Thermo-Fluids:
Power Generation

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Summary of Proposal

Germany has been known to the best economy in Europe in recent years. However people don't have the same idea about Germany in terms of its power generation, and put countries such as Iceland at the top of their list in terms of renewable energy generation.

Being half German I was curious to find out if German energy generation is more renewable that first thought, and how in the future power generation could be provided.

From the current energy mix, it was clear to see that Germany heavily relies on imports, especially of oil and natural gas, which make up 86.4% of their imports. Their production amounts to104 171 ktoe, imports are 247 505 ktoe, and exports are only 30 886 ktoe. However, looking only at electricity, Germany does not rely too heavily on imports.

The 220 192 ktoe of consumption is split fairly evenly between industry, transport and residential at around 25% for each, and the rest on agriculture, commercial and public services, and non-energy use.

Figure 1

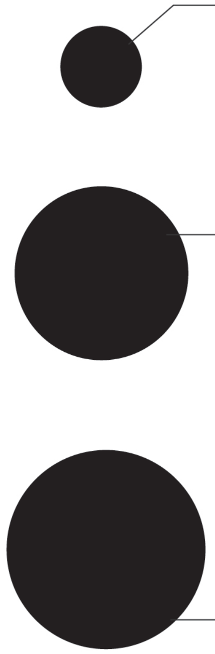
Wind and solar are the most common renewable energies, with wind dominant in the north and solar in the south. Projected energy for 2030 is due to remain constant at around 223 000 ktoe. There is due to be a dip due to COVID-19, but like the financial crisis in 2009, the country will recover and consume the same amount of energy after.

The proposed scheme put in place is to completely stop nuclear power production, in line with Germany's 'Energiewende' scheme. This can be achieved through installed on and off shore wind turbines, as well as solar panels on buildings, and in the form of solar farms. Together these proposals make up the 23916 ktoe lost by lack of nuclear energy.

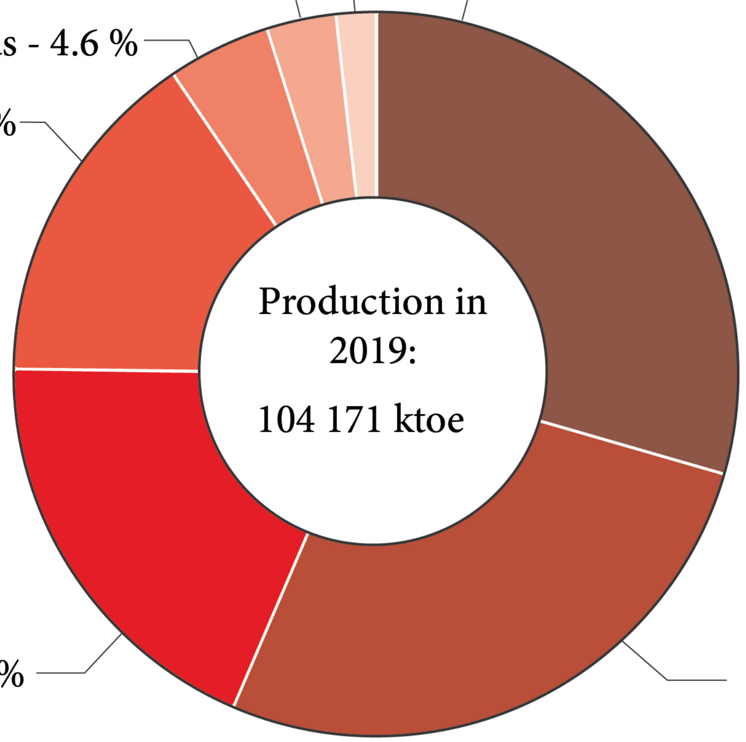
The dependability of energy was also ensured by putting HVDC lines in place to transfer excess energy from the north to the industrial south and the installation of batteries in homes that are connected to the grid, which will increase Germany's backup energy supply.

Current Energy Mix (Data from 2019)

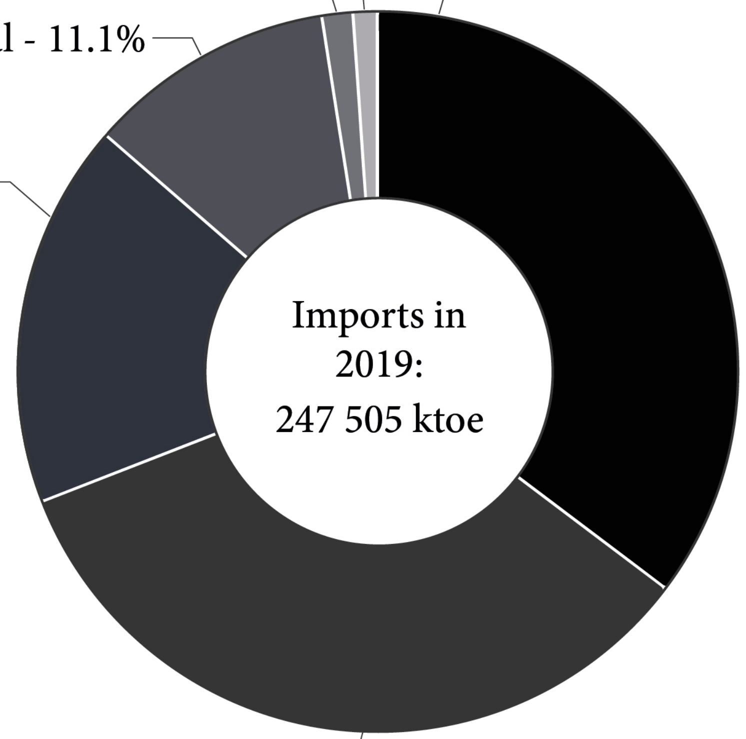
Transport + Stocks



Production



Imports



Consumption

Germanys current consumption of energy after minusing the losses.

Total Energy Supply - 300 827 ktoe

Losses = 80 645 ktoe (from electricity plants, CHP plants, heat plants, gas works, oil refinaries, coal transformation, liquification plants and energy industry own use)

Total Final Consumption - 220182 ktoe

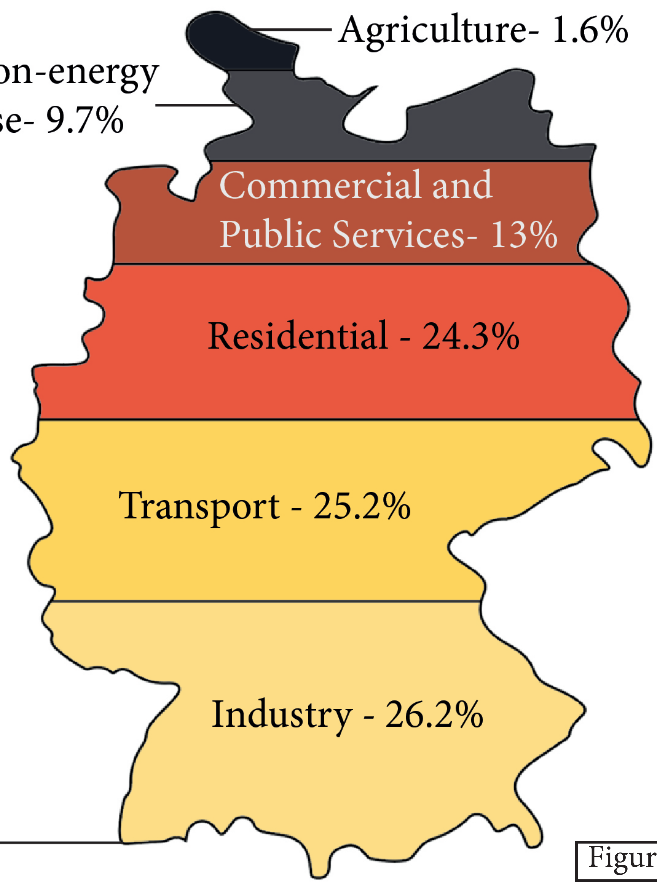


Figure 3

Exports

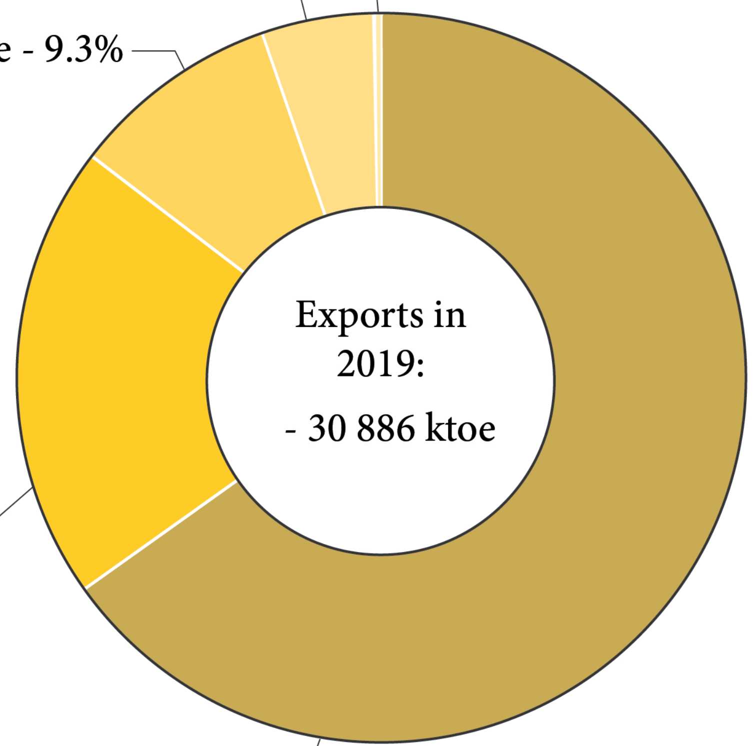


Figure 2

Source: https://www.iea.org/data-and-statistics/data-tables?country=GERMANY&energy=Balances&year=2019

Current Energy Mix

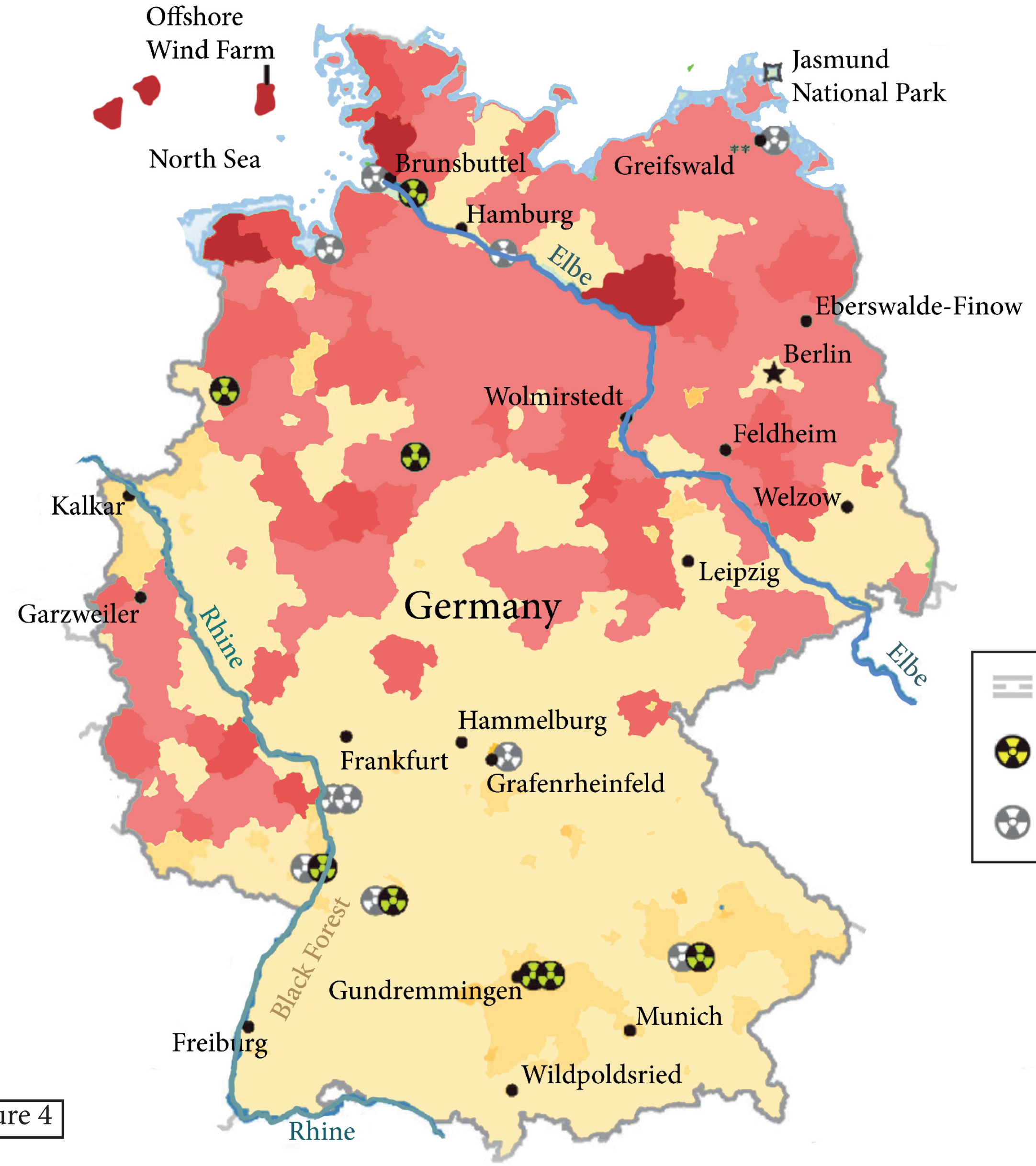


Figure 4

Wind Dominant Region

0.5 1.0 1.5 1.5+

Solar Dominant Region

0.5 1.0 1.5 1.5+

Map of Solar, Wind and Nuclear Power

(2014)

Planned Power Line

Operational Nuclear Reactor

Closed Nuclear Reactor

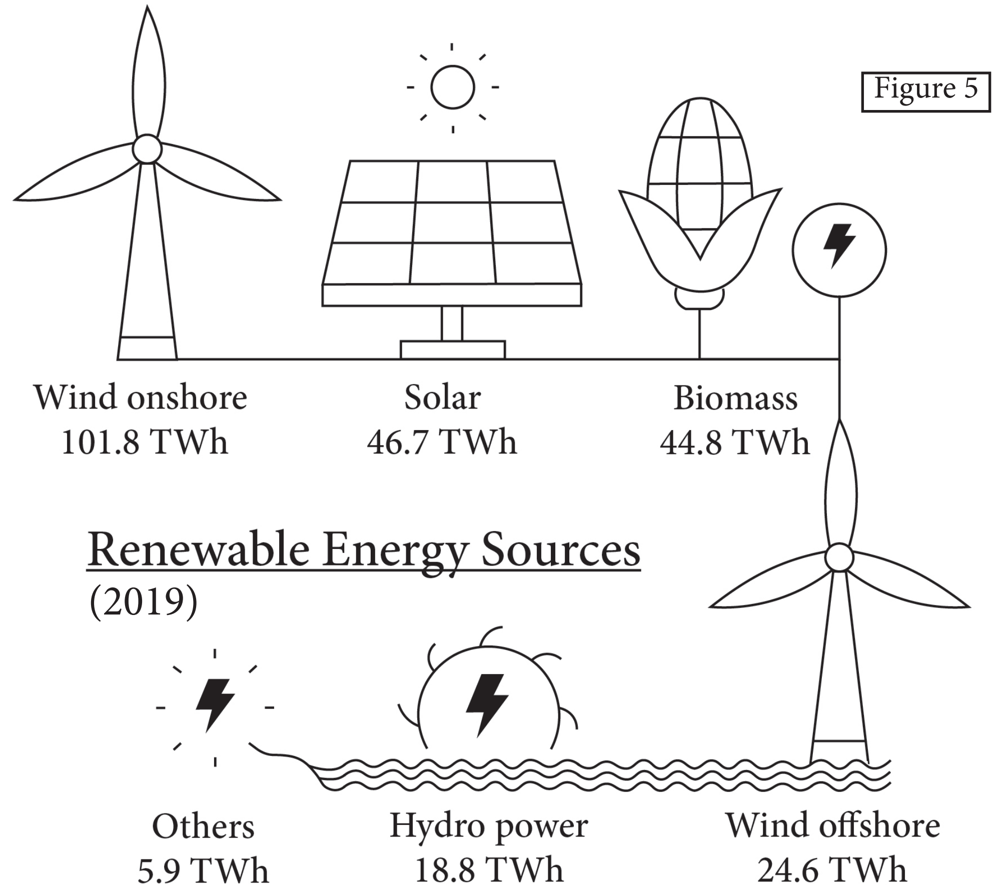


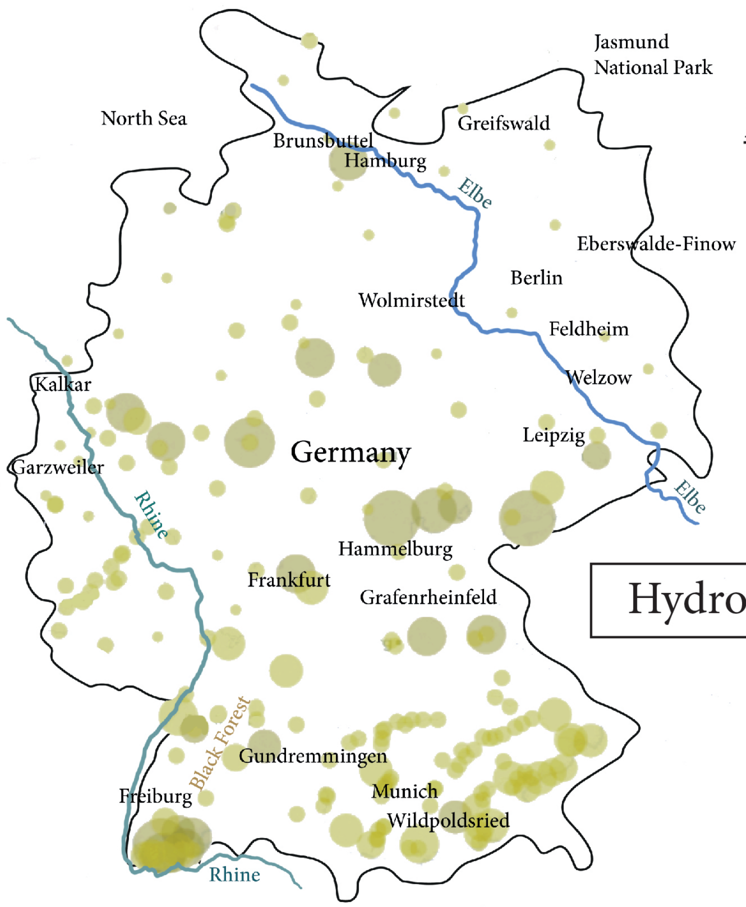
Figure 5

Renewable Energy Sources

(2019)

It can be seen that solar dominant regions are in the South of Germany, and that wind power is more prevalent in the north. Hydro power is also more common in the south, and Biomass power is evenly spread through the country.

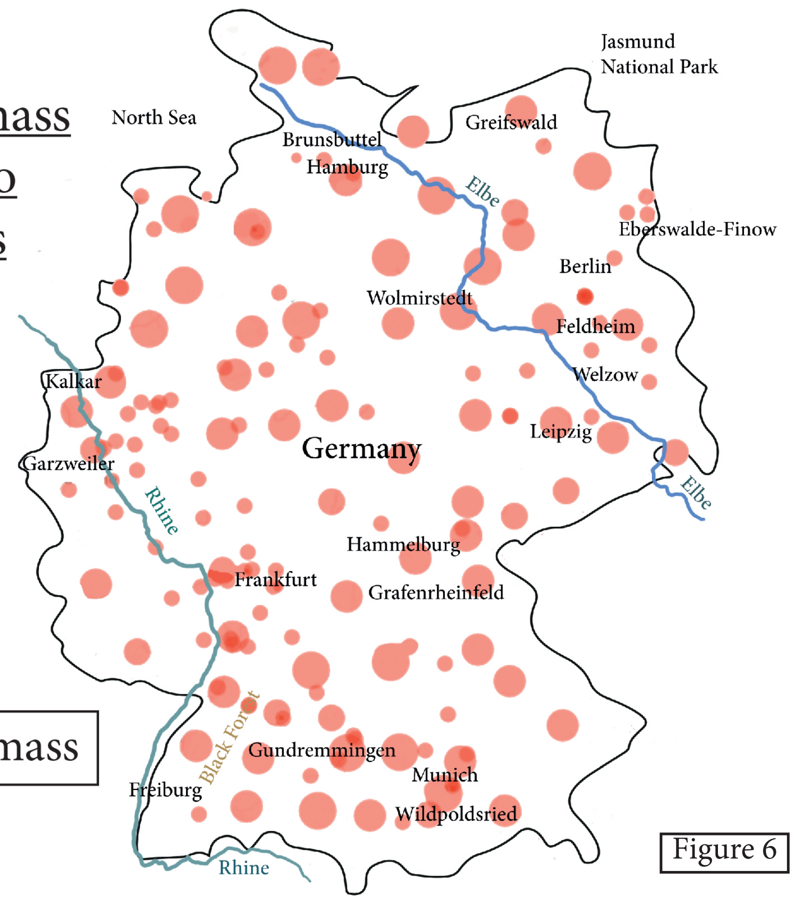
In terms of the renewable source energy values, onshore wind is by far the highest, with solar and biomass also having large shares of it.



Hydro

Map of Biomass and Hydro Locations

(2019)



Biomass

Figure 6

[1] https://www.nationalgeographic.com/magazine/2015/11/germany-renewable-energy-revolution/
[2] https://www.cleanenergywire.org/factsheets/germanys-energy-consumption-and-power-mix-charts
[3] https://www.iea.org/data-and-statistics/data-tables?country=GERMANY&energy=Balances&year=2019
[4] https://www.carbonbrief.org/how-germany-generates-its-electricity

Projected 2030 Energy Requirement

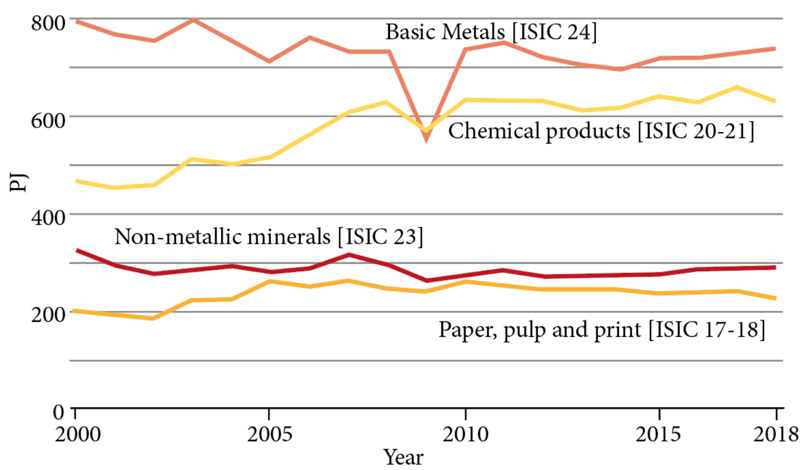
The energy requirement for Germany will depend on a number of factors such as the impact of COVID-19, as well as the energy requirements for individual sectors. Assumptions on these are made below to forecast the future demand.

Sector Breakdown

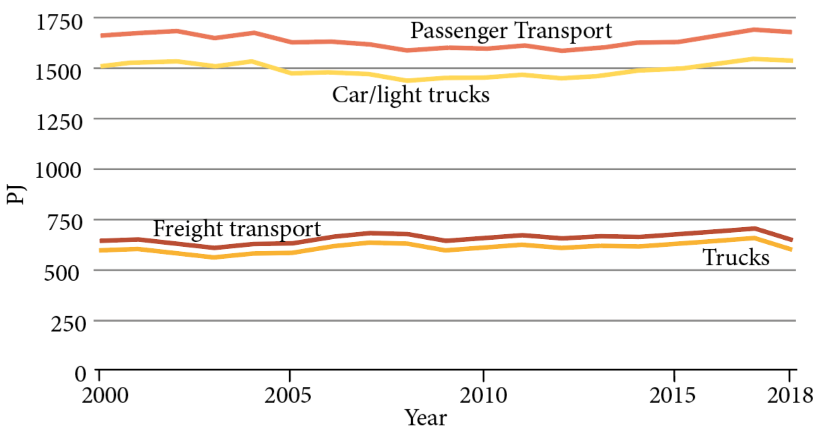
In the last decade, TFC (total final consumption) varied between 215 Mtoe and 229 Mtoe, a total difference of just 6%.

Within the residential and services sector, the heating energy is the main consumption of energy in these sectors. Between 2008 to 2018 the energy from heating has decreased by 18.7% in the services sector and 18% in residential, but from the graphs it can be seen that the value heavily fluctuates due to whether that year is warm or cold, although an overall decrease can be visualised.

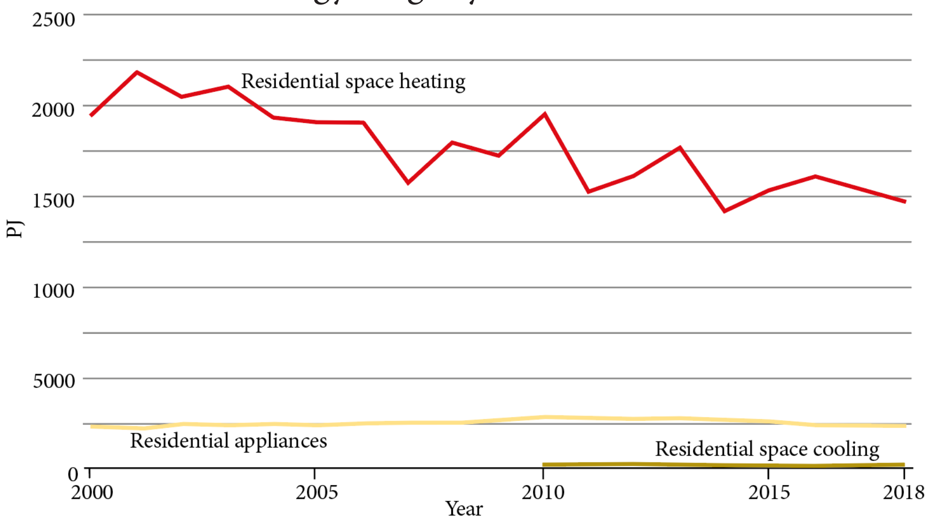
Energy usage by industry sector — Figure 7



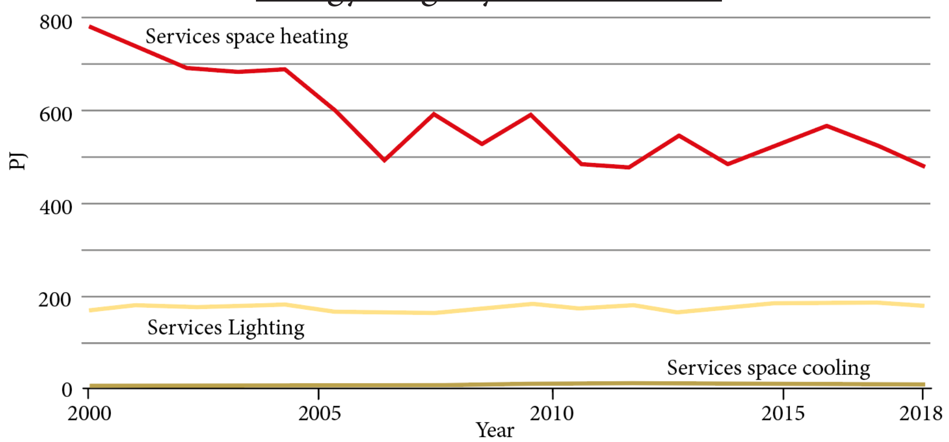
Energy usage by transport sector — Figure 8



Energy usage by residential sector — Figure 9



Energy usage by services sector — Figure 10



Transport sector consumption has increased by 8% in the last five years. From the graphs, it can be seen that this is mostly down to passenger transport and cars/light trucks.

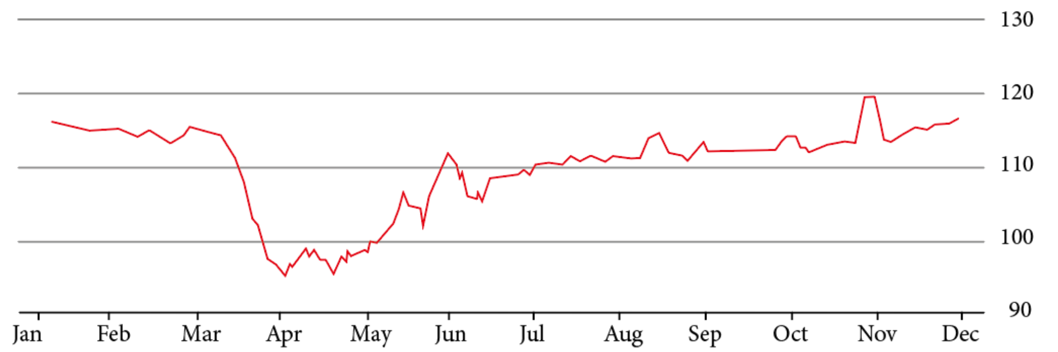
The industry sector has also been constant in the last 10 years. There is a dip after the financial crisis. However we can assume that this will remain constant.

From these 4 largest sectors, we can assume that the energy requirement actually remains fairly constant, as it has in the last decade, despite falling during COVID-19.

COVID-19 Impact

During COVID-19, there was a great reduction in energy due to lack of the service industry and industrial sector. This also meant that there was a less transportation, as seen in the truck toll mileage graph[2].

Figure 11



Consumption in the industry sector fell in 2009 after the global financial crisis, but recovered quickly and is back to pre-crisis levels, which will most likely be the same after COVID-19.

From the European commission electricity report, it can be seen that electricity consumption fell by 11% in the second quarter of 2020. However it was reported that by September the figures had almost returned to normal. This is backed up by the Germany truck mileage graph.

Teleworking increased from 15% before COVID-19 to roughly 25% currently in Europe. This is likely to mean a reduction in passenger transport.

Projected requirement

Using these findings from various sources, a projection of 223000 ktoe could be made on the energy graph.

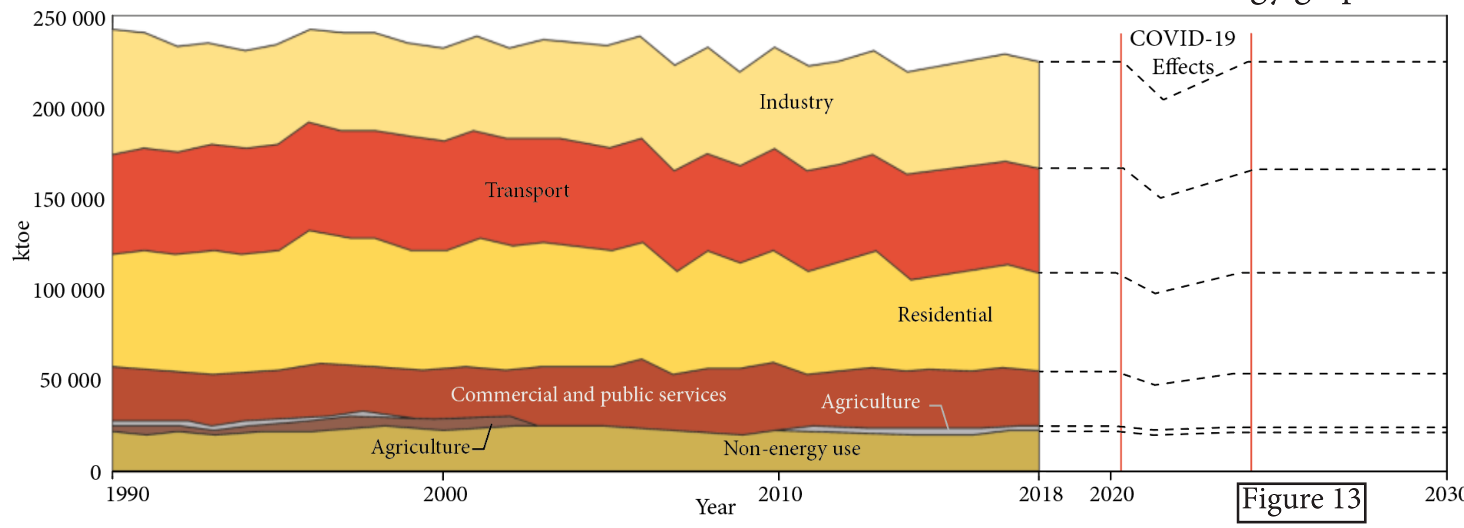


Figure 13

[1] https://ec.europa.eu/info/news/market-reports-2nd-quarter-highlight-impact-covid-lockdown-electricity-and-gas-markets-2020-oct-12_en
[2] https://www.destatis.de/EN/Themes/Cross-Section/Corona/Economy/context-economy.html

Sector graphs from: https://www.iea.org/data-and-statistics?country=GERMANY&fuel=Energy%20consumption&indicator=ManufacturingConsBySubsector

Proposed Scheme

As Germany will have a fairly constant energy demand over the next 10 years, the scheme should be to transfer to renewable energy and rely less on imported energy. Oil and natural gas could be attempted to be phased out, but oil is necessary for transport fuels, and the majority of transport will still run of fossil fuels by 2030. Natural gas is needed residentially, for uses such as gas boilers. Therefore this shouldn't be attempted to be replaced either. In line with Germany's Energiewende scheme[1], nuclear power production should be phased out, so this 18.7% of produced energy will have to be made up for. Germany also has an issue of excess power in the north of the country, and a deficit in the industrialised south, and the lack of grid infrastructure means that this energy cannot be moved. Therefore the proposal should also focus on installing 'electric highways'.

Offshore Turbines

There are currently almost 1500 offshore turbines in Germany[2]. This could realistically quadruple by 2030, meaning an extra 4500 turbines. The energy this would provide can be found. A 4 MW[3] turbine at 45 % efficiency[4] for a year produces:

$$0.45 \times (24 \times 365) \times (4 \times 10^6) = 1.58 \times 10^{10} W\ H$$

Multiplying this by the number of turbines gives the energy potential:

$$1.58 \times 10^{10} \times 4500 = 71.1 \times 10^{12}\ W\ H$$

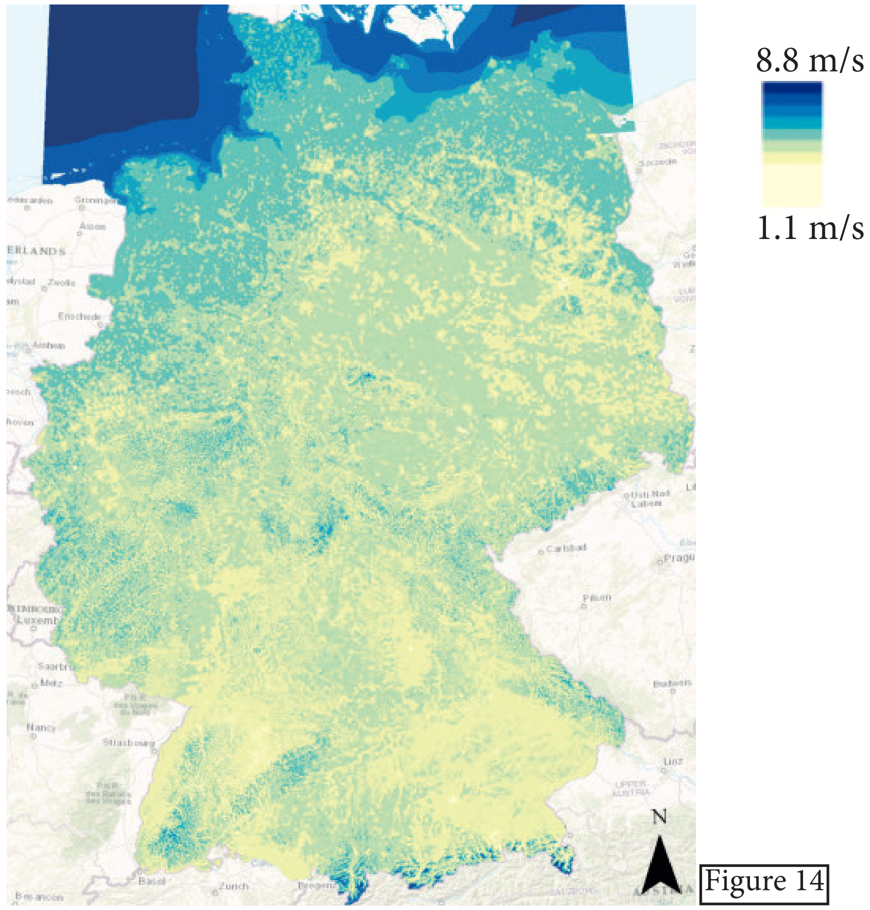


Figure 14

Energy to Replace Nuclear

23916 ktoe of nuclear energy was produced in 2019. From figure 4, it can be seen that the majority of energy produced from these nuclear stations is in the south. Therefore to reduce stress on the grid, the solution should be in the south of Germany.

$$1\ ktoe = 11630\ MW\ H$$

$$23916\ \times 11630 = 278 \times 10^{12}\ W\ H$$

This can be done through a combination of renewable energy.

Onshore Turbines

Over 29000 onshore turbines are in operation in Germany[5]. Given that German turbine farm production only started in 2008, if this value can be increase by 20000, then this will reduce energy from other sources. At 30% efficiency for onshore[4] at a power of 2 MW[3]:

$$0.3 \times (24 \times 365) \times (2 \times 10^6) = \ 0.526 \times 10^{10} W\ H$$

Multiplying this by turbine number gives:

$$0.526 \times 10^{10} \times 20000 = \ 105.1 \times 10^{12}\ W\ H$$

If this value is added to the offshore value, there will be over 175 TW H of energy per year. However this is still around 102 TW H short of the energy needed to replace nuclear. This deficit can be covered by solar energy.

Solar in Homes

Solar is already widely used in Germany and are continuing to expand[6]. However, this proposal aims to increase the energy output.

By installing them on homes, the homeowner pays for them and although the may be slightly subsidised by the government, it will be more cost efficient than building solar farms.

According to a study carried out by BMVi[7] the total area without restrictions for solar panel instillations is 150 GW on buildings. If the load hours for solar panels is 1030[8] and 50% capacity is installed:

$$(1030) \times (150 \times 10^9) \times 0.5 = \ 77.25 \times 10^{12} W\ H$$

77.35 TW H of energy can be provided by panels installed only on buildings, predominantly in the south of Germany, where there is more irradiation in order to achieve the load hours value.

With the 77.35 TW H leaving just under 25 TW H needed to be able to completely replace nuclear power. To do this, solar can also be installed as 'farms', with examples already in Germany including Solarpark Meuro[9].

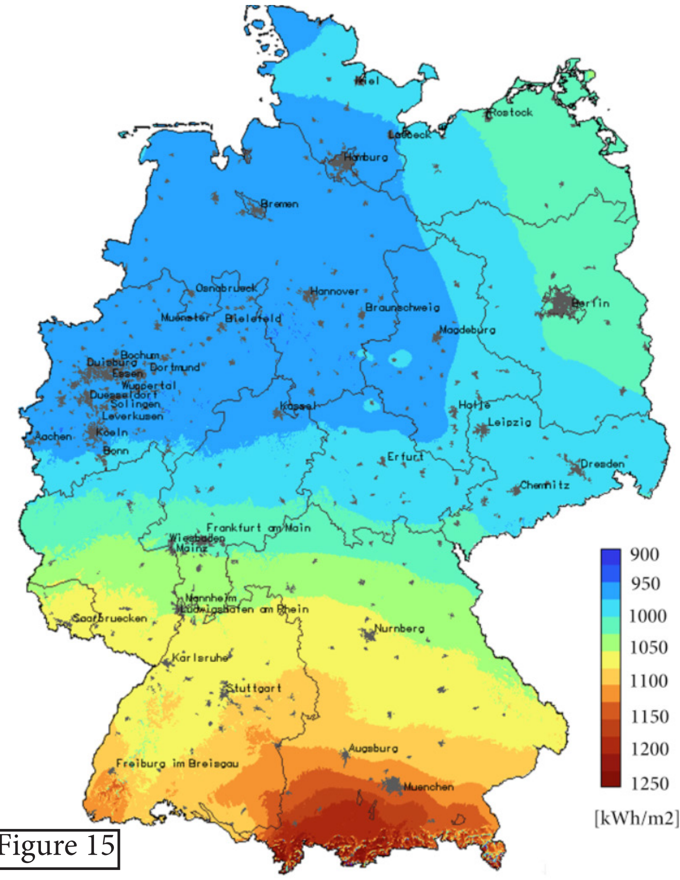


Figure 15

[1]https://www.world-nuclear.org/information-library/energy-and-the-environment/energiewende.aspx [2] https://www.cleanenergywire.org/factsheets/german-offshore-wind-power-output-business-and-perspectives#:~:text=In%202019%2C%20Germany%20added%20176,Sea%20and%20the%20Baltic%20Sea. [3] https://www.irena.org/wind#:~:text=Today's%20new%20wind%20power%20projects,to%202%20MW%20in%202014. [4] https://www.goodenergy.co.uk/how-do-wind-turbines-work/#:~:text=A%20wind%20turbine%20is%20typically,after%20going%20through%20the%20turbine. [5] https://www.cleanenergywire.org/factsheets/german-onshore-wind-power-output-business-and-perspectives#:~:text=By%20July%202020%2C%20about%2029.546,merely%201%20GW%20in%202019. [6] https://www.wired.com/story/in-germany-solar-powered-homes-are-catching-on/#:~:text=Germany%20now%20has%20some%2044,those%20homeowners%20are%20buying%20batteries. [7] https://www.bbsr.bund.de/BBSR/DE/veroeffentlichungen/ministerien/bmvi/bmvi-online/2015/DL_BMVI_Online_08_15.pdf?__blob=publicationFile&v=1 [8] https://www.cleanenergywire.org/factsheets/solar-power-germany-output-business-perspectives#:~:text=Fraunhofer%20ISE%20says%20solar%20panels,that%20wind%20power%20can%20deliver. load hours [9] https://www.sunwindenergy.com/news/solarpark-meuro-named-power-gen-international-2012-solar-project-year Figure 14: https://www.sciencedirect.com/science/article/pii/S030142152030392X Figure 15: https://resbroker.wordpress.com/projects-for-sale-2/photo-voltaic-projects-for-sale/photovoltaic-power-germany/

Proposed Scheme

Solar Farms

As 25 TW H more is needed to replace the nuclear power energy production, the power for solar farms can be calculated. Again using 1030 yearly load hours:

$$\frac{25 \times 10^{12}}{1030} = 24.3\ GW$$

24.3 GW is the power required from solar farms. In comparison, Germany's current solar output is over 40 GW[1], with a lot of its construction on beginning 10 years ago, so for 10 years time this is not an unrealistic proposal.

In terms of land used for this, the Solarpark Meuro outputs 166 MW[1], and is 200 hectares. The energy required is equivalent to:

$$\frac{24.3 \times 10^{9}}{166 \times 10^{6}} = 146.4\ parks$$

As the park uses 200 hectares the total hectares for the proposal can be found:

$$146.4 \times 200 = 29277\ hectares$$

The size of Germany's arable land is 11763000 hectares[2]. The percentage of land taken up by the new proposal can be found:

$$\frac{29277}{11763000} \times 100 = 0.25\%$$

This is a very small value, showing that space isn't an issue. As it is for arable land, cattle can still be farmed on the same land as solar panels, so this is not an issue.

Figure 16

HVDC Connections

With the addition of a number of offshore turbines, and onshore turbines in the northern parts of Germany where wind speeds are higher, the larger amount of energy in the north will need to be moved to the south, and the German grid in the north has experienced being maxed out before[3].

The HVDC transmission lines will have a power rating of at least 1000MV[4]. There could be two main lines connected the north to the south. They proposed lines have been mapped out, being positioned so that they are close to large industrial cities of Munich and Stuttgart to supply power to them. The left line will mainly transport the energy from offshore wind turbines, and the line on the right will transport energy from onshore turbines.

The HVDC has a lower transmission cost than AC and lower power losses. For these long distances, these are key factors in the decision for this proposal for the scheme.

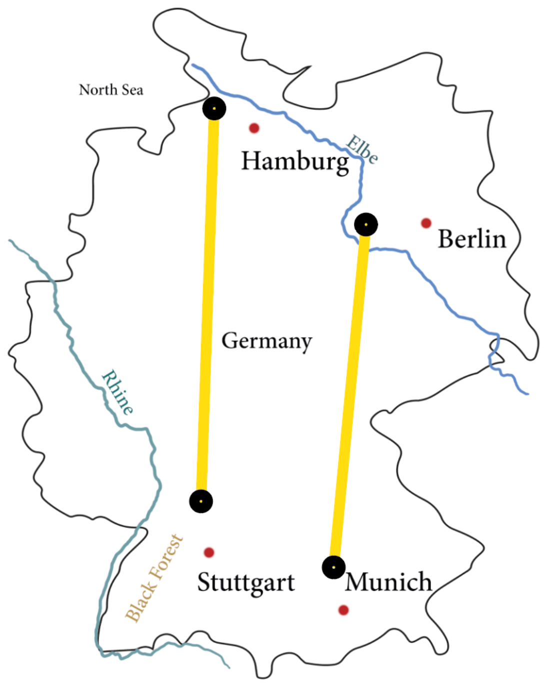


Figure 17

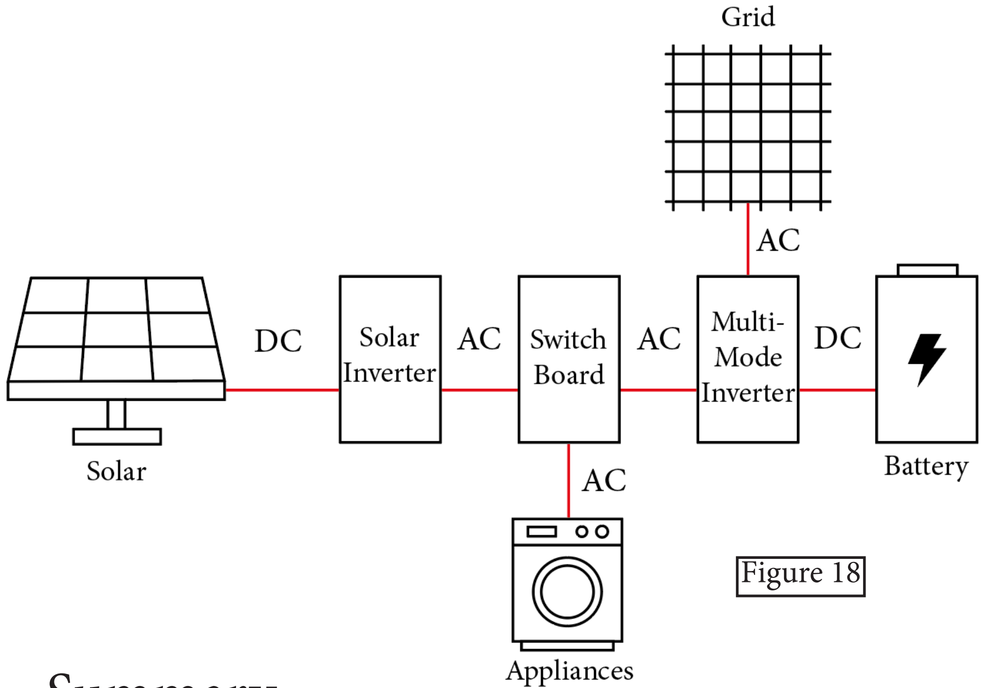


Figure 18

Battery Boom

Another way to improve the dependability of the proposed solution is by having houses and buildings with batteries to store generated energy e.g. by rooftop solar panels.

This is so that in situations of energy deficit, the country can use these grid connected batteries for energy. The idea is seen in the figure to the left. It is already widely used (Tesla has used this idea[5]), and is becoming more frequent in Germany[6], especially with the costs of them decreasing and lithium battery technology evolving.

Summary

Through this proposed scheme, calculations for the installation of on and offshore wind energy, and solar power has replaced the nuclear power of Germany, one of the aims of Germany's Energiewende (energy transition). The HVDC connections and battery instillation has also meant that the future supply of energy is not only plentiful, but also dependable, and deficits and overloads in areas do not occur again.

With data to back up these proposals, and progress from the last 10 years, there is no reason why the complete phasing out of nuclear energy is not feasible by 2030.

[1] https://en.wikipedia.org/wiki/Solar_power_in_Germany#Solar_PV_by_type
[2] https://data.worldbank.org/indicator/AG.LND.ARBL.HA?locations=DE
[3] https://www.greentechmedia.com/articles/read/germanys-stressed-grid-is-causing-trouble-across-europe
[4] https://www.hitachiabb-powergrids.com/offering/product-and-system/hvdc/hvdc-classic
[5] https://www.tesla.com/en_gb/powerwall
[6] https://www.wired.com/story/in-germany-solar-powered-homes-are-catching-on/