Energy-Environment-Economy analysis of Germany, with a focus on electricity, cost, and carbon emissions

Royal Institute of Technology
MJ2508 PRO1
Group 9

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    - Model set up
    - Key assumptions
    - Results

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- Executive summary
- Wrote section 2. Background and litterature review
- Table of contents
- formatting

1.Executive summary

Germany is Europe’s largest economy, with a GDP of 4.07 trillion in 2022. Germany is also Europe’s biggest CO2 emitter and emitted 675 million tons of CO2 in 2021. The nation is contributing to the EU's nationally determined contributions (NDC) and its own national reduction targets and laws. In 2021, the German Federal Government even tightened climate change regulations with the aim of reaching greenhouse neutrality by 2045. The path to reach this goal is outlined in the Federal Climate Change Act and guided by several policies, plans and programs, yet the nation is not currently on track to reach its set targets. Achieving net-zero is a complex economic, technical, and social transformation. One that requires efficient policies and action in order to mitigate the worst effects of climate change. Reaching this net-zero target would have a positive impact beyond Germanys boarders as it is an export driven economy and the world’s biggest exporter of electricity.

As the rest of Europe, Germany needs to find the most cost-optimal and fast way to reach its CO2 reduction goals whilst supporting an increase in electricity demand. Germany have phased out nuclear energy for electricity production and have a plan for phasing out coal. Something that Germany are not phasing out, but on the other hand is expanding, is LNG terminals and gas infrastructure. We wanted to explore alternatives to fossil fuels. Therefore, the aim of this study has been to investigate a re-introduction of nuclear energy in Germany's energy mix and a phasing out of natural gas in stages. We are trying to achieve this by re-commissioning nuclear plants which got decommissioned in the last five years

Results show that this re-introduction of nuclear energy would reduce CO2 emissions for Germany more than the NDC scenario, however, the social cost would be marginally higher. In order to further evaluate the results, a study of handling of nuclear waste would need to be included.

2. Background & Literature review

2.1 Background about the region and country

Located in western Europe, Germany is one of the largest countries on the continent, encompassing a substantial landmass. It shares borders with several neighbouring nations; Denmark, the Netherlands, Belgium, Luxembourg, Switzerland, Liechtenstein, Austria, Czechia, and Poland (see to Figure 1).

Figure 1: Map Germany and its neighboring countries (CIA, u.d.)

With a population of 84 million as of 2022 and a surface area of 357,592 km^2, Germany ranks among the most densely populated nations in Europe, with an overall population density of 233 inhabitants per square kilometre. This density is not uniform across the country, with 39.4% of the population living in urban or densely populated areas, notable concentrations in urban centres such as Berlin, Bremen, and Hamburg. As of 2022, Germany had an annual population growth rate of 1.1% and an average of 2.0 children per person. As seen in figure 2, in 2011, Germany experienced a steep drop in population, which can be attributed to low birth rates. The subsequent uptake in population can be attributed to an increase in immigration. During the pandemic, the population growth slowed down, which can be attributed to fall in immigration during the pandemic. (The World Bank, u.d.)

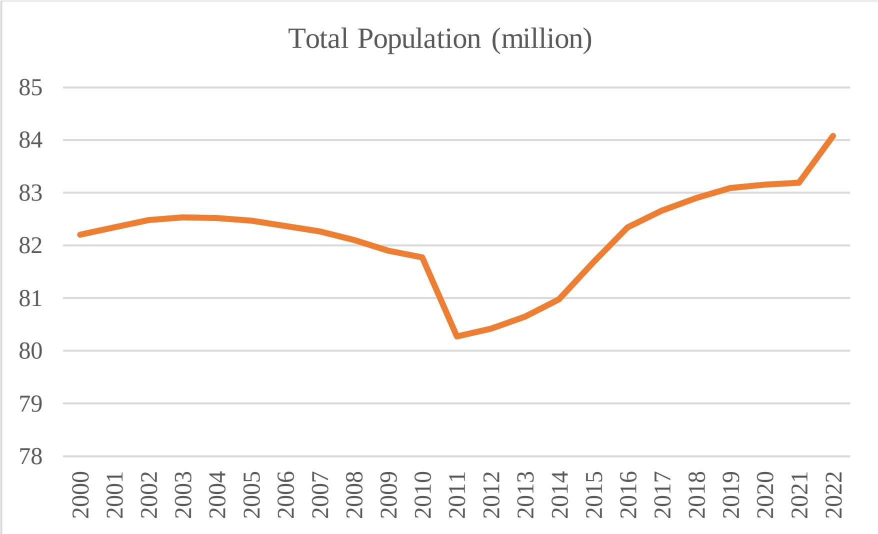

Figure 2: Population Germany, 2000-2022 (The World Bank, u.d.)

Germany is the largest national economy in Europe, with a GDP of USD 4.07 trillion in 2022 and a GDP annual growth rate of 1.8% the same year. This lands GDP per capita in 2022 at USD 48,432.5. The same year, 69% of GDP value add came from services, 24% from industry, 6% from construction and 1% from agriculture, forestry and fishing. (Federal Statistical Office of Germany, u.d.)

The German Voluntary National Review to the High Level Political Forum on Sustainable Development (2021), the United Nations central platform for follow-up and review of the 2030 Agenda for Sustainable Development and the 17 SDG Goals, gives an insight into the perspective on sustainable development strategies the German officials are currently pursuing. It discusses SDG 7 and how the guiding principles of national climate and energy policies are focused around the decarbonization of energy systems using renewable energy sources as a contribution to greenhouse gas neutrality by 2045, energy conservation, and attaining the greatest possible energy efficiency. This gives us a perspective on the vision of German officials in meeting SDG Targets.

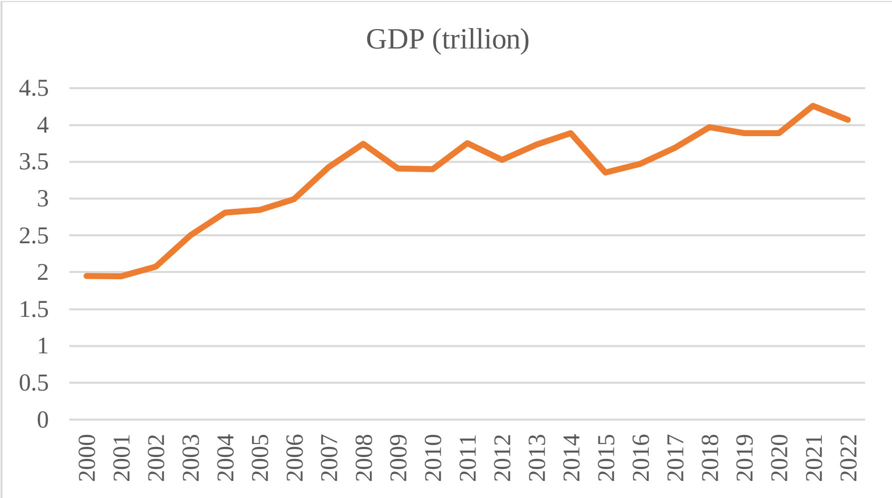

Figure 3: GDP Germany, 2000-2022 (The World Bank, u.d.)

Germanys total CO2 emissions year 2021 was 675 million tons (see figure 4), of which electricity and heat accounted for approximately 53% of those emissions, at 356 million tons of CO2 (Our World in Data, 2023).

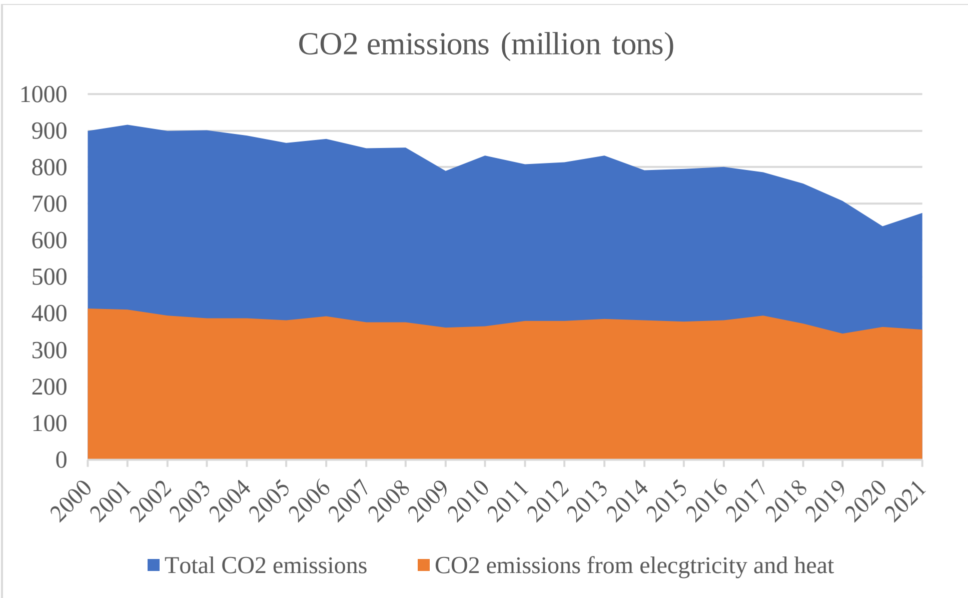

Figure 4: CO2 emissions Germany between 2000 and 2021 (Our World in Data, 2023)

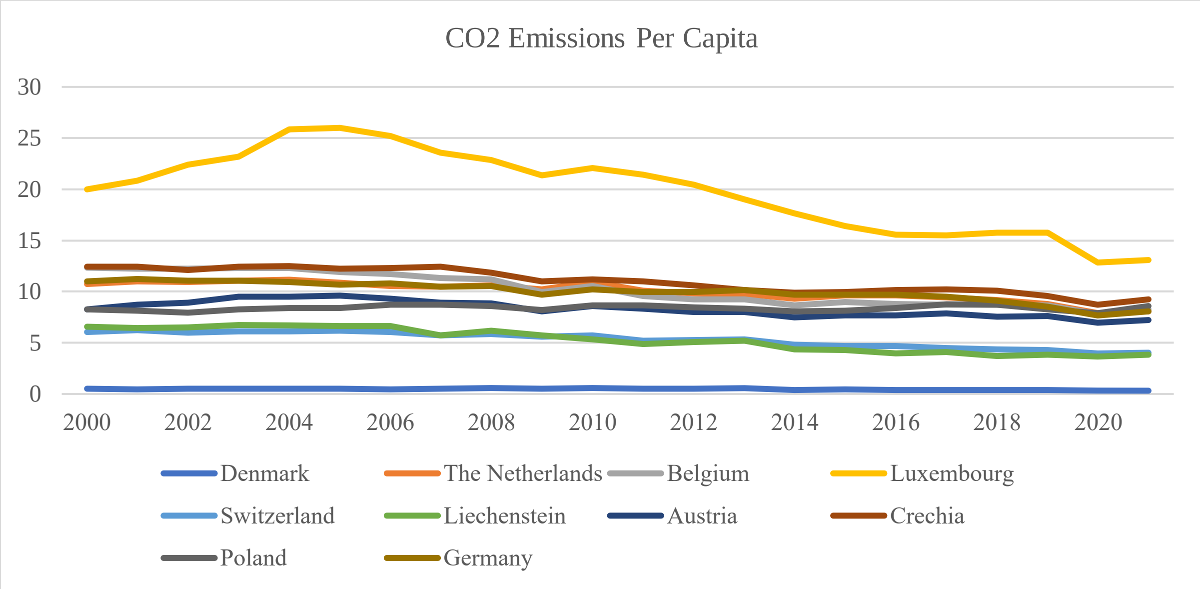

Figure 5: CO2 emissions per capita, Germany and its neighboring countries, 2000-2021 (Our World in Data, 2023)

When all of the countries' per capita emissions are compared, it is evident that Germany has a long way to go when compared to the average EU per capita emissions of 5.5 t CO2/capita. Policies and objectives can only go so far, and the majority of decarbonization in Europe will fall on consumers in the form of mandates to update their application/end-use technology, potentially leading to a new sort of energy poverty or "Technology Poverty." The move to renewable energy sources, such as wind and solar power, is intended to contribute to a more sustainable and cost-effective energy system, based on existing decarbonization goals and programs such as Energiewende. The cost of energy generation falls over time as the percentage of renewables in the power sector increases, potentially lessening the economic burden on customers. This would contribute to the reduction of energy poverty by making energy more affordable and accessible to a greater population. The financial incentives for renewable self-supply address the issue even further. The 2021 Renewable Energy Sources Act exempts such circumstances from the EEG surcharge to a larger extent than before.

The dedication to continual monitoring and evaluation of the impact of decarbonization programs enables quick modifications. This adaptable strategy aids in the mitigation of unforeseen outcomes, ensuring that the transition to a low-carbon economy is as inclusive as feasible. The German federal government's emphasis on community-based energy initiatives and decentralized energy generation promotes inclusion. The Energiewende intends to guarantee that the benefits of decarbonization are distributed more evenly by including citizens in the transition process. By actively engaging communities in the deployment of sustainable technologies, this method may assist in preventing the creation of technological poverty.

2.2 Energy balances of the country

With 273 960 TJ in exports, Germany was, and remains, the biggest electricity exporter in the world. In 2020, the biggest export destinations were Austria (18.1%), Poland (17.8%), Italy (16.8%), Switzerland (11.6%) and Czechia (11.5%). Between 2020 and 2021, the fastest growing export markets were Italy, Switzerland and Austria. In 2021, Germany exported USD 9.88 billion in electricity. This made net electricity trade for Germany USD 3.9 billion, as the nation imported USD 5.98 billion in electricity, mainly from France (22.6%), Czechia (15.7%), Denmark (15.3%), Netherlands (12.7%) and Switzerland (12.4%). This made Germany the second largest electricity importer in the world in 2021, with the fastest growing import markets between 2020 and 2021 being Czechia, Denmark and France. (OEC, 2023)

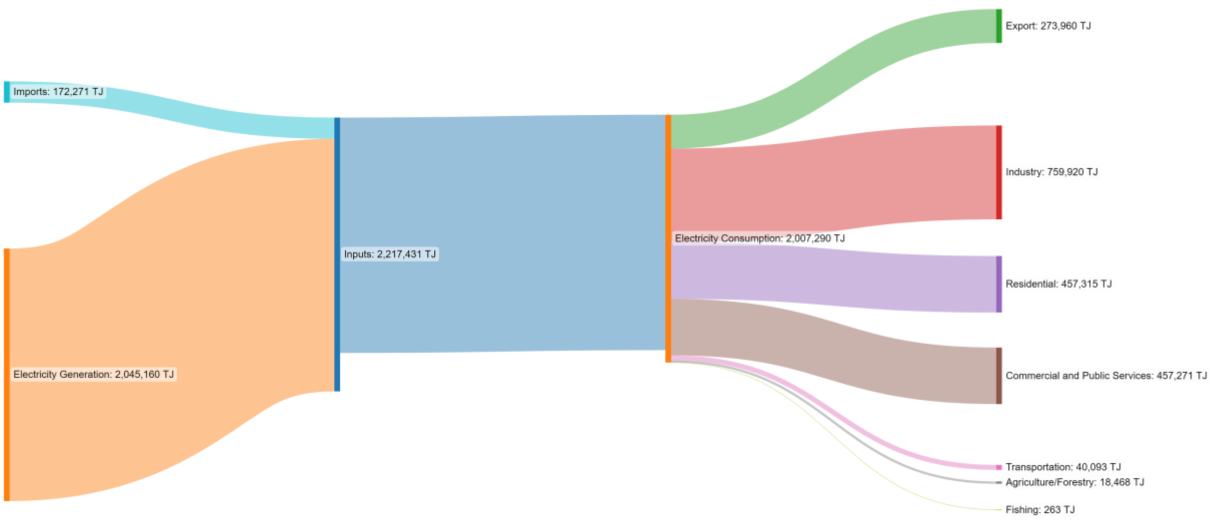

Figure 6: Sankey diagram of electricity flow, Germany, 2020 (IEA, 2023)

For the electricity consumed in Germany, the three biggest end-use sectors are industry at 37,4 %, residential at 22,8% and commercial and public services at 22,8%. All together consuming approximately 83% of total electricity inputs in 2020. (IEA, 2023)

2.3 Current and Future Operating Technologies

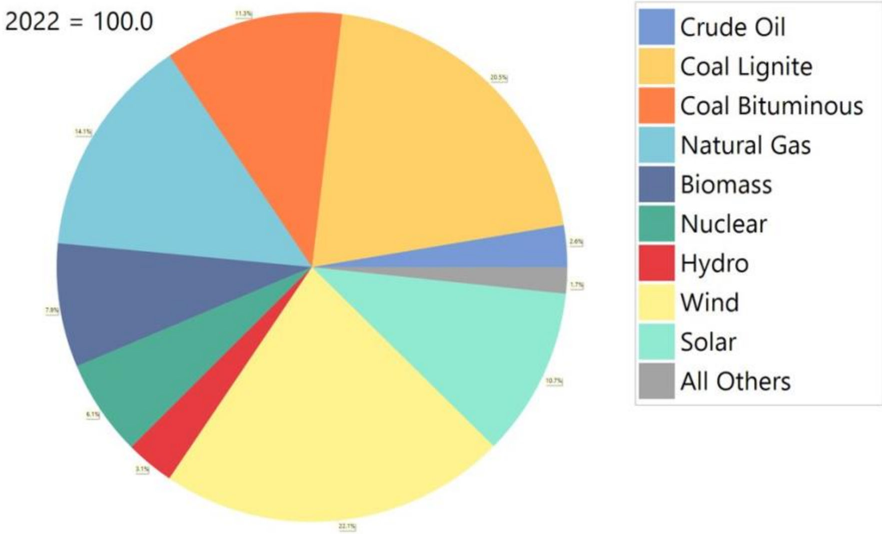

Figure 7: Electricity Demand for the year 2022 in million gigajoules

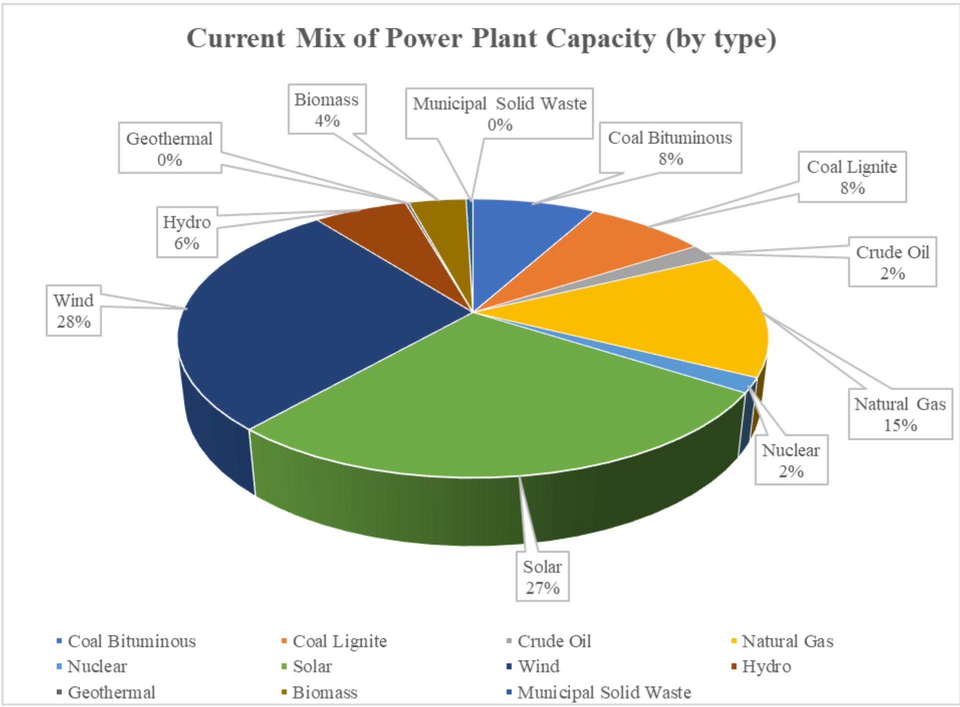

Figure 8: Current Mix of Power Plants Capacity in MW

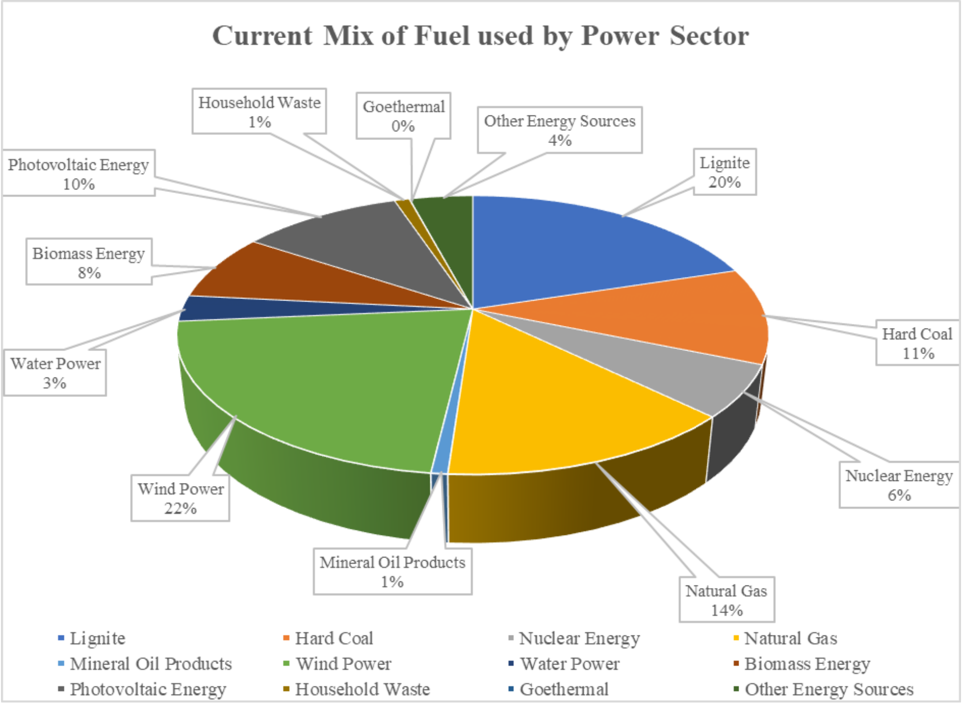

Figure 9: Current Mix of Fuel used by Power Sector for the year 2022 in billion KWh

2.4 Policies and Mitigation Plans

At the core of Germany's energy landscape lies the Energiewende, a transformative initiative originating from the anti-nuclear movement. Launched in the 1990s, this initiative represents a long-term energy and climate strategy reaching 2050. The Energiewende has four primary political objectives: addressing climate change, mitigating nuclear risks, improving energy security, and ensuring competitiveness and growth. This comprehensive transformation plan encompasses a range of policies and measures geared towards significantly increasing the integration of renewable energy sources and improving the overall efficiency of the country's energy system. (Agora Energiewende, 2015)

See Table 1 for some of the most important policies in place supporting the Energiewende, and some of their respective targets.

Table 1: Energy and Climate Policies and Targets (The Federal Govermnet, 2023)

Policy	Aim and Targets	Implemented
Federal Climate Change Act	• Climate Neutrality by 2045 • Negative emissions by 2050 • Sectorial GHG emission reduction targets	2019
The Easter Package	• Changes to regulatory framework to introduce higher auction volumes and accelerate permitting procedures for renewables	2022

The Climate Action Program 2030	• CO2 pricing scheme for the transport sector and for heating buildings. • Phasing out coal for electricity production by 2038	2019
The Renewable Energy Sources Act	• Legally binding target to increase renewable electricity sources to 80% of electricity consumption by 2030	2000
Energy Efficiency Strategy 2050	• Reducing energy consumption by 30% in 2030, compared to 2008 • Reducing energy consumption by 50% in 2050, compared to 2008	2019

Germany also demonstrates a strong commitment to the 2030 Agenda for Sustainable Development and the Paris Agreement by assuming leadership roles for the G7 and G20. Despite its dedication, Germany has remaining challenges for all 17 SDG goals, with major challenges remaining for SDG 12, responsible consumption, and production and 13, Climate Action. According to the Sustainable Development Report, in 2022, 56.9% of the SDG targets were achieved or on track, 8.3 had limited progress and 34.7% were worsening. (Sustainable Development Report, u.d.)

Germany have made significant progress towards their set targets yet are not on track to reach all of them. There is room for improvement for the government regarding evaluating and screening old and new policies to prevent long-standing policies from hindering process to set targets. For example, Germany continues to maintain subsidies, such as diesel discount, which goes against their newer Climate Action Act scheme. Similarly, there are no existing institutional mechanisms to address similar incoherencies regarding national regulations that impact developing countries.

2.5 Aim of study / Research Question

In this project, the aim is for you to plan and carry out an extensive 3-E analysis (Energy-Environment-Economy, specifically electricity-cost-CO_2) for Germany through modelling with LEAP. One modelled scenario will be business as usual for Germany, working from existing policies and projections in 2022. The second scenario models a re-introduction of Germanys Nuclear power plants for electricity generation to support electrification of industries and transportation whilst lowering emissions from electricity generation.

The research question for this study is: ‘Would the re-introduction of existing power plants in Germany for electricity generation be more cost efficient and get the nation closer to reaching its set CO_2 reduction targets and electrification targets.”

3. Methodology

3.1 Short description of LEAP

Low Emissions Analysis Platform (LEAP), is a tool used to analyze the energy policies and climate change for a country. It was developed by the Stockholm Environment Institute. Many countries, especially developing nations, have started using the software for integrated resource planning, greenhouse gas (GHG) mitigation assessments, and Low Emission Development Strategies (LEDS).

Across all economic sectors, energy consumption, output, and resource extraction may be monitored with LEAP, an integrated modeling tool that is scenario-based. It can be applied to the accounting of sources and sinks of greenhouse gas (GHG) emissions from both the energy and non-energy sectors. LEAP is well-suited to studies of the climatic co-benefits of local air pollution reduction since it can be used to track greenhouse gas emissions as well as analyze emissions of short-lived climate pollutants (SLCPs) and local and regional air pollutants.

It is also used to generate models of various energy systems, each requiring customised data structures; it is not a model of any specific energy system. On the demand side, LEAP supports a broad variety of modelling approaches, ranging from top-down macroeconomic modelling to bottom-up, end-use accounting procedures. A number of additional optional specialised approaches are also included with LEAP, such as stock-turnover modelling for applications like transportation planning. On the supply side, LEAP offers a selection of accounting, simulation, and optimisation techniques that are both sufficiently transparent and flexible to enable LEAP to effortlessly integrate information and outcomes from other, more specialised models and robust enough to model capacity expansion planning and electric sector generation modelling.

Two fundamental conceptual levels are used by LEAP. All of the "non-controversial" energy, emissions, and cost-benefit accounting computations are handled at one level by LEAP's built-in calculations. Using spreadsheet-like expressions, users can define time-varying data or build a wide range of complex multi-variable models at the second level. This allows econometric and simulation approaches to be integrated into LEAP's overall accounting framework. The most recent iterations of LEAP also provide optimisation modelling, enabling the creation of least-cost models of dispatch and capacity development for the electric system, which may be subject to a variety of restrictions like CO2 limitations or local air pollution. Scenario analysis is the foundation of LEAP's design. Scenarios are coherent narratives that illustrate possible future developments for an energy system. Policy analysts can use LEAP to generate and assess different scenarios by contrasting their energy needs, socioeconomic costs and benefits, and environmental effects. Individual policy measures can be described using the LEAP Scenario Manager, pictured on the right. These measures can then be coupled in various ways to create alternative integrated scenarios. Using this method enables decision-makers to evaluate both the effects of a single policy and the interactions that arise from combining several policies and measures.

3.1 Model set-up

The model comprises four primary branches that encompass Key Assumptions, Demand, Transformation, and Resources. This study exclusively concentrates on electricity consumption, leading to the creation of the demand sector, which is constructed based on Table 2(demand in million gigajoules). Therefore, electricity stands as the sole fuel for all sub-branches, with the final energy intensity aligning with the specifications in the aforementioned Table. The activity level within each sub-sector is depicted as a percentage share of the overall demand. This study deliberately overlooks the demand cost in the commercial and industry sectors, shifting its focus towards the import cost associated with generating electricity from various sources and technologies. Figure 8 shows the tree structure considered for demand and electricity generation considered. Demand for electricity in households, transport, industry and various commercial factors are taken into account. While the study generally overlooks demand costs, it does take into account specific costs for the housing sector at 150 USD per household per year and for the transport sector at 51,000 euros yearly.

The transformation sector is bifurcated into two primary segments: Transmission and Distribution, alongside Electricity Generation. The Transmission and Distribution segment accounts for losses that arise during the delivery of electricity to the demand sector. Within the Electricity Generation branch, there exist two sub-branches: Output Fuels and Processes. Output Fuels solely encompass electricity, whereas Processes encompass all the electricity-generating technologies employed in Germany. The processes are aggregated, representing the total electricity produced from each technology. This approach was necessary due to the challenge of acquiring data on individual plants. Considering the size of Germany, managing the vast number of power plants would have been unfeasible for this study.

Electricity production is considered from both renewable and conventional processes. The present situation of Germany is considered in baseline, NDC for 2030, and our own scenario for 2045 is simulated with LEAP.

3.3. Key assumptions

The modeling period selected spans from 2022 to 2045, with 2023 being the initial simulation year. These specific years were chosen for a specific reason: primarily to address and accommodate the aftermath of the COVID-19 pandemic. Additionally, these years were selected to incorporate and consider the price distortions resulting from the ongoing Ukrainian crisis. In contrast, the GDP data for 2020 indicated a slight decline, whereas the trajectory in 2022 resembled that of 2019, representing a pattern akin to the period before the pandemic wave. The monetary unit chosen for this analysis is US dollars. While most data is represented in USD, certain information has been used in euros to ensure maximum accuracy. However, the final results and findings are presented exclusively in USD by LEAP for consistency.

We have made certain assumptions for the industry sector's electricity demand growth rate, setting it at 1.3%. This figure is based on the country's GDP growth rate. Additionally, our other assumptions include an annual income growth rate of 1.5%, a household size of two people, and a population growth rate of (-)0.525%.

In our scenario, we've adjusted the merit order of crude oil to a value of 2. This alteration was made to facilitate an increase in electricity production from nuclear sources between the years 2024 and 2038. This adjustment aligns with the German government's commitment to retiring all coal and oil plants by 2038.

Table 2: Energy Demand final unit (Million Gigajoules)

	Base Year	**NDC Scenario**	**Our Scenario**
Modeling period	2022	2030	2045
Demographic data	84 million	83.2 million	81 million
Technology with Energy intensity	Electricity	Electricity	Electricity
System shape load	Default	Default	Default
Dispatch Rule	Merit order	Merit order	Merit order

Energy Losses	5%	4%	3.5%
Shortfall Rule	Shortfall to import	Shortfall to import	Shortfall to import

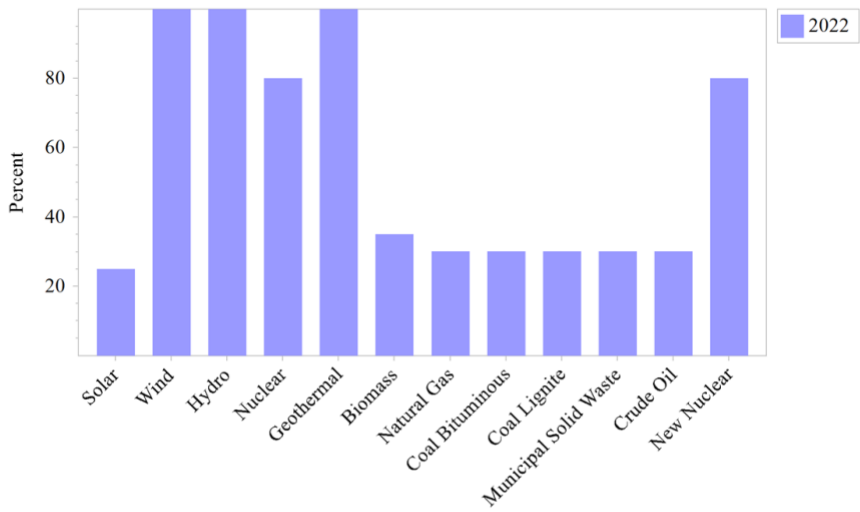

Figure 10: Assumed Process Efficiency for Different Fuels

Figure 9 explains the efficiency we have considered for different fuels. Further details can be found in Table 3 below in the data collection part.

3.4 Data collection – electricity generation technologies & fuels

Table 3. Technologies and their techno-economic characteristics in Germany.

Name of Technology	**Total capacity**	**Fuel**	**Capacity factor**	**Fuel cost**	**Efficiency**	**Availability**	**Average lifetime**	**Capital cost**	**Operating and maintenance cost**
	MW	*Type*	*%*	*USD/GJ*	*%*	*%*	*Years*	*MUSD/GW*	*MUSD/GW/year*
Coal bituminous	19010	Coal bituminous	55	4.98	30	70	30	2080.6	24.44
Coal lignite	18670	Coal lignite	56	8.95	30	75	30	2169.7	30
Crude oil	4700	Crude oil	20	14.71	30	100	30	950	22

Natural gas	34250	Natural gas	28	35.56	30	70	30	1200	22.22
Nuclear	4060	Nuclear	95.4	0.13	80	80	50	2800	109.52
Solar	65000	Solar	30	0	25	100	25	1400	14.78
Wind	66200	Wind	24	0	100	100	25	2000	50
Hydro	14500	Hydro	33	0	100	100	70	7000	131.44
Geothermal	500	Geothermal	63	0	100	100	30	4198	73.33
Biomass	8910	Biomass	53	0	35	100	30	4755.6	177.78
Municipal solid waste	1068	Municipal solid waste	57	0	30	100	30	24000	486.71

3.6 Demand projections

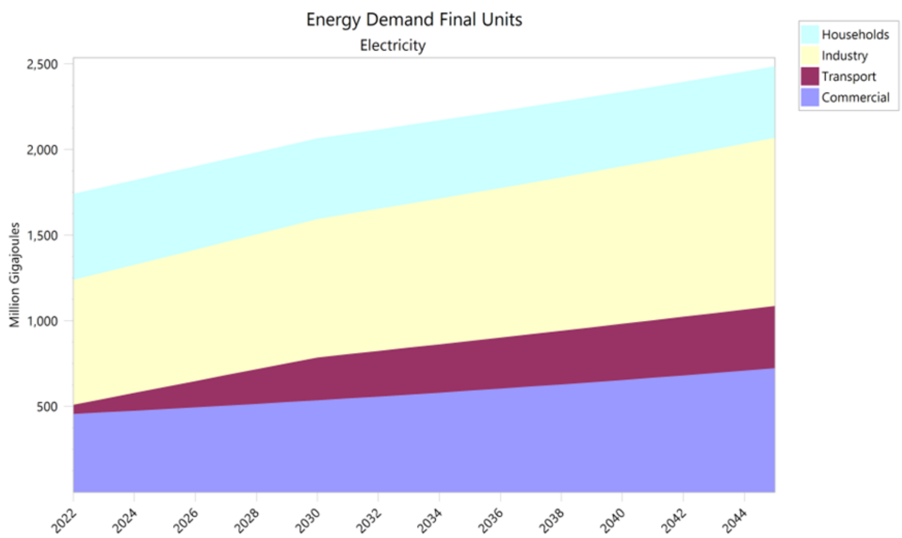

Figure 11: Demand projection of electricity in sectors considered.

The electricity demand for households is considered to be decreasing by 0.6% per year. This assumption is made based on the decrease in the number of households in the country and by taking into account the increase in efficiency. The demand in the industry sector is increasing by 1.3% every year based on the GDP growth rate. The transport sector is divided into rail and road, which are further divided into passenger and freight. The number of electric vehicles on the road has increased from 1.04 million (2022) to 15 million in 2030 and to 25 million by 2045. The transport sector will grow as a sector 0.6% per year till 2030(Federal transport infrastructure report). Electricity consumption is considered to be reduced by 0.5% per vehicle by considering the improvement in the efficiency of vehicles. In the rail sector, in 2022, 53.98% of the network was electrified. We consider it to be electrified by 75% in 2030 and 95 % by the end of 2045. For the commercial sector, agricultural, construction, and fishing sectors demand is increasing by 2.47% whereas the trade sector is growing by 2% (AGEB, November 2023).

3.7 Scenarios

3.7.1 The NDC Scenario

Germany is contributing to the EU's nationally determined contribution (NDC) and its own national reduction targets and laws. In 2021, the German Federal Government even tightened climate change regulations with the aim of reaching greenhouse neutrality by 2045 (Die Bundesregierung, 2021). The path to reach this goal is outlined in the Federal Climate Change Act, where it is stated that greenhouse gas emissions should be reduced by at least 65% by 2030 and 88% by 2040, relative to emission levels of 1990. As of 2020, these emissions were down by 36.90% relative to 1990. For electricity generation, this entails an aim of at least 80% renewable electricity production by 2030. Looking at Germany's electricity mix as of 2022, as seen in Table 4, it becomes evident that a substantial and rapid upsurge in renewable energy is needed to meet this target, as most of the nation’s electricity production relies on fossil fuels. Furthermore, the transport sector has a target of at least 15 million electric cars on Germany's roads by 2030, marking a significant shift toward electrification.

Table 4: Gross Electricity Production Germany, 2022 (German Federal Statistical Office, 2023)

Energy source	Billion kWh	Percentage
Total	571.3	100
Lignite	116.2	20.1
Nuclear	34.7	6.0
Natural Gas	79.8	13.8
Mineral Oil	4.4	0.8
Renewables	254.0	44.0
Wind	125.3	21.7
Water	17.5	3.0
Biomass	44.6	7.7
Photovoltaic	60.8	10.5
Household waste	5.6	1.0
Geothermal	0.2	0.0

Other	23.8	4.1

Russia's invasion of Ukraine affected short-term LNG buildout and increased Germany's coal consumption. The government aims to accelerate the coal phase-out from 2038. There are currently no phase-out plans for oil and gas. Over the next 10 years, Germany intends to significantly increase its reliance on renewable energy sources while simultaneously adding more gas power plants.

3.7.2 Our Own Scenario

Despite ambitious targets and climate laws, Germany is not on track to reach its renewable energy uptake targets and CO2 reduction goals. We started to explore ways for Germany to reduce emissions from its biggest emitting sectors: energy, industry, and transport. Reducing emissions from these sectors often includes electrification and increasing demand for clean electricity generation. Since Germany still heavily depends on imported fossils for its electricity supply and the uptake in renewables is going too slowly – we will be looking into a re-introduction of Nuclear Energy to reduce GHG emissions from Germany's electricity production, as well as to support an increased electricity demand as a result from electrification of industry, transport, and the built environment.

We approach this scenario by pursuing the recommissioning of previously decommissioned nuclear plants within the last five years. This strategy aims to restore these facilities, providing an aggregate capacity of 12.074 gigawatts (GW) for electricity generation from nuclear sources as shown in highlighted plants in Table 5.

Table 5: Nuclear power plants in Germany

Reactor Name	**Model**	**Reactor Type**	**Reference Unit Power (MWe)**	**Permanent Shutdown**
AVR Juelich	Pebble bed reactor prototype	HTGR	13	1988-12-31
Biblis A	PWR	PWR	1167	2011-08-06
Biblis B	PWR	PWR	1240	2011-08-06
Brokdorf	PWR	PWR	1410	2021-12-31
Brunsbuettel	BWR-69	BWR	771	2011-08-06
Emsland	Konvoi	PWR	1335	2023-04-15
Grafenrheinfeld	PWR	PWR	1275	2015-06-27
Greifswald 1	VVER V-230	PWR	408	1990-02-14
Greifswald 2	VVER V-230	PWR	408	1990-02-14

Greifswald 3	VVER V-230	PWR	408	1990-02-28
Greifswald 4	VVER V-230	PWR	408	1990-07-22
Greifswald 5	VVER V-213	PWR	408	1989-11-24
Grohnde	PWR	PWR	1360	2021-12-31
Gundremmingen A	-	BWR	237	1977-01-13
Gundremmingen B	BWR-72	BWR	1284	2017-12-31
Gundremmingen C	BWR-72	BWR	1288	2021-12-31
HDR Grosswelzheim	Superheated steam reactor	BWR	25	1971-04-20
Isar 1	BWR-69	BWR	878	2011-08-06
Isar 2	Konvoi	PWR	1410	2023-04-15
KNK II	Prototype	FBR	17	1991-08-23
Kruemmel	BWR-69	BWR	1346	2011-08-06
Lingen	BWR with fossil fuel-fired superheater	BWR	183	1977-01-05
Muelheim Kaerlich	PWR	PWR	1219	1988-09-09
Mzfr	-	PHWR	52	1984-05-03
Neckarwestheim 1	PWR	PWR	785	2011-08-06
Neckarwestheim 2	Konvoi	PWR	1310	2023-04-15
Niederaichbach	pressure tube reactor	HWGCR	100	1974-07-31
Obrigheim	-	PWR	340	2005-05-11
Philippsburg 1	BWR-69	BWR	890	2011-08-06
Philippsburg 2	PWR	PWR	1402	2019-12-31
Rheinsberg	VVER-70	PWR	62	1990-06-01
Stade	-	PWR	640	2003-11-14
THTR-300	Pebble bed reactor	HTGR	296	1988-09-29
Unterweser	PWR	PWR	1345	2011-08-06
VAK Kahl	BWR	BWR	15	1985-11-25
Wuergassen	-	BWR	640	1994-08-26

4. Results & Discussion

4.1 Demand, installed capacity, and power generation

As per the demand projection discussed earlier, we anticipate the need to fulfill 2488 million gigajoules of electricity, as depicted in Table 6 below. This amount accounts for a 42% increase from the 2022 levels. In our scenario, by 2045, nuclear power generation surged to 14%, a substantial increase from 6.1% in 2022 and starting at 0% in 2023. Conversely, in the NDC scenario, there's a notable increase in electricity generation from natural gas, primarily sourced from imports, notably from neighboring countries like Russia. Hence, there is a high import cost which eventually increase the cost of electricity for german citizens there's a significant surge in electricity generation from natural gas, primarily obtained through imports, especially from neighboring countries like Russia. Consequently, this leads to a substantial increase in import costs, eventually raising the overall cost of electricity for German citizens.

Table 6: Demand projections

Sector	Demand in 2045	Demand in 2022
Households	418.57 million GJ	503.36 million GJ
Industry	981.17 million GJ	729 million GJ
Transport	364.80 million GJ	53.15 million GJ
Commercial	723.28 million GJ	456.90 million GJ
Total Demand	2,487.82 million GJ	1742.41 million GJ

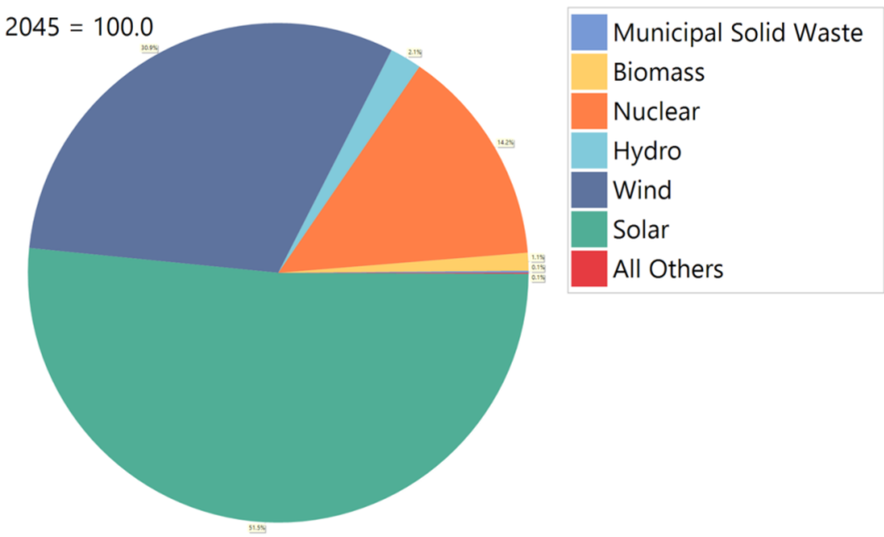

Figure 12: Outputs by Feedstock Fuel Scenario: Our Scenario

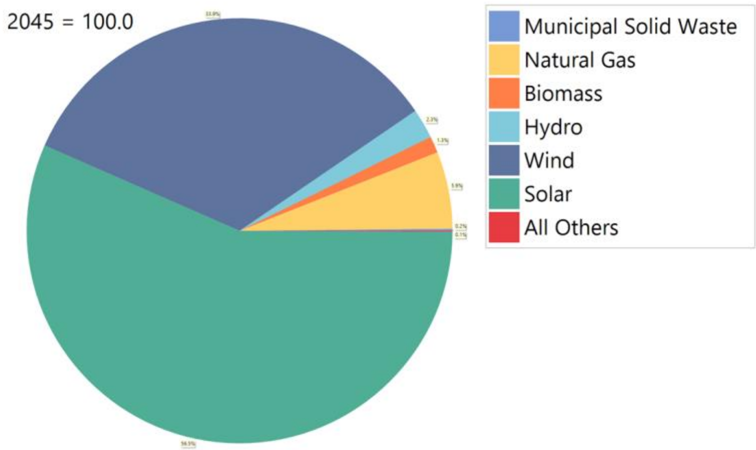

Figure 13: Outputs by Feedstock Fuel Scenario: NDC 2030 scenario

4.2 Carbon dioxide emissions

From the graphs below it is evident that the emissions are decreasing from 2022 to 2045 for NDC as well as our own scenario. Coal contributed to the major chunk of emissions in 2022 amounting up to 270 million metric tonnes of CO_2. The declining emission from coal is due to the gradual phase out of coal by 2038 in NDC scenario. Coal plants are retired after 2038 that is why it is not seen in the graph after 2038. The declining emission from natural gas is because the major share of demand was met from renewables. In our own scenario we can see that the emissions declined from 2022 to 2045. It is seen that since the reliance is on nuclear and renewable energies a steady decrease in emissions towards the year 2045 in our own scenario. From the emissions seen in our own scenario bringing back of nuclear will reduce the carbon emissions to zero. So, it is advisable to bring back nuclear and rely more own renewables as per the emissions are considered. The goal SDG 7 can be achieved by implementing our own scenario.

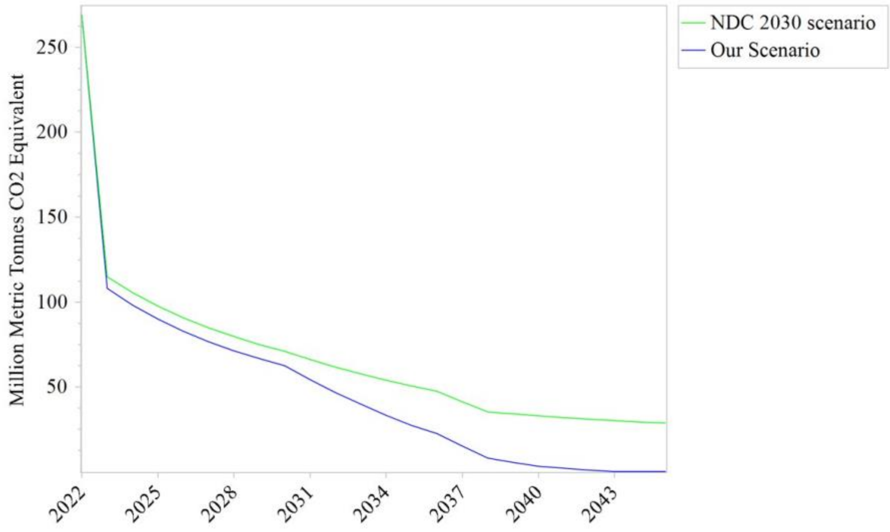

Figure 14: Comparative Carbon emission in both the scenarios.

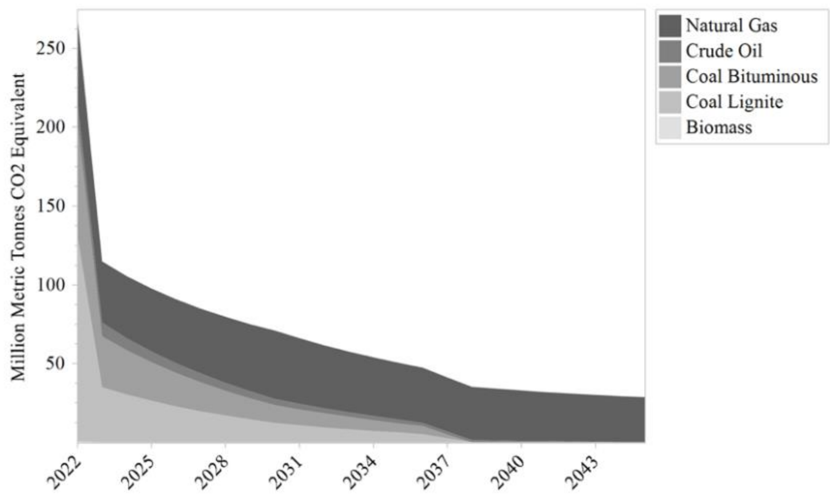

Figure 15: 100-Year GWP: Direct (At Point of Emissions) Scenario: NDC 2030 scenario, All GHGs

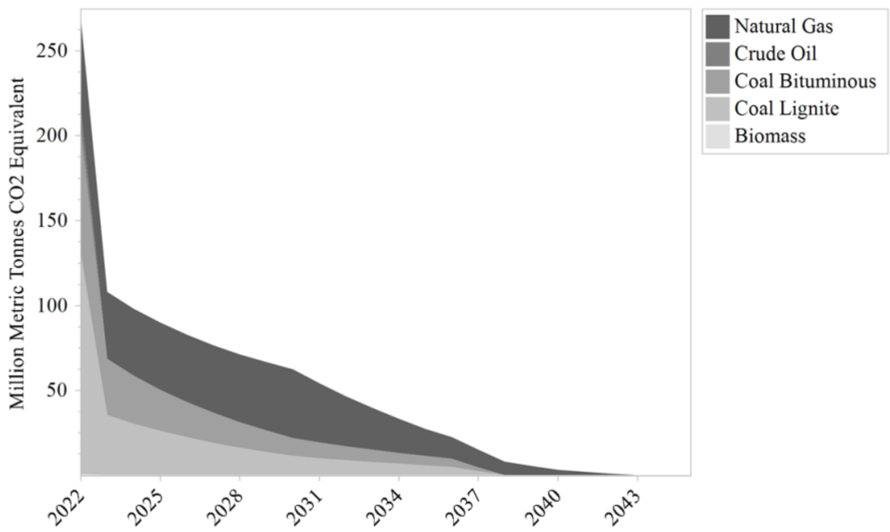

Figure 16: 100-Year GWP: Direct (At Point of Emissions) Scenario: Our Scenario, All GHGs

4.3 Social Cost of technology system

The social costs of different technologies for the two different scenarios have been exhibited below. From the graphs it is evident that the social costs are continuously increasing over the period. This is the result of Germany's effort to increase renewables. The major share of the social costs comes from the solar and wind in both the scenarios because of their high production owing to the increase in demand. In the NDC scenario there is a decline in the social cost contribution of coal because of Germany's determination to reduce carbon emissions in energy production. As a result, there is an increased dependence on natural gas which is mainly through imports. In our own scenario pertaining to our ambitious goal to decrease fossil fuel, more investments on nuclear energy are made which corresponds to a slightly more overall social cost of our own scenario by 2.21% for 2045. This is because nuclear power plant's CAPEX cost per gigawatt is higher. Due to the geography of Germany, availability of sun and wind is intermittent which impacts grid stability. This being the major reason for choosing nuclear despite the high cost of maintenance and operation of the nuclear plant. The capex cost is high for nuclear because of the higher need of safety controls as well the nuclear waste management. Nuclear waste management is a critical issue that needs to be addressed by Germany because the major chunk of the nuclear waste is stored in interim storage. Their efforts to find a final storage repository have failed because of the protests from the environmentalists and the public. Deep geological burial disposal methods must be brought in place as in other countries like Finland.

To reduce the dependence on fossil fuels, Germany is adopting electrification of transport in both the scenarios. The high cost generated due to the high demand of electric vehicles and electrification of rails has also a significant contribution in increasing the social cost.

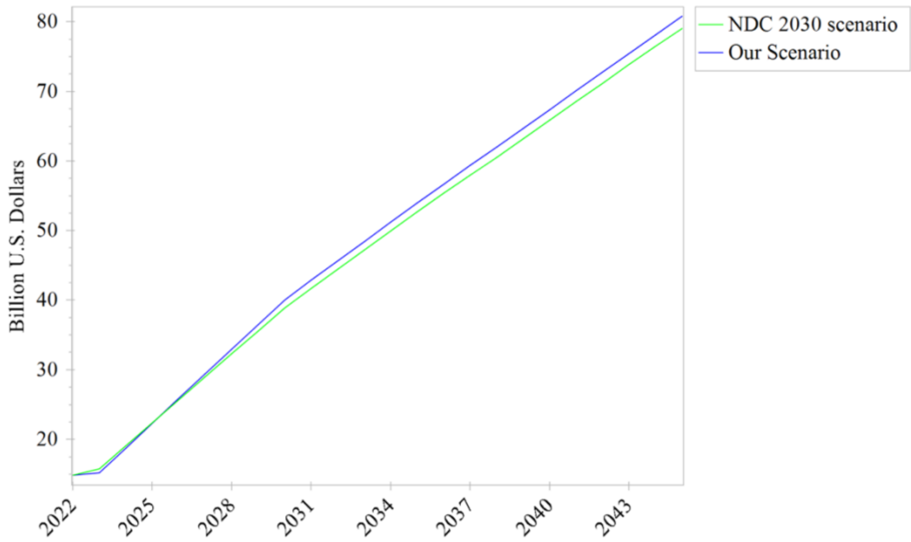

Figure17: Comparison of social cost of NDC scenario and our own scenario.

In Figure 16, our scenario demonstrates a higher social cost, albeit with a marginal difference. This is primarily attributed to the integration of nuclear energy into the power mix. Figures 17 and 18 illustrate that the overall social cost for solar and wind remains comparable in both scenarios. The key distinction lies in the increased capacity from nuclear power and the reduced reliance on natural gas.

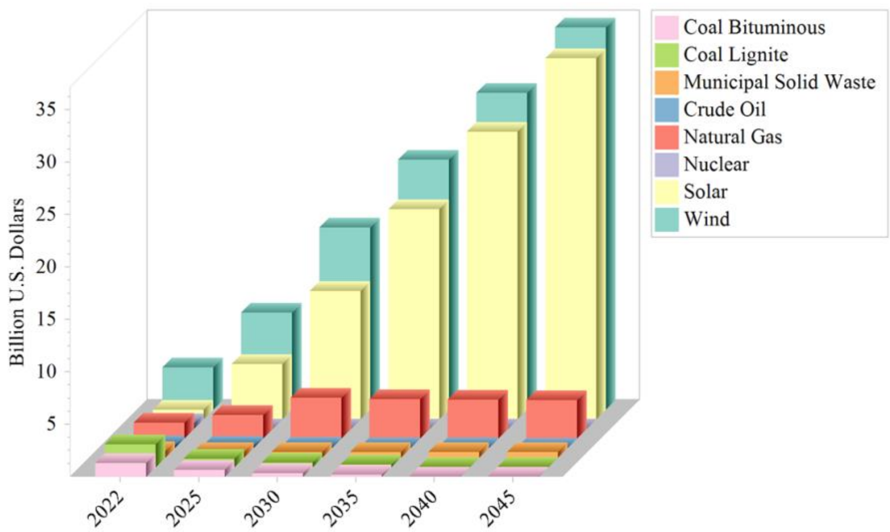

Figure 18: Presentation of social costs of the system per different technologies (NDC Scenario)

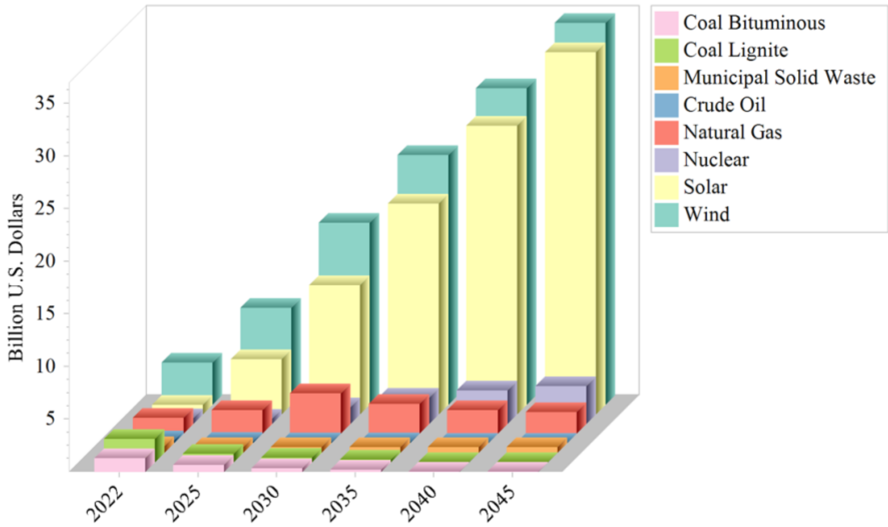

Figure 19: Presentation of social costs of the system per different technologies (Our own Scenario)

To gain a comprehensive understanding of the rising social costs associated with nuclear power, please refer to Figures 19 and 20. Figure 19 illustrates the higher social costs linked to natural gas electricity generation, which are projected to decrease. Figure 20 showcases our scenario, where we plan to retire natural gas power generation and replace it with nuclear power generation. This transition aims to mitigate social costs and their subsequent decline over time.

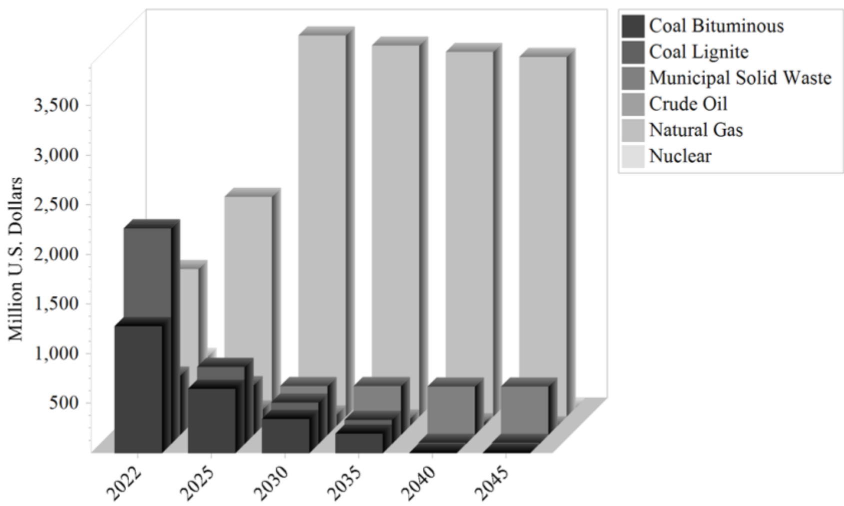

Figure 20: Presentation of social costs of the system per different technologies (NDC 2030 Scenario)

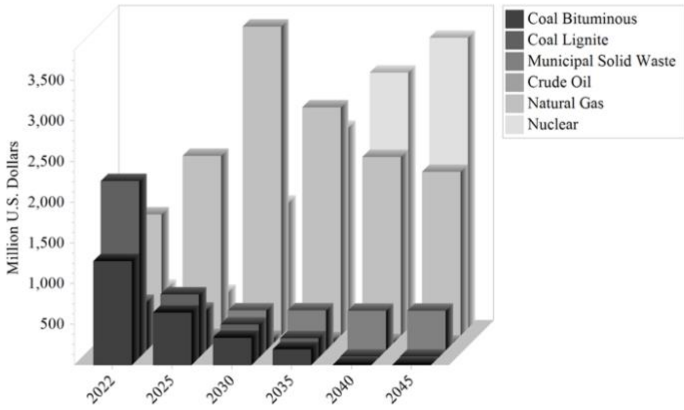

Figure 21: Presentation of social costs of the system per different technologies (Our own Scenario)

5. Conclusion and policy implications

Germany has eliminated nuclear and is mainly depending on coal and natural gas. In NDC, when coal and natural gas were considered along with other renewables, the emissions were still quite a lot because of coal power plants. According to German policies, coal power plants will be shut down by 2038. The only support to renewables will be natural gas import after 2038.

In our scenario, the capacity of renewables is increased along with the re-introduction of nuclear power plants. This will reduce the country's dependency on imports of natural gas and will also help in attaining net zero emissions.

Policy Implications

Germany is working towards increasing its renewable capacity and as they are the seasonal producer of electricity, it should work on energy storage policies. It includes battery manufacturing.

Future Work

In the future, we can study electrification in the heating sector. Also, if we re-introduce nuclear power, the study of its waste disposal can be done.

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Annex

- Final Electricity Demand by sector (Million GJ)

Branch	Households	Industry	Transport	Commercial	Total
2022	503.4	729.0	53.2	456.9	1,742.4
2023	499.3	738.5	78.6	466.1	1,782.5
2024	495.4	748.1	103.9	475.5	1,822.8
2025	491.4	757.8	128.9	485.1	1,863.2
2026	487.5	767.7	153.7	494.9	1,903.7
2027	483.6	777.6	178.3	504.9	1,944.3
2028	479.7	787.7	202.7	515.0	1,985.2
2029	475.9	798.0	226.8	525.4	2,026.1
2030	472.1	808.4	250.8	536.0	2,067.3
2031	468.3	818.9	258.9	546.8	2,092.9
2032	464.6	829.5	266.9	557.9	2,118.9
2033	460.9	840.3	274.9	569.1	2,145.2
2034	457.2	851.2	282.8	580.6	2,171.8
2035	453.5	862.3	290.6	592.3	2,198.7
2036	449.9	873.5	298.3	604.3	2,226.0
2037	446.3	884.8	306.0	616.5	2,253.6
2038	442.7	896.4	313.6	628.9	2,281.6
2039	439.2	908.0	321.1	641.6	2,309.9
2040	435.7	919.8	328.6	654.5	2,338.6
2041	432.2	931.8	336.0	667.7	2,367.7
2042	428.8	943.9	343.3	681.2	2,397.1
2043	425.3	956.1	350.5	695.0	2,427.0
2044	421.9	968.6	357.7	709.0	2,457.2
2045	418.6	981.2	364.8	723.3	2,487.8
Total	11,033.3	20,379.0	6,070.9	13,928.5	51,411.5

- Installed capacity by technology (GW): our scenario

Branch	All Others	Hydro	Biomass	Coal Bitum	Coal Lignite	Crude Oil	Natural Ga	Nuclear	Solar	Wind	Total
2022	1.6	14.5	8.9	19.0	18.7	4.7	34.3	4.1	65.0	66.2	236.9
2023	1.6	14.7	8.9	18.7	18.7	4.5	37.4	-	78.1	74.8	257.4
2024	1.6	14.9	8.9	17.4	17.4	4.3	40.5	0.7	91.3	83.4	280.3
2025	1.6	15.1	8.9	16.0	16.0	4.1	43.6	1.5	104.4	92.0	303.2
2026	1.6	15.3	8.9	14.7	14.7	3.9	46.8	2.2	117.5	100.6	326.0
2027	1.6	15.4	8.9	13.3	13.3	3.7	49.9	2.9	130.6	109.2	348.9
2028	1.6	15.6	8.9	12.0	12.0	3.5	53.0	3.6	143.8	117.8	371.8
2029	1.6	15.8	8.9	10.6	10.6	3.3	56.2	4.4	156.9	126.4	394.7
2030	1.6	16.0	8.9	9.3	9.3	3.1	59.3	5.1	170.0	135.0	417.5
2031	1.6	16.0	8.9	8.6	8.6	2.9	53.0	5.7	185.3	142.0	432.5
2032	1.6	16.0	8.9	7.9	7.9	2.7	46.7	6.3	200.7	149.0	447.6
2033	1.6	16.0	8.9	7.2	7.2	2.5	40.4	7.0	216.0	156.0	462.6
2034	1.6	16.0	8.9	6.4	6.4	2.2	34.1	7.6	231.3	163.0	477.6
2035	1.6	16.0	8.9	5.7	5.7	2.0	27.8	8.2	246.7	170.0	492.6
2036	1.6	16.0	8.9	5.0	5.0	1.8	23.5	8.7	262.0	177.0	509.5
2037	1.6	16.0	8.9	2.5	2.5	1.6	19.3	9.1	277.3	184.0	522.9
2038	1.6	16.0	8.9	-	-	1.4	15.1	9.6	292.7	191.0	536.2
2039	1.6	16.0	8.9	-	-	1.2	10.8	10.0	308.0	198.0	554.6
2040	1.6	16.0	8.9	-	-	1.0	6.6	10.5	323.3	205.0	573.0
2041	1.6	16.0	8.9	-	-	0.8	4.4	10.8	338.7	212.0	593.2
2042	1.6	16.0	8.9	-	-	0.6	2.2	11.1	354.0	219.0	613.4
2043	1.6	16.0	8.9	-	-	0.4	-	11.4	369.3	226.0	633.6
2044	1.6	16.0	8.9	-	-	0.2	-	11.7	384.7	233.0	656.1
2045	1.6	16.0	8.9	-	-	-	-	12.0	400.0	240.0	678.5
Total	37.6	377.3	213.8	174.4	174.0	56.4	704.9	164.2	5,447.5	3,770.4	11,120.4

NDC scenario

Branch	All Others	Hydro	Biomass	Coal Bitum	Coal Lignite	Municipal S	Crude Oil	Natural Ga	Solar	Wind	Total
2022	4.6	14.5	8.9	19.0	18.7	1.1	4.7	34.3	65.0	66.2	236.9
2023	0.5	14.7	8.9	18.7	18.7	1.1	4.5	37.4	78.1	74.8	257.4
2024	0.5	14.9	8.9	17.4	17.4	1.1	4.3	40.5	91.3	83.4	279.6
2025	0.5	15.1	8.9	16.0	16.0	1.1	4.1	43.6	104.4	92.0	301.7
2026	0.5	15.3	8.9	14.7	14.7	1.1	3.9	46.8	117.5	100.6	323.9
2027	0.5	15.4	8.9	13.3	13.3	1.1	3.7	49.9	130.6	109.2	346.0
2028	0.5	15.6	8.9	12.0	12.0	1.1	3.5	53.0	143.8	117.8	368.1
2029	0.5	15.8	8.9	10.6	10.6	1.1	3.3	56.2	156.9	126.4	390.3
2030	0.5	16.0	8.9	9.3	9.3	1.1	3.1	59.3	170.0	135.0	412.4
2031	0.5	16.0	8.9	8.6	8.6	1.1	2.9	59.3	185.3	142.0	433.1
2032	0.5	16.0	8.9	7.9	7.9	1.1	2.7	59.3	200.7	149.0	453.8
2033	0.5	16.0	8.9	7.2	7.2	1.1	2.5	59.3	216.0	156.0	474.5
2034	0.5	16.0	8.9	6.4	6.4	1.1	2.2	59.3	231.3	163.0	495.2
2035	0.5	16.0	8.9	5.7	5.7	1.1	2.0	59.3	246.7	170.0	515.9
2036	0.5	16.0	8.9	5.0	5.0	1.1	1.8	59.3	262.0	177.0	536.6
2037	0.5	16.0	8.9	2.5	2.5	1.1	1.6	59.3	277.3	184.0	553.8
2038	0.5	16.0	8.9	-	-	1.1	1.4	59.3	292.7	191.0	570.9
2039	0.5	16.0	8.9	-	-	1.1	1.2	59.3	308.0	198.0	593.0
2040	0.5	16.0	8.9	-	-	1.1	1.0	59.3	323.3	205.0	615.1
2041	0.5	16.0	8.9	-	-	1.1	0.8	59.3	338.7	212.0	637.3
2042	0.5	16.0	8.9	-	-	1.1	0.6	59.3	354.0	219.0	659.4
2043	0.5	16.0	8.9	-	-	1.1	0.4	59.3	369.3	226.0	681.5
2044	0.5	16.0	8.9	-	-	1.1	0.2	59.3	384.7	233.0	703.6
2045	0.5	16.0	8.9	-	-	1.1	-	59.3	400.0	240.0	725.8
Total	16.1	377.3	213.8	174.4	174.0	25.6	56.4	1,310.5	5,447.5	3,770.4	11,566.0

- Power generation (Million GJ) by energy source: Our scenario

Branch	All Others	Hydro	Biomass	Coal Bitum	Coal Lignite	Municipal S	Natural Ga	Nuclear	Solar	Wind	Total
2022	54.7	63.0	160.6	231.8	418.3	33.5	287.3	124.9	218.9	451.1	2,044.1
2023	4.1	119.1	72.2	106.3	113.8	8.7	212.2	-	633.5	606.5	1,876.4
2024	3.7	111.2	66.6	91.0	97.5	8.0	212.1	22.5	682.4	623.7	1,918.7
2025	3.5	104.7	61.9	78.0	83.6	7.4	212.3	44.9	725.5	639.4	1,961.2
2026	3.3	99.1	57.9	66.8	71.6	6.9	212.9	67.4	763.9	654.0	2,003.9
2027	3.1	94.4	54.5	57.1	61.2	6.5	213.6	89.9	798.7	667.7	2,046.7
2028	2.9	90.3	51.5	48.5	52.0	6.2	214.5	112.4	830.7	680.7	2,089.6
2029	2.7	86.7	48.9	40.9	43.8	5.9	215.6	134.8	860.3	693.2	2,132.8
2030	2.6	83.6	46.5	34.0	36.4	5.6	216.8	157.3	888.0	705.2	2,176.1
2031	2.5	80.4	44.8	30.2	32.3	5.4	186.4	176.5	931.2	713.4	2,203.1
2032	2.4	77.5	43.1	26.7	28.6	5.2	158.2	195.8	971.6	721.4	2,230.4
2033	2.3	74.8	41.6	23.4	25.1	5.0	132.1	215.0	1,009.6	729.2	2,258.1
2034	2.3	72.3	40.3	20.4	21.8	4.8	107.8	234.2	1,045.5	736.7	2,286.1
2035	2.2	70.0	39.0	17.5	18.8	4.7	85.1	253.4	1,079.7	744.1	2,314.5
2036	2.1	67.9	37.8	14.9	15.9	4.5	69.9	267.7	1,111.5	750.9	2,343.2
2037	2.1	66.2	36.9	7.3	7.8	4.4	55.9	282.0	1,148.0	761.7	2,372.2
2038	2.0	64.7	36.0	-	-	4.3	42.7	296.3	1,183.4	772.3	2,401.7
2039	2.0	62.8	35.0	-	-	4.2	29.8	310.5	1,209.6	777.6	2,431.5
2040	1.9	61.1	34.0	-	-	4.1	17.7	324.8	1,235.0	783.0	2,461.7
2041	1.9	59.5	33.1	-	-	4.0	11.5	334.0	1,259.7	788.6	2,492.3
2042	1.8	58.0	32.3	-	-	3.9	5.6	343.2	1,284.0	794.4	2,523.3
2043	1.8	56.7	31.6	-	-	3.8	-	352.4	1,308.1	800.4	2,554.7
2044	1.7	55.3	30.8	-	-	3.7	-	361.7	1,328.6	804.8	2,586.5
2045	1.7	54.0	30.1	-	-	3.6	-	370.9	1,349.1	809.5	2,618.8
Total	111.2	1,833.3	1,167.1	894.6	1,128.5	154.1	2,900.0	5,072.5	23,856.5	17,209.5	54,327.4

NDC scenario

Branch	All Others	Hydro	Biomass	Coal Bitum	Coal Lignite	Municipal S	Crude Oil	Natural Ga	Solar	Wind	Total
2022	125.6	63.0	160.6	231.8	418.3	33.5	54.0	287.3	218.9	451.1	2,044.1
2023	4.0	116.8	70.9	104.2	111.7	8.5	35.8	208.1	621.4	595.0	1,876.4
2024	3.7	110.7	66.3	90.5	97.0	7.9	31.9	211.0	679.0	620.6	1,918.7
2025	3.5	105.6	62.5	78.6	84.3	7.5	28.6	214.1	731.6	644.9	1,961.2
2026	3.3	101.3	59.2	68.3	73.1	7.1	25.8	217.4	780.3	668.1	2,003.9
2027	3.2	97.6	56.3	59.0	63.2	6.8	23.3	220.9	825.9	690.5	2,046.7
2028	3.0	94.5	53.9	50.7	54.4	6.5	21.0	224.5	869.1	712.2	2,089.6
2029	2.9	91.7	51.7	43.2	46.3	6.2	19.0	228.1	910.2	733.4	2,132.8
2030	2.8	89.4	49.8	36.4	39.0	6.0	17.1	231.9	949.7	754.1	2,176.1
2031	2.7	85.8	47.8	32.2	34.5	5.7	15.3	222.7	994.3	761.8	2,203.1
2032	2.6	82.7	46.0	28.5	30.5	5.5	13.7	214.5	1,036.7	769.8	2,230.4
2033	2.5	79.8	44.4	25.0	26.8	5.3	12.2	207.0	1,077.1	777.9	2,258.1
2034	2.4	77.2	43.0	21.7	23.3	5.2	10.8	200.2	1,115.9	786.3	2,286.1
2035	2.3	74.8	41.7	18.7	20.1	5.0	9.6	194.1	1,153.3	794.9	2,314.5
2036	2.3	72.6	40.5	15.9	17.1	4.8	8.4	188.5	1,189.5	803.6	2,343.2
2037	2.2	71.0	39.5	7.8	8.3	4.7	7.3	184.2	1,230.7	816.5	2,372.2
2038	2.2	69.5	38.7	-	-	4.6	6.2	180.3	1,270.9	829.4	2,401.7
2039	2.1	67.6	37.7	-	-	4.5	5.2	175.5	1,302.0	837.0	2,431.5
2040	2.1	65.9	36.7	-	-	4.4	4.2	171.1	1,332.5	844.8	2,461.7
2041	2.0	64.4	35.8	-	-	4.3	3.3	167.0	1,362.5	852.9	2,492.3
2042	2.0	62.9	35.0	-	-	4.2	2.4	163.3	1,392.2	861.3	2,523.3
2043	1.9	61.6	34.3	-	-	4.1	1.6	159.8	1,421.6	869.9	2,554.7
2044	1.9	60.3	33.6	-	-	4.0	0.8	156.5	1,450.7	878.7	2,586.5
2045	1.8	59.2	33.0	-	-	4.0	-	153.5	1,479.6	887.7	2,618.8
Total	185.0	1,926.0	1,218.7	912.7	1,147.8	160.3	357.4	4,781.4	25,395.6	18,242.3	54,327.4

- Actual Availability per power plant (%)

Branch	All Others	Hydro	Geotherma	Biomass	Coal Bitum	Coal Lignite	Municipal S	Natural Ga	Nuclear	Solar	Wind	Total
2022	36.4	13.8	4.6	57.1	38.7	71.0	99.4	26.6	97.6	10.7	21.6	477.5
2023	-	25.7	25.7	25.7	18.0	19.3	25.7	18.0	-	25.7	25.7	209.6
2024	-	23.7	23.7	23.7	16.6	17.8	23.7	16.6	98.0	23.7	23.7	291.3
2025	-	22.0	22.0	22.0	15.4	16.5	22.0	15.4	98.0	22.0	22.0	277.6
2026	-	20.6	20.6	20.6	14.4	15.5	20.6	14.4	98.0	20.6	20.6	266.0
2027	-	19.4	19.4	19.4	13.6	14.5	19.4	13.6	98.0	19.4	19.4	256.0
2028	-	18.3	18.3	18.3	12.8	13.7	18.3	12.8	98.0	18.3	18.3	247.3
2029	-	17.4	17.4	17.4	12.2	13.0	17.4	12.2	98.0	17.4	17.4	239.7
2030	-	16.6	16.6	16.6	11.6	12.4	16.6	11.6	98.0	16.6	16.6	233.0
2031	-	15.9	15.9	15.9	11.2	11.9	15.9	11.2	98.0	15.9	15.9	227.8
2032	-	15.4	15.4	15.4	10.7	11.5	15.4	10.7	98.0	15.4	15.4	223.1
2033	-	14.8	14.8	14.8	10.4	11.1	14.8	10.4	98.0	14.8	14.8	218.8
2034	-	14.3	14.3	14.3	10.0	10.7	14.3	10.0	98.0	14.3	14.3	214.8
2035	-	13.9	13.9	13.9	9.7	10.4	13.9	9.7	98.0	13.9	13.9	211.1
2036	-	13.5	13.5	13.5	9.4	10.1	13.5	9.4	98.0	13.5	13.5	207.6
2037	-	13.1	13.1	13.1	9.2	9.8	13.1	9.2	98.0	13.1	13.1	205.0
2038	-	12.8	12.8	12.8	-	-	12.8	9.0	98.0	12.8	12.8	183.9
2039	-	12.5	12.5	12.5	-	-	12.5	8.7	98.0	12.5	12.5	181.4
2040	-	12.1	12.1	12.1	-	-	12.1	8.5	98.0	12.1	12.1	179.2
2041	-	11.8	11.8	11.8	-	-	11.8	8.3	98.0	11.8	11.8	177.0
2042	-	11.5	11.5	11.5	-	-	11.5	8.1	98.0	11.5	11.5	175.1
2043	-	11.2	11.2	11.2	-	-	11.2	-	98.0	11.2	11.2	165.4
2044	-	11.0	11.0	11.0	-	-	11.0	-	98.0	11.0	11.0	163.7
2045	-	10.7	10.7	10.7	-	-	10.7	-	98.0	10.7	10.7	162.2
Total	36.4	372.0	362.8	415.3	223.9	269.5	457.6	254.3	2,253.6	368.9	379.8	5,394.2

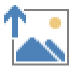
- CO_2 emissions (MtonCO_2)

Branch	Biomass	Coal Bitum	Coal Lignite	Crude Oil	Natural Ga	Total
2022	0.9	71.9	129.7	13.1	53.5	269.1
2023	0.4	33.0	35.3	-	39.5	108.2
2024	0.4	28.2	30.2	-	39.5	98.3
2025	0.3	24.2	25.9	-	39.5	90.0
2026	0.3	20.7	22.2	-	39.6	82.9
2027	0.3	17.7	19.0	-	39.8	76.7
2028	0.3	15.0	16.1	-	39.9	71.4
2029	0.3	12.7	13.6	-	40.1	66.7
2030	0.3	10.5	11.3	-	40.4	62.5
2031	0.3	9.4	10.0	-	34.7	54.3
2032	0.2	8.3	8.9	-	29.4	46.8
2033	0.2	7.3	7.8	-	24.6	39.9
2034	0.2	6.3	6.8	-	20.1	33.4
2035	0.2	5.4	5.8	-	15.8	27.3
2036	0.2	4.6	4.9	-	13.0	22.8
2037	0.2	2.3	2.4	-	10.4	15.3
2038	0.2	-	-	-	7.9	8.1
2039	0.2	-	-	-	5.6	5.7
2040	0.2	-	-	-	3.3	3.5
2041	0.2	-	-	-	2.1	2.3
2042	0.2	-	-	-	1.0	1.2
2043	0.2	-	-	-	-	0.2
2044	0.2	-	-	-	-	0.2
2045	0.2	-	-	-	-	0.2
Total	6.5	277.5	350.0	13.1	539.8	1,186.9

NDC scenario

Branch	Biomass	Coal Bituminous	Coal Lignite	Crude Oil	Natural Gas	Total
2022	0.9	71.9	129.7	13.1	53.5	269.1
2023	0.4	32.3	34.6	8.7	38.7	114.8
2024	0.4	28.1	30.1	7.7	39.3	105.5
2025	0.3	24.4	26.1	7.0	39.9	97.7
2026	0.3	21.2	22.7	6.3	40.5	90.9
2027	0.3	18.3	19.6	5.6	41.1	85.0
2028	0.3	15.7	16.9	5.1	41.8	79.8
2029	0.3	13.4	14.4	4.6	42.5	75.1
2030	0.3	11.3	12.1	4.2	43.2	71.0
2031	0.3	10.0	10.7	3.7	41.5	66.2
2032	0.3	8.8	9.5	3.3	39.9	61.8
2033	0.2	7.7	8.3	3.0	38.5	57.8
2034	0.2	6.7	7.2	2.6	37.3	54.1
2035	0.2	5.8	6.2	2.3	36.1	50.7
2036	0.2	4.9	5.3	2.0	35.1	47.6
2037	0.2	2.4	2.6	1.8	34.3	41.3
2038	0.2	-	-	1.5	33.5	35.3
2039	0.2	-	-	1.3	32.7	34.1
2040	0.2	-	-	1.0	31.8	33.1
2041	0.2	-	-	0.8	31.1	32.1
2042	0.2	-	-	0.6	30.4	31.2
2043	0.2	-	-	0.4	29.7	30.3
2044	0.2	-	-	0.2	29.1	29.5
2045	0.2	-	-	-	28.6	28.8
Total	6.8	283.1	356.0	86.7	889.9	1,622.6

- The social cost of the system per technology (MUSD) :own scenario



NDC

Branch	All Others	Hydro	Biomass	Coal Bitum	Coal Lignite	Municipal !	Crude Oil	Natural Ga:	Solar	Wind	Total
2022	0.5	1.7	1.9	1.3	2.2	0.6	0.2	1.5	0.9	4.0	14.8
2023	0.0	1.8	1.7	0.8	1.0	0.5	0.2	1.6	2.3	5.9	15.7
2024	0.0	1.9	1.6	0.7	0.9	0.5	0.2	1.9	3.8	7.6	19.1
2025	0.0	2.0	1.6	0.6	0.8	0.5	0.2	2.2	5.2	9.2	22.4
2026	0.0	2.1	1.6	0.6	0.7	0.5	0.1	2.5	6.6	10.8	25.7
2027	0.0	2.2	1.6	0.5	0.6	0.5	0.1	2.9	8.1	12.5	29.0
2028	0.0	2.3	1.6	0.5	0.5	0.5	0.1	3.2	9.5	14.1	32.3
2029	0.0	2.5	1.6	0.4	0.5	0.5	0.1	3.5	10.8	15.7	35.6
2030	0.0	2.6	1.6	0.3	0.4	0.5	0.1	3.8	12.2	17.4	38.9
2031	0.0	2.6	1.6	0.3	0.4	0.5	0.1	3.8	13.8	18.7	41.7
2032	0.0	2.6	1.6	0.3	0.3	0.5	0.1	3.8	15.4	19.9	44.5
2033	0.0	2.6	1.6	0.2	0.3	0.5	0.1	3.8	16.9	21.2	47.2
2034	0.0	2.6	1.6	0.2	0.3	0.5	0.1	3.8	18.5	22.5	50.0
2035	0.0	2.6	1.6	0.2	0.2	0.5	0.1	3.7	20.0	23.8	52.7
2036	0.0	2.6	1.6	0.2	0.2	0.5	0.1	3.7	21.5	25.1	55.4
2037	0.0	2.6	1.6	0.1	0.1	0.5	0.1	3.7	23.0	26.4	57.9
2038	0.0	2.6	1.5	-	0.0	0.5	0.0	3.7	24.5	27.6	60.5
2039	0.0	2.6	1.5	-	0.0	0.5	0.0	3.7	25.9	28.9	63.2
2040	0.0	2.6	1.5	-	0.0	0.5	0.0	3.7	27.4	30.2	65.9
2041	0.0	2.6	1.5	-	0.0	0.5	0.0	3.7	28.8	31.4	68.6
2042	0.0	2.6	1.5	-	0.0	0.5	0.0	3.6	30.2	32.7	71.2
2043	0.0	2.6	1.5	-	0.0	0.5	0.0	3.6	31.6	33.9	73.8
2044	0.0	2.6	1.5	-	0.0	0.5	0.0	3.6	33.0	35.2	76.5
2045	0.0	2.6	1.5	-	0.0	0.5	-	3.6	34.4	36.4	79.1
Total	1.3	57.7	38.1	7.2	9.4	11.8	2.1	78.6	424.3	511.1	1,141.7