbers so they created their own tables. Consumers Energy believes that the county was not following state tax laws. Consumers Energy is hoping to share the narrative with the media [11].

Additionally, specifically wind farms have received resistance in Michigan. For example, in Trufant, Michigan; voters recently were able to shut down a huge project for a 375 megawatt wind farm, including throwing out multiple officials from office for supporting the project. It was seen as a potential threat to health and property values by locals, calling them an “eyesore” and criticizing their effect on wildlife [21].

This conflict is further highlighted by analyzing the distribution of wind farms across the state. The following diagram shows the distribution of wind farms across Michigan, illustrating that most farms are located on the east side of Michigan. However, when analyzing the diagram that looks at the average speeds of offshore winds, there is some discrepancy revealed. The wind farms are not necessarily located where the strongest offshore winds are, which are much stronger on the west side of Michigan [22].

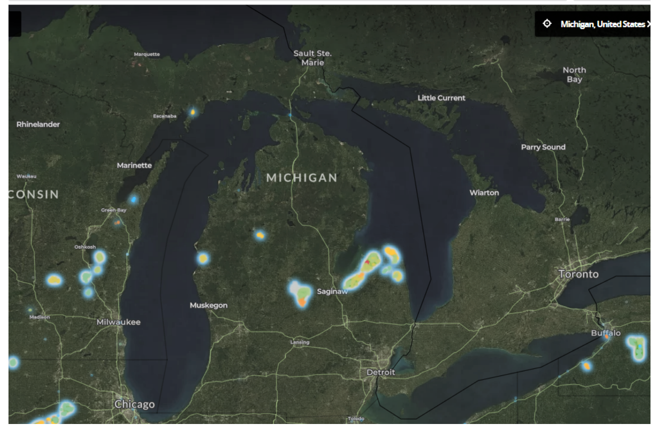

Figure 3: This is a map of the distribution of wind farm locations in Michigan [23].

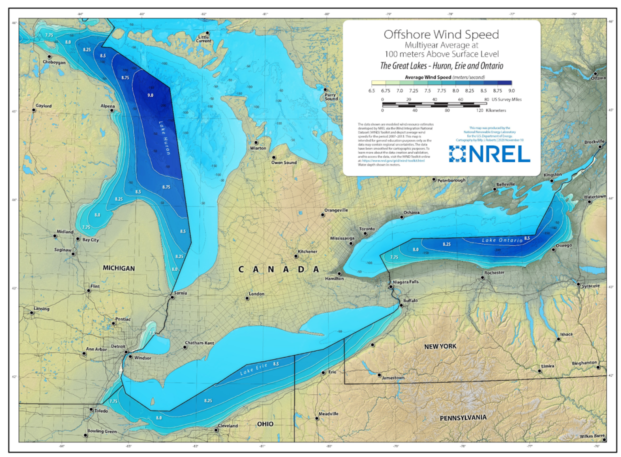

Figure 4: This diagram measures average offshore wind speeds in Michigan on Lake Huron, Lake Erie, and Lake Ontario [24].

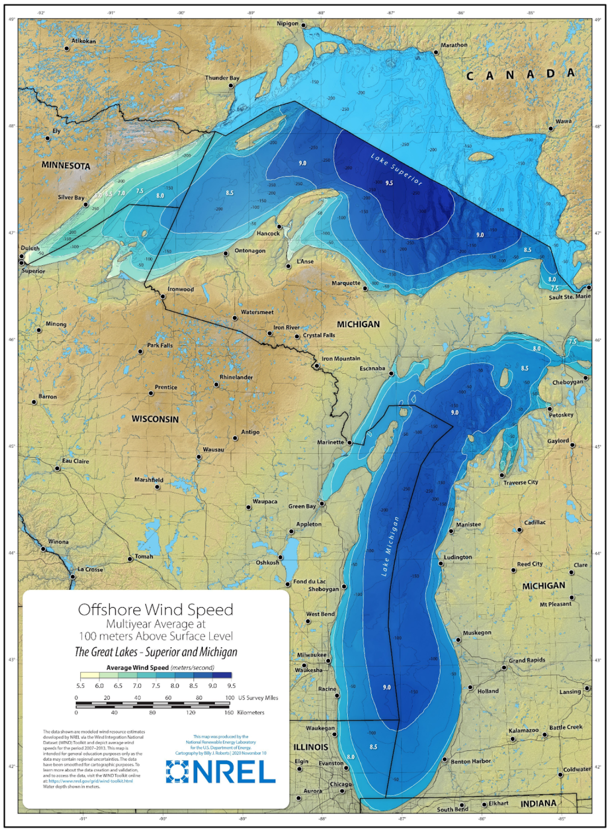

Figure 5: This diagram measures offshore wind speeds in Michigan on Lake Michigan and on Lake Superior [25].

Through some of these conflicts, it is clear where improvement can be made for an efficient and peaceful transition. An entirely new plan is not necessary, but modifications can be made to existing plans.

The first of these areas is to increase the spread of awareness. The movement to preserve Michigan's natural beauty at the expense of electrical generation is one that does not look at the bigger picture. Without cooperation with Michigan's highest producers of renewable energy, a transition is not possible and natural beauty will continue on its decline from the use of fossil fuels. Also, studies have shown that renewable energy is much cheaper in the long run. At a certain point, this becomes an issue of branding, as even though energy providers are trying to gain support, the full story must be understood to get people involved. DTE's MIGreenPower plan has given people who wish to help a chance to help in the transition at the personal level. This is where the power of the media comes into play. Media can bring the conversation from political debates to the personal lives of the public. The branding of this issue has had the reputation of being a "fight to be won" against carbon emissions, a relatively binary vision of the issue that relates to the customer resistance and county political action. The MIGreenPower program gives off a more collaborative message with multiple possibilities for improvement, advertising it more as a "solution to be made".

Also, with many organizations related to similar goals, poor communication and discussion to organize plans can lead to chaos. The Tuscola County lawsuit is a perfect example of this, showing how the poor communication about the tax tables resulted in the retaliation from Consumers Energy. Among the Michigan Renewable Energy Collective, Consumers Energy, the Michigan Tax Tribunal, and the county, there could have been better communication to discuss the taxes from the beginning, as well as communication between the county and Consumers Energy about what could be done that would not harm businesses. With the dispute about the Enbridge Pipeline that was supposed to be shut down, that was a complication between a business and the government. Stricter laws could be enforced to keep these businesses in compliance, so goals are met with ease, showing the effects of strong politics on this issue.

Finally, the Eastern Interconnection is huge and spans an area of a large diversity of weather. Michigan has programs that can handle natural disasters very well, but that does not mean much if other states cannot do the same. Greater initial investment in these areas would mean that individual states would have an easier time focusing on their own development, while still being under the supervision of MISO. Studies have even been conducted to analyze the economic benefits of connecting the Western and Eastern interconnections [26].

Michigan is a place of many amazing features of nature, and for the most part, people have agreed that this is something that is worth preserving. Those mindsets have been uniting to try to save it through action, and overall Michigan is showing an optimistic future for energy.

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The best car for a sustainable future

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Abstract

The aim of our research is to find answers to the following questions: *What would be the best option for a car to use in a sustainable environment? Are electric cars the best solution for a polluted-free future? Are there any disadvantages in building or commercialising electric cars?*

In this project, we want to find the answers to the above questions through a deep analysis of the different types of cars such as the hybrid, electric, diesel or natural gas.
Firstly, we shall examine the electric car, which is considered to be the most promising alternative due to its low environmental impact and reduced operating cost. However, it appears to still face some challenges and problems that are not often mentioned.
Secondly, the hydrogen car will also be discussed and analysed. This vehicle has the advantage of producing zero emissions and having a greater autonomy, but it still faces the challenge of a lack of refuelling infrastructure and a high cost. With the analysed statistics and the acquired information we aim to compare the different points of view, both economically and scientifically.
Nowadays, a standard city is not prepared to sustain the cost and the required energy to power all cars. Based upon this research and project, we
propose to find out what the ideal car is and which can combine sustainability and comfort.

Keywords

Sustainability, energy, cars, CO_2 emissions.

1.Introduction

Currently, the car is the most widely-used form of transport in Spain, and its use is one of the main causes of global warming, pollution and the destruction of ecosystems in our country and all over the world.

One of the most important things in energy transition is to adopt sustainable cars and to promote renewable energies for their production and use. It also reduces greenhouse gas emissions, moderates global warming and preserves ecosystems.

To solve this problem, our goal is to find out what the best type of car is for our sustainable future. But, to begin with, we need to understand what we mean by sustainability.

1.1 Sustainability

Probably, the first thing we immediately think of when we are asked what sustainability is would be that it is eco-friendly and helps the environment. Unfortunately, most people who think in this way have an incomplete understanding because sustainability goes much further than the environment.
Sustainability is based on the balance and relationship between environment, economy and society. It defends the fact that nature is not an endless source of resources and seeks to protect, preserve and use them rationally. It also aims to promote economic growth that generates equitable wealth without harming natural resources. And finally, social sustainability promotes the development of people, communities and cultures to achieve an overall standard of quality of life.
So to sum up, sustainability is best defined as satisfying the needs of the present without compromising the ability of future generations to meet their own needs.

2. Sustainable car

Our definition of a sustainable car is an eco-friendly means of transport in its production, use and disuse. A vehicle that saves pollutant emissions during its construction, that has zero pollutant emissions during its use, and which contains a battery that is recyclable. It is also economically viable for all, and meets the needs of the present.

2.1 Types of cars

Nowadays, there are different types of vehicles. In order to find out which is the best sustainable car, we have to compare the various types that currently exist and carry out an analysis.

2.2 Electric car

Electric cars are driven by its motor, which is powered by a 100% electric power source.
Their batteries can be recharged directly via charging points.

ELECTRIC CAR	
ADVANTAGES	**DISADVANTAGES**
It emits zero pollutant emissions while driving	The batteries are polluting for the reason that are made of lithium and magnesium (indestructible materials)
Filling the tank costs about 5€.	There is no repair on the battery.
It has about 400 km of autonomy	It takes about 7 hours to recharge the car
	Battery may catch fire

2.3 Hybrid car

A hybrid vehicle mixes an electric motor with a combustion motor (in general, gasoline engine). It reduces the consumption of fuel and the greenhouse gas emissions and of particles, in very different percentages according to the category.

HYBRID CAR	
ADVANTAGES	DISADVANTAGES
The battery is almost indestructible	Produces 46g/km of $C0_2$
If it is a non-plug-in hybrid, you only have to pay the price of gasoline.	The price is so expensive
It has a very low maintenance cost since the motor composition is easy to repair.	Has about 80 km of autonomy on 100% electric mode

2.3.1 Types of hybrid cars

There are three types of hybrid cars: MHEV (Mild Hybrid Electric Vehicle), also called micro-hybrids or light hybrids, HEV (Hybrid Electric Vehicle), conventional or self-recharging hybrids, PHEV (Plug-in Hybrid Electric Vehicle), called plug-in hybrids, are those that are connected to the grid to recharge their batteries.

The more electrical capacity the vehicle has, the more batteries it needs, and therefore the more expensive the car is, because the most expensive thing in an electrified car are the batteries.

MHEV

We could say that micro-hybrids or light hybrids use a small electric system, usually 48 Volts. This allows it to support the combustion engine, but it has hardly any power to move the car by itself. It is limited to support the combustion engine in actions, driving by inertia, or starting from a standstill, to slightly reduce emissions and consumption.

The batteries are recharged by the combustion engine as a generator, or by regenerative braking.

They have an 'ECO' label from the DGT[1].

HEV

Conventional or self-recharging hybrids already have a more powerful electric motor powered by a larger number of batteries. The car only moves in 100% electric mode over short distances and only if the acceleration is very progressive. They are especially interesting for urban use, where you are constantly braking and accelerating between traffic lights and traffic jams. Bearing in mind that this is

[1] *Dirección General de Tráfico*, the official body in Spain which governs vehicle rules and regulations.

where combustion-engine cars consume the most, hybrids can represent a significant fuel savings.

HEVs are recharged by using the combustion engine as a generator, or by regenerative braking. For this reason, some brands often refer to them as self-charging.

They have an 'ECO' label from the DGT.

PHEV

Plug-in hybrids are the midway point between combustion and total electrification, as they can cover long distances in 100% electric mode thanks to the batteries that power one or more electric motors, but do not renounce the presence of a classic combustion engine to ensure 'unlimited' autonomy. This makes it possible to travel in the city and even on interurban routes without wasting any gasoline, and to make long journeys with the convenience of classic refuelling at gas stations.

Recharging in PHEVs is mainly done by 'plugging in' the car to an electrical source, like pure electrics, but they also regenerate the batteries by using the combustion engine as a generator, or by regenerative braking, as hybrids do.

They have a 'ZERO' label from the DGT.

2.4 Gas car

The vehicle of gas or CNG (Compressed Natural Gas) is a vehicle which has only one internal combustion motor with capacity to use CNG and also one of gasoline.

GAS CAR	
ADVANTAGES	**DISADVANTAGES**
It has a range of about 120 km	It is difficult to recharge it because there are only 66 charging points throughout Spain.
In general terms, they reduce CO_2 emissions by 10-15% compared to gasoline cars.	The tank is highly flammable as it is filled with gas.
	Although filling the gas tank costs you about 3€, the car consumes a lot and you have to refill it many times, plus you also have to pay for the combined fuel consumption.

2.5 Gasoline car

The gasoline car has an internal combustion motor where the fuel burns to do its work.

GASOLINE CAR	
ADVANTAGES	**DISADVANTAGES**
They rely on an internal combustion engine to generate power.	Significant CO_2 emissions contributing to global warming.
It has an autonomy of 600 km	Filling the tank costs about 80€.
The maintenance is low	Noisy and stress-inducing.

2.6 Hydrogen car

A hydrogen car is a vehicle that has hydrogen as combustion. It is a model with an electric motor that receives energy from a fuel cell.

CAR HYDROGEN	
ADVANTAGES	**DISADVANTAGES**
It has a quick charge, it takes about 5 minutes.	Hydrogen is flammable and therefore dangerous if not properly stored or handled.
Produce 0 emissions during driving	Hydrogen has to be highly compressed for road use, so it is difficult to transport.
It has a range of 700 km	There are only 3 hydrochargers

Looking at this last table, we can see that the hydrogen car could be a good option for a sustainable future, but what is hydrogen? How is it produced and transformed to form the vehicle?

3. Hydrogen

On our planet we have 75% of hydrogen, which is never found alone and it's always accompanied by chemical elements such as: oxygen, water or carbon that form

organic components. It cannot be obtained in nature in a pure state, but has to be manufactured.
Also there are a lot of different types of hydrogen like green that is obtained without generating greenhouse gas emissions, it is considered the key to achieving the decarbonisation of the planet.

The most used way for now to obtain hydrogen is molecular transformation, which consists of using a variety of chemical reactions. The high temperatures of the steam are used to separate the carbon from the hydrogen which creates natural gas (CH4). This method is very polluting, since CO_2 goes up into the atmosphere and fossil fuels need to be extracted which is called gray hydrogen.

In Spain the production is 500,000 tons per year, most of it is gray hydrogen, and 1% is green, which would be 5,000 tons, but it is estimated that there will be a significant increase in the future. The government of Spain wants the country to produce 6,500 tons of green hydrogen by 2023 and 40,000 tons per year by 2040.

3.1 Production

Blue hydrogen is currently used in Spain. Is produced by separating natural gas into hydrogen and CO_2, for example, through steam methane reforming (SMR). The CO2 is not released into the atmosphere, but is captured in the process and stored. This carbon capture and storage (CCS) process minimises environmental impact.

Grey hydrogen, which was previously used in Spain, is produced in a similar way to blue hydrogen, from fossil fuels such as coal or natural gas. However, carbon emissions are released into the atmosphere causing this technology to affect the environment.

To become sustainable, Spain wants to produce mostly green hydrogen, which is produced by electrolysis by splitting water molecules into hydrogen and oxygen. The oxygen can be safely released into the atmosphere as a by-product. In the case of green hydrogen, electrolysis requires electrical power generated through renewable energies such as wind and solar. Green hydrogen is the cleanest way to produce hydrogen with the lowest CO_2 emissions and virtually zero emissions.

3.2 Transport

Hydrogen can be transported by truck, pipeline or ship. For this, it must either be compressed or liquefied, or transported by means of organic liquids carrying hydrogen (LOHC) and ammonia.

If we focus on the gas phase, we mainly find transports by:

ROAD: This is carried out by lorries and is useful as long as the main site is close to where the hydrogen is to be transported. As a negative aspect, we primarily find that hydrogen has to be transported in small quantities and travels at very high pressures, which can be dangerous.

PIPELINES: This is done through hydro-products and is very useful for transporting large quantities and traveling long distances of up to 5000 km. These pipelines run through the most important consumption and production points of countries to carry compressed hydrogen from one place to another, reducing costs. For large volumes we would talk about a few cents per 1000km.

Exporting large quantities of hydrogen would imply the implementation of many, many more large-scale renewable projects that could have a high environmental and territorial impact. There is also the risk that, in the absence of sufficient surplus renewable energy, hydrogen could be produced with fossil gas, as is the case with 99% of the H_2 currently obtained. This risk is increased by the low energy efficiency of H_2, as the independent research institute Hydrogen Science Coalition has already pointed out. In the process of producing hydrogen by electrolysis from, for example, renewable sources and during pipeline transport, up to 80% of the energy invested can be lost.

VESSELS: Hydrogen liquefies at minus 253 degrees Celsius, which is a very energy-intensive process, as approximately one third of the calorific value of hydrogen is spent on liquefying it. But the advantages are very important, such as the great potential for intercontinental transport, because you can carry much more hydrogen. A truck, for example, can carry up to four times as much.

For transport by truck or ship over long distances, it is necessary to take into consideration that evaporation losses can reach amounts between 0.2 and 0.4% of liquid hydrogen per day. In the case of maritime transport, fast ships would be required to limit the impact of these losses, although the evaporated product can be recovered and used for ship propulsion.

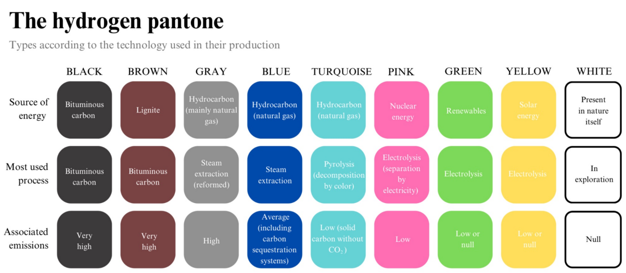
3.3 Drought

Drought is an extended period of time in which a territory suffers a deficiency in water supply. It generally occurs when rainfall is lower than usual. This phenomenon produces, therefore, an imbalance between the natural availability of water and the consumption by human activity.

In Spain rainfall is irregular, alternating long periods of absence of rain with episodes of torrential rains. The Mediterranean climate makes us particularly vulnerable to drought episodes especially in the internal basins where the bulk of the population is concentrated (more than 80%) and where only 40% of the water available in Spain is available, essentially that found in reservoirs, aquifers and wells.

This makes it difficult to progress with hydrogen production, and prevents us from implementing the hydrogen car in Spain.

3.4 Types of hydrogen



4. Gas

NGV (natural gas for vehicles) is a lower-emission (fuel)[2] that is very suitable for transport, especially for freight. There are two types of NGV: compressed natural gas (CNG) and liquefied natural gas (LNG).

There are also other fuels such as Compressed Natural Gas (CNG), which is a real alternative to the much more expensive and polluting petroleum-based fuels. CNG is made up of 80-99% methane (CH_4) and the rest is made up of additions of carbon dioxide, nitrogen and hydrocarbons. Compressed natural gas can be used directly as a fuel without chemical modification, which is a significant cost advantage compared to other fuels, but depending on where the natural gas is sourced from, it needs to undergo a purification or dehydration cycle.
Liquefied Natural Gas (LNG) is natural gas in liquid phase at a temperature of -160ºC, so it is considered a (cryogenic liquid)[3]. It is stored and transported in highly insulated containers to maintain its liquid state. The advantage of the liquid state is its smaller volume, as each litre of LNG yields approximately 570 litres of gaseous natural gas at room temperature.

LNG is 95% methane (CH_4) and contains minor proportions of ethane, propane, butane, nitrogen and carbon dioxide. It is an odourless, colourless fuel that is non-toxic and non-corrosive.

As a fuel, LNG reduces CO_2 emissions by 15%, nitrogen oxide emissions by 35% and fine particulate emissions by 95%.

LPG or liquefied petroleum gas is a fuel made from butane (composed of 4 carbon atoms and 10 hydrogen atoms) and propane (an organic compound whose saturated molecule is composed of 3 carbon atoms and 8 hydrogen atoms) under pressure, changing from a gaseous to a liquid state, occupying a smaller volume and thus facilitating its transport and distribution. It is used as a fuel in vehicles with petrol engines. The 60% of LPG is extracted from natural gas sources, while the remaining 40% is produced by oil distillation.
Vehicular LPG is called "green fuel", as it reduces emissions of nitrogen oxides by approximately 35%, carbon monoxide by 50% and hydrocarbons by 40% (relative to petrol). But it still pollutes.

5. Comparative table

In this section we will find a comparative table of different types of cars of the same brand (Toyota) and a gas car of another brand since the previous one does not have LPG vehicles.

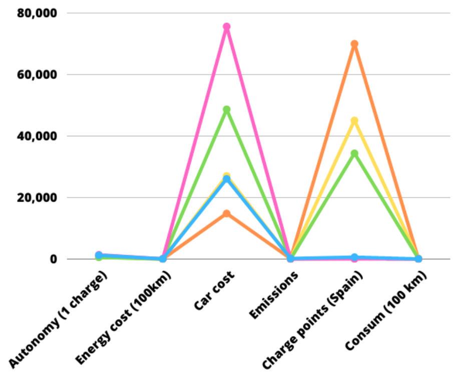
In order to make a fair comparison we have looked for cars that are similarly in the same range. Toyota is one of the largest companies in the world and it is a global manufacturer of general-purpose automobiles, that's why

TOYOTA	Autonomy (One charge)	Energy cost (100 km)	Car cost	Emissions	Charge points (Spain)	Consum (100 km)
Gasoline: Toyota-aygo x cross 2023 (36 L)	800 km	9,98€- 100km	14.799,99€	109 - 117 g/km	70000 points	4,5 l
Hybrid: Toyota-corolla	670 km	2,28€- 100km	26.400€	100 - 111 g/km	45063 points	3,9 l
Electric: Toyota-bZ4X	516 km	2,28€- 100km	48.650€	0g/km	34380 points	166 wh
Hydrogen: Toyota-mirai	1.360 km	8€- 100km	75.600€	0g/km	11 points	0,55 kg
SSANGYONG	Autonomy (One charge)	Energy cost (100 km)	Car cost	Emissions	Charge points (Spain)	Consum (100 km)
Gas: Korando ECO (50 L)	1200 km	8,08€- 100km	26.050€	172 g/km	600 points	7,5 l

[2] substance obtained by mixing chemical compounds consisting only of carbon and hydrogen, i.e., hydrocarbons, used as a fuel when mixed with air to run internal combustion engines in automobiles.

[3] liquid whose boiling point is below -90°C at an absolute pressure of 101,325 kPan (Kilopascal Metric unit of air pressure).

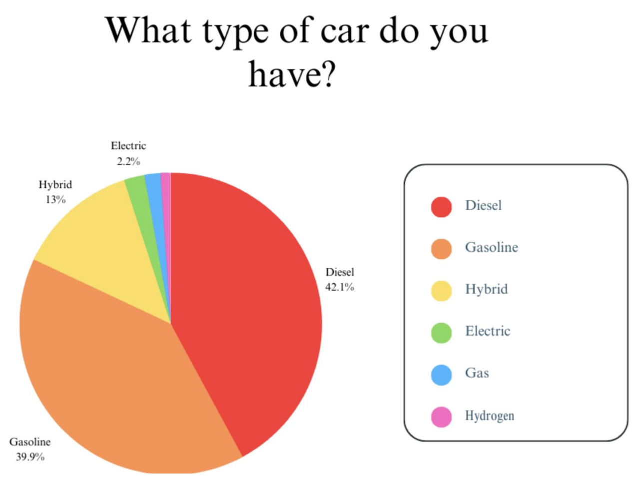
we feel it would be a meaningful option to be able to see the different characteristics of each type of car.



6. Social Survey

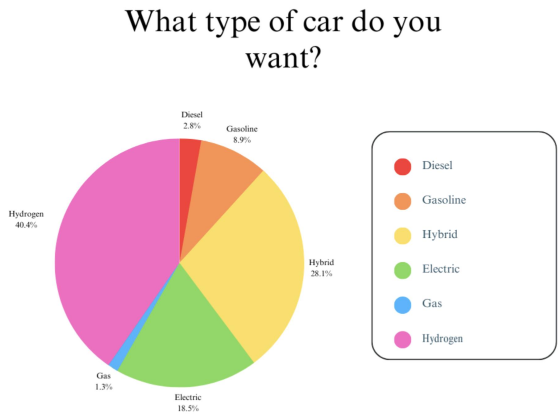
During our research we decided to survey 167 people between sixteen and seventy years old in Spain, mostly from Barcelona and surroundings. With the information collected we have created 3 different graphs for each content, where we can visualise the total percentage obtained for each answer.

6.1



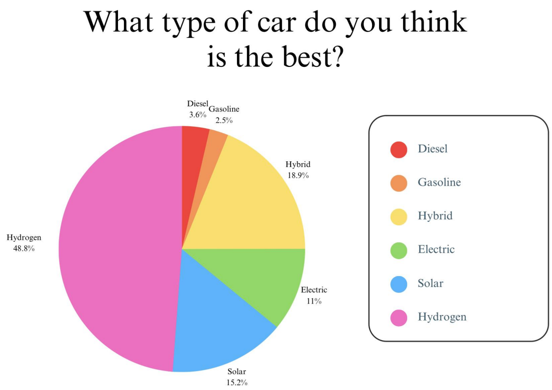
We thought it was necessary to ask different types of people around us, what type of car they have to know and to make us realise that we should make changes in our cars to improve our environment and reduce CO_2 emissions to arrive at a possible sustainable future.

6.2



We posed the question of which car they would like to have, as it is important to know what the people of Spain think in order to know if they are concerned about our environmental future.

6.3



"What kind of car do you think is the best?", this was the last question we asked them. We thought it was important to ask this question as

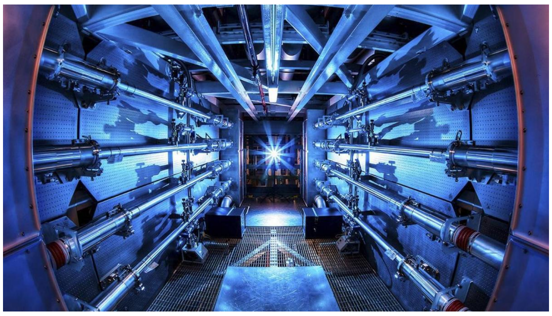
It complements the information and helps us to know the thoughts and knowledge that people currently have about "the best car" or "the most sustainable car" in order to know if society is really aware of the current state of the planet.

7. The journey to achieve an unlimited and clean energy

In December 2022, scientists at the Lawrence Livermore National Laboratory in California, part of the U.S. The Department of Energy conducted the experiment that would be the biggest game-changer in human history along with general artificial intelligence.

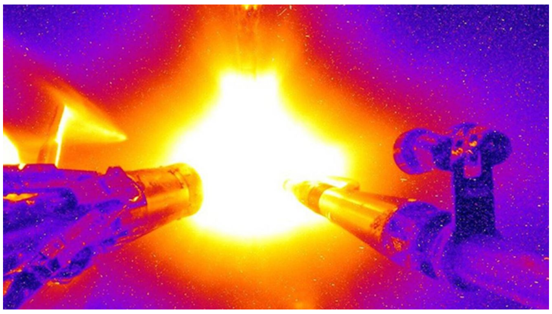
The United States was able to generate more energy than was used in a nuclear fusion reaction, with 0 C02 emissions. The net nuclear fusion achieved in the laser experiment produced 2.5 megajoules of energy, 120% of the 2.1 megajoules used to fuse a small hydrogen pellet.

This is the first time in history that energy has been generated in a controlled fusion reaction. The fact that 0.4 megajoules have been produced is a radical achievement in this race for infinite energy that will make the world stop depending on OPEC and electricity speculation, making energy cheaper for all mankind and freeing us from CO2 emissions that seriously affect the entire planet.



El confidencial

The National Ignition Facility (NIF) is a large building that is mostly filled with pipes that turn around on themselves. Inside these pipes, 192 laser beams pass through different phases until they reach energy levels capable of fusing the reactor fuel, a mixture of deuterium and tritium, to generate star-like energy, while the fuel waits inside a small cylindrical capsule.



ILEON

When the ignition button is hit, the 192 lasers fire simultaneously on the cylinder, generating X-rays that vaporise the capsule. This process causes the hydrogen grain inside the Earth to implode. Under the immense pressure and high temperature, the hydrogen atoms fuse and convert into helium, explosively producing energy in the same way as the sun does.

A few years ago it was said that we were almost at the tipping point to achieve the initiation of nuclear fusion that powers the stars. Now we have passed it. We are still some way from seeing the first commercial power plant, but it is clear that we are on our way to achieving what will be the biggest game changer in history: 100% clean, infinite energy.

8. Conclusion

At the beginning of this work we asked ourselves three questions: *What would be the best option for using a car in a sustainable environment?* [1] *Are electric cars the best solution for a pollution-free future?* [2] *Are there any disadvantages in building or marketing electric cars?* [3]

According to our research we have been able to see the different characteristics of each type of car. By informing and analysing it we have observed that at present there is no "IDEAL CAR" for a sustainable environment in Spain. Likewise, we have compared the different types of vehicles, and with the information obtained, we can say which type of car is the most suitable at present to be able to reach a sustainable future. With the current conditions in Spain, we can affirm that the best option for sustainable development is the non-plug-in hybrid car. This, while not the best in all aspects, is the most suitable.

Analysing all types of cars we can see that the gasoline car pollutes a lot and is one of the main causes of global warming. The electric car, as much as it is seen as the perfect car that does not pollute, we know that in its production and in its recharging a lot of energy is spent that gives off much CO_2 emissions that end up polluting more than an ordinary combustion car. As well, it also has very little range and is not unaffordable to a large majority of the population.. So, as much as it appears to be the car to market most today, it is not as good as believed to be. The gas car is also not as sustainable as it seems, since by mixing a combustion engine with a gas engine it still pollutes, you have to invest money in gasoline and gas, and its battery is quite explosive.

Hydrogen, if we look at its characteristics, we can see that it is quite convenient, but currently Spain is not technologically prepared as other countries, and its price is quite high, but in the not too distant future, once the problems are stabilised, it would be the perfect car for the sustainable environment, as it is energy generated by H_2O.

2.
Today, electric cars are sold as the car of the future, the sustainable car, the best car. Nevertheless, after having done some research we can refute this: Even if it does not pollute

while driving, it produces a lot of CO_2 emissions. We know that the batteries have a very short life span, that they can neither be reused or recycled, and that experts are still investigating what to do with them, so this is also a serious problem for the sustainable environment.

We also know its characteristics and we can see that it does not have much autonomy and that the cost of maintaining it is high. Therefore, as we said before, the electric car is not as good as they say it is, and thus to answer the question: No, the electric car is not the best solution for a future without pollution.

3.
Although the electric car seems to be a very good option, it does have many disadvantages. In its production, for example, it releases a lot of CO_2 emissions and its batteries are made of a material that is currently very difficult to obtain, so the price of its production and sale rises constantly. The batteries can no longer be recycled, which causes a lot of pollution, because the material they are made of (lithium) does not self-destruct for 20 to 100 years.

In marketing, there are also several disadvantages: they are sold to you as if they were a sustainable car, and we have seen that they are not as sustainable as they claim to be. Also, people are very concerned about the range, and the electric vehicle has very little range, which makes people overthink its purchase, in addition to its high price.

8.1 Final Conclusion

With all this we would have our final answer to our research. Although there is currently no best car to build a sustainable environment, the most suitable is the conventional hybrid as it reduces environmental impact, there is no need to look for a charging point and the ability to drive electrically over short distances helps to reduce fuel costs.

But when we speak of the ideal car, we are talking about the hydrogen car. Currently Spain is not technologically prepared for these cars, but with the passage of time we will be able to make common use of them, which will solve many problems, one of the most important of which is global warming.

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The Case for Hydrogen and Nuclear Energy in Singapore

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Summary

As climate change predictions grow increasingly severe, the world is scrambling to ramp up climate action, one of the ways to do so being to shift away from carbon-based energy sources to green energy sources. With 95% of Singapore's electricity generated from combustion of natural gas, there is a need for Singapore to look for alternative energy sources to adhere to her climate commitments. This paper examines plans to transition Singapore's energy system away from carbon-based sources and examines the global implications of such a transition. To do so, we analyse existing literature as well as conduct interviews with relevant hydrogen fuel experts, Professor Yeoh Lean Wang and Dr. Jim Huai Chin Lee. We find that looking only towards renewable energy sources for electricity generation would be insufficient to fulfil Singapore's energy demands, and as such to achieve a green energy system Singapore should look to the hydrogen economy, nuclear energy as well as a regional power grid in addition to renewable energy.

Keywords

Sustainable, energy, nuclear, hydrogen, renewable

1 – Introduction

Singapore's electricity generation is currently dominated by fossil fuels. To adhere to climate commitments and progress towards net-zero carbon emissions, Singapore must find cleaner energy sources, to move away from fossil fuels for electricity generation. Currently, 95% of Singapore's electricity is generated using natural gas, the least carbon-heavy fossil fuel [1]. This fuel is imported from Indonesia and Malaysia since Singapore lacks this natural resource. Along with a lack of space, this means that the transition to cleaner energy sources would continue to depend heavily on imports. Singapore's reliance on imports poses a threat to her energy security, which must be considered in evaluating the best plan for transitioning away from fossil fuels.

Another factor to consider is cost. Currently, energy generated from natural gas is still significantly cheaper than renewable sources. Absorbing these costs would strain government finances, while passing them on to consumers would elicit resentment from the populace.

With this in mind, we have chosen to explore three alternatives to carbon-based energy sources: hydrogen, solar energy and nuclear energy.

1.1 Research questions

1. What energy sources does Singapore currently use?
2. How can Singapore transition to renewable energy?
3. What global implications will this transition have?

2 - Literature Review

2.1 The Transition Plan

2.1.1 Existing hydrogen energy systems

Hydrogen is appealing for power generation while lowering carbon emissions, as its combustion does not emit any greenhouse gases. However, unlike coal, gas or oil, hydrogen is not a primary energy source and its role closely mirrors that of electricity as a secondary "energy carrier" which must first be produced using energy from another source and then transported for future use [2].

In hydrogen-based energy systems, there would be four main interdependent stages to be considered: hydrogen production, storage, safety and utilisation [3]. Additionally, as Singapore would be a net hydrogen importer, the infrastructure needed to transport hydrogen would also be a major consideration.

2.1.2 Hydrogen production

The environmental benefits of hydrogen use are heavily dependent on hydrogen production and its carbon emissions. A colour system is used to classify the forms of hydrogen production [3]. Grey hydrogen refers to unclean hydrogen, mainly produced through steam methane reforming (SMR) or cracking of fossil fuels, producing a lot of carbon emissions. SMR is currently the most developed and cheapest commercial method for hydrogen production, and with a significant amount of hydrogen produced this way. Yet, using grey hydrogen for power generation would not help Singapore reach its goal of net-zero carbon emissions.

Blue hydrogen is produced by steam methane reforming or cracking natural gas. However, it utilises carbon capture, utilisation and storage (CCUS) technologies during production to reduce carbon emissions. In theory, this makes it a viable alternative. However, the carbon intensity of blue hydrogen (135-139 g CO_{2eq} /MJ) is not far from grey hydrogen (153 g CO_{2eq} /MJ) [4]. This could be reduced if significant emissions such as those from plant operation are eliminated by using renewable energy [5]. However, there would still be upstream natural gas extraction emissions which cannot be eliminated. Even if emissions from plant operation are removed through use of renewable energy, renewable electricity would be better used to produce green hydrogen through electrolysis [4].

Green hydrogen refers to hydrogen produced using renewable energy. The issues are the cost and availability of renewable energy to power electrolysers. Hence, though not a current reality, its price can compete with blue hydrogen's in ideal scenarios. Cost reductions in renewable energy generation, coupled with more efficient electrolysers and improvements in technology, could potentially push green hydrogen prices down 80%, to below USD 2 per kilogram [6].

Other hydrogen production technologies also exist besides the main three colours of hydrogen, such as pink hydrogen which is produced by nuclear-powered electrolysis, or turquoise hydrogen which is produced through methane pyrolysis. Others use biomass as feedstock. However, most of these methods are either not clean enough to be viable production pathways for low-carbon hydrogen, or have very low efficiencies [3].

2.1.3 Hydrogen transport and storage

Hydrogen can be transported in dedicated pipelines or blended into natural gas pipelines, with estimates saying natural gas pipelines can accommodate up to a 10% blend of hydrogen [7]. However, blending into the existing natural gas network will impact all consumers, so dedicated hydrogen transport is desired [7]. Each method of hydrogen transport has its unique challenges.

If demand exists to transport large quantities of gaseous hydrogen, the next issue is hydrogen embrittlement and leaks [8]. Building new pipelines will also have significant upfront capital costs. In addition, the volumetric energy density (VED) of gaseous hydrogen is very low under normal pressure conditions. Creating such conditions would be impractical [9] since liquid hydrogen (LH_2) has a superior VED, which makes it a more feasible carrier. However, liquefaction costs and power consumption (10 kWh/kg-H_2) along with boil-off losses during delivery pose significant challenges to the use of LH_2 as a carrier for hydrogen [8,10].

There are also other potential carriers for hydrogen, such as methanol, toluene or ammonia. However, though these carriers may be able to more efficiently transport hydrogen, there would also be high costs associated with the synthesis of hydrogen carriers, and the following decomposition to give hydrogen [8]. There will also be inefficiencies and energy required for these processes. In addition, ammonia gas is highly toxic, which represents a safety concern.

2.1.4 Hydrogen utilisation for energy production

There are two main existing methods: hydrogen fuel cells and combined cycle gas turbines. Hydrogen fuel cells are more energy-efficient than gas turbines, but are significantly more expensive, require high-purity hydrogen and are more land-intensive when deployed at scale, making them unsuitable for utility-scale power production at present. Nevertheless, they could be a good solution for low-carbon microgrids and decentralised power generation.

However, combined cycle gas turbines seem to be a more feasible option for power generation using hydrogen soon. Utility-scale natural gas combined with cycle gas turbines that can combust a blend of up to 30-50% hydrogen by volume are already commercially available, and turbines that can combust 100% hydrogen are expected to be commercially available by 2030. Yet, this transition is also expected to require limited retrofits [7].

2.1.5 Safety

Due to its chemical properties, hydrogen can pose significant safety risks. These relate to the properties of materials used to store and transport hydrogen, such as hydrogen embrittlement or permeation, as well as the handling of hydrogen, such as gaseous or LH_2 leakage or hydrogen jet fires. The flammability of hydrogen causes public concern about hydrogen-related hazards, especially considering past catastrophic incidents like the hydrogen explosion at the Fukushima nuclear power plant in 2011 [11]. Hence, increasing operational safety and alleviating the concerns of the public will both be issues if hydrogen is used as a potential energy vector in Singapore.

2.1.6 Nuclear

Nuclear energy systems are appealing due to their self-sustainability in producing low-carbon energy through a chain reaction of nuclear fissions. Nuclear power plants generate heat through fission of Uranium-235 to power turbines for electricity. Currently, around 450 nuclear reactors provide roughly 11% of the world's electricity. Fourth-generation nuclear power refers to a new class of advanced nuclear reactors that are designed to be safer, more efficient, and more sustainable than previous generations of nuclear power plants. These reactors incorporate advanced materials, designs, and cooling systems, and are intended to be more economical, flexible, and scalable than current nuclear technology [12]. High temperature electrolysis and sulfur–iodine cycles are now possible, for the efficient production of hydrogen and the synthesis of carbon-neutral fuels.

Although nuclear power is not renewable, as it relies on a rare, finite source Uranium-235, it is a low-carbon source [13]. Nuclear produces lifetime carbon emissions of 5.1g CO_2eq/kWh, half of wind (12g CO_2eq/kWh) and solar (11g CO_2eq/kWh). Nuclear waste is recyclable, with 95% remaining as pure uranium, along with 1% of actinides, being recyclable as fuel [14]. More than 90% of its potential energy still remain in the fuel, even after five years of operation in a reactor [15].

Nuclear energy has both a high efficiency and capacity factor. Capacity factor refers to the ratio of actual production to the projected amount a plant could produce at peak optimisation. Nuclear energy has a capacity factor of 92.6%, thrice of wind (34.6%) and solar (24.6%) plants [16], due to lower maintenance and longer operational periods between refueling (1.5-2 years), as compared to lack of availability of fuel from solar and wind. Nuclear energy is highly efficient, owing to Generation IV technology allowing new plants to have high efficiency. The thermal efficiency of HTR-PM is about 42% with two reactors, two subcritical steam generators and one steam turbine [17].

2.1.7 Challenges facing adoption of Nuclear Energy

Nuclear radiation is a worry for a large proportion of Singapore citizens. A 2021 study by Nanyang Technological University (NTU) showed that 22% of Singaporeans surveyed were in favor of nuclear energy development [18]. Another NTU study in 2018 showed that survey participants mistakenly perceived that the daily operation of nuclear power plants can emit radiation that harms the environment and public health [19].

However, passive nuclear radiation from working in a nuclear power plant or living around a nuclear power plant is not as dangerous as people think. People living 50 miles from a nuclear power plant would receive an average radiation dose of about 0.01 millirem per year. In comparison, the average person in the United States receives an exposure of 300 millirem per year from natural background sources of radiation [20]. Nuclear energy releases less radiation into the environment than any other major energy source. The worse offender is coal, whose waste concentrates the radioactive uranium and thorium it is composed of.

The real danger of nuclear radiation comes from nuclear meltdowns. Nuclear meltdowns result when cooling systems of nuclear power plants are damaged or fail to operate properly, resulting in the fuel rods overheating and exposing the radioactive material. One notable case is Chernobyl, which faced a steam explosion, killing 2, and 28 more from radiation poisoning, resulting in radioactive contamination in the surrounding area. However, this indicates that even the worst possible accident at a nuclear power plant was far less destructive than other major industrial accidents across the past century. "Measured as early deaths per electricity units produced by the Chernobyl facility (9 years of operation, total electricity production of 36 GWe-years, 31 early deaths) yields 0.86 death/GWe-year)," concludes Zbigniew Jaworowski [21], the former UNSCEAR chairman active during the Chernobyl accident. "This rate is lower than the average fatalities from [accidents involving] a majority of other energy sources. For example, the Chernobyl rate is nine times lower than the death rate from liquefied gas… and 47 times lower than from hydroelectric stations."

2.1.8 Nuclear waste management

Most of the waste (90% of total volume) is composed of only lightly contaminated items, such as tools and work clothing, and contains only 1% of the total radioactivity. In contrast, high-level waste – mostly used nuclear or spent fuel that has been designated as waste from the nuclear reactions – accounts for just 3% of the total volume of waste but contains 95% of the total radioactivity. Approximately 97% of waste – the vast majority (~94%) being uranium – could be used as fuel in certain types of reactors. Recycling has, to date, mostly been focused on the extraction of plutonium and uranium, as these elements can be reused in conventional reactors. This separated plutonium and uranium can subsequently be mixed with fresh uranium and made into new fuel rods [22].

2.1.9 Solar as an unsuitable alternative

Singapore has increased its solar capacity by more than 9 times since 2015 [23]. The Tengah Reservoir contains one of the world's "largest inland floating systems", covering 45 football fields' area. The Singapore Green Plan aims to increase the capacity to 2 Gigawatts by 2030, from the current 630 megawatts. Solar energy has also shown growth in other industries in Singapore, such as being used to power water treatment by the PUB [24]. Though still in early stages, several promising businesses have begun selling solar energy equipment, targeting industrial projects and households.

According to one such firm, Solar AI, adoption of solar panels by households in Singapore is due to a “lack of trust and awareness”, with misconceptions about energy availability during periods with no sunlight (e.g. night time) [25]. It was also attributed to “an expensive and complicated acquisition process”, and the simple reason that most of the population resides in high-rise flats that are unsuitable for a single household to buy solar panels for.

From a policy point of view, solar panels struggle to become commonplace due to significant land constraints and high cloud coverage, along with insufficient battery capacity.

2.2 Global implications

2.2.1 Hydrogen

Given that the use of hydrogen for electricity generation in Singapore will be dependent on imports, it is important to consider the impact of this on the countries we import energy from. For one, we must be sure that the hydrogen imported is produced cleanly. Much of the world’s hydrogen is still produced using fossil fuels, and if Singapore were to import this grey hydrogen for energy production, while Singapore would not produce emissions in combusting the hydrogen for energy, it would be merely outsourcing carbon footprint.

Another debate is whether renewable energy would be better suited to meeting local demand in exporting countries rather than being used to produce green hydrogen for export. Given that there are inefficiencies in using renewable energy to produce green hydrogen, it seems that directly using renewables to replace fossil fuels in local electricity generation would do more to reduce global carbon emissions as opposed to using it to produce green hydrogen for export. Thus, green hydrogen should only be a means to store excess renewable energy.

Finally, the issue of importing hydrogen spawns concerns of energy colonialism. Looking at the EU’s plans for adoption of green hydrogen as an example, most of the green hydrogen they plan to use will be imported from North Africa or the Middle East. However, there are concerns over land and water use, possible ecological damage and energy scarcity that the projects required to generate green hydrogen in exporting countries could cause [26].

2.2.2 Nuclear

The adoption of nuclear technologies in Singapore would depend on not just national but global perceptions on the safety of nuclear technology. With Singapore being a small island state with high population density (8330.64 per km^2), Singapore will likely not be a pioneer of changed public perceptions regarding nuclear technology, due to the major consequence of nuclear meltdowns likely affecting the entire country with a small area of 734.3 km^2. Peter Godfrey, managing director for Asia Pacific at British non-profit Energy Institute, has stated that Singapore "will wait for Europe, it will wait for a lot of other people to get into the nuclear game again, before they jump into it.” [26]. Adoption of nuclear technologies such as small modular reactors or underground reactors will indicate to other countries that existing nuclear technologies are safe enough to be used in more urban areas and that negative public perception can be feasibly changed.

2.2.3 Solar

The widespread adoption of solar in Singapore is unlikely to have a significant on the solar policies of other countries. This is because many other countries have already taken notable steps to encourage and mandate the use of solar energy in a bid to spur a transition to sustainable economies. For example, Japan is making solar panels on new homes and buildings compulsory from

April 2025 [27]. “Solar energy is likely to be the fastest growing energy sub segment in 2023 with demand set to increase 20-30%”, according to Bloomberg Intelligence [28]. Solar power technology has existed since the 1840s [29], and has been around much longer than hydrogen and nuclear energy became commercially viable.

Singapore thus lags in solar energy discourse because of the unique challenges facing it as mentioned in section 2.1. However, if Singapore were to find a significant way to adopt solar energy in its energy makeup, it would pave the way for other countries that also face similar land constraints to do so.

3 – Methodology

To properly assess the feasibility of each solution, we interviewed 2 local sustainability experts, Prof. Yeoh Lean Wang and Doctor Jim Huai-Chin Lee, to gain their perspective on the nuances in implemented such solutions.

Professor Yeoh is the Chief Sustainability Officer of the Agency for Science, Technology and Research (A*STAR) Singapore. As Chief Sustainability Officer, he directs the R&D in energy and environmental sustainability focusing on decarbonisation and sustainable green materials and processes.

Doctor Jim Lee is the Senior Assistant Director in the Office of Sustainability. Dr Lee provides insights and supports researchers in grant proposal planning for Decarbonisation and Hydrogen projects and facilitates stakeholder discussions across the Singapore R&D landscape. Prior to that, Dr Lee was part of the Strategy Management team at ISCEE[2], and oversaw Project and Portfolio Analytics and managed the institute’s Hydrogen Strategy. He played a pivotal role in research in Green Chemistry, Green Processes and Decarbonisation, with special emphasis in Hydrogen and Synthetic Biology. We asked them about the feasibility of each of the 3 approaches, as well as Singapore's future sustainability plans and any potential alternatives.

4 - Analysis of Results

We propose that Singapore transitions to the following energy strategy**:**

- Importing of green hydrogen
- Several nuclear and hydrogen microreactors to supplement supply
- Regional power grid with ASEAN to further diversify renewable energy supply
- Continue to maximise the land area used for solar energy farming

4.1 Singapore’s development and acquisition of alternative energy sources

With renewable energies like solar being the most developed technologies, it makes sense to exploit them as much as Singapore can in the transition to net-zero.

In Singapore, solar is the most promising renewable, and the government aims to hit a 2-gigawatt peak solar production. According to Prof. Yeoh, developments have also been made in the adoption of geothermal energy, as even until very recently researchers have only been able to drill down 1 kilometre into the Earth before facing issues with lubrication of the drilling equipment. However, 4-5 kilometres of depth is required to obtain enough heat for energy generation. Nevertheless, they find potential in several hot springs in the Mandai area. However, even if exploited to the fullest potential, renewable energy alone cannot account for Singapore’s electricity usage.

Nuclear technology is also relatively mature, and the technology makes it possible for Singapore to explore setting up nuclear and hydrogen microreactors for electricity generation locally. However, land constraints will also mean that these will not be able to account for the bulk of electricity generation.

This means that Singapore will have to continue to look to a regional power grid and hydrogen energy as the two sources to address the bulk of our electricity needs while looking to net-zero. While it is debatable which of the two is more cost-effective and feasible, Singapore should be looking to utilise both sources for the sake of energy security. As Singapore will not be self-sufficient in electricity generation, we must rely on diversification to achieve energy security.

Regarding hydrogen, because Singapore does not currently have a viable source of locally-produced renewable energy, the production of green hydrogen is a challenge as renewable energy is a factor of production. Nevertheless, if Singapore were indeed to develop a local source of renewable energy, it would make sense to use that electricity directly, instead of using the energy to produce green hydrogen to then produce electricity again. Therefore, the use of locally-produced green hydrogen, if anything, is limited to niche industrial processes that require hydrogen itself. For example, powering high temperature glass furnaces used in refineries or hydrocarbon production. In these settings, it is unfeasible to use electricity to provide power, but rather hydrogen is a suitable fuel to be burned directly.

The next best alternative, according to Prof. Yeoh, is blue hydrogen which involves capturing, via sequestration, the CO_2 emitted during steam methane reforming. However, this faces a similar hurdle to green hydrogen, as the natural gas fed into steam methane reforming, can instead be burned directly to produce energy and with proper CUSS. It is more efficient to do so rather than using natural gas to produce hydrogen, which is in turn burned to produce electricity. Furthermore, a lot more effort needs to be invested into storing the CO_2

produced to qualify as blue hydrogen. Carbon capture sequestration requires land and oil fields to store for 50 to 100 years, but Singapore's land is in tight supply. In addition, from our literature review, blue hydrogen still carries significant emissions and is not much cleaner compared to natural gas.

As such, Singapore should look to importing green hydrogen from other countries for electricity generation, instead of producing it locally.

4.2 Potential challenges in Singapore's Transition

According to Dr. Lee, it is important for Singapore to consider the monetary costs of its transition. It has to be done without straining government budget.

4.2.1 Nuclear

Currently, implementation of nuclear technology remains unfeasible, due to most prominently a lack of public acceptance.

Prof. Yeoh noted that with the development and increasing usage of Generation 4 nuclear fission reactors with technology such as negative void coefficients as well as high temperature gas that prevents nuclear meltdowns and makes nuclear power plants inherently safe, and thus the safety of nuclear power plants is not an issue. Prof. Yeoh also stated that land constraints are not an issue due to micro power plants being small enough to locate on offshore islands in Singapore.

However, Prof. Yeoh and Dr. Lee has stated that public awareness and acceptance regarding nuclear waste disposal, geo terrorism and nuclear meltdowns are the major issue, referring us to the NTU study [18] on public perception, where only 22% of respondents were accepting of nuclear technology.

4.2.2 Hydrogen

At present, both the production and the transport of hydrogen remains economically unfeasible. As earlier mentioned in the literature review, price of green hydrogen is about USD 10 per kg [6]. This would put costs of hydrogen at more than 10 times the cost of natural gas per unit of energy. In addition, there is also the issue of hydrogen transport, which given the many issues outlined in the literature review above, is likely to be more expensive than the cost of transporting natural gas.

4.2.3 Hydrogen fusion

Hydrogen fusion is a niche technology that recently experienced a breakthrough in its ability to produce a significant amount of energy. However, it remains an unsuitable form of renewable energy because the emissions only last on an order of microseconds and cannot be sustained, making it unfeasible to be applied in the real world. It is also unrealistic to expect any significant changes in fusion technology in the next 50 years.

4.2.4 Solar energy

Prof. Yeoh noted that the application of solar energy in Singapore is severely limited by significant cloud cover resulting in a peak period of 4 hours of sunlight per day. The energy generated is not sufficient to be relied on, however, it is one of the more promising renewable energy sources for Singapore.

4.2.5 Alternative forms of sustainable energy

Prof. Yeoh also mentioned several other forms of sustainable energy that are unsuitable in Singapore, such as wind energy which is generated by harnessing the kinetic energy of wind to spin turbines. However, because the turbines are so large, very wide areas of clear land and field are required – of which Singapore faces severe constraints. Furthermore, sufficiently high wind speeds are necessary, but they only reach a maximum of 7 to 8 ms^{-1} along coastal areas according to Prof. Yeoh, which is not enough for significant energy generation by means of wind.

Hydroelectric energy makes use of running water in streams or rivers to turn electricity turbines. Singapore lacks water bodies that move fast enough, as well as dams to increase water flow.

These insights are supported by those presented by Singapore's Government Technology Agency [30,31].

4.3 Potential mitigations

4.3.1 Hydrogen

In addressing the concerns of technical and economic feasibility with regards to hydrogen, the Singapore government and local energy companies can partner with other countries to explore more economical ways of importing hydrogen as well as continue in research and development of hydrogen technology. Some research suggests that the delivered cost of hydrogen could fall to less than 2 USD per kg, which would make it competitive with current natural gas prices in many places of the world [6, 31]. To this end, some Singaporean companies have already begun to make efforts. For example, City Energy and Senoko Energy, two local energy companies have signed a memorandum of understanding to study the technical feasibility of import and supply of hydrogen to the companies' facilities in Singapore. City Energy is also exploring hydrogen energy opportunities with Petronas, a Malaysian firm.

4.3.2 Nuclear

To address the issue of lacking public acceptance of nuclear technology, Prof. Yeoh notes that Singapore has set up a nuclear institute in the National University of Singapore in 2014, focusing on nuclear safety and public perception, reaching out with local science centers to educate students and locals on the effects of radiation and proper nuclear safety, in hopes that perceptions can shift.

Prof. Yeoh also notes that other countries with similar public awareness programmes have found success, such as a study done in the United Kingdom where public acceptance has increased from 22% to 45% for nuclear technology, and as such Singapore will eventually be able to reach appropriate levels of public awareness, however it would take considerable amounts of time.

5 – Global Implications

5.1 Potential impact of Singapore's Transition on other countries

5.1.1 ASEAN countries

We propose that Singapore sets up a regional power grid with Association of South East Asia Nations (ASEAN) countries in order to capitalise on the geographical advantages of each that allows for specialisation in different renewable energies, as it is difficult for Singapore to produce its own. Hence, greater regional cooperation and coordination are required when trading such a valuable commodity. Infrastructure must be carefully inspected, such as for the repurposing of natural gas pipes between Singapore and other countries to transport hydrogen. Standards to prevent discriminatory or unfair prices for different forms of renewable energy must be agreed upon. Otherwise, the regional power grid would be beneficial in ensuring a diverse and sustainable supply of renewable energy for individual countries.

5.1.2 Venturing beyond Asia

Singapore as a small island state has a significant place in the world economy as a trading port and business hub. As the world, under the UN Sustainability goals, heads towards net-zero systems and renewable energy architectures, Singapore may find a place in facilitating the mobility of renewable factors of energy production between states. Hence, Singapore's transition to renewable energy and in so doing the decarbonisation of its trading and port industry, could be instrumental for other countries to ensure that their production of renewable energy via factor imports is indeed, completely net-zero with a closed carbon loop.

In a similar way, Singapore's transition to renewable energy will aid the Multinational Companies (MNCs) with bases and operations in Singapore to decarbonise too. The implementation of carbon tax and tradeable permits would allow these MNCs to become more profitable while becoming increasingly decarbonised. These strategies could also be adopted in their home countries.

It has also been previously established that Singapore will be a net importer of hydrogen. This would require increasing cooperation with hydrogen-producing countries.

5.2 Proposals to aid other countries towards decarbonised energy systems

Singapore can make use of its research capabilities to develop technologies that can aid other countries in the transition towards decarbonised energy systems. One area which Singapore can contribute to is research regarding CCUS technologies. As mentioned by Prof. Yeoh, two of Singapore's greatest areas of research expertise are in membrane technology and in catalyst development. Singapore can work towards developing membranes that can be used to capture carbon dioxide, which can then be sequestered or utilised, reducing carbon emissions. Singapore can continue its history in developing catalysts that can aid in the conversion of captured carbon dioxide into high value products, such as methanol, to solve the issue of where to store captured carbon dioxide.

In addition, Prof. Yeoh also mentioned that Singapore can continue to encourage and help MNCs with local operations to decarbonise. In helping these MNCs to decarbonise, since their operations are all over the world, we are in effect helping in decarbonisation efforts in other countries.

6 – Limitations

Limitations of Singapore's strategy are that it assumes either technological development or change in global mindsets. As such, the Singapore government posits that 3 different energy scenarios must be accounted for, with differing proportions of carbon-neutral energies employed in each scenario.

The first scenario posits that technology develops rapidly and are cooperated by strong global cooperation. As such, Singapore relies on hydrogen and electricity imports from other countries, with solar and geothermal energy complementing them. However, this assumes global cooperation and willingness to change to carbon-neutral energies, which given current situations is not likely to occur.

The second scenario assumes clean technology advances stagnate, in which Singapore joins a climate action bloc. In this scenario, complete carbon neutrality cannot be achieved, with Singapore continuing to employ natural gas and relying on the purchase of imported electricity.

The last scenario claims that Singapore cannot rely on cooperative mechanisms such as energy imports due to geopolitical fragmentation, and as such initiates its own investments into local decarbonization technologies. This is the only scenario in which Singapore is likely to employ nuclear technology due to its many issues, and relies predominantly on hydrogen technology.

Another limitation of our strategy is our neglect of research into geothermal energy, which Singapore is also considering employing sparingly in its carbon-neutral plan. Geothermal energy only releases trace amounts of carbon dioxide and hydrogen sulphide from geothermal fluids. However, geothermal energy encounters multiple issues such as the reliance on advancements in technology such as carbon sequestration to reach full carbon neutrality as well as Singapore's lack of prominent geothermal sites. However, the Singapore government is expanding its study nationwide for Singapore's deep geothermal resource potential, which can solve the potential issues regarding implementation of geothermal energy usage.

6.1 Limitations of our methodology and study

This study had attempted to conduct a general survey of Singapore's youth population to investigate their perception on the proposed energy transition strategy. It was unfortunately unable to amount to anything significant due to difficulties in gathering survey respondents and obtaining a quality of responses that matched the insights we were trying to convey. This data would have certainly been valuable in aiding in our understanding of the possible ways that this strategy can be adjusted to suit the population.

In addition, scholarly sources and literature on how Singapore should be adopting renewable energy strategies considering sociocultural factors, rather than from a purely scientific point of view, were lacking. Rather, most of this information was obtained from mainstream media sites, and the only expert opinion we could obtain was that from Prof. Yeoh and Dr. Jim. Hence, the insights and strategy proposed in this paper may be limited in this sense.

7 – Conclusion

Our research shows that looking to a wide variety of sources: imported hydrogen, a regional power grid, nuclear energy and renewable energy is what Singapore should do in looking to transition away from carbon-based energy sources. However, the feasibility of imported hydrogen and a regional power grid, which would make up the bulk of a theoretical net-zero electricity generation system in Singapore, are heavily dependent on technological developments, as well as the extent of regional cooperation. Therefore, Singapore must be flexible in its transition away from carbon-based energy sources and be ready to adapt to different developments to decide on the most optimal energy split that is both feasible and works towards its net-zero.

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Appendix: Interview Transcript

Dr Tan	Thank you and so Prof Yeoh don't worry what we are doing is I'll get the students, as per practice, to type out a transcript for you to actually have a look through, and definitely you will have the opportunity to make any changes, edit as that you deem fit. So maybe I can start off by introducing my team of students and what they are doing before I get them to self introduce [themselves]. So basically this is for an international research competition and we are looking to get the youths to be interested in some of the challenging issues of today to try to propose some of the solutions so that it ultimately effect change, and in this TiltShift competition we are getting the students to think about energy, the energy crisis; so they have actually looked at particular areas of energy which later they will share more with you, and we will be using some of these results to actually present at a research competition virtually in October this year and that's set to take place in Australia. So maybe at this point in time can I - I would like to just invite 3 of them to self introduce. So boys go ahead maybe introduce your - you know which level are you at - J1, J2 - and your names. Ya go ahead.
Ethan	I think I'll just go first. Can everyone hear me sorry? ... I'm Ethan and I'm in J1 this year. the subjects I'm taking in school are physics, econ[omic]s and maths.
Joshua	I'm Joshua and I believe I've interviewed both Professor Yeoh and Doctor Jim at the Raffles Science Symposium. Really grateful to be here [and] really nice to see you again.
Prof. Yeoh	Thank you. I think you all are a bit soft can speak up a bit so I can hear you. Go ahead Jeremiah?
Jeremiah	Hi I'm Jeremiah I'm also from J1. [school bell rings]
Prof. Yeoh	Haha school bell
Jeremiah	Ya school bell.
Dr Tan	Uh Jeremiah I think you were cut.
Jeremiah	Yea sorry, sorry it's the school bell. I'm Jeremiah, I'm from J1 as well. Yea that's... yea.
Prof Yeoh	Ok thanks. Ok so I have Jim with ,me I'm also glad that Jim is able to join us today. So (uh) please go ahead and ask questions and I will try my best, and Jim feel free to jump in any time to complement as much as you can. Thank you. Go ahead. how shall we start?
Ethan	So thank you once again for agreeing to help us with this project I think I'll just give some context about the topic first. So our TiltShift project this year - our task is basically to investigate our country's energy system and propose a plan to transition our energy system away from carbon based sources. So for the research we've done so far we've mainly been focusing on hydrogen and nuclear energy. So most of the questions we'll ask today … yea. So I think I'll just start with the first question. So the first question we wanted to ask is, is there any possibility of Singapore producing hydrogen locally for power generation, or if we were to use hydrogen for power generation, would it be totally dependent on imported hydrogen?
Prof Yeoh	Ah depending on what? The last sentence?
Ethan	Depending totally on imports.
Prof Yeoh	On imports. Ok. So um first is that if you want to produce green hydrogen, I think that is what you are looking for, you need renewable [energy] - you need green energy to produce hydrogen. But we don't have a lot of green hydrogen - I mean green renewable [energy]. So solar is the only more promising renewables in Singapore. So if you look around we don't have tidal wave, no geothermal - although [for] geothermal they are trying to study the effects at Mandai1, the hot springs. Recently they actually did some work where they encountered some problems with the coolant (drilling mud) for the drill So I think they managed to drill down to about 1 Kim when they encountered problems. And there's a plan to drill another borehole in Sembawang possibly up to 4 or 5km hoping to get enough heat for energy generation So there is also no wind. Wind - maximum wind speed within Singapore is about 3 metres per second, around the coast will be about 5 metres per second, you talk about offshore island[s] it is probably maybe 5, 5 to 7 or 8 metres per second and wind speed of 3 to 5 metre per second are not good enough to turn turbine[s] effectively. We have one turbine installed at Pulau Semakau... I think it's rotating but I don't think it's generating energy

	cost effectively So we don't [have] hydropower. There's no dam, there's no river the fast flowing rivers so the only that we actually deem more promising is solar but even [if] you talk about solar you know Singapore got 80% cloud cover so the average peak hour - peak sun hour is about 4 hours a day so it's actually quite quite bad lah in the sense from a solar perspective it's quite bad. But we only have solar. The plan is to go up to I think 2 gigawatts of solar and that's all. 2 gigawatt peak of solar and because you only (size) 4 hours a day ah but effective hour is... you have to take the gigawatt and multiply by the number of hours a day to really know how much gigawatt hour of energy you are getting. So it's not a lot of energy you could get from solar in Singapore.. Then for you want to produce green hydrogen if you don't have renewable then it's really a challenge. But the logic is also if I have renewable, then I might as well just use renewable electricity directly use rather than I convert it to hydrogen then I burn hydrogen to produce electricity. Doesn't make sense. So from hydrogen perspective, I would see that if we import green - our strategy is to import green electricity and green hydrogen, then for hydrogen perspective it's we should try to use hydrogen in areas that are actually hard to abate carbon emissions. For example we talk about all they high temperature processes and furnaces for hydrocarbon production or refineries, at this moment, it's still not possible to use electricity to power that kind of high temperature furnaces so we can consider hydrogen as well. So this is where we are now. Ok then uh you asked besides green hydrogen what other alternatives we have - ah - blue hydrogen so blue hydrogen is hydrogen that you produce from other hydrocarbon and you capture the carbon either you store it or convert the CO_2 into useful product. So it is possible for us produce blue hydrogen with the natural gas we imported. Now 95% of our electricity is from natural gas. With natural gas, we can produce hydrogen using a process called methane steam reforming. In the process CO_2 is also produced. So if I can capture the CO_2 then the hydrogen is considered as blue hydrogen. If you ask do we have capacity to do blue hydrogen I think we have.... and the facilities. Our natural gas contains about 70% to 90% of methane. Ok but my counter argument is that why do I produce blue hydrogen and use blue hydrogen when I'm going to burn to produce electricity if I can use natural gas to produce electricity and capture the CO_2. Ok so those are some of the arguments that you have to think through, not just thinking about what's the end product because everyone says hydrogen is a clean energy - when you burn hydrogen you get water then you don't care about the process it takes to direct hydrogen. So you need to think through. If you use methane to reduce blue hydrogen to produce electricity, why not just burn methane directly to produce electricity and capture the CO_2? So if I have a chance at approximating the capture of CO_2 and use methane to generate electricity verses if I have to take methane to produce green - blue hydrogen and then burn, I think the process will consume a lot more comparing to I just burn methane. Ok so that is carbon capture sequestration - means that if I can capture the carbon and I sequestrate it means that I find oil field, means that I store - you will store for 50 years 100 years you can store it forever that is one of the things. So you look at Singapore it will be a land constraint. We don't have oil field, empty oil field to store so if we have to do that then we have to commemorate other countries send the CO_2 somewhere else to [be] sequestrated. (what I am trying to say here is that since we don't have much land space or oil fields to store CO_2, the other alternative is to convert the CO_2 to high value product such as sustainable aviation fuel or methanol) But there is recently a new thinking from the industry to say that instead of I pay to store my CO_2 somewhere else why don't I take the CO_2 and generate revenue to produce high value products. I take CO_2 to produce sustainable aviation fuel which will help to decarbonise the aviation industry, I can convert CO_2 to methanol - methanol is the one of the fuel for the maritime industry so the maritime is looking at methanol, ammonia as two possible fuels for... methanol you have to make sure it is green methanol. Green means in a

	sense that if I burn methanol I must be able to capture the CO_2 and close the CO_2 loop. Ok so those are the some of the considerations that when you really want to think of hydrogen as a clean energy think about all the different consequences the process that you need to get there... produce green hydrogen. Another alternative that we can produce green hydrogen is I mean uh blue hydrogen before we call steam reforming. Means that the natural gas we crack it to produce solid carbon as well as hydrogen. This is good in the sense that now I don't have to separate hydrogen from the CO_2 because solid carbon is not the gaseous form so there's separate them much better in the sense that the whole process of producing hydrogen will be cleaner alternative way to produce blue hydrogen methane. It is called methane pyrolysis or methane cracking where we use high temperature to crack the methane to produce H_2 and solid carbon. In this case, there will not be any CO_2 emitted to the atmosphere. So this are examples I think if we look at blue hydrogen I think that probably we can do that but having said that the long term plan is for us to also phase out natural gas to work towards green electricity and green hydrogen. So the long term plan is for us to phase out natural gas, so the pit stop is to produce blue hydrogen will not be there so these are some of the considerations that when we talk about using green hydrogen as a fuel for green energy in Singapore. We need to think of this whole plan in totality - make sure that we don't say that we don't use natural gas to produce hydrogen but you know in the long run we are not going to continue to use natural gas. There is a progressive step to also phase out natural gas. Ok ya so I stop here - Jim you got anything to add please feel free.
Dr Jim	Yup sure thank you Prof Yeoh, and of course I maybe just to add on, I think there was a you know maybe - maybe there's a lot of sort of I guess talks on you know what are the different colours of hydrogen right, so you know I think Prof Yeoh mentioned about the blue hydrogen - which is basically you know the steam methane reformed with the CCUS. And then you have the turquoise hydrogen which is basically the methane cracking or the methane pyrolysis. Now the difference between those two is basically the presence of oxygen which they methane cracking does not have - so there's no chance of generating oxygen but just a fine point is that even though you don't generate the carbon dioxide, the challenge - what are the challenges which our scientists are trying to solve at the moment, is what do you do with the carbon. Of course, depending on the approach that you take you could generate different qualities of carbon from - basically you know the pretty standard carbon black which doesn't get you a lot of value, or the other approach would be looking at things such as graphite or graphene, some of the more high value carbon forms. So this is what I think scientists in the field are trying to work on at the moment, and if I recall correctly right now if you look at the prices between steam methane reform and CCUS, turquoise or methane cracking and electrolysis - there are 3 different colours right the blue, the turquoise and the green and you could say maybe in sequence of which one is greener right based on colours - well the SMR one with CCUS project price at 2050 is about \$2.19 right, as methane pyrolysis is closer to 3 dollars and electrolysis of course that one takes you know a little bit more energy and or high tech approach – that's actually about 3 point 8 dollars. So you know besides talking about how potentially green and simple it is for a particular country and just as Prof Yeoh mentioned you know green electricity is needed for some of these options - sometimes the costs will need to be considered as well. Thanks boys.
Prof. Yeoh	Ok there is also pink hydrogen did you mention? Thats by nuclear.
Dr. Jim	Yes, yea
Prof. Yeoh	Ya and any questions please go and that ask.
Dr. Tan	Jeremiah or Joshua maybe this is an opportune time to bring in your nuclear questions or questions about nuclear energy.
Prof. Yeoh	Ok. You asking about whether it's feasible to do nuclear in Singapore?
Dr. Tan	Ah yes they have some questions about nuclear Energy maybe they can ask.
Prof. Yeoh	Yes please go ahead.
Joshua	Hi if you don't mind I think I'll ask about nuclear energy. This is more specifically to the fusion and fission technology. So given recent breakthroughs in hydrogen fusion

	technology, how long do you think it will take for fusion technology to become viable and readily accessibly and will there be any potential safety concerns similar to nuclear fusion?
Prof. Yeoh	Ok you are talking about fusion right? Fusion.
Joshua	Yea, fusion
Prof. Yeoh	Ok so fusion they the joke is that they always say it's 50 years. So today if you ask they say it's 50 years from now, tomorrow you ask it's 50 years, 10 years later you ask it's also 50 years. The reason is because I think it's very difficult to get an ignition. So when you put deuterium and tritium together to fuse to get you find that it's very difficult to sustain the ignition, so that's the greatest challenge that the fusion community is taking care so that is one part. Second part is that even if you can sustain that, how [will] you bring the [heat out], that means how you conduct the heat out you produce because if you put in the tokamak machine – it is actually, in the sense that it is within the containment [parameters], somehow you bring the heat out that is generated. So these are the 2 challenges. Of course the greatest challenge is sustaining the ignition, that one is the most difficult and then there are a lot of experiments done in China, US and Europe in various fronts of the work and most of them when they say they have managed to sustain the ignition - most of them is they don't use tritium because tritium firstly is radioactive it is difficult to produce, they need to generate tritium on the fly so the actual sustaining of the emissions is still on order of microseconds, milliseconds, nanoseconds so it's still quite impossible but recently there has been more companies want to give back to Commonwealth Fusion. Commonwealth Fusion is a spinoff from MIT and they are able to use high temperature superconductor to generate very strong magnetic field so if I can generate strong magnetic field it means that I can make my tokamak smaller, because high magnetic field if can make it smaller it means that it's easier to control in that sense so making it smaller means that what they are trying to do is, that they think they can control the plasma for this factor - and in the eyes of Commonwealth Fusion you talk to the CEP they will tell you that it can commercialise this within 15 years - that was 3 years ago so now it's 12 years ah you ask me whether it's a realistic time frame, actually I'm quite doubtful because there's still a lot of challenges of fusion. There are many issues that need to be resolved. Researchers are always more optimistic because they need to get venture capitalist to fund them. So firstly to sustain emissions that's one. The other thing is that because if you are subjected to so high magnetic fields, the force is going to be quite big and if you have an asymmetric shield in the plasma, the magnetic field big and so the containment becomes a problem - how to design the containment [becomes an issue]. The other thing is also because when you talk about all this plasma, there is a lot of neutrons that will actually cause damage to the metal. So what they do is that one of the metals they are looking at is tungsten. Tungsten also has issues with maintaining the plasma at that temperature. I mean although I felt that there are few companies out there that are trying to push [through], I mean smaller companies trying to push for better progress compared to ITER. You know ITER is the [most established] company that has started working many years ago and so far they are still making progress, but of course there are different schools of thought people think either is succinct, faster some people think that commonwealth fusion. So the jury is still out there. if you think whether is it 15 years I'm quite doubtful I think 30 years and you all want to build something that [can be mass-produced]. So this is limited knowledge on my end, I have visited [reactors that use] fusion, so this are some of the discussions that I had, there are of course the researchers are optimistic for a few reasons, 1 is that you need to get funding, so optimism helps reach out to better companies to get funding, therefore i think there's always good reason to be optimistic and push for success. But of course, there are physical limitations, when I say theoretical limitations, you need to overcome before you are able to achieve fusion. Whether there is any risk for fusion, there is still radiation, but i think it's not as dangerous as fission if there is a meltdown, for fission, if there is a meltdown, there is a lot radiation that we are looking at, whereas for fusion, tritium [is released].
Dr Jim	Think about that maybe just, you know, a short comment. So, you know, we're always

	happy to see, I noticed this, you know, a lot of these different variety of questions. And we always encourage people to, you know, continue that line of questions and think further ahead. So that you try to cover all bases and all aspects, not just technology, but sometimes, in terms of finance. And also, I think, when, you know, for example, public acceptance and awareness is also very important, especially on the topic of nuclear energy, because, you know, as the usual things when they say, you know, what we do with the nuclear waste, or what about Geo terrorist, terrorism. And I think NTU recently done a study, and I think the general consensus, they had a few focus groups, so, participant ranging from 18 to 69, in terms of age, so, it's a wide range of participants and the general feedback, and the study showed that people are still reluctant and unaccepting of nuclear technology. So I think one of the findings suggested that it will take a long time, of course, for the technology to develop, but that's also kind of the silver lining, and that this is also ample time for us and for you all, if you potentially want to venture into technology development or elsewhere. That, you know, raising public awareness to know what is the current state of the art, what are concerns? What are the mitigation plans I can put in place, right? So that you know that you're not only developing technology, but also prepare the public for the [technological] acceptance, or even in some cases, for example, in, you know, technology systems, recycling, or sustainable materials, user compliance is that's also very important in terms of developing a solution that is fully sustainable, because you want everyone to be able to utilize it correctly. But that's just one sure problem
Prof Yeoh	Okay, so we will talk about recent, I think, although there's a lot of concern. But you are maybe aware that fourth generation (Gen IV) kind of reactors that are inherently safe. I'll give you an example, Tsinghua University has been working on high temperature gas cooled reactor (HTGR). HTGR Is operational ah Shangdong, Shi Dao Bay, they have 210 megawatt electric turbine driven by 2 250MW thermal HGTR reactors.. They claim. In fact, they're tested in many times and Qing Hua university that they will purposely have an overheating once they are overheating what they need to do is shut it down and then go back the next day they come back to work it is operating safely. So, so, this is a kind of inherent safety. What happened is that, firstly, they operate at 800 - 900 degrees but the uranium they encapsulated in Silicon Carbide and insulated can withstand up to 1600 degrees. So, because you operate at 800 degrees it will never reach 1600 Then you'll never have meltdown. and they also put in what we call negative temperature coefficient whereby when the temperature, the neutrons become erratic and the reactivity decrease. you need to have neutrons to collide with the uranium atom to create the speed. At a certain speed if the temperature is too high, it will become erratic, there will be no collision and there will be no fission. temperature and the reaction comes down the temperature come down. So, this is what we call a negative temperature coefficient, it is for safety. So those are some of the things that they put in place. The other thing is that because they operate at 200 mega watt of core reactor, it means that should be an overheat and meltdown. They can get rid of the decayed heat by natural ventilation, so, they don't need forced ventilation whereby all the fans, the generator that responsible for the cooling gets flooded as a result. So, those are some of the advances in fission is already happening it's already been deployed operational in China, talking about Gen 4 reactors.
Jeremiah	Hi, my next question is How realistic is it for Singapore to have any form of nuclear generation power whether it be from like a one large nuclear generator or even merely several small micro reactors
Prof Yeoh	As mentioned earlier but the technology's already here as far as the nuclear fission. The most challenging is public acceptance. We set up a nuclear institute in NUS in 2014, i was the one who set it up and we focus on nuclear safety cause we want to make sure we understand nuclear safety, has to be when we or even our neighbouring countries would adopted nuclear fission as one of the ways of power we would be in the position to evaluate the safety considerations, and put in all the safety measures to prevent nuclear meltdown. So, the biggest challenge is public acceptance, the Institute has reached out to Science Centre to help reach out to the students, to the educate the students on the effects of radiation. So, it basically is to explain that, yes nuclear is not properly managed can be quite bad, should there be a meltdown that the consequences can be bad but if you understand radiation, understand how nuclear power operate, increasingly we hope to educate the public.

	I think in order for Singapore reach net zero in 2050, there is already the 2050 committee report that was published has openly stated that Singapore will consider nuclear fission as one of the solutions, and so we cannot rule out that nuclear will be one of our main energy because in the long run if you have reach net zero after looking at all the options of decarbonisation, and clean energy factor like hydrogen, wind, we have to consider nuclear as one of our option. But I say, the most important now is to educate the public to understand, and then there's public acceptance. And there was study UK, like, if they have this kind of public awareness program, the public acceptance has increased by 22%, up to 45%, as a result of this public awareness program, so, so these are things that we try to also learn from, at least at UK, Korea, Japan, how they manage, it will take time.
Joshua	Okay, thanks. Thanks for that was a pretty good, pretty good answer, I guess a good summary about how like the only issue we're facing right now is public perception. We're also thinking about maybe the possibility of having a regional power grid with ASEAN nations. So a regional power grid, maybe just each country produce their own energy and share with each other. There's obviously going to be the commercial aspect, but we wanted to kind of understand a bit better what might the political or economic implications of such a system.
Prof Yeoh	okay, you're talking about the regional grid and what are the challenges? Okay, I think this is definitely a good idea, the power grid, whereby you can share power, help out each other in the event of any failure. Having a regional power grid is always, I mean, technically is a good idea. There is always also concern about energy security, if they are not self sufficient. What if our power grid is cut? So I think the other consideration though, I would advocate using a power grid should be one of the solution. But we should not totally rely. So therefore, Singapore, you look at our long term energy transition strategy, regional power grids is one solution, but in addition to that, they will bring electricity, will important green hydrogen, we look at design, long term battery backups, we make sure that we have renewable energy and so on. So the whole process, the whole idea is energy security. Because we don't have self sufficiency, Singapore relies on diversification as we diversify our sources of supply, so that should one of the sources cut off, they'll still have the rest to rely on. So when I say support, so we buy green hydrogen, then you can look at multiple sources. Look at Middle East, look at Chile, you look at Australia, even Indonesia, and Malaysia. So those are countries that have enough renewable energy to produce green hydrogen. so I wouldn't say that regional power grid is not a solution, it is one of them. But the whole issue of energy security is about diversification of sources. Similarly you look at our energy, our natural gas, it is so we reached out to different countries so that diversification of sources.
Jeremiah	Yeah, sorry. Considering that other countries such as like the UK and Korea and Japan, as you have previously stated have a lot like, more like, I guess progressive in a sense, public perceptions on nuclear energy, as well as considering Singapore's land constraints, Is it possible for Singapore to directly outsource, by like, I guess funding and building nuclear power plants in maybe less land constrained and maybe more accepting countries? And then directly send the power back over to Singapore for Singapore's use would that will be realistic in any way
Prof Yeoh	Yeah, I think ultimately is all about cost effectiveness. Cost Effectiveness means that if let's say if I do it somewhere else, then I send it back to Singapore, you have to take into consideration the costs of making submarine cables, the losses involved. So the technical feasibility pats need to be looked into. They were looking at having a solar farm Australia, and then they lay undersea cable from Australia, all the way to Singapore, to deliver electricity to Singapore. I think somehow the deal didn't get through, internally there were disagreement in terms of costing and profitability. Therefore, I think when you want to look at having remote sources, being able to export energy to Singapore, it is all about technical feasibility. It's all about costs, because costs are just always a factor when we talk about feasibility. Therefore, unless you can find cost effective solution. These are all the options because it's not new. Australia has considered that using cables. They have also considered. What if I take solar energy to produce hydrogen? Convert it into hydrogen carrier, either ammonia or MCH, that's another carrier such that you can bring it to Singapore. So these are some of the cost effectiveness considerations. To find a solution.

Dr Jim	and if I may just quickly add on, I think that, you know, what Prof Yeoh and also what Joshua asks, right. About the regional, the regional grid, actually, you know, we already doing that, in fact, I think last year in June, there's already been a trial, right, which is the, which is the Laos, Thailand, Malaysia, Singapore regional power grid. They've actually trial [it], I think it basically they generate electricity from hydropower. So from a dam in Laos, that they utilize the power grids in both Thailand and Malaysia, to pipe the electricity to Singapore, which is what the validating 2000 kilometres in terms of the total distance. So right from that, I think 100 megawatts, right. And I think in the target for 2050, for the regional power grid, right, the Singapore target, which is basically the 2050 target is about 4.5 gigawatts of electricity. So hopefully, they can then, you know, meet a portion or of the energy mix in Singapore, which I think by that time they estimated to be about I think, a terawatt hour. Today, energy demand, but in total, so that's, that's, that's one of the scenarios in which, you know, we can have a good energy mix. And of course, that's also one of the key focuses right now on to the strategy of Singapore. Obviously, we were always looking out for new potential technology, hence why the Prof Yeoh mentioned about the geothermal. So people try to exploit it and again, right now they're also saying based on the study they've done, they also say the same thing. It's all about the costs as well because right now it's not really cost effective, and researchers are currently working on that.
Joshua	Like what is Singapore's role in this global effort?
Prof Yeoh	Okay, can you repeat your question? I didn't get, how can Singapore help?
Joshua	How can Singapore help other countries in their transition to renewable energy?
Prof Yeoh	And then, second question?
Joshua	Another question would be, what would be the impact of Singapore's transition on other countries.
Prof Yeoh	Okay, how Singapore can help other countries, I think what is important is our research capability. We did very good research in our membrane, when we had our water issue, we did R&D in membranes so that we use the reverse osmosis method to actually, do our water treatment to get NEWater. As a result of this, we have expertise in membrane R&D. And the spin-off is that now, instead of having membrane that can filter off minerals, we can now use membranes to filter off carbon dioxide for example. So, this is what we are doing now that we actually use the membrane now to carbon capture, to capture carbon so that we can take the carbon dioxide to either sequester it or make it into useful product, so that's one. The other area that we, we do well is in catalyst development. We have a long history in catalyst development. Why catalysts are important, is when we want to do carbon dioxide conversion to high value product. So we started 10 years ago to design carbon dioxide [catalyst] and this has been operationalized, commercialized in Japan. It took us 10 years to design catalyst, that can have a yield of more than 95%, if I'm not wrong, it's gone up to 99%. I think there's 95% [at] commercial scale. Then recently, we apply automation, AI machine learning to do catalyst optimization. So, if you go to Jurong Island in our lab, in our Institute of sustainability for chemical energy and environment, we actually have a system whereby we, we can do catalyst synthesis on a 16 channel, automatically, and we can run the tests 16 channel at one time 24 [hours] by seven [days a week]. So, as a result of doing this now, we can optimize the catalyst five times faster. So, when we used to do carbon dioxide to methane, it took us 10 years. Now, we do carbon dioxide to methanol it only took us two years. So, this is a kind of capability we have in Singapore. So, when ExxonMobil they actually came to Singapore to set up what they call Singapore energy centre. So I asked them what why did you come to Singapore? The engineer told me that because we have world class membrane and we have world class catalyst research here, that's why they think they can do this carbon dioxide to x, I mean the high value product. We can, if we can do this, we can capture carbon dioxide we can do carbon dioxide to x, it means that we are able to close the carbon loop, closing the carbon loop means every time you burn carbon dioxide you capture it, convert to high value product as burn it you capture, as long as you close the carbon loop, You will not generate extra carbon dioxide. Keep the carbon dioxide [and] you will not heat up the environment. So we think that our membrane and our catalyst environment can share with whatever company, countries that actually need to develop CCUS that means carbon capture utilization and sequestration technology to decarbonize. Then, what's the impact? In fact, the impact, for us to be able to well, is always positive in the sense that it helps neighbouring country to decarbonise. So

	the main thing now is that our focus now is to make sure that we also help the MNCs in Singapore to decarbonise. Look at Jurong Island itself we have the, more than 40 percent of greenhouse gases actually come from Jurong Island, from the industry. Therefore, if I can decarbonize the industry in Jurong Island we have won a big step in reaching towards net-zero for Singapore. So this impact is significant in the sense that if I help the MNCs, if I help the SMEs to decarbonize, we will also help them to reduce their carbon tax, when we help them reduce the carbon tax means that we will become more profitable, operating [incentive] to decarbonize Singapore, so this is, I see that we are creating a positive impact, not only neighbouring country, but globally. Because for these MNCs, their operation is all over the world, so if we can find solution for them, we will actually to a large effect help them to decarbonize, and then they can become more profitable because they don't pay a lot of carbon tax. Over to you. Jim, feel free to add if there's anything that, your views, your opinion or how we can do better?
Dr Jim	Yeah I think Prof Yeoh covered it very nicely maybe just, you know, some small points on, you know, the hydrogen sort of demands in the mix. So I, as you know, right, hydrogen doesn't just, you know, come in terms of hydrogen, there is a little potential hydrogen carriers, for example, by price or profit mentioned, there's methanol, right there is also ammonia, which, which can be, you know, a little bit more, it takes a bit more caution to utilize it, but it has tremendous potential. Right and, of course, there's also the hydrogen in terms of its liquid form but that takes a little bit of energy, and also that has another set of challenge, which is the boil off rate that you need to control, which is about 1% leakage per day, which then also, you know, brings, you know, brings up the issue that Prof Yeoh mentioned is about the unintended consequences of using something that's seemingly sustainable, which is hydrogen leaking into the atmosphere that causes, you know, more and more global warming than [being a sustainable energy source]. So, in terms of the use of hydrogen, right, you know, basically you need to think about which sector would demand it more, for example, maritime, right, right now, I think, out of 1000 orders of new ships that's been built, right, only 11 of them are based on methanol, but the majority of the base, they call it the alternative fuels are actually still LNG based, or their LNG, but they're still natural fuels. So you know, that's one challenge there. For aviation, they're talking about sustainable aviation fuel, which you can make based on you know, using you know, carbon dioxide has been captured. So basically the CCUS and upgraded to, to be sustainable aviation fuel versus hydrogen, but then hydrogen because they are in density, you'd probably be thinking about four times the volume there, right? So that might not be a good choice, because you'd also have to redesign the airplane. But also you need to think about ways to produce the hydrogen, do you produce it right next to the airport, but then that also has safety considerations as well right?. So, there's a lot to think about when we, when you want to get to the new technologies. Not only is it feasible, but Technology, technically, technically feasible, but you also want to talk about the cost, as well. Right? And of course, there's also the safety consideration, too. So, you know, I think like I mentioned earlier on, right, we were really happy to hear the line of questions that you've come up with, but we definitely encourage you to think further with the questions that you ask. So that's all from my side, over to you
Prof Yeoh	Yeah, yeah okay thanks. So I think, now looking at it safety consideration is one of the key issue on our mind, to make sure that if I bring in new energy vector, safety must be one of the considerations, because even you've talked about now, you are saying that, I want to consider ammonia as one of the hydrogen carrier, because if I produce hydrogen somewhere else, how to bring it to Singapore, what they do is that they convert it to ammonia and then ship ammonia to Singapore. And then in Singapore, if I want to [produce] hydrogen, I crack the ammonia to become hydrogen. But you know, ammonia is very toxic. So people are very concerned about ammonia gas is very toxic. 35 parts per million is a lethal dose, if you inhale it for like 15 minutes you die. So that's, that's why. So ammonia is very toxic. Then you will ask yourself, when I bring ammonia to Singapore, if I take ammonia, I burn ammonia to produce electricity, versus I take ammonia, I crack ammonia to produce hydrogen to burn to produce electricity the amount of electricity is the same but I put in more energy to crack. Because for every time, if you calculate the formula for every ton of ammonia you only have 176 kg of hydrogen. So I take one ton I cracked it, I have only 176, the amount of energy 176 produce versus I use one ton ammonia without cracking, it's the same, it's the same energy you do some calculation you'll find that it's about the same. One kg of hydrogen is approximately 30 to 33 kilowatt hours. You

	calculate you will know that. So does it make sense to take ammonia and crack it to produce hydrogen? So these are some of the considerations that we are thinking about. Then ammonia, now we look at the standard for just the cloud dispersion is 10km safety zone, so 10km for Singapore you have one ammonia storage, you have to sanitize 10 km, I think it's very, very, land constraint. So this is where we are funding researchers to do research, how can I reduce my safety zone and yet not compromising? This is something that we're doing now. And one thing I've been, off my mind I think is how about using water, means every time should there be a leakage, if I have water, ammonia dissolves very quickly to become ammonium hydroxide, then it's no longer toxic, it doesn't go into the air and cause all this lethal dosage, the toxicity. So that is something you have to think about. You'll be surprised that Singapore may be able to come up with a better solution. I give you an example, when we started our underground ammo base in Mandai and we, if we adopted NATO standard for safety for sterilization of the land, we would not be able to implement in Singapore because the amount of land that you need to sterilise is a lot right. So, we did our own study, DSTA and MINDEF did our own study. We do our own simulation, we actually do blast test in Sweden to test all the safety consideration, and then we managed to reduce the safety zone from 240 hectares down to 130. So that is 2.54 times safety zone, and because of that, we move our ammo dump from Seletar airbase to this underground, we save 1000 hectares of land. So this is the type of value add our researchers did. And after we did that, we take our standard and all our data, we went to NATO to tell them we have done this. And now, you know, our standard has been accepted by NATO, for safety zone. So I'm saying that when you challenge the researcher. You will be surprised that they can actually do fabulous things and they can come up with good solutions. So, this is what we want to do the lesson from the ammo base, we are challenging now our researchers.
Joshua	saying that I've definitely learned a lot. I'm amazed by expertise that Professor Yeoh and Dr Jim have shown. I'm very, very grateful for this. Learnt so much for not just the chemistry, the science side of things, but also political, economic, social concerns surrounding renewable energy. And I went in thinking that, you know, hydrogen was the answer. But now I've come to see the merits of nuclear energy, solar energy, I've seen the constraints of hydrogen energy never realized that it's not as simple as we think, it really isn't as simple. So I'm really grateful. Thank you for coming down and enlightening us today. I'm sure that this time that we've had while aid our research a lot, and it certainly has value added quite a bit. So I'm looking forward to getting down to the analysis and writing the report, and we'll be sure to send it to you, as well. Thank you so much.
Prof Yeoh	Okay, before that I forgot something that I wanted to share with you. You know, if you, the Chinese are operating the high temperature gas pool at 800-900 degrees. If you operate at that kind of temperature, let's say 900 to 1000 degrees, you can use that heat to split water, and produce hydrogen for free. So this one must remember, that next time if we ever have a high-temperature gas cooling reactor in Singapore, we can have the best of both worlds, we can have green electricity, and then split the hydrogen, uh the water into hydrogen and oxygen and we can get the green hydrogen for free, so food for thought.
Dr Tan	That's amazing. Thank you so much for all the inspiring stories. I think I would not have read this in any textbook. I mean, suffice to say that my students and I, we are humbled by all the sharing by Jim and Prof Yeoh, and I hope that my students I mean, as young champions can continue to actually effect more change, especially with their generation continuing to advocate for things that they strongly believe in specifically for this area of alternative sources of energy. Let us go back and we will give this much food for thought and then we will wrap this up and we will actually give you some of the materials that we have prepared for your reference. Thank you so much for your time we have actually exceeded by a bit. So thank you for your generosity in sharing and for your time. And boys can we just say thank you to Jim and Prof Yeoh. Have a good weekend ahead, thank you

~ End

Austria's use of Architecture in Contribution to the Energy Transition and its Application to Conversion of Energy Inefficient Buildings

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Summary

This paper provides an overview of Austria's Energy System in the context of the ongoing global Energy Transition, with a specific focus on sustainable building practices and the conversion of old buildings in relation to monument protection in Austria. Vienna, located in central Europe, boasts a cityscape characterized by old buildings, many of which are not environmentally friendly, for example due to their reliance on oil heaters.

In this project case studies of innovative houses are presented, examining the materials used and assessing their sustainability. Our objective is to analyze the differences between old and new buildings and explore potential modifications that could enhance the sustainability of the older structures while respecting monument protection guidelines. These changes could influence Austria's energy system, allowing the country to focus more on the transition towards renewable energy sources.

Currently, Austria heavily relies on oil and natural gas imports in its energy system. However, by implementing the suggestions outlined in this study, Austria could prioritize in more environmentally friendly energy sources. These areas represent significant opportunities for improvement in Austria's energy sector. The aim is to compare Austria's energy system with those of other countries worldwide, drawing inspiration and seeking opportunities for adaptation and improvement.

Key Words

Austria, Sustainable Building, Monument Protection, Conversion of old Buildings, Green Alternatives

1 Introduction

Vienna, Austria is known for its beautiful historic architecture. However, these old buildings pose challenges for the environment and sustainable renovations. Many of these structures heavily rely on unsustainable heating methods, contributing to Austria's energy system predominantly fueled by oil and gas. By transforming aging buildings into eco-friendly homes and constructing new sustainable houses, Austria can gradually shift its energy system, reducing emissions and energy consumption. These changes will play a crucial role in the global fight against climate change, benefiting Austria and beyond.

2 Austria's Energy System

The majority of all the energy produced in Austria (domestic production) constitutes of biogenic energy sources and hydropower. While biogenic energy sources and hydropower account for respectively 47.7 and 26.5 percent of the overall energy produced in Austria, ambient heat takes up a minority of 5.1 percent whereas 5.3 percent consist of combustible waste. Furthermore, 4,6 percent of produced energy is composed of wind energy. In addition, gas and oil, obtained from domestic production amount to 4,5 percent each. Lastly, Photovoltaic takes up 1,9 percent of Austria's energy production.

Austria's gross domestic energy consumption consists mainly of oil, as, biogenic energy, hydropower and wind. Compared with the EU average it is very similar in terms of oil, gas and ambient heat. The differences lie in nuclear energy, which is not produced in Austria and hydro power, which is more represented in Austria. Hydropower constitutes a significant part of Austria's energy production, being both 100% CO2 neutral and non-volatile. Its contribution is bolstered by Austria's abundance of water bodies, which can be harnessed to generate energy. [1]

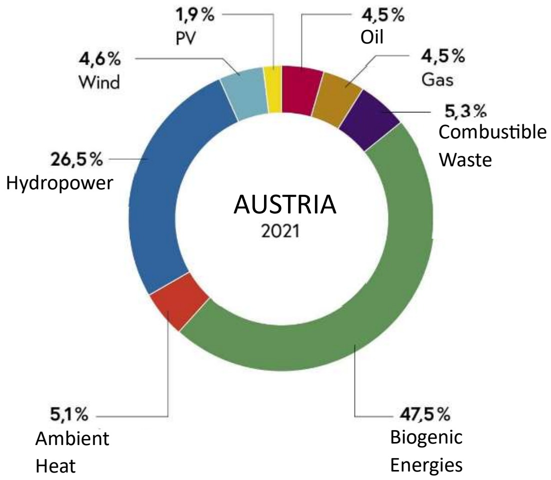

Figure 1: Primary Energy Generation in Austria

3 Sustainable Building

This chapter highlights the influence of architecture on climate change, while presenting both benefits and challenges of sustainable construction and furthermore including estimated costs. Case studies, where challenges of green building sector were successfully overcome, are analyzed in the end of the section.

3.1 The Influence of Architecture on Climate Change

According to the OECD, the building sector accounted for 25 to 40 percent of final energy consumption in OECD member states, including Austria, until 2006. A significant portion of this energy is utilized for heating and cooling systems in residential buildings. Numerous sources suggest that approximately 30% of energy is wasted during periods of air conditioning usage due to, for example, improperly maintained windows. Additionally, a substantial amount of energy is expended in constructing new, unsustainable homes [2].

highlight the adverse impacts of construction at both local and global levels. Local impacts include pollution such as noise, dust, and odours. On a global scale, construction contributes to climate change and ecosystem alterations, with global warming being one of the consequences [3]

3.2 Benefits and Challenges of Sustainable Construction and Design

According to C. S. Hayles and T. Kooloos [2], the advantages of sustainable construction outweigh the negative aspects. Green buildings offer various benefits, including direct economic advantages, indirect social and psychological benefits, like the impact of mental conditions including depression and anxiety or the less polluted air, that might help people with spending time outdoors, and environmental benefits [6]. It is worth noting that incorporating green principles during the construction of a new building can result in 40% greater savings and performance compared to retrofitting green technology into an existing traditional facility [7]. Additionally, green building projects often cost less than demolition projects when considering material sales and savings from avoiding landfill. Improving a building's thermal properties can lead to reduced consumption, lower costs, and decreased CO2 emissions. Moreover, lower CO2 emissions can result in reduced CO2 taxes. Another benefit associated with green houses is the lower energy costs.

However, sustainable building also presents challenges. The initial construction process may incur higher costs, although long-term benefits offset this. Acquiring the necessary knowledge and dealing with complexities can pose complications in designing and constructing a new green house. Some materials for sustainable buildings may be challenging to source, and integrating certain technologies into the house can require specialized labor.

3.3 Costs

There is a prevalent perception that sustainable houses come with a higher price tag than what the market is willing to pay, but this is often not the case [4]. This misconception is attributed to the lack of accurate, comprehensive, and quantifiable information regarding the financial and economic impacts of high-performance buildings. A recent report conducted by the Rocky Mountain Institute provided an estimated cost range for sustainable houses, ranging from \$26 000 to \$240 000 [8]. Approximately 60% of the total cost is allocated to the construction of the house, encompassing raw materials, internal appliances, and finishes.

Green houses contribute to reduced daily energy consumption for their owners. To achieve this, energy-saving appliances are typically installed in these houses. Although these appliances may have higher upfront costs, the long-term effect is a significant reduction in energy bills, ultimately making the overall cost of the house more affordable.

3.4 Location and Placement

Location plays a crucial role in constructing a sustainable house. It is essential to determine the precise placement of the house to maximize the utilization of natural heat sources like sunlight. Without adequate tree cover, certain rooms may become excessively hot, while a lack of south-facing windows can result in insufficient or no heat reaching certain rooms.

Internal air temperatures in a sustainable house can also vary. These houses harness natural heat from the sun, which can make it challenging to regulate the internal temperature effectively. Some rooms may be warmer in the morning, while others may experience warmth in the evening. Additionally, these temperature variations differ between summer and winter. Living in areas with significant temperature fluctuations can pose issues in maintaining a consistent internal climate.

3.5 Case Studies

In the following, two case studies discuss two innovative buildings in Vienna. They are analysed with regards to the materials and energy consumption as well as production. This in turn should provide a basis for suggestions on sustainable conversion of old buildings.

3.5.1 LISI Building

The LISI building is a project of the Vienna University of Technology, designed and constructed to reduce energy consumption and represent an example of a sustainable innovative prototype while being attractive for residents. LISI stands for “Living Inspired by Sustainable Innovation”. The residential building’s interior measures 64 m^2 and can be doubled by opening the sliding door in the North and South of the room. In 2013 the house won the Solar Decathlon, an international architectural and energy technology competition.

Due to the photovoltaic system on the roof, LISI produces more energy than required to cover the house’s demand, including warmwater and heating or cooling. Thus, LISI presents an example of a plus energy residential building [9].

The house was built of 96 percent timber, including solid spruce wood construction, solid oak wood and other types of wood, that are local in Austria. These chosen materials represent good isolators in comparison with concrete or bricks [10] and thus reduce the energy consumption (heating and cooling). Beneficial in matters of preserving raw materials, all parts of the tree were used, solid wood for construction and surfaces, bark as a surface material in the interior and wood shavings for furniture [11].

In addition to isolating materials, other components were included to achieve a balanced energy budget. While on average, a single-family house in Austria consumes 25,000 kWh of heat energy per year, which accounts for almost 80 percent of total energy consumption, with hot water excluded [12], the LISI house reduced the energy consumption to 5722 kWh, including further components than heat energy only. This was done with a well-insulated thermal hull and LED lights, along with power efficiency concerning the appliances and the HVAC system (heating, ventilation and air conditioning).

Regarding the heating system a combination of an air heat pump and a floor heating system with additional air streams below, that pre-heat the air before it enters the room, was chosen. Furthermore, air exchange is done by the ventilation system, which also propels the air streams, to prevent heat and humidity. Recovering the energy that is stored in the warm or humid air and releasing it into the fresh incoming air, makes this system more energy efficient than “classic” ventilation via opening the windows [31].

Energy wises the demand for the ventilation system and all further consumers, including heating, cooling and appliances is met and exceeded in any case, as can be seen in the two tests in Vienna and Irvine, in California, though production through the photovoltaic system varies, depending on the building’s location. While in Vienna lower production in winter is equalised within the warmer months, it surpasses the stimulated energy use in Irvine throughout the whole year.

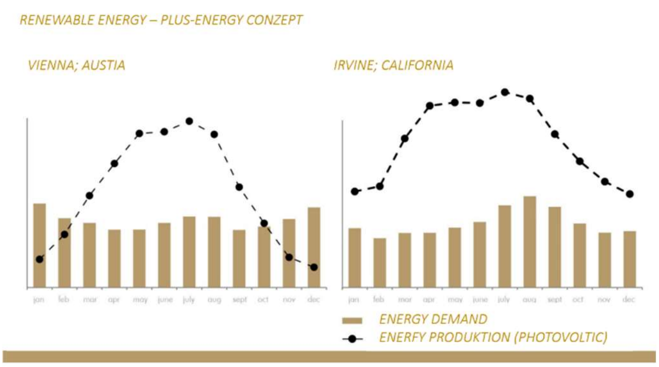

Figure 2: Plus-Energy Concept

The 35 polycrystalline silicon modules, installed on the building's roof, cover heating, cooling and hot water as well as the cooker, the washing machine, the dryer and the lights [29;30].

3.5.2 TU Vienna "Am Getreidemarkt"

The university building TU Vienna "Am Getreidemarkt" is the first plus energy office skyscraper worldwide, including office computers and servers, located in the centre of Vienna. While it was built rather unsustainable, the renovation reduced its footprint. Offering space for 700 workers, the primary energy demand is covered with the photovoltaic system, the usage of thermal discharge from the servers and energy recovery from the elevators. Before renovation, the construction's primary energy consumption was beyond 13 times higher (Figure 1), but was heavily decreased by implementing core ventilation, which ventilates the stairwell and corridor area with cool outside air at night and thus lowers the cooling demand. Additionally, energy efficient LED lighting and further contribute to the reduction.

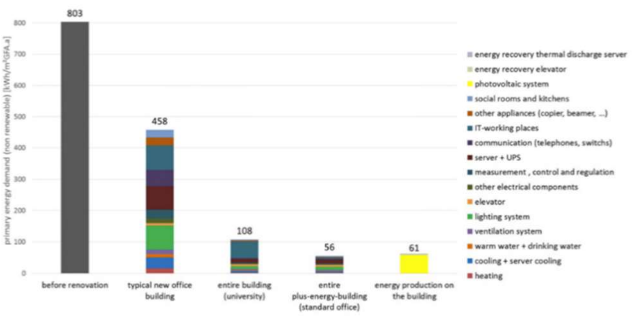

Figure 3: Non Renewable Primary Energy Demand

The energy demand is covered through the photovoltaic system on the roof and in the facade, the usage of thermal discharge from the servers and the thermal activation system.

Optimizing the passive house envelope, and thus the thermal isolation of the building influences the heating of the building and decreases the consumption to a sixth.

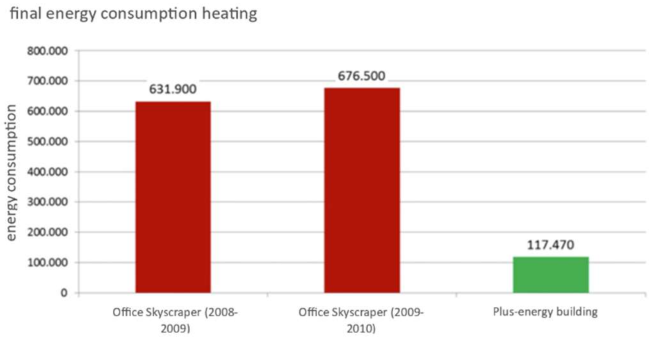

Figure 4: Heating Energy Consumption

As a matter of fact, the passive house envelope is the foundation in the building process of the plus-energy building and when aiming for a plus-energy-standard. Outer walls, the flat roof, and glass surfaces, such as rotating windows and fixed glazing are furnished with triple insulating glazing, were isolated in the renovating process. All those measures lead to a lower energy consumption and, along with the solar panels producing more than the required energy, the goal of a plus-energy building was achieved. [13; 14; 15; 28]

4 Conversion of old buildings

The conversion of old buildings in Vienna has gained significant attention due to several reasons, including the preservation of historical and cultural heritage, sustainable urban development, and the integration of green energy solutions. This section explores the reasons for the need to convert old buildings, the challenges associated with monument protection, and how such conversions can contribute to the adoption of green energy in these structures.

4.1 Reasons for the Need to Convert Old Buildings in Vienna

Vienna, a city famous for its cultural heritage and stunning architecture, faces the task of preserving its historical and cultural essence while addressing environmental challenges and ensuring sustainability. The conversion of old buildings in Vienna serves as a crucial solution to these pressing concerns, with several reasons driving the need for such conversions.

Firstly, sustainability plays an important role in Vienna's vision for the future. The city has long been dedicated to sustainable development and aims to serve as a role model for environmental responsibility, as outlined in Vienna's Smart City Strategy [22]. By repurposing old buildings, Vienna can minimize its ecological footprint and reduce the need for new construction. This approach not only saves natural resources but also supports urban regeneration and fosters a sustainable and inclusive urban environment.

Secondly, the conversion of old buildings in Vienna contributes to energy efficiency and helps fight climate change. Many old buildings suffer from poor insulation and outdated heating and cooling systems, resulting in significant energy inefficiency. Converting these structures presents an opportunity to improve their energy performance by implementing energy-efficient technologies. Upgrades like insulation improvements, energy-saving appliances, and renewable energy systems can significantly reduce carbon emissions from buildings, aligning with Vienna's very ambitious climate targets and enhancing the city's resilience to future environmental challenges.

And thirdly, the preservation of Vienna’s historical and cultural character is a driving force behind the urgency to convert old buildings as well. The city has a rich architectural heritage, featuring magnificent palaces, historic landmarks, and charming neighborhoods. Converting old buildings gives an opportunity to preserve their historical and cultural value while still adapting them to modern needs and standards. By respecting the original architectural elements, materials, and designs, the conversion process ensures the aesthetic, value, and authenticity of these structures are maintained. Such an approach nurtures a sense of community and awareness, enabling future generations to connect with and learn from Vienna's remarkable history. [17; 19; 20]

4.2 Challenges and Monument Protection in Vienna's Old Building Conversions

While the conversion of old buildings in Vienna presents numerous benefits, it also comes with some challenges, particularly regarding monument protection. Vienna places great emphasis on protecting its architectural heritage and has established strict regulations to ensure the preservation of its historic buildings.

One of the main challenges lies in balancing the preservation of the buildings' historical value with the need for energy efficiency and sustainability. Historic buildings often possess distinctive architectural features and materials, such as meticulously decorated facades, floorboards and old parquet floors, wooden beam ceilings, stucco decorations and hundreds of years old box windows, all elements of the Barock, Historicism and many more different eras in the Viennese architecture that hold immense cultural significance. Introducing energy-efficient technologies, such as better insulation and modern heating systems (HVAC), must be approached carefully to minimize any visual changes and preserve the original character of the buildings. Striking the right balance between preserving the historical value and enhancing energy efficiency requires careful consideration and expertise.

Compliance with monument protection regulations is another challenge faced during the conversion. Property owners and developers must navigate complex guidelines to ensure their projects fit these regulations. This involves preserving the facade, structure, and important interior features of the buildings while making them suitable for modern living standards [16; 21]. The stringent requirements and limitations set by monument protection regulations can add complexity to the conversion process. [16; 18; 21]

4.2.1 Overcoming those Challenges

Vienna's old buildings often pose technical and aesthetic constraints that further complicate the conversion process. Architectural elements like load-bearing walls and delicate decorations require careful consideration to maintain structural integrity and historical authenticity. For example, integrating modern amenities, such as elevators and accessibility features, can be challenging due to limited space and the need for seamless integration with the existing architecture. Moreover, preserving decorative features and artistic details demands specialized knowledge and craftsmanship, which not many workers possess. This is why a rise in innovative alternatives to conventional building methods, ranging from eco-friendly seismic coats to hidden photovoltaic systems, can be noticed.

Those include, for example, a photovoltaic window glass created by the Spanish company Onyx Solar [23].
While solar glass mimics regular window glass, several photovoltaic cells embedded in the glass ensure the capture of sunlight and generation of energy. An additional benefit is its ability to absorb both ultraviolet as well as infrared radiation, thereby reducing potential harm caused by them [24]. With the widespread implementation of photovoltaic glass, cities worldwide could be filled with solar power plants integrated seamlessly within regular buildings [25]. Therefore, this technology has the

power to reduce dependance on imported energy and could ultimately contribute to a decline in energy costs.

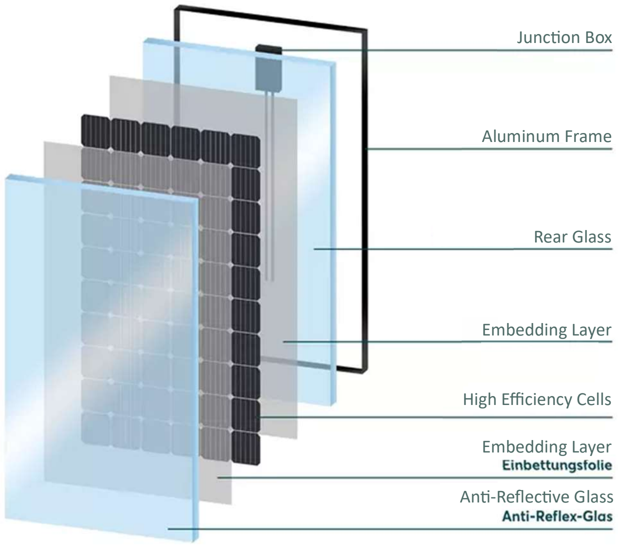

Figure 5: Structure of Photovoltaic Glass

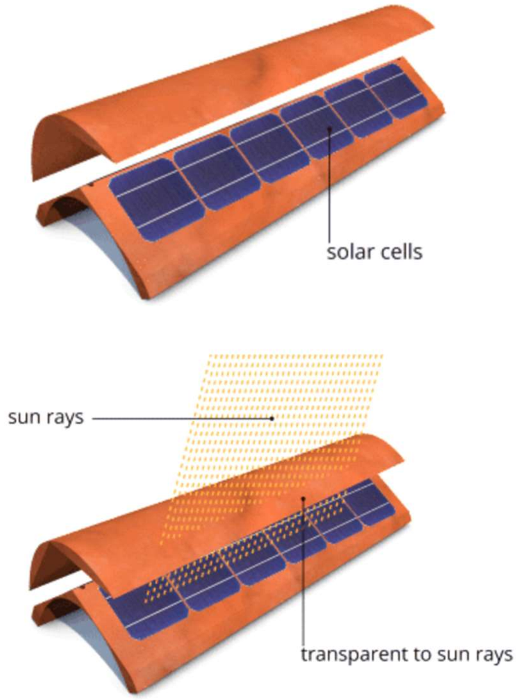

Figure 6:Structure of the Clay Tiles

In some cases, the installation of new windows violates monument protection laws, which increases the importance of designing other inconspicuous alternatives to solar power plants.

An example of such alternatives are photovoltaic tiles created by the company "Dyaqua". These tiles have been successfully implemented in the restoration of Ancient Pompeii in Italy. They imitate the appearance of traditional clay tiles, seamlessly blending in with the original architectural elements and therefore conforming to monument protection laws. Notably, the "Dyaqua" tiles are designed using non-toxic materials that are either sourced from natural origins or repurposed which also makes them recyclable. The difference between conventional clay tiles and the solar panel tiles lies within the structure of the solar tile. Between two layers of the tile's surface, which is made of a material transparent to sunlight, lies a layer consisting of solar panels. Moreover, the solar tiles react phototactically when activated by light, allowing them to purify the air and cleanse the surface of the modules. Additionally, the tiles show resilience against high static loads, chemical solvents and atmospheric elements, intensifying their durability and longevity.

This technology opens the possibility of creating tiles that resemble the architectural styles found in cities around the world. Those can be utilized in construction and renovation projects by serving as replacements for historic tiles while also providing an alternative to conventional tiles. In fact, they have the potential to extensively cover urban areas, functioning as generators of energy without the requirement of large, visually prominent solar panels [26].

Another notable technology contributing to the improvement of buildings is the Eco-Friendly Ductile Cementitious Composite (EDCC), a seismic coating developed in British Columbia, Canada. This region experiences significant seismic activity, and many of the existing buildings lack sufficient resilience against earthquakes. As a result, there is an ongoing effort to retrofit cities, with a particular emphasis on schools. Professor Nemkumar Banthia and his team at the University of British Columbia have led the development of a spray-on seismic coat designed to reinforce buildings that cannot be replaced due to cultural significance. [27]
This innovative coating, composed of polymer-based fibers, fly ash, and various industrial additives, strengthens the walls of these buildings while also enhancing their flexibility. By applying the EDCC coating, the chances of destructive damage during seismic events are significantly reduced. This technology offers a practical solution for improving the seismic resistance of vulnerable structures,

safeguarding them against potential earthquake-related destruction.
Although seismic coatings have been available in the market for some time, the Eco-Friendly Ductile Cementitious Composite distinguishes itself by incorporating industrial byproducts and replacing a significant amount of cement with fly ash and silica fume. This substitution is noteworthy as the production of cement is responsible for approximately 9% of global CO2 emissions. Consequently, EDCC presents an environmentally friendly alternative to many conventional seismic coatings.
Furthermore, the applications of EDCC extend beyond retrofitting buildings in seismic-prone regions. Its utilization can also play a significant role in strengthening pipelines, offshore platforms, industrial floors, pavements and blast-resistant structures. While Austria may not experience earthquakes to the same extent as countries like Japan or Italy, the adoption of EDCC contributes to the global goal of ensuring the safety and well-being of people in various regions while also reducing the environmental impact associated with traditional cement-based coatings [27].

4.3 Concrete steps towards a suitable conversion for Vienna's schools

To implement real changes, we propose a targeted strategy for improving energy efficiency in Vienna's school buildings. First, we suggest taking things step by step. We should begin with a test program in a few schools to see if it is possible and if it makes financial sense. In these projects, we can focus on implementing all the technologies mentioned before needed. By taking this approach, we expect the starting expenses to be around 18.00€ to 36.000€ per school or higher, with variations depending on how big the school building is, where it is located and what shape it is in.

To put this investment into perspective, here are some estimated potential energy savings and cost reductions. Based on our analysis of the current energy costs in Vienna, we project that implementing these upgrades in each school could lead to an average annual energy cost reduction of approximately €5.000-€7.000 once again based on the school's size and shape. Throughout the usual lifespan of a school building, these savings add up significantly, making the initial investment more than just worth spending. And afterwards this strategy even provides extra funds that can be used for the children's school trips and classes.

Regarding just the renewable energy integration, our research reveals that solar panel/tiles installations on school rooftops are possible for the majority of buildings. Estimated installation costs range from 16.900€ to 23.900 € per school, depending on capacity, location and many other small factors. These installations could generate an average of 5.000€ worth of electricity annually per school, significantly and in some cases fully reducing reliance on conventional energy sources. To encourage the use of clean energy, we suggest checking if there is any special government help or money for schools that want to become more energy efficient. This can make it easier for schools to afford these changes and switch to cleaner energy.

5 Global Perspective

After looking at various technologies and approaches related to sustainable building practices and the conversion of old buildings, with a particular focus on Austria, Vienna. The insights shown in this paper have the potential for global application, contributing to more sustainable, energy-efficient, and resilient buildings worldwide.

First and foremost, the usage of advanced insulation, high-performance windows, and efficient HVAC systems improve energy efficiency in building construction. Such measures reduce energy consumption while improving thermal comfort, serving as a blueprint for global efforts to lower the energy demand in buildings.

Moreover, the integration of renewable energy technologies is crucial for a sustainable and energy efficient building. Converting old buildings provides a unique opportunity to incorporate solutions such as panels, small wind turbines, and geothermal systems. These technologies empower buildings to generate clean energy on-site, diminishing reliance on fossil fuels and reducing greenhouse gas emissions—an approach ripe for global adoption.

Another innovative technology offered is photovoltaic glass. This specialized glass contains solar cells embedded within its structure, allowing buildings to capture sunlight and generate energy without the need for conventional solar panels. This revolutionary technology not only provides an aesthetically pleasing and inconspicuous way to harness solar power at sight but also contributes to reducing dependence on imported energy sources, which is essential for the idea global energy sustainability.

Furthermore, inconspicuous photovoltaic tiles, like those developed by the company "Dyaqua" offer an alternative to traditional roofing materials while seamlessly blending with historical architectural styles. These tiles not only generate clean energy but also adhere to monument protection laws, making them a viable solution for both preserving cultural heritage and promoting sustainable energy production. The potential for such technologies to be implemented in cities around the world is huge, transforming urban areas into little solar power centers.

Beyond the aspect of energy, some noteworthy innovations in seismic coatings are currently being done by the Eco-Friendly Ductile Cementitious Composite (EDCC). Developed in British Columbia, Canada, this technology strengthens buildings against seismic events, a critical consideration for regions often exposed to earthquakes. What sets EDCC apart is its environmentally friendly composition, which reduces the carbon footprint associated with traditional seismic coatings. Nevertheless, this technology can also extend its benefits beyond regions at risk of earthquakes, contributing to global safety and sustainability efforts.

To sum up, the technologies and practices discussed are by far exceeding Austria's borders and offer a global perspective on solutions and ideas for sustainable building. From energy-efficient building systems to renewable energy integration, photovoltaic innovations, and environmentally friendly seismic coatings, these approaches have the potential to revolutionize building construction worldwide. As cities struggle with the challenges of preserving their cultural heritage and addressing sustainability goals, the lessons learned from Vienna can inspire and guide projects across the globe towards more sustainable, energy-efficient, and resilient buildings.

6 Conclusion

In conclusion, this paper discusses Vienna's architecture in the context of energy transition by considering past applications in the construction of new buildings as well as the implementations made in the conversion of energy inefficient buildings, where finite resources, inefficient isolation or outdated heating systems are traditionally used.

Based on the analyses of LISI and "Am Getreidemarkt", significant factors for the reduction of energy consumption in green architecture include the use of renewable materials, for example wood, good isolation and an efficient core ventilation. Furthermore, the energy demand should be covered by renewable energy sources, for example photovoltaic plants or energy recovering installations.

These changes should be applied to a large number of buildings to accommodate the energy transition in Austria, to not only reduce aspects directly related to the inhabitants of said buildings, for example the heating costs, but also encounter the globally ongoing climate crisis.

However, in cities like Vienna, there are many limitations and protections concerning old and culturally significant buildings in need of such changes, blocking the chance of implementing those and making them more sustainable.

A way future research should go is finding out new ways to secure the cultural significance of those monument protected buildings while also adapting them to fit present-day standards.

With them being easily adaptable to new settings, these changes can then be enforced globally, playing a crucial role in the fight against climate change.

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Appendix

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Extinguishing the flames: shifting from gas to electric appliances in Australia

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Summary

With Australia falling behind its 2030 carbon emission goals, and its transition to renewable energy sources slower than other countries, the following two-fold proposal is made to support this transition.

• Support Australia’s transition to renewable energy sources by switching from the use of gas appliances to electric appliances which are powered by solar or wind energy.

• Support Australians to reduce their energy consumption and therefore cut emissions, using strategies outlined in the recent ANZ The Forgotten Fuel Series 2023 Report: Putting Energy Efficiency to Work.

We provide a case for Australia to transition from non-renewable energy power sources to green electricity with a focus on a shift from gas appliances to electric only appliances. We provide guidelines for Australian households and businesses to reduce their energy use, to positively impact the environment and also reduce household and business costs, which are important in the current volatile economic climate.

Keywords

Net zero, fossil fuels, climate change, sustainability, green energy

1 Introduction

The design thinking process was used to direct the research process. This process has five stages: Empathise, Define, Ideate, Prototype and Test.

In the Empathise stage, information about renewable and non-renewable energy use and sources in the Australian context was researched and collated. Questions were generated to direct further research. Access to a key energy report from the ANZ was provided by an industry expert [1]. Key insights were identified, allowing the focus of the research to be refined and defined.

The next three stages were cyclical, with proposal ideas generated and collated on a collaborative Miro board. Ideas were sorted using an Impact Matrix which considered the levels of resourcing and impact for each idea. High impact ideas with both low and high levels of resourcing were developed, with arguments for each interrogated using the Three Pillars of Sustainability Framework [2].

During the Prototyping and Testing stages, questions arising from the research and proposal generation were shared for expert feedback and input.

2 Background information

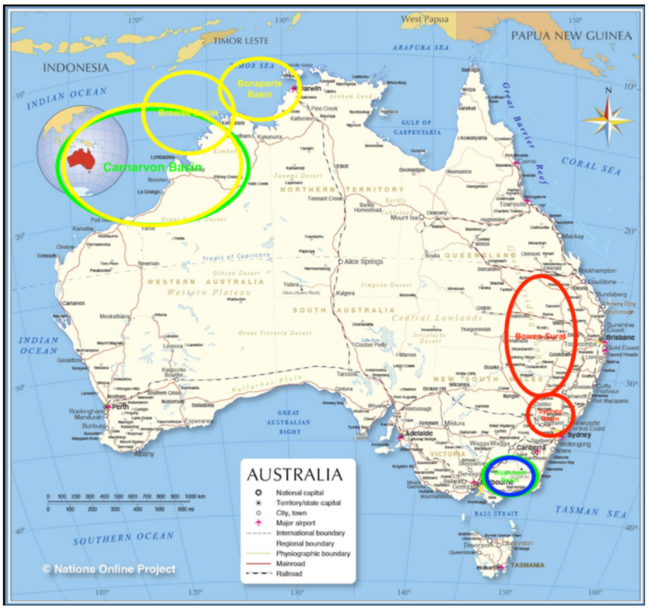
Australia is heavily reliant on non-renewable energy sources, including coal and gas, despite having the climate and space to harness renewable energy sources. Australia is the world’s sixth largest country, with over 7 million square kilometres of land, most of which is unused [3]. It has vast potential for harnessing solar power, due to its climate and considerable desert spaces. Australia’s ongoing use of non-renewable sources of energy is contributing to carbon emissions which are impacting climate change.

2.1 What sources of energy are currently available in Australia?

Australia relies on both clean energy and fossilised fuel energy. The clean sources of energy used in Australia include solar, wind, and hydro power.

2.2 Fossilised Energy Sources

The fossilised energy sources used in Australia include coal, oil and gas. In Australia, fossil fuels contributed 71% of total electricity generation in 2021 in Australia. Of this percentage, 51% was coal [4].



Green	Crude Oil
Yellow	Natural Gas
Red	Black coal
Blue	Brown coal

Figure 1. Location of fossilised fuel energy resources in Australia.

2.2.1 Coal

Australia has large stores of black coal located in Bowen-Surat in Queensland and the Sydney Basin. Australia’s brown coal resources are mainly located in the Gippsland Basin. Coal is mostly used in the industrial and transport sectors and its primary use is the generation of electricity [5].

2.2.2 Gas

Australia has large conventional gas resources, mainly located in Carnarvon, Browse, and Bonaparte basins found off the Northwest coast. There are smaller resources in the Gippsland Basin, and the Cooper-Eromanga basin in South Australia [5]. Natural gas is used for heating, cooking and electricity generation in both private and public environments.

2.2.3 Crude Oil

Australia's crude oil reserves are mainly located in the Carnarvon and Gippsland basins. These reserves are small by world standards, however there are undeveloped gas fields believed to have large reserves [5]. Crude oil is refined so that it can be used in many petroleum-based products such as gasoline, heating oils, diesel, lubricants and ethane [6].

2.2.4 Solar

Australia receives the most solar radiation compared to other continents. The amount of solar radiation received is about 10,000 times greater than Australia's total energy consumption. Solar power is popular in both homes and businesses as its primary use is for heating, water heating, electricity generation and solar lighting [7].

2.2.5 Wind Power

Wind power is Australia's cheapest source of large renewable energy currently. In 2020, wind supplied 9.9% of Australia's overall electricity [8]. It is mainly used to generate mechanical power or electricity.

2.2.6 Hydro

In 2020, hydro power supplied 6.4% of Australia's total energy. Hydro power accounted for 23.3% of Australia's total clean energy produced [9]. Hydro power is fed into the electrical grid to provide electricity to businesses, industries and households. Most hydro power is generated via large hydroelectric power plants in New South Wales and Tasmania. As much of Australia's landscape is dry, there are limitations to the location of hydro power plants.

2.2.7 Nuclear

Although Australia does not use uranium for nuclear power, it has more than one third of the world's known economic uranium resources [5]. Nuclear energy is used for powering desalination plants, providing heat for metal refining, and generating hydrogen and electricity. The electricity produced can be used to power homes, schools, businesses and other buildings.

2.3 What type of energy is consumed?

Australia's four key sources of energy are oil, coal, gas and renewables.

Table 1. Types of energy consumed in Australia from 2020-2021[10].

Oil	36.2%
Coal	28.7%
Gas	27.1%
Renewables	8%

Australia has a broad range of renewable energy sources with the highest percentages of renewable energy sources coming from biomass and solar. Wind power is a fast-growing source of energy. Hydroelectricity has been generated for decades and accounts for just over 10% of renewable energy sources, with over 100 hydroelectric power stations mainly located in New South Wales (55%) and Tasmania (29%). These power stations are in areas with high rainfall and the high levels of elevation required to produce electricity [9].

Table 2. Renewable energy consumed in Australia from 2020 – 2021[11].

Biomass	37%
Municipal and Industrial waste	1%
Biogas Total	3.9%
Biofuels Total	1.3%
Hydro	11.8%
Wind	19.1%
Solar PV	21.6%
Solar Hot Water	4.3%

2.4 How much energy is consumed?

In Australia, the total consumption of electrical energy per year is 237.39 billion kWh (kilowatt hour). This is 9128 kWh per person on average. Hydro power makes up 6.4% of Australia's primary energy consumption and produces 23.3% of Australia's total clean energy. Wind power is currently Australia's cheapest source of large renewable energy. Wind turbines capture energy within the area swept by their blades and makes up 2% of Australia's primary energy consumption. Solar, in comparison, provides 12% of Australia's overall energy sources [10].

Since Australians use such large amounts of electricity, it is important to reduce energy consumption. Australians can reduce their energy consumption by making sure to use electricity and energy effectively in simple ways such as turning lights and appliances off when they are not using them. Households can also reduce their use of energy-intensive appliances by hanging clothes out to dry instead of using a dryer or keeping windows shut to reduce the amount of air conditioning needed in hot weather. Other small actions such as taking shorter showers, using less hot water and upgrading home insulation are all effective ways to reduce household energy consumption [1].

2.5 What sources of energy are imported and/or exported?

Coal is Australia's largest commodity export. Annual thermal and metallurgical coal exports are worth more than $40 billion, and coal is mainly exported to Japan, India, the European Union, Republic of Korea and Taiwan [5].

Table 3. Australian Resource Imports and Exports [12].

Country	Resource import from Australia	Resource exported to Australia
European Union	Crude Oil, Liquefied Natural gas, Coal	
Germany	Green Hydrogen	
India	Mineral fuel/coal briquettes	Refined petroleum
Japan	LNG (Liquified Natural Gas), Thermal coal exports	Refined Petroleum
The Netherlands	Coal briquettes	
Republic of Korea	Iron ore, Coal, Natural Gas	Refined petroleum
Singapore	*plans to import clean energy	
Taiwan	Coal and LNG	
The United Kingdom	Crude oil/natural gas/petroleum products	coal
The United States	Coal, LNG	Refined petroleum

Australia imports refined petroleum. Our local production of petroleum does not meet the demand, as it is used for diesel and jet fuel. Transport fuels are in high demand due to the physical distances needed to be covered. As a result, Australia relies on imports from other countries to bridge the gap in production.

Several countries import resources from Australia such as LNG, coal, crude oil, natural gas and green hydrogen. These energy resources are mainly used to generate electricity and commonly found in residential, industrial and commercial settings. These are all examples of fossil fuels, except for green hydrogen which Germany imports as part of the Australia and Germany clean energy partnership [13].

3 Transition Plan

Our proposal is twofold:

- Support Australia's overall transition from non-renewable sources of electricity for power, such a solar and wind, by promoting a shift from gas appliances to electric appliances powered by renewable sources. Provide strategies at the individual and systematic levels.

- Support Australians to reduce their energy consumption and therefore cut emissions, by raising awareness of and using strategies outlined in the recent ANZ The Forgotten Fuel Series 2023 report: Putting Energy Efficiency to Work.

3.1 What energy sources would be used?

By shifting from gas appliances to electric appliances, we propose that renewable energy sources can be targeted, in particular solar and wind power. Although these energy sources are both currently in use, there is scope to develop them further as they have already proven to work well in Australia [14]. This option was discussed with energy expert, Mathew Forwood, who agreed that in the medium term solar and wind power are "already economic and technically proven".

3.2 How would energy sources be developed?

In our proposal we suggest Australians switch from using gas appliances to appliances using clean electric energy, alongside reducing Australia's energy consumption. No new energy sources need to be acquired or developed in our transition plan, rather, current use of solar and wind power needs to be developed to reduce and ultimately phase out the reliance on fossil fuels. Solar and wind are well-developed sources of energy in Australia, although there is still considerable potential to grow both industries [8].

The government will need to continue to incentivise companies to invest in the development of solar and wind power generation, including the construction of wind and solar farms, as well as large-scale electricity storage batteries. Suitable areas for solar and wind energy generation need to be identified and leveraged, as a full transition from gas to electric energy will involve an increase in the consumption of renewable energy sources related to electricity production.

3.3 What are some of the anticipated challenges?

We anticipate many challenges along the way. Whilst our proposal promotes the use of home-based solar energy production, solar panels have a limited life span of around 21 years, are difficult to recycle, and a consistent system has not yet been developed [15]. Installation of solar power can be expensive, and some rental properties may not have access to it, including high rise apartments. This clean energy source may be hard to market due to the challenges associated with it.

Proposing the idea that electrical appliances should be discounted is likely to result in job losses for those in the gas sector as well as businesses making gas appliances. At the systems level, we propose free retraining programs are offered for those in gas-related jobs. Whilst this idea would be beneficial, there may be negativity from some areas of the workforce for having to change professions.

As an incentive to switching to clean energy, we propose that the electricity charges are changed to reduce bills. The challenges associated with this include the negative economic impact on energy supply companies, and the need for the government to support energy companies through the provision of rebates or tax incentives.

4 Arguments to or for the proposal

4.1 Three Pillars of Sustainability Framework

The Three Pillars of Sustainability Framework was first used in the late 1980s. The three pillars, representing the environment, society and the economy, are used to understand sustainability. Each has a particular focus however all are intertwined. The environment pillar focuses on a commitment to protect the environment and measuring a business's carbon footprint. The social pillar acknowledges social issues, aims to reduce social inequality by focusing on working together, and includes the need for a safe workplace. The economic pillar considers ways to improve the standard of living and efficient use of assets for businesses and organisations to remain profitable [2].

4.2 Key proposal 1: Change gas appliances to electric appliances

4. 3 Strategies focused on individuals

4.3.1 Community awareness

A wide-ranging community awareness program would need to be implemented, to include businesses, organisations and schools to promote the importance of transitioning from gas to clean electricity appliances. This is proposed to raise awareness about the benefits of clean energy and would include highlighting the health issues around gas use, as well as helping people make informed decisions [16].

From an environmental perspective, a decrease in gas appliance usage should result in decreased gas emissions. From a social perspective, providing people with information provides them with the opportunity to understand the situation and make informed decisions. Shifting from gas appliances could potentially protect human health and provide people with a common cause with which to unite. Finally, from an economic perspective, the cost of the campaign would need to be considered as well as ways to educate formally and informally.

4.3.2 Reduced electricity bills

A reduced electricity bill might serve as an incentive for citizens to transition from gas-based appliances to electricity-based appliances. If a reduced bill is given for the initial amount of energy used, it would provide an incentive for individuals to use less energy altogether.
From an environmental perspective, by providing a cheaper source of energy, and encouraging people to use less of it, carbon emissions can be reduced in both regards. From a social perspective, the collective incentive to reduce electricity consumption would provide a common cause for communities to unite, however a social drawback may be the potential difference in individuals' ability to replace appliances which are less energy efficient. From an economic perspective, this approach would have a negative impact on energy supply companies. The government would need to support these companies through rebates or tax.

4.3.3 Real time feedback

A community-based approach to this transition might involve the implementation of a monitor, app or meter, with visualisations to assist individual households or communities in their energy tracking. With this approach, education would be provided relating to the transition to clean energy and the monitor/meter/app's link to energy reduction strategies. It is a tangible way of knowing about progress, may serve as a motivation tool for individuals and communities, and provide a sense of collective responsibility.

From an environmental perspective, the increased awareness around energy use may serve to decrease individuals' energy use. This decreased use of energy in general should lead to decreased carbon emissions. If the monitor/meter/app provided information about the type of energy being used, people may be inclined to use cleaner types of energy, further decreasing carbon emissions.

From a social perspective, this common cause has the potential to bind communities. It may promote conversations and awareness relating to the transition to clean energy. One drawback is that not everyone may want to engage or use this app or meter, which may decrease the general effectiveness of this suggestion. From an economic perspective, jobs would be created to develop and maintain the technology, however it may be expensive to develop, roll out and maintain.

4.3.4 Discounted electrical appliances

Discounted electrical appliances could provide an incentive for individuals to switch to electric to save money. There would be a likely increase in business for those selling electrical appliances as well as companies manufacturing electrical appliances.

From an environmental perspective, the decreased use of gas appliances should result in lower carbon emissions. From a social point of view, there may be job losses for those in the gas sector, and decreased sales for gas appliance businesses. A social benefit is that more people in general would be able to afford electric appliances, and there are likely to be more conversions to electricity. From an economic perspective, companies would have to be supported in some way to make up for the discounts, which could be funded via the taxpayer.

One argument against this proposal is that there is no guarantee that the purchase will use clean electricity to power the discounted appliance.

4.4 Strategies for systems

4.4.1 Retraining programs

Free retraining programs for those in gas-related jobs would include auditing the skills of workers, and currently available training programs, to determine whether new programs needed to be designed and implemented.

From an environmental perspective, this approach would provide an opportunity to build the environmental workforce. From a social perspective, this may help to mitigate a potential sense of unfairness from losing jobs based in the fossil fuel industry. From an economic perspective, these programs should be free. If individuals have no income, then there would be challenges for them to pay for a monetized retraining program. The government would need to fund the programs, so there would be high initial costs, but there may be long-term gains for the community by reducing potential long-term unemployment.

4.4.2 Reduce tax on electrical appliances

One approach to the transition to clean energy involves reducing taxes on electrical appliances for customers who can show evidence of sourcing energy from green sources. This would make it cheaper for people who use green energy in households, incentivising people to make the transition.

From an environmental perspective, there would be more options for interacting with a renewable electricity source. From a social perspective, this would increase awareness about individuals' household energy sources, however green energy currently costs more than non-renewable energy sources, so some people may not be able to afford this option. There is the potential for mistrust in the general community about whether shifting from gas to electric appliances is cheaper in the long run.

From an economic perspective, individuals would need to choose green energy to access the discount, which has the real potential to increase household bills due to the current higher cost of green energy.

4.4.3 Recycling and/or reusing gas appliances

With the proposed transition away from gas-generated energy, waste would be created in the form of unused gas appliances. One approach to managing this would be to set up systems for recycling or reusing gas appliances, either as stand-alone facilities or as part of a current recycling plants.

From an environmental perspective, this would reduce landfill and repurposed or recycled materials could be used for a sustainable purpose. From a social perspective, people may feel better about not sending their appliances to landfill, and it should encourage the normalisation of sustainable practices as recycling becomes a central part of household routines.

From an economic perspective, setting up and developing systems for recycling gas appliances can be expensive, especially as it involves creating a new industry, however this could lead to an increase in employment, as it has the potential to provide new job opportunities. In terms of recycling infrastructure, a long-term view needs considering for when gas appliances no longer need recycling/repurposing.

4.4.4 Systematic approach

To ensure a smooth transition from gas to electric appliances, a common approach and communication from all States and Territories across Australia is required. This is necessary for systematic change to support a national approach. A consistent national approach should support sustainable environmental practices. Viewing with a social lens, this proposal could result in a consistent message across all States and Territories in Australia. From an economic perspective, impacts include the creation of more jobs, and the expense of implementation. Time is also a factor, as gaining consensus within and beyond legislative bodies is a slow process.

4.4.5 Construction company tax

It is proposed that housing construction companies which include gas appliances are taxed at a higher rate. To properly prepare for this change, a plan to increase taxes must be developed, and legal advice sought. The government will need an increased budget to aid the development of clean energy sources. Many companies may have reduced profits due to the increased costs of building sustainable homes, so incentives need to be considered to change building practices. Since this would involve legislation, a Federal Government response would be required, as only Victoria and the Australian Capital Territory currently have legislation in place [17].

If most houses in the future use clean energy, the decrease in the number gas appliances should result in a decrease in carbon dioxide emissions. Companies will probably increase their prices, meaning the resulting tax burden is likely to be shouldered by the customer, and this may decrease the percentage overall of people buying houses with gas appliances. This change could possibly shift the community's mindset since the government would have mandated and supported the decision.

4.4.6 Reduction in stamp duty

Stamp duty is a tax that is paid by buyers to the State Government each time they purchase a building. The rates of stamp duty vary across Australian States and Territories. It is proposed that stamp duty is reduced or removed for houses which have no gas appliances. For this proposal to succeed, advertising, campaigning, and building awareness would be the first step, as well as legislating in each State and Territory. The government's income will be reduced due to the decrease in income from stamp duty, meaning alternative sources of revenue would need to be found. To counter this loss of income, it is proposed that taxes for other items, such as sugar could be increased.

Reducing or even removing stamp duty from non-gas-powered homes is likely to make non-gas-powered homes more affordable and normalise these sustainable practices. Environmentally, reducing the use of gas appliances will produce less carbon and therefore support sustainability. Socially, people may be impacted by unemployment both directly, in gas-appliance related professions, and indirectly. From an equity perspective, more people should be able to afford a home of their own. From an economic perspective, it is likely that the shortfall in income for the government would be paid for via taxpayers, with higher income brackets targeted. This could create a backlash from some sectors of the community.

5 Summary of arguments

Application of the Three Pillars of Sustainability Framework to the arguments suggests that while there is value to all proposal elements, investment in community awareness building (4.3.1), reduced electricity bills (4.3.2), recycling of gas appliances (4.3.3) and development of a systematic, national approach (4.4.4) should be pursued in the short term. Other elements have significant economic or social challenges, so may need further investigation and development to be implemented beyond their current form. Overall, the key challenges relate to funding, changes in employment and equitable access to clean energy and gas appliances.

6 How can some of these challenges be overcome?

Implementation of this proposal requires a strong commitment from the Federal and State Governments of Australia, alongside support from local councils. If Australia is truly committed to reducing gas emissions and lowering our carbon footprint, then long-term decisions need to be made.

Infrastructure will always require considerable amounts of money. There will need to be opportunities for businesses and government to work together to ensure funds are available. This may be through investment programs, changes to taxes and other financial incentives.

Building community awareness is important. The results of the Federal election in 2022, where there was a significant increase in the number of independents who defeated sitting members through well organised community campaigns, demonstrate the power of such an approach. Individuals were able to raise issues of importance, with climate change being at the forefront for many. Harnessing individuals through the formation of focused groups, such as climate change groups, and the development of strategic plans are all key elements.

7 Guidelines for households and businesses to reduce their energy consumption.

Reducing energy consumption is another vital part of our transition plan as the energy we use in our homes, businesses and vehicles is responsible for around 80 percent of our emissions. In order to reach net zero by 2050 Australian citizens must switch to energy efficient appliances and households. According to modelling, a household could save at least $2,275 annually by converting a typical one-star Melbourne home to a four-star property, hence the suggestion we focus on developing energy efficient households which reduce their overall energy usage. It is also important to reduce heating and cooling energy usage. Using reverse cycle air conditioning instead of other forms of heating and cooling is more energy efficient and can produce between three to six times as much heating or cooling energy [1].

8 Global Implications

8.1 What is the potential impact of the proposal for energy transition on other countries?

The potential impact of the proposal for energy transition will significantly impact other countries in partnership with Australia. As Australia is a large importer of non-renewable energy, such as petroleum, countries that export non-renewable energy to Australia will consequentially lose money if Australia approve the proposal for energy transition. Looking deeper into the manufacturing perspective, manufacturing companies overseas that specifically produce and export gas appliances for Australia will also be impacted.

If Australia is committed to a full-scale energy transition, it can be anticipated that mining of some resources would be reduced or ceased. This would have an impact on other countries' access to these resources, especially if their transition plans are behind Australia's. These impacts could be economical, social and environmental.

When trading between countries occurs, there is a deal, agreement, treaty or contract created. It is possible that Australia may have to break one or more of these to move forward with their energy transition plans. These decisions could impact the good relationships we have with other countries, and we may lose export and import opportunities for other non-energy related goods and services.

8.2 How might Australia aid other countries to transition to renewable clean electricity?

Australia can aid other countries to transition to renewable clean electricity by acting as a role model and provide successful transition steps that other countries can follow. Additionally, Australia can assist with helping other countries to set goals and develop a transition timeline, through the provision of consultants and related aid.

Partnerships can also be made. Australia can consider developing connections with other countries and look to provide financial support so other less financially stable countries can access the resources needed to transition. While financial aid can be extremely beneficial, technical support can also be provided to ensure other countries can also be equipped with the necessary equipment and skills to transition to renewable clean energy. This may involve providing Australian experts to work in multidisciplinary teams with other countries in transition partnerships.

Australia's education system is well developed, so we could also offer scholarships at the tertiary level and support energy transition education programs. This could potentially raise awareness of the importance of energy transition at a local level, while building the expertise needed at an infrastructure level.

9 Conclusion

There are several approaches that can be taken simultaneously to support the transition from gas appliances to electric appliances powered by green energy. The proposed plan is multi-faceted, with arguments focused at the individual and systems levels. Some recommendations offer quick, short-term solutions, such as campaigning to raise awareness and assist people to make informed decisions about their appliances and power sources. Other aspects of the proposal require long-term timelines and significant work with organisations, businesses and government. When interrogated with the Three Pillars of Sustainability Framework, both positive and negative impacts were apparent for each argument, however the overall conclusion is that each of the strategies presented in this paper have valid reasons to be considered and implemented either in the short or long term.

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Energy Transition - Australia

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Summary

Australia is a large, developed nation with a complex energy system. The nation relies mainly on coal as a source of energy for electricity production, with coal being used to produce around 70% of the country's energy requirements. Apart from coal, the country also uses smaller amounts of sources including natural gas and hydroelectricity. Due to this reliance on fossil fuels Australia is contributing heavily to the climate crisis, and the ever-increasing figures on energy production from carbon-based sources will only exacerbate this problem. Australia is already working towards transitioning towards a carbon-free future, with goals in alignment with the Paris Agreement of net zero emissions by 2050, but more action needs to be taken towards the promotion and usage of renewable sources not only on large scale, but also for small, domestic, and household uses. Solar power is a renewable, fully carbonless source of energy which has already been extensively used in industry and commercial settings, and many large companies have taken this transition away from grid electricity. Australia has some of the biggest uptakes of solar panels in the world however most households do not have solar panels, and even less use personal storage batteries. If households around Australia were to transition to these renewable energies through a variety of ways, with educational campaigns on the implications and benefits of solar, solar batteries in households, and other renewable sources, the country would see a significant boost towards achieving its goals of net zero by 2050, setting the country up to be a leader in global renewable energy across all sectors of consumption.

Keywords

Renewables, Solar, Coal

1. The Australian Energy System

1.1 Australian Energy Sources

Australia relies on numerous types and forms of energy to produce the nation's electricity, ranging from proven sources of fossil fuels to newer, renewable forms of energy including hydro and nuclear power. Together, these energy sources provide the nation with much-needed electricity on household, commercial and industry levels.

1.1.1 Coal

Coal is currently Australia's largest energy resource. In 2017, coal was used to produce about 60% of the nation's electricity requirements [1]. Australia mostly used coal as a source for powering power stations across the country. Australia also exports a large amount of black coal and brown coal. For coal, mining is one of Australia's key industries, and Australia has some of the largest coal reserves on the planet. The mining industry makes a considerable economic contribution to Australia and is extremely important to the export market [2]. The mining sector accounts for roughly 10% of Australia's total energy use. Its energy is mainly supplied by diesel (41%), natural gas (33%), and grid electricity (21%) . Coal is around 20 times worse for the environment compared to solar power (per kW generated) and 80 times worse compared to wind [3].

1.1.2 Natural Gas

Natural gases are naturally occurring mixtures of hydrocarbons consisting primarily of methane, along with several less significant trace elements. In Australia, Gas and oil are extracted from "conventional reservoirs," which are areas underground made up of permeable rock which release gas upon drilling. These reservoirs occur most commonly on Eastern and western parts of the country, with two main large reservoirs, the Eastern Gas Market and the Western Gas market [4].

Australia's natural gas consumption has been increasing slightly over the past decade. In 2009, Australian power stations and factories consumed around 29.1 billion cubic metres of natural gas, increasing to 38.8 billion in 2015 and 43.1 in 2020, ranking 25th in the world for consumption and 16th in the world for production [5]. Australia produces around 23 billion cubic metres of gas each year [5]. Furthermore, in terms of electricity generation, Australia's reliance on natural gas has also increased steadily over the past decade, with 7% of electricity generated with natural gas in 1995, compared to almost 20% (17.8%) of electricity generation in 2021 [6]. Natural gas is used in households and industry for a variety of purposes, including for cooking and heating.

1.1.3 Hydro

Hydroelectricity is relatively new, introduced in Australia in masses from 1951 to 1996. The power stations responsible for hydroelectricity are located mainly in NSW (55%) and Tasmania (29%). One of the Hydropower stations called the Snowy-Mountain Hydro-electric scheme is one of the most complex hydro stations in the world. With over 120 stations in Australia, 5-7% of the nation's electricity is produced by hydropower [7].

1.1.4 Nuclear

There are no operating nuclear power stations in Australia apart from a single nuclear reactor located in Sydney used not for nuclear power production, rather medical radioisotopes. The country has been debating the usage of nuclear energy for a long time while maintaining a strict ban in all states and territories. Even though Australia has sizable uranium deposits and a thriving uranium mining sector, the development of nuclear power has encountered political and popular resistance. This opposition has been significantly shaped by worries about safety, the handling of radioactive waste, and environmental effects [8].

1.2 Australian Energy Consumption

1.2.1 Household

To begin with, a large portion of Australia's total energy consumption is taken up for household and domestic consumption. According to the Australian Bureau of Statistics, 1215 Petajoules of energy were consumed by houses and domestic sectors in the 2020-21 financial year, accounting for around 7% of the net Australian energy supply in 2020 [9]. In addition to this, unlike many other energy-consuming sectors, where energy consumption dropped due to the COVID-19 Pandemic affecting operations and commercial function, household energy consumption remained high, even increasing by an estimated 12% in the years 2021-2022 alone.

Several factors influence energy consumption in a single household, the largest factor being household size. A study conducted by finder.com found that energy consumption in households exponentially increased as the number of people living in a household increased, with usage tripling from an average of 777kwh in a 1-person house to almost 2000kwh in a 4-person household. Location and seasons also heavily affect household energy consumption. In Brisbane, a city known for hot summers and warmer temperatures year-round, energy consumption across households peaked during summer, a 4-person household consuming 2000kwh of energy, compared to 1800kwh in winter [9], most likely due to increased air-conditioning usage due to these warmer average temperatures. This starkly contrasts from Melbourne, a more temperate city, where energy consumption peaks in winter (the exact opposite to Brisbane), a household of the same size consuming around 1800kwh, and 1300kwh in summer, clearly illustrating how energy consumption often changes with seasons, peaking in seasons with highest/lowest temperatures [10]. In essence, a 3-person (average household size in Australia) household consumes approximately 5000kwh of energy per year, varying depending on location, season, and household size [10].

1.2.2 Industrial

33% of Australia's energy was used by the industrial sector in 2022, which is a significant amount when compared to other [11]. With over 104,000 businesses in Australia, the energy that is used to serve function for these factories uses only 35.9% of electricity from renewable [12]. 23% of carbon emissions in Australia come from industrial uses alone with most of this energy coming from burning fossil fuels into energy .

Mining is one of Australia's key industries, and the country is rich in natural assets. The mining industry makes a considerable economic contribution to Australia and is extremely important to the export market. The mining sector accounts for roughly 10% of Australia's total energy use [13]. Its energy is mainly supplied by diesel (41%), natural gas (33%), and grid electricity (21%) [14].

Public healthcare services are also a major industry in Australia. Victorian public health services consumed 4.853 petajoules (PJ) of stationary energy compared to mining with 812 PJ. 89% of this was related to electricity and natural [15].

Consuming 37% of the world's energy, manufacturing is a dominant player in global energy consumption. As a developed island nation, Australia's manufacturing frontline has been receding over the past decade. However, due to advancing technologies, Australia has been able to maintain more than $100 billion in annual manufacturing output , complementing our exporting sector [16].

1.2.3 Commercial

Commercial use of electricity involves most businesses, including places like restaurants, shopping centres, and offices. The Australia Bureau of Statistics data states that, annually, businesses consume over 154,000 gigawatt hours of electricity, around $20 billion of expenses. The commercial building sector accounts for 25% of overall national electricity use, and 10% of national carbon emissions [17].

The most energy intensive devices in businesses include air conditioning systems and heaters, lighting, office devices such as computers, servers, printers, and refrigerators or other kitchen appliances [17].

On average, Tasmania and New South Wales businesses spend the most on electricity, nearly 4 times as much as businesses located in the northern territory [17].

1.3.1 Australian Energy Imports

To boost its indigenous output, Australia imports refined petroleum goods like gasoline and diesel. These imports aid in maintaining a steady supply of fuel for transportation. Australia imports crude oil to meet its domestic petroleum needs. These imports come from various sources, including Southeast Asia and the Middle East. The country's domestic oil production has declined, making it reliant on imports for a significant portion of its oil supply [18].

1.3.2 Australian Energy Exports

Australia is one of the biggest exporters of coal in the world, with a focus on metallurgical coal (used in the manufacture of steel) and thermal coal (used in the production of electricity). The principal export markets are China, Japan, South Korea, and India [19]. Australia has relied heavily on coal exports as a source of income, but environmental concerns are putting increasing pressure on countries throughout the world to cut back on coal use.

Australia has multiple LNG (Liquefied Natural Gas) projects along its coastline and is a significant LNG exporter. Japan, China, South Korea, and Taiwan are among the major export destinations for Australian LNG. Although it has raised domestic gas prices, the expansion of LNG infrastructure has improved Australia's reputation as an energy exporter [20].

Figure 1: Imports and Exports of Australia

2. Transition Plan

2.1 Future Energy Sources

Australia's geographic position and climate make it a country with an abundance of solar resources. It boasts some of the greatest levels of sun exposure, which makes it the perfect place to produce solar power. Both home and utility-scale solar energy projects have advanced significantly throughout the nation to date.

The advancement for storing energy, such as batteries, has been motivated by the erratic generation of solar energy as a result of environmental factors. Solar power's dependability may be improved by storing extra energy produced during bright times for use on overcast days or at night. This advancement has made solar energy suited even better for use in Australia as it is a permanent solution that can now be used in bad conditions or at night when it previously wasn't able to. The future of solar energy is solid as currently over 70 percent of homes across Australia use energy from the sun [21].

Hydropower is a relatively new solution as a renewable energy source and thus is a smaller solution however it is still a good idea to consider as in the future there will be new infrastructure and facilities for it. 23.3% of clean energy was produced through hydropower in 2020 and responsible for 6.4 percent of total energy produced in Australia [22].

Geothermal energy is obtained from the inherent heat of the Earth and is a sustainable and renewable source of energy. It makes use of the heat that is trapped beneath the surface of the Earth to produce electricity or offer direct heating and cooling for a variety of purposes. It is estimated that 1% of the geothermal energy shallower than five kilometres and hotter than 150°C could supply Australia's total energy requirements for 26 000 years [23]. It is possible to obtain geothermal energy without using fossil fuels like coal, gas, or oil. Only around one-sixth of the carbon dioxide produced by a natural gas power plant is produced by geothermal energy, and very little, if any, nitrous oxide or sulphur dioxide is produced.

Offshore wind energy is the term used to describe the production of electricity using wind turbines positioned offshore. In contrast to onshore wind turbines, offshore wind farms provide various benefits, including higher wind speeds and less aesthetic effect. They do this by utilising the robust and reliable wind resources present at sea. Due to the difficult marine environment, these facilities need specialised technology for turbine foundations and maintenance, yet they have the potential to provide large volumes of clean energy.

On the other side, onshore wind energy uses wind turbines that are positioned on land. Onshore wind farms may encounter local opposition, despite being simpler, cheaper, and easier to establish and operate than offshore equivalents, yet they are nevertheless a vital component of renewable energy initiatives in many nations. [24]

2.2 Transition Challenges

There are several challenges and implications associated with the transition of Australia towards cleaner, more renewable solar energy from current sources of coal and natural gas. According to Geoscience Australia, our country receives 58 million PJ of solar radiation each year, yet, only 1/10000th of this energy is actually consumed each year, making up only 0.1% of Australia's total primary energy consumption [25].

One of the largest reasons for this disparity is the conditions solar energy requires to function efficiently and effectively. Solar panels require light. Not a lot of it, but to function, the silicon in the panels must be exposed to photons of light, which releases electrons and produces an electric charge, meaning the less light, the less energy. This is shown by the fact that an estimated 20kw of generating power, around 12% of an average solar panel's output during the day, is lost [26]. In states like Tasmania or Canberra, where there are over 174 cloudy days, compared to 44 sunny days each year, the amount of electricity lost from domestic solar production is not to be ignored.

Additionally, weather isn't the only factor affecting solar output in Australia. The vastness of Australia's geography and climatic variability cause differences in solar energy output. For example, the country's arid heartland faces searing temperatures and frequent droughts, which can lower solar panel effectiveness and demand more maintenance. According to Energymatters.com, "As a solar cell gets hotter, the number of electrons that are already in the excited state increases. This reduces the voltage that the panel can generate and lowers its efficiency. This results in less electricity being generated and, ultimately, a reduced power output from your solar system" [27].

In fact, solar panels have a Pmax value, or the temperature coefficient for the maximum power output, calculated by subtracting 25 from the temperature and multiplying it by a certain percentage, with normal solar panels standing around 04%. On a hot 40-degree day, almost 5% of energy is lost to heat [28].

Additionally, although rare, certain Australian locations are also vulnerable to significant weather occurrences such as cyclones, which can destroy solar arrays and interrupt energy production. The cost of solar panels also serves as a hinderance to the transition towards cleaner solar energy. InstyleSolar.com states that "Solar panels in Australia can cost between $2,900 and $14,100 depending on the solar system size, location, brand, and quality," and to add to that, the most common type of solar setup, 6kw, costs $5000-8000, even after government rebates have been applied [29]. In essence, with 3.3 million households already adopting solar [30], transitioning even half of the 7.7 million estimated houses in Australia would cost everyday Australians over 16 billion dollars, and with cost of living the highest in years, and inflation skyrocketing due to worldwide events, this is a staggering sum indeed.

One of the largest problems associated with the transition of energy towards solar panels is the misinformation associated with them, as well as political factors influencing their use on household levels. According to the Australian Competition and Consumer Commission (ACCC), there was a significant increase in scam reports related to solar installations and energy services. In 2020, the ACCC's Scam watch received over 2,000 reports related to solar scams, marking a substantial increase from previous years, and demonstrating the extent at which corrupt salespeople go to for unsuspecting residents to buy their panels [31] .

There are many "techniques" or "methods" used by these salespeople to grab the resident's attention, including the usage of outrageous electricity claims such as claiming residents will no longer have an electricity bill without even looking at the current electricity bill. Although Australians are, for the most part, resistance to these methods, vulnerable populations like the elderly are often pulled into these plots, assuming they're doing good for the environment. Salespeople and solar marketing also over-exaggerate statistics of solar panels, claiming efficiency rates of "50% or more," when, are only at around "30%" [32]. Some have even gone to lengths to impersonate the clean energy council, stating that they're "*calling on behalf of the Clean Energy Council, providing free solar*," misleading residents not only on the role of the CEC, but also on the price of solar panels [31].

In summary, there are several challenges and implications associated with the transition of Australia towards cleaner, more renewable solar energy from current sources of coal and natural gas including both issues from local weather systems and also consumer misinformation.

2.3 Energy Solutions

Solar power is a clean, renewable energy source that is becoming increasingly popular in Australia. Solar panels were first invented in 1883 [33], and convert sunlight into electricity, which can then be used to power your home or office. In Australia, solar systems and production are among the most common in the world, due to the country's high levels of sunlight [34]. As of 2022, nearly one third of Australian homes had solar systems installed [35]. This number is expected to continue to grow in the coming years, as solar power becomes more affordable and accessible with increased focus on sustainability and advancements in photovoltaic technology.

There are many benefits to installing solar panels on your home. Solar panels can help you reduce your electricity bills, save money on your carbon footprint, and become more energy independent. Many Australians can install solar systems and have the system pay for itself by reducing electricity costs in less than 5 years [36]. Battery systems allow excess power generated to be stored for times where the solar panels are less effective (bad weather, overnight) and further reduce the need to purchase electricity. However, there are also some challenges to installing solar panels. The upfront costs can be expensive, although there are many government subsidies available to help lessen the cost [37] and solar power has gotten much cheaper in the last few years. Additionally, it can be difficult for some people to install solar panels, such as those who live in apartments or units.

Despite the challenges, solar power systems are a viable option for many Australian homeowners. It is a clean, renewable energy source that can help you reduce your electricity bills and save money on your carbon footprint. Other forms of renewable energy exist, such as hydropower or wind power, though unless an individual lives with access to a river and necessary permissions, is generally a large-scale project built by the government. Personal wind turbines exist, but solar panels are more reliable in terms of energy production and require less maintenance [38].

3. Global Implications

3.1 Australia's impact

There are several expected positive and negative effects of Australia's transition on other countries. Beginning with the positives, Australia would be a world leader in terms of using solar power and renewables as a main source of energy. Such a transition would mark a substantial step toward combatting climate change. Australia is one of the world's largest per capita greenhouse gas emitters due to its historical reliance on fossil fuels, particularly coal, with each person emits, on average, 15 tons of greenhouse gases, ranking 11th in the world [39]. By enacting a plan towards transitioning towards solar energy, the country could drastically reduce its carbon footprint, leading to a positive ripple effect worldwide.

As a major contributor to greenhouse gas emissions, Australia's shift to solar power would set an example for other nations, encouraging them to adopt cleaner energy sources and accelerating global efforts to combat climate change. With many countries already setting goals of net zero by 2050, this transition could not be less relevant to global efforts towards reducing climate change.

Additionally, energy exports available to the world from Australia would drastically increase. As discussed previously, Australia exports 15,421 Petajoules of energy, with 67% of that being produced from black coal [18]. With a transition towards solar energy, Australia would no doubt increase the amount of energy available to the rest of the world, due to large amounts of surplus, this in turn leading to economic benefits for both global cooperators and Australia itself.

The renewable energy sector could see substantial growth, fostering innovation, creating jobs, and bolstering economic stability. This growth could also position Australia as a global leader in renewable energy technology, potentially exporting its expertise and technology to other countries, thereby contributing to global sustainable development. In summary, the transition to solar will no doubt place Australia as a global world leader in working towards a greener future.

3.2 Global aid

Australia has the potential to help other nations globally in moving to renewable energy systems. This is due to Australia's abundant renewable energy resources, a strong renewable energy sector, and significant financial resources compared to many neighbouring countries. Australia is also a member of the United Nations and has ratified the UN Global Goals, including the goal of achieving 100% renewable energy by the year 2050 [40].

Australia can help other nations in moving to renewable energies in multiple ways, such as sharing knowledge and infrastructure - Australian companies and research institutions can provide technical assistance and training to other countries on renewable energy technologies. Australia can also help and support other countries to develop and implement renewable energy policies and regulations. Australia can also assist by investing in renewable energy projects in other countries: This could involve investing in the construction of new renewable energy power plants or in the development of renewable energy infrastructure. Australia can also provide financial assistance to other countries to help them reduce the cost of moving to renewable energy [41].

One specific example of how Australia is already helping and can help other nations to move to renewable energies is through Australian government support for the Pacific Islands. Australia is working with Pacific Island countries to develop renewable energy projects, such as solar and wind farms. Australia is also providing training to Pacific Island countries on renewable energy technologies [42].

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Australia's Sustainable Energy Transition to Biofuels

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Summary

In the midst of a global climate crisis, finding renewable energy sources is pivotal to a more sustainable future. There is a growing trend across the planet to phase out fossil fuels in favour of energy sources that reduce carbon emissions. Although Australia can be considered a mineral and energy resource rich country, oil and petroleum transport fuels represent a major weakness in the nation's energy and resource portfolio. Australia's current energy consumption is dominated by coal with 92% of Australia's energy demand in 2020-21 accounted for by fossil fuels, such as oil, coal and gas. It is anticipated that Australia's domestic oil reserves will be exhausted in 10-15 years. Establishing a nationwide goal of replacing dependence on fossil fuels with renewable fuels over the next 50 years would offer an equally wide range of multi-economic, infrastructure, and social benefits on a national and global scale. Our aim is to accelerate Australia's transition towards renewable energy and to meet net zero by 2050, by integrating biofuels (including bioethanol, biodiesel and biogas) into the transport sector, converting biofuel technology and application from lab to commercial use. Biofuels are the source of chemical energy derived from biomass (organic feedstocks from plant and animals) and the production of this energy involves anaerobic fermentation. This paper will provide an overview of the scientific processes involved in producing biofuels, and a case for their feasible implementation into the aviation and transport sector. We have analyzed scientific literature and conducted secondary research to create a framework of how Australia can integrate biofuels as a step towards a more sustainable future and net zero.

Keywords
Australia, biofuels, feedstocks, organic waste, decarbonisation

Introduction

Australia's current energy systems are made up of various sources, but predominantly include fossil fuels such as coal, gas and oil. In 2020-21, non-renewables were responsible for 71% of all electricity production in the nation [1] Plentiful gas resources are found offshore in coastal basins and there is an abundance of coal and gas in Australia, with black and brown coal deposits located across the country. However, despite contributing 51% to the nation's total energy generation [2], in the past ten years, coal consumption has fallen an average of 2.4% whilst renewables have grown 4.6% [3]. Renewable energy resources in Australia primarily consist of solar power, hydro, wind and geothermal power plants. Hydro energy structures are strongly developed in Australia, with over 120 hydroelectric power stations currently using flowing water to generate around 7% of the nation's electricity. Furthermore, large-scale wind farms throughout Australia hold immense potential, with wind energy rapidly increasing in use. In 2021, it accounted for 10% of electricity generation [4], a figure which continues to surge as more infrastructure is developed. Geothermal energy also appears promising, as major potential resources have been investigated and located. Despite this, geothermal energy systems are not yet fully developed and thus do not contribute to Australia's power systems [5]. Moreover, methods of biofuel production are still being researched and are yet to be fully established. Within Australia, there is minimal development and use of biofuel in the energy sector, with it being the source of a mere 4% of Australia's total energy consumption.

Australia is a leading producer and exporter of coal and liquified natural gas (LNG). The country's exports of these non-renewable energy sources account for more than two-thirds of total production. As one of the largest exporters of coal in the world [6], the trading of fossil fuels significantly contributes to the country's economic prosperity. Australia's energy imports include refined petroleum products primarily from countries in Asia, such as Singapore, which in 2021, Australia imported $6.57 billion in refined petroleum form [7]. Crude oil is another imported source of energy that fuels Australia's transportation sector. In 2020-21, the COVID-19 pandemic and international restrictions led to a 6% decrease in Australia's energy exports and imports [8], partly due to lowered demand.

Proposed Transition for Australian Energy System:

POLICY

Nationwide fuel blending mandates should be in place to provide a standard that increases both effectiveness and productivity of the integration of biofuels. As of currently there are separate mandates per state which have varying requirements of the types of fuels sold.

To accelerate this, there should be a demand on the government to introduce incentives for industry adoption of renewable fuels whilst simultaneously eliminating disincentives such as fossil fuel tax rebates [9]. The long-standing fossil fuels rebates have been sustaining Australia's mining sector, reflecting the government's political interests and their reticence to change. Thus, for Australia to remain accountable and contribute its share to the Paris agreement (the global commitment "to limit the temperature increase to 1.5°C above pre-industrial levels, before 2050") [10], there must be a price placed on burning traditional diesels and a push for policies and processes to change.

DEVELOPMENT and INFRASTRUCTURE

Investments in co-location of 1st and 2nd generation biofuel plants. These are also known as biorefinery systems that use a combination of the two, allowing both low-carbon and economic sustainable solutions to be met [11]. This decreases the high funding involved in advanced biofuels whilst increases the effectiveness of reaching decarbonising goals (in comparison to using primarily conventional biofuels). The application of "drop in" fuels align with existing infrastructure and engine platforms. Furthermore, the implementation of biorefinery systems not only enables the production of biofuel but a wide range of other valuable resources such as bioelectricity, bioheat, biochemicals and protein-based feed. These investments enable Australia to take advantage of the Australian resources that biofuel demands (to grow its feedstocks) whilst limiting the land degradation. Moreover, this infrastructure stimulates regional development and overall increases Australia's fuel security.

TRADE

Feedstocks including cereals, maize, sugar beet, sugar cane, and rapeseed should be exported globally on a larger scale to support the economy. Exporting feedstocks will aid the transition of fossil fuel exportation as it becomes obsolete.

To facilitate phasing out the fossil fuel exportation, our plan acknowledges the importance in supporting those who are currently working in mining companies and helping them potentially relocate to alternative jobs created by the development of the biofuel industry. This promotes the support of the public who may be concerned regarding the stability of their employment and income. In hopes to increase the demand for relocation and financial support from the government, wider education campaigns will be implemented.

Due to the biofuels compatibility with current oil fuel infrastructures, it allows fuels to be easily implemented into aviation construction, heavy transport and maritime sectors. Application of biofuels in these industries alleviates some of the pressure caused by carbon emissions taxes placed on transport companies (including major airlines and courier services).

Furthermore, our plan seeks to invest in technological and educational sectors that support the development involved in biofuels to equip Australians with experts in the industry and provide more job opportunities.

RAISING PUBLIC AWARENESS

Increasing community engagement is a pivotal step in gaining support for the transition to bioenergy.

It is important to raise the profile of bioenergy solutions and ensure that successful case studies are well-represented in the media.

Education campaigns must be employed to communicate to the public that biofuels are safe and viable for long-term use. One particular example of this is promoting the potential of biofuels in sustainable aviation.

How are biofuels produced?

Biofuels are the result of anaerobic fermentation by plants and yeast. In all living organisms, glucose, produced from photosynthesis or derived from food, is converted into ATP energy, through the process of cellular respiration. In the absence of oxygen, organisms bypass the Krebs Cycle and the Electron Transport Chain, and instead undergo anaerobic fermentation. This occurs in the cytoplasm of cells and begins with Glycolysis. Glucose is converted into two pyruvate molecules, with two ATP molecules also being produced. Pyruvate is then used to produce carbon dioxide and ethanol, which can be blended with gasoline to become a fuel [12]. This process can be described by Eq.(1).

$$C_6H_{12}O_6 \dashrightarrow 2C_2H_5OH + 2CO_2 + 2ATP \qquad (1)$$

The term biogas describes a mixture of gases, consisting of approximately 60% methane and 40% carbon dioxide, that are the products of anaerobic digestion. This process occurs in a large gas-sealed container known as a digester. Gas is generated from the fermentation of organic matter, such as manure, sewage, food waste and agriculture waste, by a range of bacteria and microorganisms in the absence of oxygen. The biomass provides a source of 'food' for the bacteria to anaerobically convert into energy, producing carbon dioxide and methane as byproducts. The gases produced, which chemically resemble natural gas, are collected through pipes on the top of the digester and can be used to generate electricity to power cities and fuel for transport. Digestate is the term used to describe the leftover solid feedstocks after anaerobic digestion has occurred. It is a valuable fertilizer and a sustainable substitute to petroleum-based fertilizers, such ammonium nitrate.

Biodiesel is derived from plant oils or animal fats, inclusive of cooking oil and grease. The chemical structure of fats and oils consists of chains of organic molecules, known as fatty acids, connected to a glycerol molecule. This compound is termed triglyceride. Within a processing plant, triglycerides are combined with alcohol, usually methanol, to separate the fatty acid chains from the glycerol molecule. The long-chain esters produced have similar appearance and qualities to the hydrocarbons that make up regular diesel. However, biodiesel has limited viability in Australia as it has very different properties to regular diesel. It has a low cloud point, since it is derived from fatty acids, and becomes more viscous as temperature drops. These properties hinder its ability to function like regular diesel [13].

Potential Sources and Processes for Producing Biofuels

Currently the most commercially viable biofuel technologies are known as first generation processes. These describe feedstocks derived directly from crops such as cereals, maize, sugar beet, sugar cane, and rapeseed which are commonly used in Europe to produce biodiesel [14]. Australia is the third largest sugar cane producer worldwide and a leader in the production of oil crops such as canola, which puts the country in an advantageous position to generate biofuels and export feedstocks. Australia is already sustainably producing enough crop for bioenergy but around half of its canola produce is being sold to European biofuel markets where policies are driving greater and more positive demand.

Second generation processes are still being developed but will revolutionise the industry as they are produced from the waste products of other industries. Lignocellulose, for example, is the thick lignin cellulose complex found in cell walls of plants. The forestry and agriculture industry generate large amounts of lignocellulosic wastes but fortunately, these can be converted in biofuel. As newspapers become obsolete and the paper industry declines, lignocellulosic waste could especially become more plentiful. Organic wastes and residues are the by-products of other industries. Examples of these are livestock residues, such as manure, as well as wastes from municipal solid waste, construction and demolition and commercial and industrial sectors. Currently in Australia, 22% of organic wastes and residues are sent to landfill and only 7% are used for energy recovery [15].

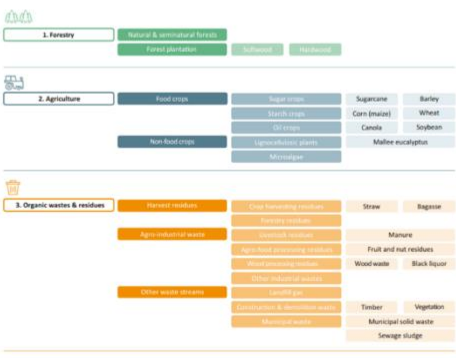

Figure 1: An overview of different biofuel feedstocks.

Advanced Biofuels vs. Conventional Biofuels

Australia should aim to develop and use sustainable, low-carbon, advanced biofuels (2nd, 3rd or 4th generation biofuels, depending on the type of feedstock) rather than conventional biofuels (1st generation biofuels). Conventional biofuels are typically derived from vegetable oils and sugarcane, corn, and wheat. Blends with petroleum are limited due to high oxygen and moisture content, sedimentation, and cold flow issues (when solid material deforms after mechanical stress) involved in these feedstocks. This causes existing fuel infrastructure and existing vehicles such as planes and ships to reject this form of fuel. Moreover, conventional biofuels are produced almost exclusively from the human food chain, which ultimately takes food resources away from the population. This becomes especially impractical as the population continues to grow and world hunger statistics increase.

On the other hand, advanced biofuels are renewable and present notable advantages that elevate its appeal over conventional production. Diesel, green diesel, Fischer–Tropsch (FT)-diesel, bio-jet fuel, and bio-gasoline are liquid advanced biofuels derived from sustainable sources of organic matter that do not compete with food production. The feedstocks are non-edible biomass, derived from the residue and waste of agricultural sectors (straw, cotton trash, sawdust and vegetation removed by agricultural thinning), rubber content, mining tires, grease, and demolition waste. This increases the sustainability as it mitigates waste production, offsetting more carbon emissions (e.g. methane that would have been emitted from landfill). It may also use high yield grass and woody biomass as feedstocks which can be grown in high yields and on semi-arable land (land which is not capable of sustaining crops on a regular basis). This ensures no food sources are being sacrificed for fuels, whilst limiting land degradation. Furthermore, byproducts of advanced biofuel production including bioelectricity, bioheat, biochemicals and protein-based feed which may also be sold to compensate for the investment of infrastructure and production. Another advantage is that cellulosic ethanol, bio-CNG, bio-LNG are other forms of biofuels which have a much higher potential to reduce emissions [16]. Some of these are termed "drop-in fuels" as they can be applied in existing distribution infrastructure and engine platforms. Therefore, the use of advanced biofuels and implementation of biorefinery systems not only opens up a diverse range of different biomass sources but is also compatible with existing infrastructures designed for petroleum inputs and transport, increasing the efficiency of transporting to commercial markets. These long-term benefits are why Australia should invest in the advanced biofuel facilities rather than conventional biofuel options.

However, some economic challenges still prevail; advanced biofuels are currently more costly in comparison to their counterpart, partially due to the cost of enzymes which must be tailor made for the type of feedstock during the production of cellulosic ethanol. Though current research is focused on reducing these costs, it is estimated that the investment required for production facilities alone is estimated to be $25-30 billion [16].

Drop-in fuels

Drop-in fuels, also termed renewable gasoline, are alternative fuels that can be used as direct replacements for conventional fossil fuels without significant modifications to existing engines or infrastructure. As they consist of similar properties and energy densities as the fossil fuel counterparts, they are compatible with current combustion engines and distribution systems. These specific biofuels do not require blending with petroleum unlike most biofuel consumption that occurs as a blend with gasoline, diesel fuel and heating oil. Drop in fuels are currently produced using lipids from a variety of oils, paving the way as part of transport sector decarbonisation. However, amount of appropriate feedstock is limited, preventing the production of sufficient quantities of drop in fuels to be produced to cover all projected biofuel demand in the transport sector. Therefore, the use of cheaper and more readily available feedstock such as lignocellulosic feedstocks has proved a more desirable option. This development is currently underway with focusses on thermochemical, biochemical and hybrid pathways.

Benefits for Australia

Australia has the potential to benefit greatly from the transition to bioenergy in areas of waste reduction, meeting emissions reduction targets and economic growth. According to Bioenergy Australia, by the beginning of 2030, Australia's bioenergy sector could contribute an additional $10 billion to the country's annual GDP and create 26,200 new jobs by supporting long-term regional employment. This number increases to an extra 10,000 jobs by 2050 [17]. As the majority of feedstocks for biofuels are derived from the agricultural sector, investments in bioenergy provide additional revenue streams for regional farmers and support economic stability in local communities. By locally producing biofuels, Australia's reliance on imported oil and petroleum fuels is reduced, improving the country's overall fuel stability, especially in times of conflict and widespread disease. Deriving energy from organic wastes and residues offers a novel and alternate method of waste treatment. Resources, such as lignocellulosic waste, would otherwise have been burned without any attempt at energy recovery, ultimately increasing greenhouse gas emissions. The most obvious benefit to this transition is the reduction in greenhouse gas emissions. As a renewable source of energy for generating electricity, heat, gas and transport, biofuels redirect our energy sector away from burning fossil fuels. It is estimated that by 2030, bioenergy could abate emissions by 9% nationwide [18].

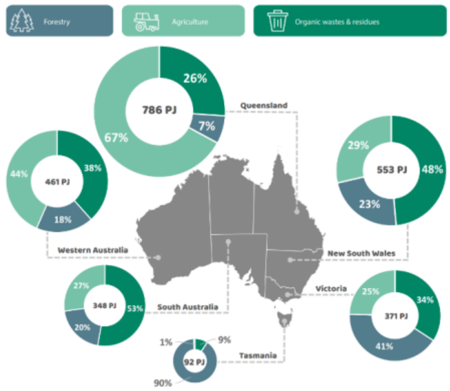

Figure 2: A breakdown of Australia's biofuel resource potential.

Issues for Consideration in the Transition to Biofuels

Cultivation of land for biofuel production may result in dire environmental consequences. The conversion of natural vegetation to cultivate biofuel feedstocks risks releasing a significant amount of carbon from soil and plant biomass. Other environmental impacts include soil erosion, nutrient depletion, water consumption and loss of biodiversity which should be taken into account if it is planned to enlarge the biofuel industry to a greater scale. Land use changes in relation to biofuels can occur in 2 ways: indirect and direct. Direct refers to the transformation of previously uncultivated areas, such as grasslands or forests, into croplands for feedstock production for only biofuel use. Indirect land use change refers to using previous land areas for crop and food production to produce biofuels, whilst inducing the displacement of these crops to new land areas. The 'food versus fuel' debate is an ongoing dispute that emerges from utilising grains and oilseeds for biofuel production instead of for human and animal food. As the global population increases at an alarming rate, and hunger and malnutrition become more prevalent issues, our land use must be evaluated critically. It is estimated that 100 million hectares of land are needed for feedstocks to meet the 2060 target. This figure will increase as a growing population seeks more land to produce food and biofuels.

Transport and storage costs also have an influence on the economic viability of bioenergy. The transport of raw materials over long distances to reach processing plants is costly, but the establishment of biohubs appears as an optimistic solution. The G21 Geelong Region Alliance in Victoria and Daintree Bio Precinct in Queensland are in development to become bioenergy hubs strategically located in areas that maximise availability for resources and minimise the need for transportation [19].

Biofuel Currently in Australia and Application Aviation sector

At the moment the nation's leader in biofuel policies is Queensland. They have partnered with various sectors (including aviation, construction, heavy transport and maritime) in taking their steps towards integrating biofuels into these industries [20]. The Queensland government encourages more biofuel plant locations because it would help achieve decarbonization goals, increase fuel security and create job opportunities. Specifically, the Mercurious biorefinery pilot plant in Mackay (Queensland University of Technology Renewable Bio Commodities Pilot Plant) makes sustainable aviation fuel and renewable diesel [21]. The most common organic matter being used to process biofuels is easily fermentable sugars from grain sorghum, used cooking oil, molasses from sugar cane processing. The location of these bio plants would be effective and efficient as Queensland is responsible for 95% of Australia's sugarcane grown and produced [22]. Cutting transport distances leads to an increase in the net surplus of sustainable energy.

The Queensland University of Technology (QUT) are helping the Queensland government to reach their decarbonization goals as they contribute to the production of biofuel blends for jets and other engines, as the biofuel produced is carbon negative. Since the organic matter requires photosynthesis involving the uptake of CO_2, once the biofuel is burned, it reaches net zero CO_2 emissions. This becomes crucial for the aviation sector as aeroplanes alone contribute to a total of 1 billion tons of CO_2 per year, which is more than the emissions of most countries including Australia [23] which emits approximately 463.9 million metric tons. [24]. The aviation sector contributes to 2.5% of the world's total carbon emissions.

Sustainable Aviation Fuel Roadmap

Biofuels are critical to the decarbonization of the aviation sector. To minimise their carbon emissions, Qantas and Airbus have invested in sustainable aviation fuel (SAF) and have plans to build a $400 million ethanol-based fuel facility in North Queensland that is expected to finish construction in 2026. The facility will transform crops, such as sugarcane into jet fuel through anaerobic fermentation to produce bioethanol. According to Queensland's deputy premier, Steven Miles, this project is in line with the state's Energy and Jobs plan and will revolutionise the state's economy and decarbonization ambitions [25]. With their rich supply of feedstocks, Queensland is in the perfect position to capitalize on the global shift to green jet fuels and become the leader of a local SAF industry. Queensland could be producing the millions of litres of SAF needed to power flights across Australia and around the globe, creating more regional jobs in the process.

The International Air Transport Association states that SAF may offer over 65% of the emissions reductions required for aviation to attain net zero by 2050 [26]. Reducing these emissions improves local air quality, particularly in areas with a high density of flight movements, such as airports. Additionally, bio-derived fuels reduce CO_2 emissions throughout their lifespan compared to fossil-derived fuels. The quantity of CO_2 taken up by plants throughout the development of their biomass is about similar to when fuel is consumed in a combustion engine, producing carbon that is merely returning to the atmosphere. As a result, these lifespan phases cancel one another out. The manufacturing of bioderived fuels does, however, result in extra pollutants, such as equipment required for agricultural cultivation and harvesting, transporting biomass, refueling, and other tasks. When all of these factors are taken into consideration, bioderived fuels, while not emission-free, are nonetheless projected to give a decrease in emissions overall when compared to fossil fuels.

The Qantas group is currently sourcing its SAF overseas, but domestically producing bioethanol will represent a significant milestone towards net zero emissions by 2025. Qantas became the first Australian airline to continuously acquire SAF in December 2021, delivered at London Heathrow airport. 3.2 million gallons of SAF was purchased at London Heathrow in the financial year 2022. The implementation of Sustainable Aviation Fuel is increasing across in the globe, but especially in Europe, the UK, and the US. Businesses and governments are collaborating to find ways to gradually decarbonize the aviation sector through government fuel subsidies, SAF blending mandates, financial incentives (e.g. capital grants, loans, tax incentives), and additional project-based funding [27].

The development of Sustainable Aviation Fuel in Australia is just one prime example of how biofuels have a growing importance in our journey towards Net Zero.

Australia’s Impact on Other Countries

<u>Global energy security:</u> Increased biofuel production in Australia will contribute to global energy diversification, mostly targeting the reduction of dependence of fossil fuels and mitigating geopolitical risks associated with oil rich regions

<u>Technology knowledge:</u> Australia's transition to biofuels means the country will gain expertise and knowledge in sustainable agriculture and biofuel production which could

be shared with countries, promoting the adoption of ecofriendly practices and fostering innovation.

Encouraging the transition of biofuels in developing nations: Developing countries, many being located in Africa, may have a lot to gain from Australia's experience, as they also are rich in biowaste as well as having enormous natural resources in the form of biomass. Our nation's transition to biofuels motivates and provides an insight into an effective plan along with potential points of improvement.

Rural development: It is expected that if the 2060 biofuel production goal is reached in Australia, more than 250,000–400,000 new employment roles will be available [28], creating job opportunities and improving livelihoods in regions that may be struggling economically.

International trade: It is estimated that biofuels could contribute around 10 billion to Australia's economy by 2030 [29]. The globally decreasing demand for coal will gradually limit the amount exported by Australia. $112.8 billion worth of coal was exported by Australia in 2022 [30], which is currently the third largest exporter of fossil fuels. Mining less coal may negatively affect Australia's economy and standing as a major coal exporter and disrupt relationship with other countries dependent on trade partnerships.

Minimise reliance on international importations: Currently Australia imports 90% of its petroleum fuel from overseas, with a significant 25% coming from Singapore [31]. The recent COVID-19 pandemic has revealed critical vulnerabilities that show that we need to enhance our nation's self-sufficiency and reduce dependance on petroleum imports, so that we are not at risk of supply constraints during times of global or political upheaval. However, reducing importations may also impact the economic growth and activity of petroleum exports in the nations that we currently depend on.

Conclusion

Currently, humans are facing a massive crisis due to augmentation of global energy demand and simultaneous increase of CO2 emissions due to the overconsumption of fossil fuels, triggering alarm to both humankind and the environment. The depletion of petroleum derived fuel has created exigencies for a more sustainable, reliable, and renewable fuel source. Australia's vast landmass presents a great potential for a generous supply of biofuel production, however, as highlighted in this discussion, the nation stands far behind amongst countries who have already seen to its extensive implementation.

The clear pathway to the transition of biofuels lies in several key elements highlighted prior in our discussion: implementation of policy framework and national tax rebates that incite use of biofuel blending in transportation fuels, the development of advanced biorefinery systems as both an economic and sustainable production strategy, and exporting the nation's generous feedstock internationally to further increase the adoption of biofuels as fossil fuels become obsolete. Overall, the proposed transition plan sits well within the nation's reach. By meticulously implementing this plan, Australia can not only significantly reduce its carbon footprint but also contribute to global sustainability efforts, thus inspiring other nations to follow suit and collectively work together towards a greener and more resilient planet.

Acknowledgements

To Professor Akshat Tanksale of the Department of Chemical and Biological Engineering at Monash University, our deepest gratitude for taking the time to review our paper and giving us generous advice that has been instrumental to our research. His expertise as the Carbon Theme Leader of the Woodside-Monash Energy Partnership and Deputy Director of the newly launched ARC Research Hub for Carbon Utilisation and Recycling has provided us with crucial insights to the research and viability of biofuels within the industry.

We would also like to give a sincere thank you to our wonderful teacher Mrs. Bridget Forster for her unwavering support throughout this project. As the Head of Kerferd Library and the 2023 Reading Australia Fellow for Teachers of English and Literacy and Teacher Librarians, Mrs. Forster has kindly lent her time and effort to make this report possible, and she has provided us with the opportunity to extend our knowledge and participate in this project.

Finally, we thank the organisers at GALESS, for holding this conference and encouraging bright young minds to be a part of the solution to a complex and global problem.

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Appendix

Figure 1: ARENA (2021) *Australia's Resource Availability* [online] https://arena.gov.au/assets/2021/11/appendix-resource-availability-australias-bioenergy-roadmap.pdf

Figure 2: ARENA (2021) *Australia's Resource Availability* [online] https://arena.gov.au/assets/2021/11/appendix-resource-availability-australias-bioenergy-roadmap.pdf

Tiltshift Challenge: Energy Transitions.

Camberwell Grammar School, Melbourne, Australia.

GALESS research team: Alex Zhang; Leonard Lee and Ivan Zhang. Teacher facilitators: Ms Jo Menzies (School Sustainability Co-ordinator), Mr Paul Double (Head of Enrichment).

In our state of Victoria in particular, and in Australia in general, there has been a great deal written by sectors involved in the energy space, with direct reference at the customer delivery stage, about plans for a sustainable future with energy reserves and usage.

This sustainability is set amongst a backdrop of doing what is best for the environment to stem the tide of climate change issues which affect human standards of living and the natural world.

With the increasing calls for sustainable energy initiatives from world bodies, and with the realisation from the general public in Victoria that in order to provide a sustainable future action must be taken, our research into what vested business interests are actually doing and planning to do rather than talking about doing without substance, our team will test the resolve of these vested interests by examining their past, present and future policies and commitments in printed pamphlets, in the spoken and written media and in observing what has been achieved to date.

To this end, two energy companies, a State Government Department and political party policies are being examined carefully in an attempt to uncover the resolve of energy providers to deliver on their undertakings.

REVISION OF TASK

After much debate and difficulty in getting key corporate and government bodies to find a time to talk with us, it was decided to change emphasis in information gathering and target our school community instead.

We viewed the likelihood of key corporate and government bodies actually talking to us in an open and progressive dialogue would be minimal as all of these bodies want to justify their existence with positive spin about what they are doing in the energy transition area and would not be open minded enough to cast a critical eye over their own organisations.

Thus, it was decided to target our school community and garner their perceptions about what is the ‘state of play’ with our current system and what we could do in the future to make successful transitions to a cleaner energy usage future.

Questions were devised by our team which attempted to elicit responses about what is known by our school community at present and what should occur in the future. With over 100 responses we were encouraged and delighted with the responses we received and the focus of this research project is these responses which would help us in our future planning.

Tiltshift Energy Research Report Questions 1a, 1b, 1c

Australia has relied on the fossil fuels found in abundance in the ground. Natural resources such as coal and gas have been mined to provide the relatively small (by world standards) Australian population with easily accessible energy sources. Not only has the Australian population consumed these fossil fuels for its energy needs but has readily exported gas and coal to other nations around the world, but particularly in heavily populated Asian nations.

Up until recently there has been little regard for the 'elephant in the room' concerning the deterioration of the Earth's climate and rising sea levels due to this exploitation. 'Dig it up and ship it out' has been the mantra for Australia's export economy in regard to fossil fuels. This accessible and relatively cheap way of making money has contributed to Australia's high standard of living in the short term with scant regard to the long term consequences.

Energy: Current State

International pressure to meet targets in reducing carbon emissions has been slow to have an effect in Australia over the last decade. Easy money to be made by maintaining the status quo of fossil fuel use has overridden the dire need to look at this destructive medium to long term environmental problem this course of action promotes.

Although blessed with an abundance of sunshine, the solar energy industry has been slow to 'take off' in the energy space. Governments have slowly introduced solar benefits to consumers and the whole solar industry is now making up for lost ground, (from years of neglect), and households and commercial operations are now embracing the benefits of installing solar options.

The Victorian State Government has taken back the energy space from the private companies by re-establishing an old energy body (The State Electricity Commission) which was a powerful energy body in Victoria before the industry was privatised 30+ years ago.

Recent publicity suggests the State Government is now turning its attention to the energy transition space:

https://www.danandrews.com.au/energy
https://www.danandrews.com.au/labors-plan-for-net-zero-emissions
https://www.danandrews.com.au/news/putting-power-back-in-the-hands-of-victorians
https://www.danandrews.com.au/batteries

The newly established SEC (State Electricity Commission) states its aim quite clearly:

https://www.vic.gov.au/state-electricity-commission-victoria

The Greens are also putting together their policies in the Green Energy space.

https://greens.org.au/vic/policies
https://greens.org.au/vic/policies/energy-policy

The major Victorian State opposition, the Liberal/National Party coalition, traditionally a more conservative style of government also have their own policies emerging.

https://vic.liberal.org.au/news/2022-07-18-real-solutions-to-lock-in-climate-action-and

vhttps://vic.nationals.org.au/media-releases/real-solutions-to-lock-in-climate-action-and-build-victorias-energy-system-of-the-future/

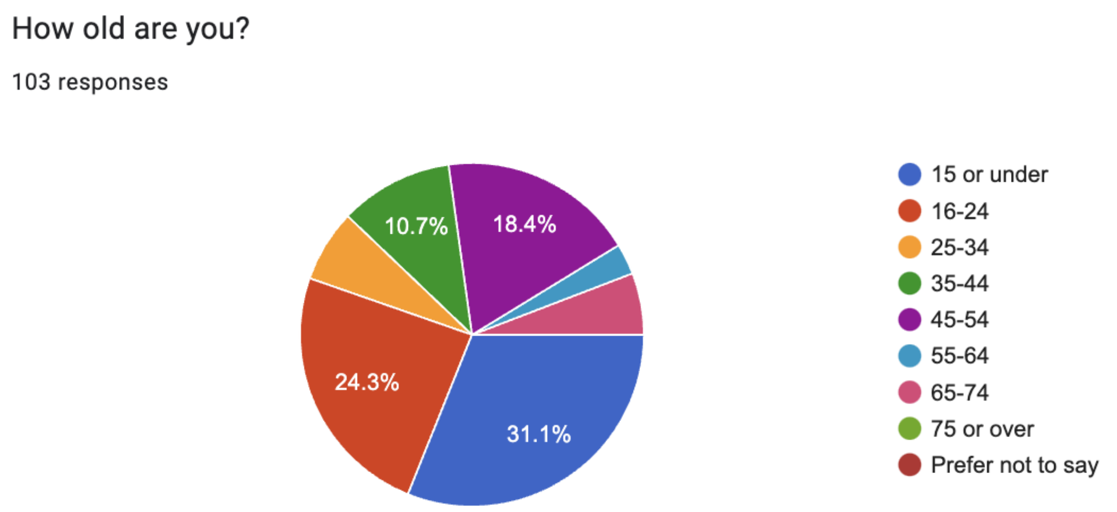
Selected energy companies will also interviewed with questions after researching their publicly stated policies

AGL ENERGY
https://www.agl.com.au/content/dam/digital/agl/documents/about-agl/sustainability/ctap.pdf

ORIGIN ENERGY
https://www.originenergy.com.au/about/investors-media/climate-transition-action-plan/

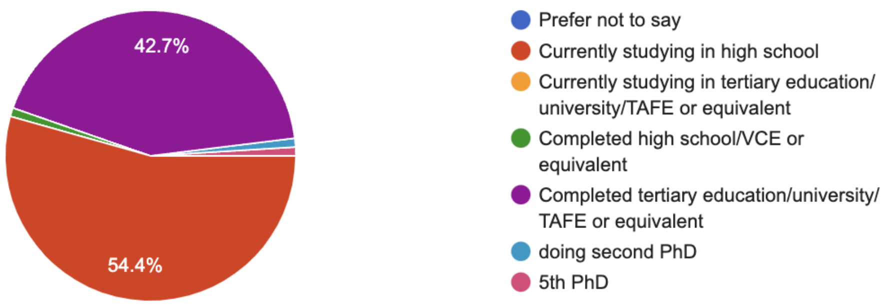
The publicly stated aims will be examined and it will be interesting to see the responses from these organisations when the questions about what was the current state of you your organisation 10 years ago and 10 years into the future as well as examining the documentation above as a current stance on energy transition.

The Survey and Results



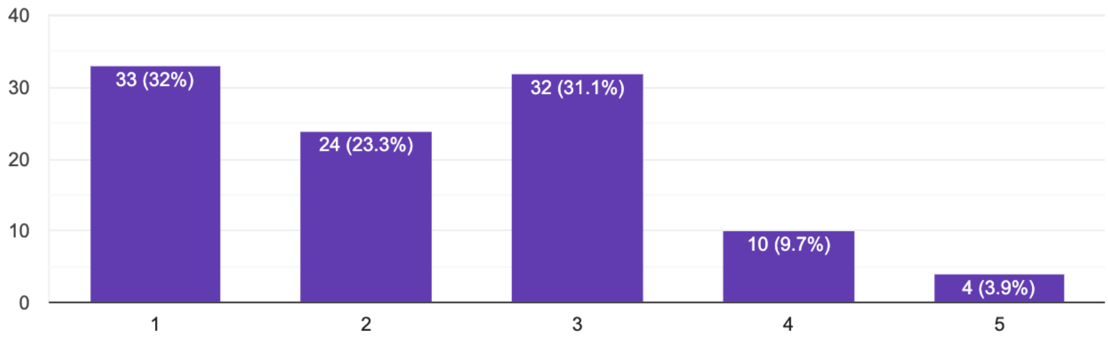
What is your current level of education?

103 responses



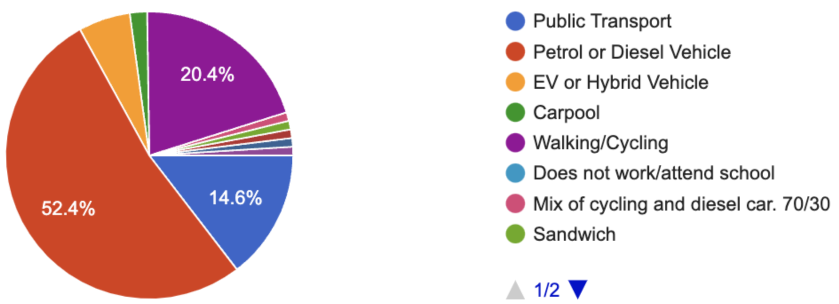
How well do you know your State Government's future energy plans?

103 responses



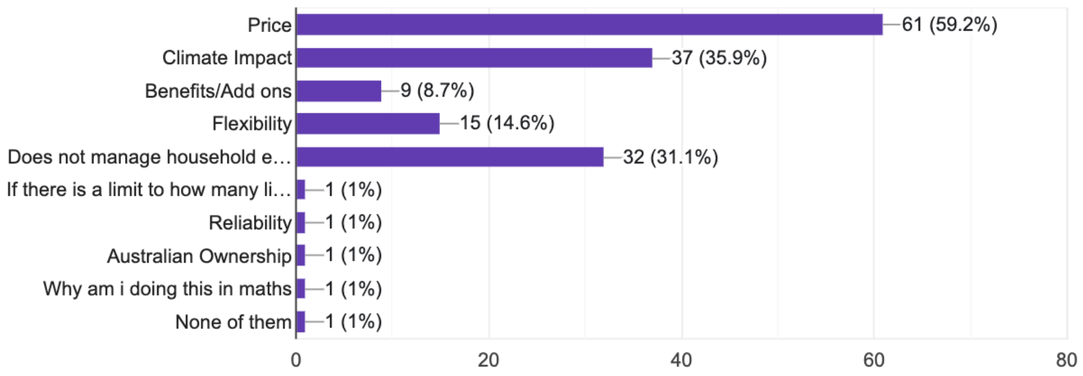
How do you get to work/school?

103 responses



When considering your household energy provider, which issue(s) are the most important to you?

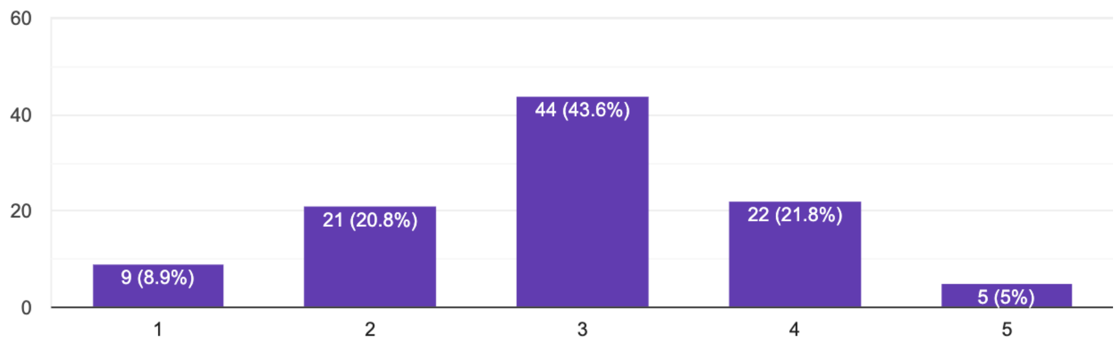
103 responses



How would you rate your household's energy usage

Copy

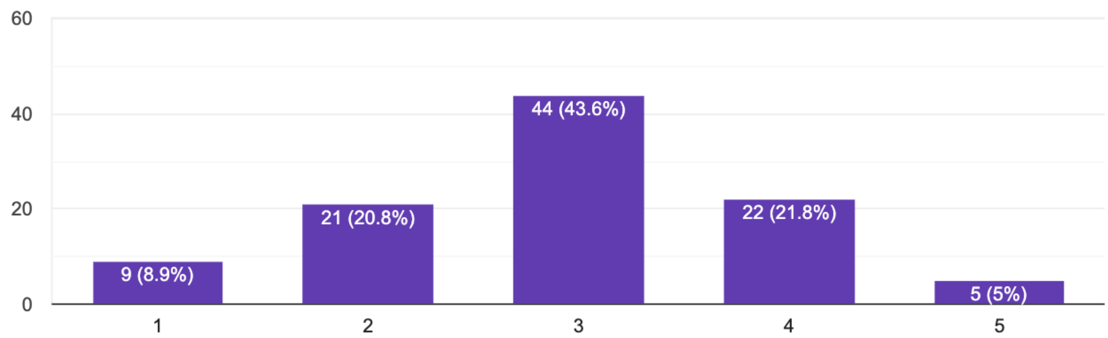
101 responses



How would you rate your household's energy usage

Copy

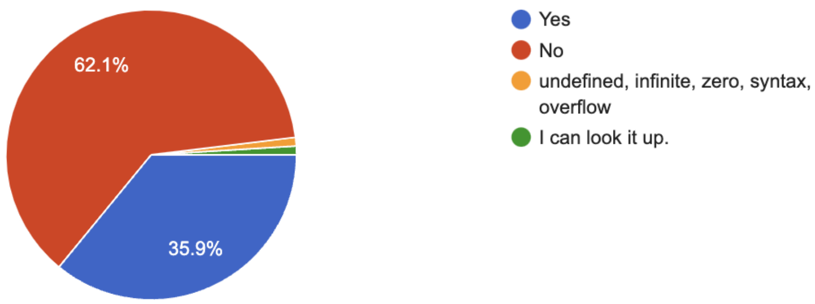
101 responses



Do you know how much energy your household uses on a monthly basis?

Copy

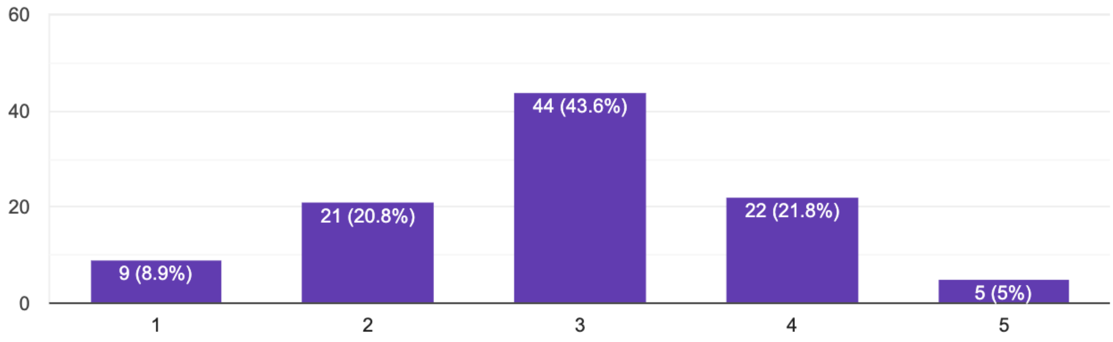
103 responses



How would you rate your household's energy usage

Copy

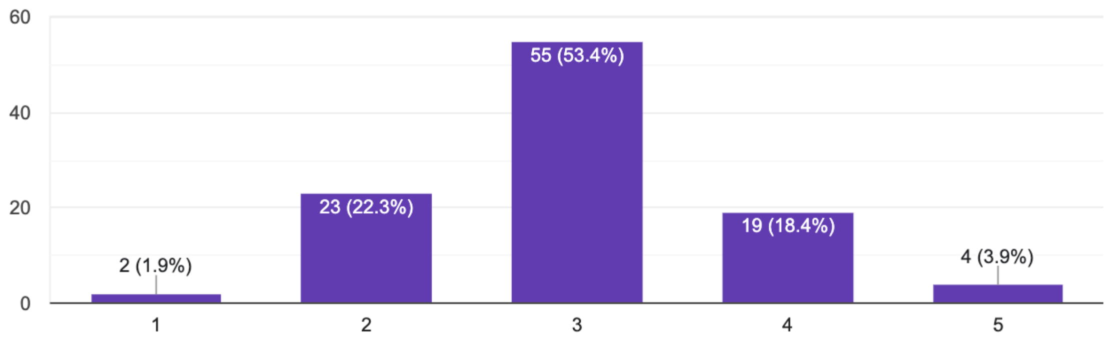
101 responses



How energy efficient is your house?

Copy

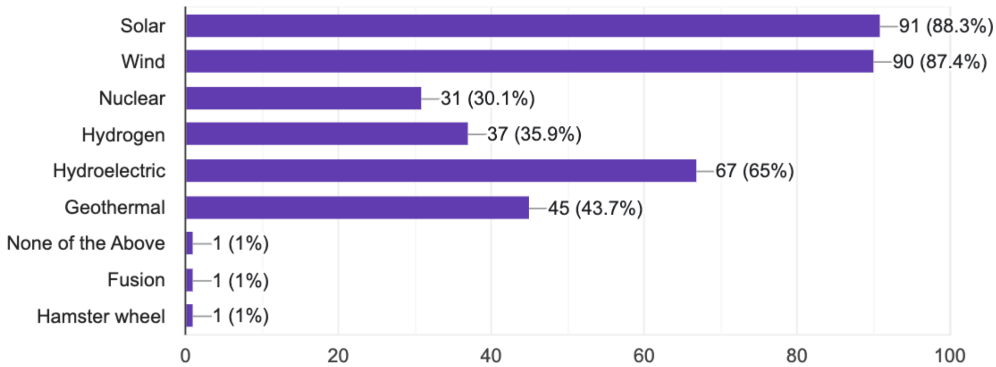
103 responses

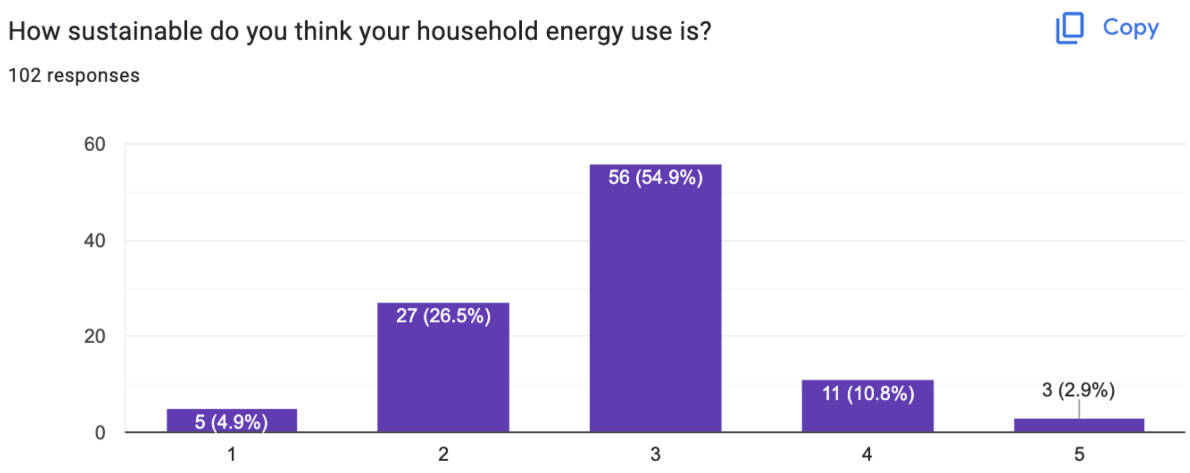


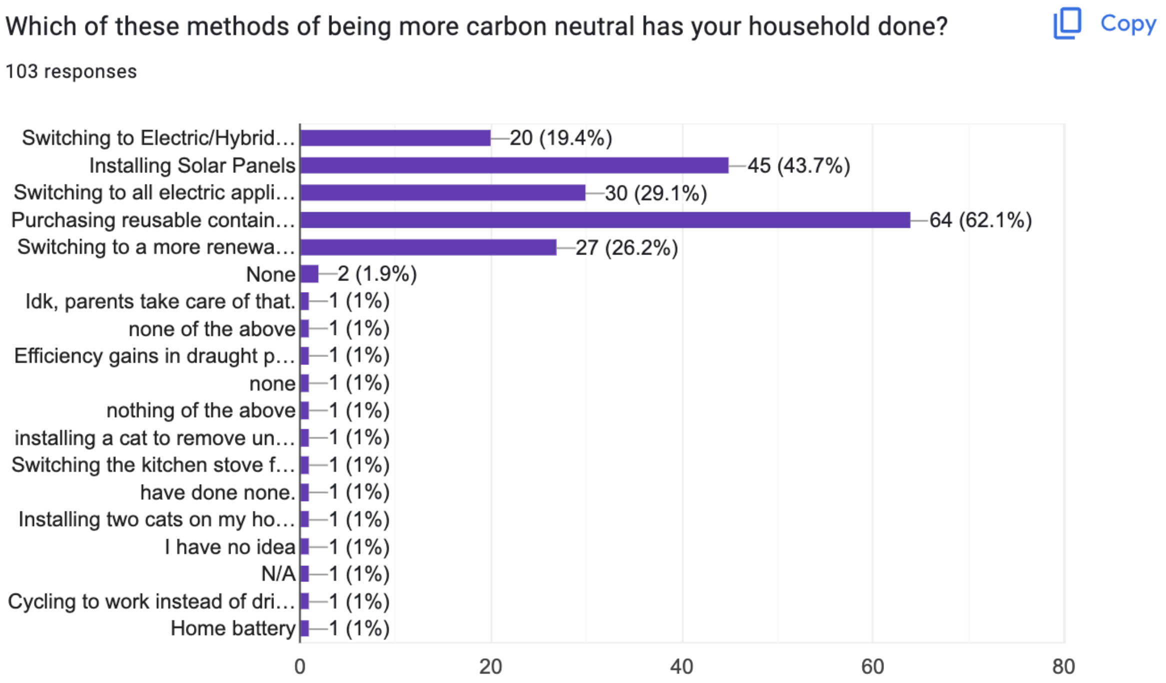
Which of these do you think are appropriate forms of clean energy for the future of Australia ?

Copy

103 responses







Interpretation of Results

The main upshot of these results is that people want price effective energy supplied to their homes before any other consideration. This means that even though there have been many advertisements about the climate effects of using fossil fuels, price still predominates.

Other observations:
Broad Ideas:

- State government isn't doing enough
  - Subsidies
  - Investment
  - Awareness campaigns
  -
- People care about cost more than anything else

  - Environment is a secondary issue to most - example - most people drive petrol/diesel cars to get to work, as it is the most convenient/cheap method
  - They care about their own gain first
  - Shows that the state government's awareness campaigns are largely ineffective
- Most of the demographic surveyed don't have a clear understanding of Australia's future energy plans
  - They don't understand the different responsibilities of the local, state and federal government
- Overall there is pessimism about the current environment but hope for the future
  - People say that the government is in the right direction, but they are doing so too slowly
- Not much satisfaction in what the government is doing
- Majority of people don't actually know the energy usage of their homes
  - Most likely because they are too young and not paying the bills.
- Some people are interested in nuclear energy for Australia.

Consumers have 5 main ideas which they see as 'saving the planet' from global warming:

- Switching vehicles to hybrids or EV's (no mention of limiting number of vehicles per household.
- Installing solar panels
- Switching to all electric appliances (does this mean phasing out gas for domestic use?)
- Purchasing reusable containers
- Switching to renewable energy sources.

Final Words

According to the survey, many people value climate change and hope for a green future. However, money comes first, and people mostly go with energy options where it is the most economical. This is because of various factors such as the ongoing inflation, and financial pressures they experience. As it is seen, more than half of the people surveyed relied on petrol or diesel cars to get to work, as it is the cheapest option, as opposed to other options such as electric vehicles or green public transport options.