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Make the European Green Deal Real – Combining Climate Neutrality and Economic Recovery

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Make the European Green Deal Real – Combining Climate Neutrality and Economic Recovery

Berlin, June 2020

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Highlights

The European Green Deal (EGD), a package of measures "to put Europe on a pathway to a sustainable future, while leaving no one behind", can combine climate neutrality with a sustainable economic recovery of Europe coming out of the Corona pandemic crisis. However, this requires a tightening of climate targets for 2030 already, and the development of an ambitious climate policy pathway, replacing the current "business as usual". In particular, the recovery programs must target energy efficiency and innovations for sustainable technologies, such as renewable energies, storage, and other flexibility options. This study analyzes selected areas of the European Green Deal critically, focusing on the core objective of achieving climate neutrality. The study uses energy system modeling to describe an ambitious approach to achieve climate neutrality in the spirit of the Paris climate agreement (called "Paris"-scenario) aiming for carbon neutrality by 2040. Particular focus is placed on justice and solidarity between stakeholders that are affected differently.

The reference benchmark of the EGD must be climate neutrality, and coherence with the 2015 Paris climate agreement for a pathway limiting the increase of the global mean temperature to far below 2°, and if possible to 1.5°. Significant increases in energy efficiency and energy savings through behavioral change can lead to a reduction of primary energy demand by about 50% by 2050 (basis: 2015). Even under these optimistic assumptions, an increase of the greenhouse gas emission reductions ("ambition level") is necessary for 2030 and 2040, to reach climate neutrality. An appropriate target for 2030 is in the range of 60% to 65% reduction (basis: 1990), instead of the "business-as-usual", i.e. only a 40% reduction target for 2030.

Despite declining final energy consumption, the trend towards electrification is increasing the demand for electricity, which is likely to more than double between 2020 (approx. 4,000 terrawatt-hours, TWh) and 2050. The declining shares of fossil and fissile power generation will be replaced mainly by onshore wind and solar photovoltaic capacities. Offshore wind plays a certain role, especially in the countries bordering the North Sea. At the end of the period, in the 2040s, 100% of supply will be secured by renewable energies.

Some progress can be observed at the national level to end the use of coal, though these programs need to be accelerated to phase out coal by the early 2030s the latest. Focus now needs to shift on phasing out fossil natural gas, the climate effects of which have been largely underestimated thus far. Nuclear power is expensive, dangerous, and has unresolved issues of storing radioactive waste; according to model results, no more nuclear power plant would be constructed beyond 2020.

The “Paris”-climate scenario can be designed in a cost-efficient manner, and become an important element of the economic recovery process. Although the energy system costs increase slightly with respect to the business as usual (BAU, ~ € 200 billion), these costs are by far outweighed by avoided costs: Being in line with the Paris agreement saves 15 Gigatons (Gt) of CO_2 until 2030, and more than 60 Gt of CO_2 by 2050. This is worth more than € 10 trillion in terms of avoided environmental and climate damage. Another important macroeconomic effect comes from investments into renewable energies and storage facilities, in the range of € 3,000 billion. Note that over two thirds of these investments could be financed through savings of fossil fuel imports (~ € 2,000 billion). This would also substantially reduce the EU’s import dependency.

Solidarity is an integral part of the EGD (“leaving no one behind”) and has to play out at the national and at sub-national levels. At the national level, the tightening of the EU climate protection targets within the framework of the Green Deal has different effects on individual member states; this must be taken into account in implementation. At the local level, the “Just Transition Fund” (JTF) has an endowment of € 7.5 bn. that – in conjunction with the regional fund and the social cohesion fund – is supposed to leverage significant amounts of public and private funding to foster structural change. Particular care must be taken to ensure that the funds are not misused for the de facto stabilization of fossil development paths, e.g. by placing money for CO_2 capture technologies.

In this critical moment, learning from lessons of past transitions, avoiding one-way decisions to strengthen the status quo is as important as combining the decarbonization challenged with economic recovery. Policy makers need to resist strong pressure for subsidizing fossil fuels, or fossil fuel use. This includes tax incentives for diesel fuel, subsidies for fossil-fueled gas power plants for combined heat and power generation and subsidies for fossil natural gas infrastructure, e.g. in the Projects of Common Interest (PCI) program. The European Green Deal has to be a “real deal” to be sustainable, both for climate neutrality and economic recovery.

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Executive summary

Introduction: Objective and approach of the study

Make the EGD a "real" deal for climate neutrality and economic recovery

The European Green Deal (in the following: EGD) has been developed before the outbreak of the Corona-pandemic to "put Europe on a pathway to a sustainable future, while leaving no one behind". The objective of the EGD is to place Europe on the trajectory of a climate neutral, circular economic system. Aspects of a fair distribution of profits and burdens play a special role, which is also made clear by the reference to an "inclusive approach" of the EGD. The focus of the EGD is thus on measures that strengthen the importance of environmental and climate protection for the innovative and economic power of the EU and its member states on the way to climate neutrality. It consists of several sub-areas, such as e.g. "clean, reliable and affordable energy", "sustainable transport", "building efficiency and renovation" and "industry for a clean and circular economy".

The corona pandemic and the resulting economic crisis have considerably increased the importance of the EGD: on the one hand, there is a synergy between stimulus packages and sustainable technologies, such as renewable energy, neglected for many years. On the other hand, however, it must also be prevented that, under the impact of the political and economic crisis, the conventional stakeholders of the outdated fossil (coal, gas, oil) and fissile (nuclear) energy system become the brake on sustainable development through subsidies. The recent example of extensive subsidies for the fossil natural gas industry represents a first low point in the European "green" deal here, raising doubts about the seriousness of the package.

This study analyzes selected areas of the EGD that could contribute significantly to the path towards climate neutrality, including the electricity generation sector, transportation, and industry. The study was written by a team of researchers at the German Institute for Economic Research (DIW Berlin), Berlin University of Technology (TU Berlin), and the Research Group "CoalExit" – and combines research streams from an ongoing European H2020 project ("OpenEntrance") and two project for the German Federal Ministry of Education and Research ("CoalExit" and "Future of Fossil Fuels – FFF").[1]

[1] Links to the individual project-websites: OpenEntrance: https://openentrance.eu/; CoalExit: https://www.coalexit.tu-berlin.de/; FFF: https://www.diw.de/fff.

The study shows that a tightening of the climate targets, in combination with sectoral measures of the EGD, are necessary to achieve decarbonization. The modelling shows macroeconomic benefits of rapid decarbonization in the form of saved raw material imports, reduced environmental and climate costs, and sustainable investments. Furthermore, an explicit institutional framework is needed to actively involve those actors that would be weakened by the measures to transform their existing business models for sustainable solutions in order to reap the benefits of pan-European solutions. However, the study also highlights the dangers of hasty measures for economic recovery that contradict objectives of the EGD.

The approach: Energy system modeling, macro-indicators, and policy instrument analysis

The study uses energy system modeling to describe an ambitious approach to achieve climate neutrality in the spirit of the Paris climate agreement (called “Paris”-scenario) aiming for carbon neutrality by 2040. We use a top-down energy systems model (GENeSYS-MOD) to simulate cost-effective trajectories for the European electricity, transportation, heating and industry sectors under strict climate constraints. These results are then processed by a bottom-up energy model, called anyMOD, to calculate hourly supply and demand profiles for key years (Figure E-1). The models are also used to extract additional macroeconomic indicators, such as energy system costs, trade-balance effects from reduced fossil fuel imports, etc. For the emissions pathways, the results are also compared to a “business-as-usual” pathway, with current objectives that are clearly not Paris-compatible. A particular focus is placed on the year 2040, also to reap synergy effects with the ongoing PAC-modeling exercise.[2]

The modeling results are discussed in the specific context of different sectors. The study discusses specific policy fields of the EGD incorporating 90% of current emissions: the electricity sector (currently accounting for 55% of greenhouse gas emissions), sustainable transport (25% of GHG), and industry (10%). The only major sector not included in this study is agriculture, which will also need to be transformed but is beyond the scope of this study. Particular focus is placed on justice and solidarity between stakeholders that are affected differently, both at the macro-level of decarbonization scenarios and GHG emissions, and at the micro-level of regional structural change, addresses amongst others by the Just Transition Mechanism (JTM).

[2] See https://www.pac-scenarios.eu/.

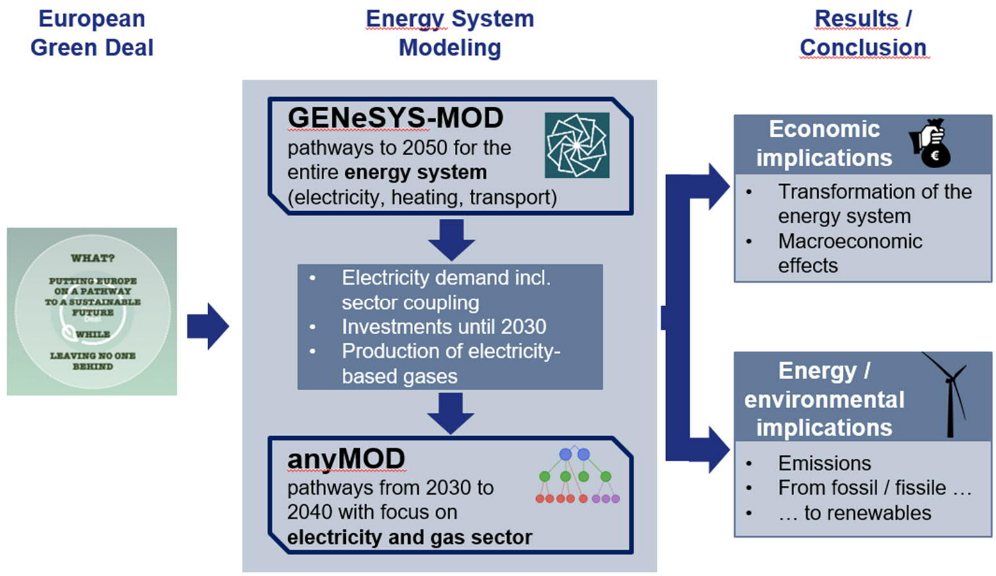

Figure E-1: Approach and methodology

Climate neutrality and economic recovery

Climate neutrality requires more ambitious GHG-emission targets for 2030 and beyond

In the climate protection scenario "Paris"[3], we assume significant increase in energy efficiency and certain behavioral parameters, which, coupled with high electrification rates across all sectors, leads to a reduction in primary energy demand (Figure E-2).

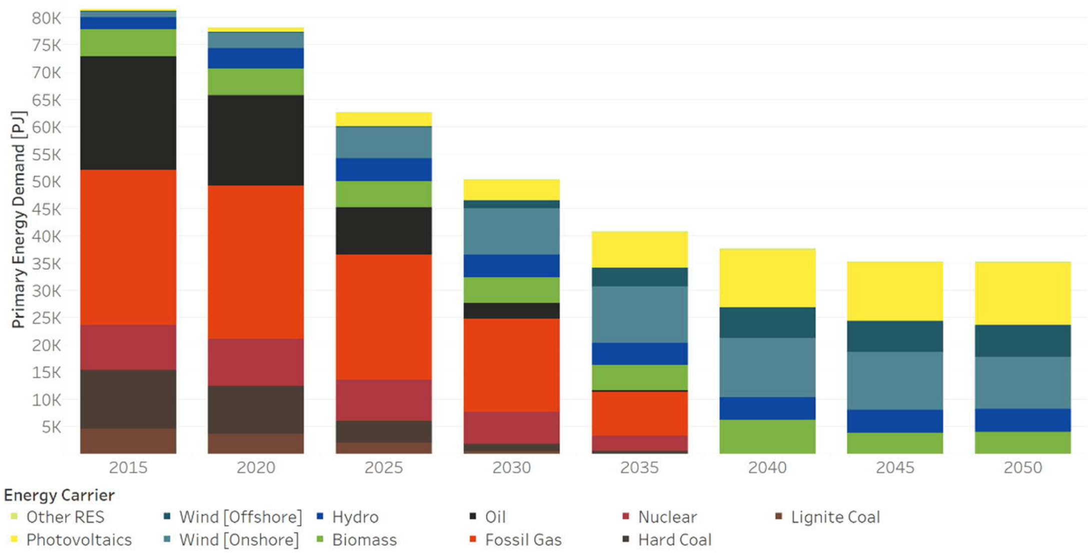

Figure E-2: Primary energy demand in Europe in the climate scenario “Paris” (2015 - 2050)

[3] The "Paris" scenario is based on the "societal commitment" scenario developed in the current EU Horizon 2020 project "Open Entrance", see for details (Auer et al. 2020); the results shown here do not reflect concrete project output from that project though.

The model results show that, although climate protection targets need to be tightened considerably in order to achieve climate neutrality, this path is the most favorable alternative, taking into account the environmental costs avoided. The goal of climate neutrality agreed at European level requires a drastic reduction in GHG emissions, far beyond the current target of 40% by 2030. If the "Paris" scenario is implemented, CO_2 emissions will decrease significantly after 2020 (Figure E-3): Depending on the distribution of restructuring, climate neutrality may be achieved already by 2040. There is no need for carbon capture technologies. Not engaging in any further climate policies, as visible in the BAU scenario, on the contrary, results in a significant budget overrun of about 15 billion tons (Gigatons, Gt) above the emissions of the Paris scenario in 2030, and over 60 Gt by 2050. This corresponds to savings of environmental costs in the climate protection scenario of over €10 trillion by 2050.

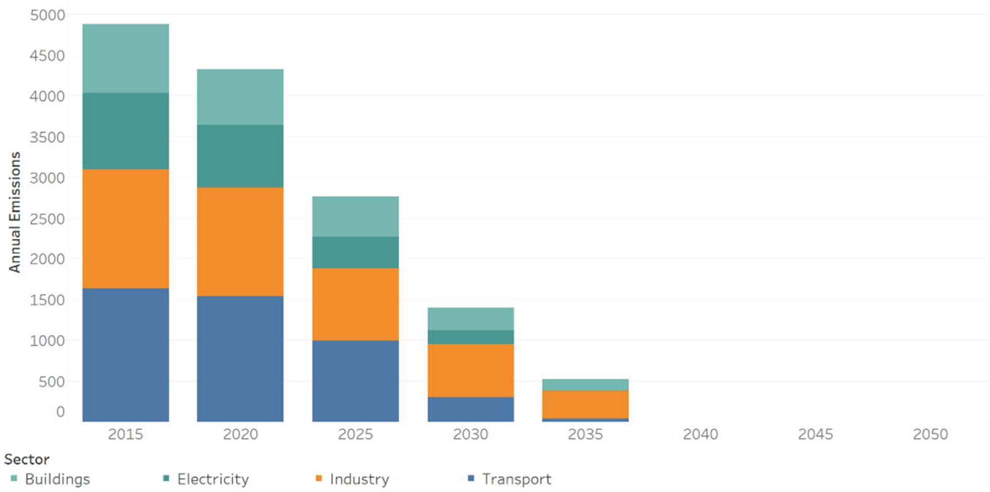

Figure E-3: CO_2-emissions in the climate scenario "Paris" in Mt CO_2

Despite efficiency improvements and declining final energy consumption, the trend towards electrification is increasing the overall demand for electricity, which will more than double between 2020 (approx. 4,000 terra-watt-hours, TWh) and 2050 (above 8,000 TWh). The declining shares of fossil (coal, gas and oil) and fissile (nuclear) power generation will be replaced mainly by onshore wind and solar photovoltaic capacities.

In view of the continuing sharp fall in costs and widespread availability, photovoltaics will increase capacity and generation sharply throughout Europe, especially from 2030. In addition to Southern Europe, solar power can also be produced cost-effectively in central European countries such as Germany and Poland. Onshore wind will also be a low-cost option in the future, and in 2050 can contribute one third of the electricity generated. Offshore wind plays a certain role, especially in the countries bordering the North Sea, and its contribution depends mainly on assumptions regarding future cost developments (Figure E-4).

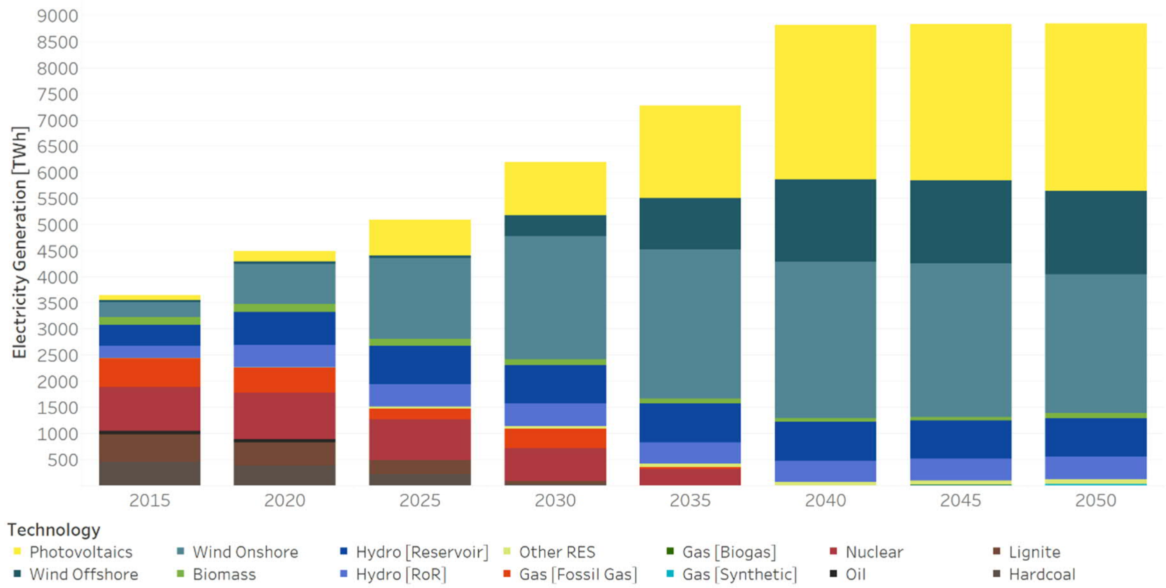

Figure E-4: Electricity generation Europe until 2050

Sector coupling and electrification are important

In the ambitious climate protection scenario, an intensive sector coupling must take place in order to achieve the goals in a cost-efficient manner throughout the system. In the transport sector, this leads, among other things, to a conversion from fossil combustion technology to electric drives, especially in passenger transport: in addition to battery-powered cars, the share of rail transport is also growing strongly. This also applies to freight transport, where the share of rail transport is increasing from the current level of approx. 20% to over 40%. In addition, biofuels and hydrogen also play a certain role. The heating sector can also be switched to renewable energies towards the 2040s. In the low-temperature range (space heating), electric heat pumps are becoming widely accepted. In the industry sector (across all temperature levels) a certain amount of bioenergy and synthetic fuels is also needed.

Macro-effects: Climate protection is cost-effective and stimulates the economic recovery

Even though it is quite ambitious, the Paris scenario can be designed in a cost-efficient manner, and become an important element of the economic recovery process. When comparing its system costs with a BAU scenario, achieving the climate targets results in additional costs of 222 billion euros within the energy system. This is, however, far outweighed by the avoided environmental and climate costs: Compared to the BAU scenario, being in line with the Paris agreement leads to savings of 15 Gigatons (Gt) of CO_2 until 2030, which accounts for almost 1,300 billion euros when taking the environmental damages of CO_2 into account, and more than 60 Gt of CO_2 by 2050. In addition, a heavily on renewable energy relying energy system requires less imports and extraction of fossil fuels (Figure E-5). Comparing the Paris scenario to the BAU scenario, almost 300 billion euros are saved until 2030 and almost 1,900 billion euros until 2050, which otherwise would go into resource imports and extraction, substantially reducing the EU's import dependency.

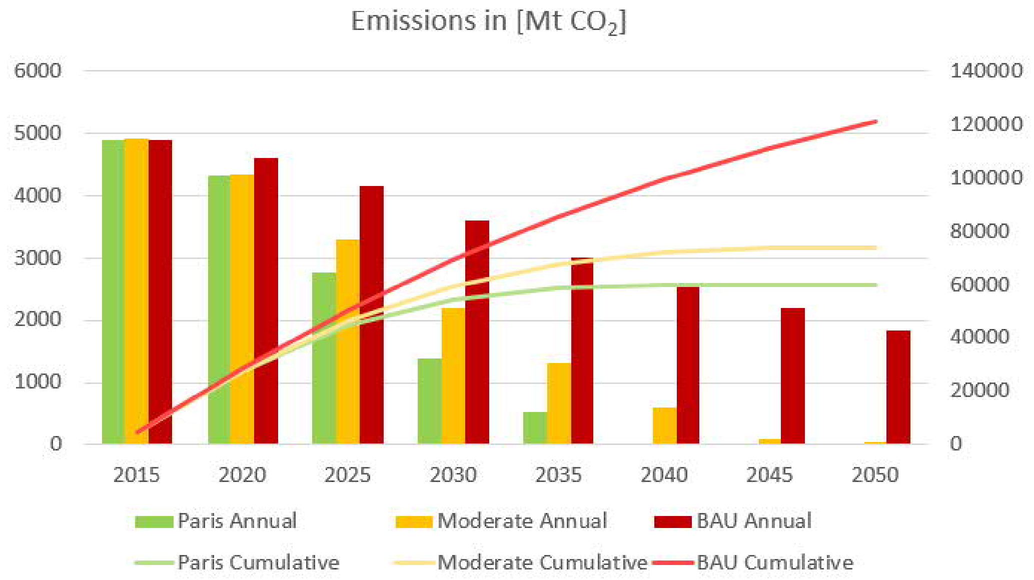

Figure E-5: Annual CO_2-emissions (left) and cumulative emissions (right) in the "Paris" scenario, compared to the moderate and the BAU scenario[4]

The model results show above all a high need for investment in renewable energy capacities. In addition, expenditures for the necessary storage technologies must also occur. More than 3,000 billion euros are required in the power sector as investments into renewable generation capacities across Europe until 2040, with additional 200 billion euros for storage capacities. This has to be taken into account in the design of the investment programs currently being prepared. In the transport sector, increased efforts must be made to achieve a sustainable expansion of rail transport. In addition, investment into public transport can increase the overall efficiency of the transportation system. The transformation in the heating sector furthermore implies a speed up of renovation of houses to decrease the overall heating demand as well as investments in the industry to switch to carbon neutral solutions.

[4] Since the BAU scenario included a different set of regions as well as reduced sectoral detail, the values were scaled to the other two scenarios.

Energy economic implications

Hourly resolution of electricity demand

Thanks to various flexibility mechanisms, the electricity and heat supply remains secure despite the switch to renewable energies. Both electricity trading in the European internal electricity market and the availability of different storage technologies contribute to this. Within the framework of a model comparison, the results of the energy system analysis were transferred into an hourly load profile for electricity. The following figures show the annual development of electricity and heat quantities for countries that were previously supplied mainly by nuclear power (France in Figure E-6) or coal (Poland in Figure E-7).

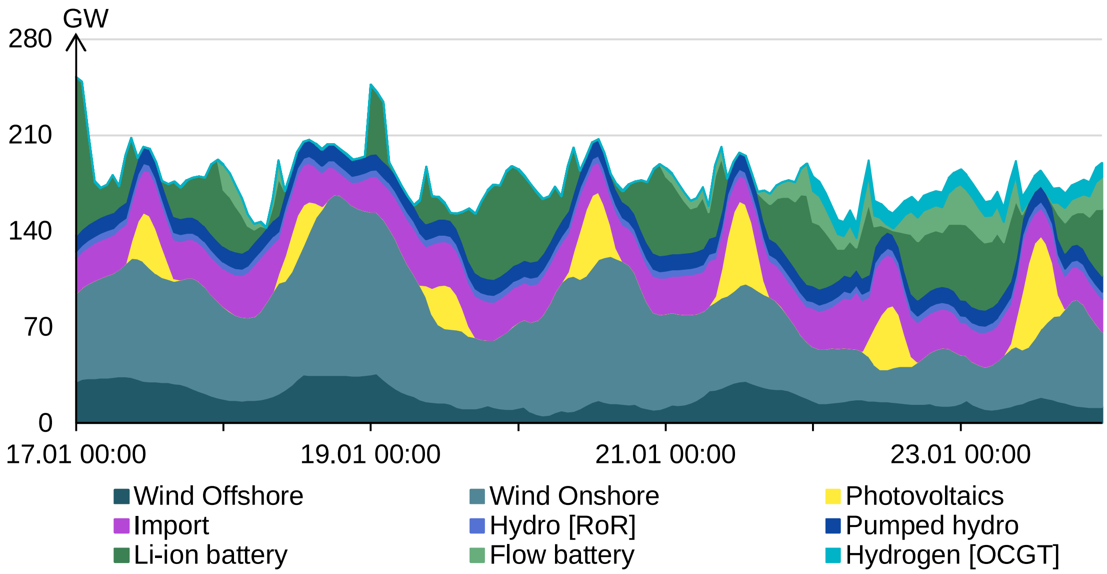

Figure E-6: Hourly load coverage of electricity demand in France in a winter week 2050

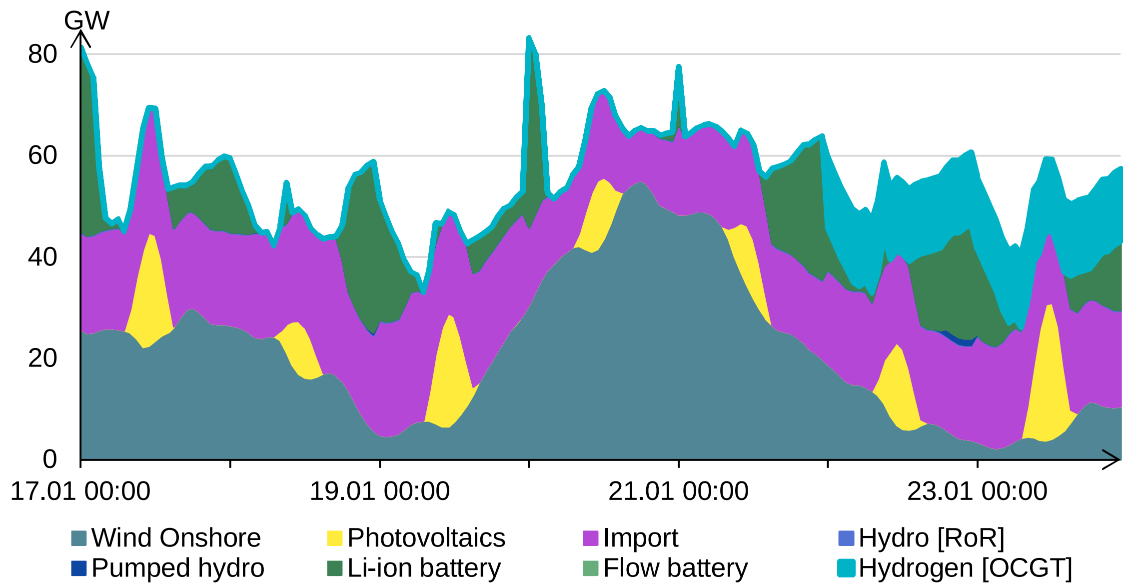

Figure E-7: Hourly load coverage of electricity demand in Poland in a winter week 2050

Coal exit, natural fossil gas exit and the end of commercial nuclear power

Some progress can be observed at the national level to end the use of coal, though these programs need to be accelerated to phase out coal by the early 2030s the latest. Focus now needs to shift on phasing out fossil natural gas, the climate effects of which have been largely underestimated thus far. Imported fossil natural gas can have higher overall greenhouse gas emissions than coal. The results also show that fossil gas is not required to succeed the energy transformation towards climate neutrality.

Some stakeholders continue to refer to fossil gas as a “bridge fuel” towards climate neutrality. This however is a myth: The cost efficient solution to climate neutrality contains no fossil gas anymore, after 2040. Neither does it include carbon capture, transport, and storage (CCTS) as an abatement technology. Even though the fossil lobby often promotes CCTS as a climate solution, it is in fact an attempt to open the gates to maintain the fossil fuel infrastructures and disguise them as “low carbon”. When it comes to decarbonization, fossil natural gas clearly belongs to the problems, and not to the solutions.

Neither is nuclear power necessary to achieve climate neutrality. In the past, individual member states (such as France and the United Kingdom) have used large amounts of nuclear energy to reach their climate targets. This is very expensive and dangerous for society when all environmental and health costs are included. According to cost-minimizing model results (that even ignore the back-end costs of decommissioning and storage and the risks of health and accidents), no more nuclear power plant would be constructed beyond 2020.

Solidarity required: Just transition

Impact on member states quite different

The tightening of the EU climate protection targets within the framework of the Green Deal has different effects on individual member states which must be taken into account in managing the upcoming transformation. The model results for individual member states can be seen in Figure E-8. They show a country-specific generation mix for 2020, with still high shares of fossil fuels and nuclear power, which shifts to 100% renewables by 2040. It is clear that countries with a high initial fossil and/or fissile endowment are hit particularly hard. Further factors to consider are the economic strength or weakness and the level of historical emissions of regions. Country-specific measures and transfer schemes are therefore needed, complementing the uniform CO_2 price for all countries within the European Emission Trading System

(ETS). Recent news - such as announcements by Greece, currently still dependent on coal, to phase it out by 2028 or formerly “king coal” UK that has managed two consecutive months without coal - show that the necessary energy transformation can be successful.

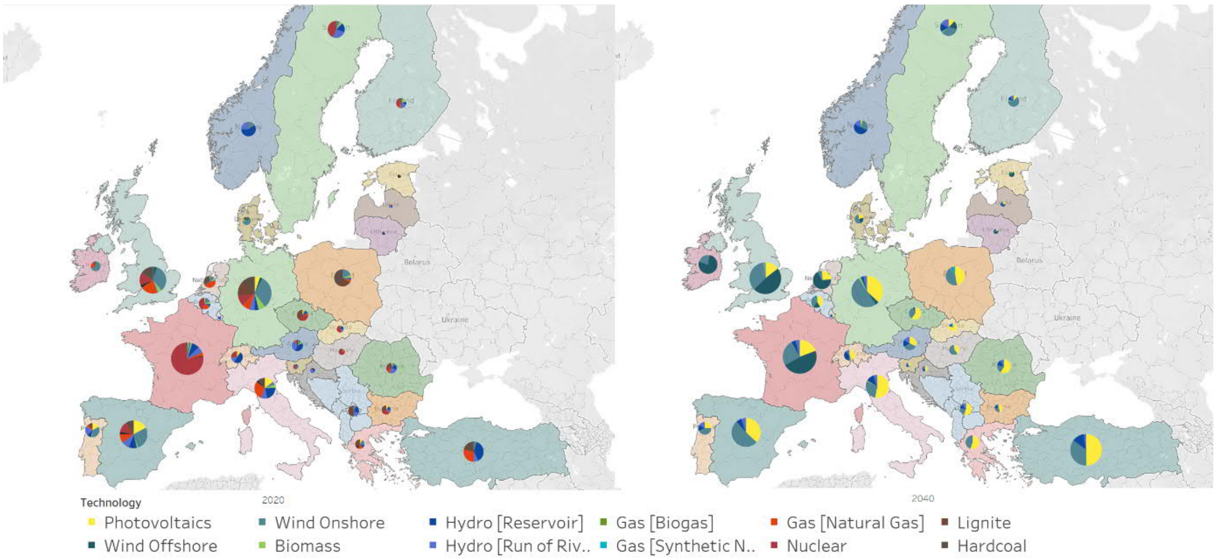

Figure E-8: Change of generation mix in Europe by country from 2020 (left) to 2040 (right)

Applying lessons learned from past transitions

The upcoming transformation of the entire energy system can profit from experiences of past industry transitions. Europe has undergone various industrial shifts, including e.g. the phase-out of hard coal mining in Germany and the UK. Economic drivers or technological improvements drove most of these changes. The EGD marks a new transformation driven by climate and environmental factors. Lessons learned from previous structural changes, however, can help to ease the effect for carbon intensive regions, which will be hit the hardest.

The main lessons of past transitions with resulting recommendations for the EGD are:

- Refrain from subsidizing the fossil/fissile industry: Instead, the formal and informal political influence of the incumbent companies must be weakened in order to overcome the lock-ins, thus enabling economic reorientation. A first step could be the abolishment of subsidies for coal production which comprise of around US$39 billion for the G20 states (Climate Transparency 2019).
- Take into account long-term effects and impacts beyond the local communities in decision making: In past transitions, the aim of leaving no one behind was not fully

met, as future generations within the region as well as international actors (to account for climate and environmental justice effects along the entire value chain) were not included in the transition's decision making processes.

- Listen to external independent advice in addition to the incumbent regime: An earlier phase-out of past transitions, as recommended by academics, would have been less expensive, caused less environmental devastation, and most likely resulted in a faster recovery of the regions.
- Diversification can minimize the risk, as no "silver bullet" exists: It is difficult to attract and predict the success of new industries. Some former coal regions were more successful in switching but are now observing a new dependence on the automotive industry, which will now have to be transformed as well. Other regions needed more time but are now profiting from a more diverse and more resilient industry portfolio.
- Participation enables locally adapted solutions and higher acceptance: The involvement of local stakeholders is important for identifying strengths and weaknesses of the regions in terms of adjusting, developing, and implementing local strategies.
- Encourage cooperation through crossing borders: Appropriate structures must be created to enable a joint post-carbon strategy for entire carbon intensive regions, independent from administrative federal or national borders. Political institutions focused on social, labor, spatial, and energy planning must combine efforts, facilitating the establishment of an integrated, coherent policy mix.

Use the "Just Transition Fund" for true decarbonization

The initial characteristics of the member states must be taken into account when setting ambitious climate targets in order to ensure equitable system transformation. A helpful vehicle in doing so is the "Just Transition Fund" (JTF) which has an endowment of € 7.5 bn. that – in conjunction with the regional fund and the social cohesion fund – is supposed to leverage significant amounts of public and private funding. The Just Transition Fund can hereby be a helpful vehicle to enable such a transition from fossil fuel based economies towards renewable energy system (Figure E-9). However, it must be borne in mind that, in order to manage structural change, local knowledge of the regions' strengths and weaknesses and opportunities for diversification is needed above all. Examples of laborious structural change in Germany, e.g. the Rhineland, suggest that the process is not necessarily improved even by the best-intentioned external interference.

Therefore, when designing the "Just Transition Mechanism" within the framework of the EGD, attention must be paid to the subsidiarity of the use of funds. In particular, care must be taken to ensure that the funds are not misused for the de facto stabilization of fossil development paths - unlike after the 2008 financial crisis. Still also now, attempts are made to use the funding for myths such as the development of CO_2 capture technologies or the support of gas as “bridge” technology, the main aim of which is to ensure the continued use of fossil fuels. In addition, there are ongoing attempts to misuse funds from the Just Transition Fund to finance nuclear power.

In 2020, unlike after the 2008 financial crisis, the EU has ratified the international Climate Agreement of Paris and declared its notion to reach carbon neutrality. Under these new circumstances, it beneficial that its members and multilateral organizations focus much more in green investment recovery packages than in the recovery of the 2008 crisis. With this, the COVID-19 crisis and its aftermath in combination with the EGD could be an opportunity to accelerate climate and sustainability efforts in Europe and bring global decarbonization and just transitions efforts substantially forward.

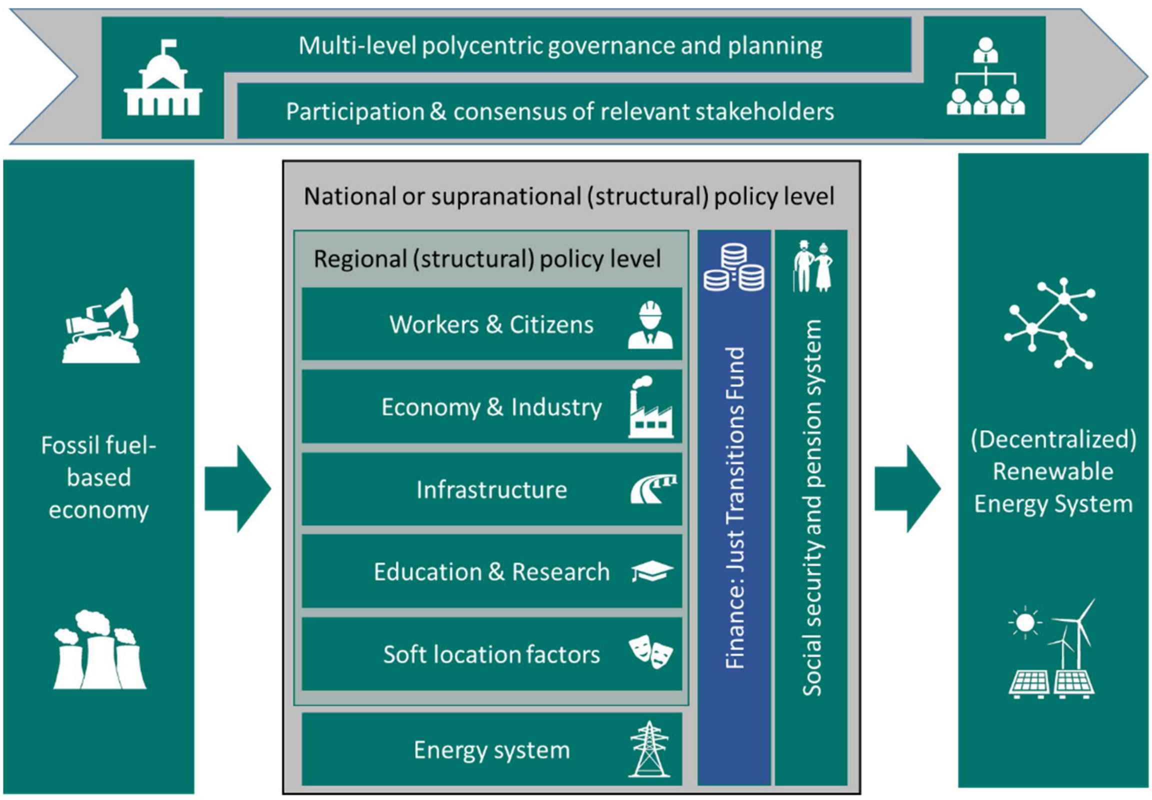

Figure E-9: Managing a just transition from a fossil fuel based to a renewable energy system through the help of a just transition fund

Concrete strategies should therefore include:

- Incentivize alternative industries in carbon intensive regions and start planning for a time after fossil fuels, taking advantage of the increased awareness of the vulnerability of coal-dependent regions and the inevitable decline of coal.
- Focus public resources in carbon intensive dependent regions on mitigating the effects of the crisis on the most vulnerable (e.g. making aid packages to fossil fuel companies conditional on maintaining employment, social security, and health and security of the employees).
- Reconsider all investments in new carbon intensive infrastructure, including coal and gas power plants, transport and extraction infrastructure, by – at the very least – withdrawing public funding for them.
- Revise aid requests by the industry, to distinguish the relative importance of COVID-19 related issues, compared to other market trends, and financial and managerial decisions, and communicating transparently the decisions about resource allocations.
- Derogation or weakening of environmental standards and regulations (e.g. air, water and soil pollution standards) should not be considered as crisis-relief measures.
- Make fund transfers or tax exemptions (e.g. accelerated depreciation schemes) conditional on plans to phase-down emissions from the sector in the medium and long term.It is in the hands of political decision makers to use the EGD as an additional means to smoothen the effects of the COVID-19 pandemic and at the same time redirect formerly carbon intensive dependent regions into a more sustainable future – even if this will mean a deathblow to some branches of carbon intensive industry such as the already dying coal industry.

Conclusions

This study analyzes selected areas of the EGD critically, that could contribute significantly to the path towards climate neutrality, including the electricity generation sector, transportation, and industry. The robust analyses throughout several projects presented in the study show that a tightening of the sectoral measures of the EGD are necessary to achieve decarbonization. Furthermore, an explicit institutional framework is needed to actively involve those actors that would be weakened by the measures to transform their existing business models for sustainable solutions in order to reap the benefits of pan-European solutions. A rapid decarbonization of the European energy system can therefore result in macroeconomic benefits in the form of saved raw material imports and lower investment and operating costs of the energy system – as shown by the presented modelling results. However, the study also highlights the dangers of hasty measures for economic recovery that contradict the objectives of the EGD.

Mistakes from the past must be avoided and concentrated policy efforts will be needed to deal with the economic and social consequences of these dying industries, in particular in coal- and carbon intensive dependent countries and regions, where the crisis will hit especially those at the bottom. Stimulus packages should be designed and justified in a way that proves how it contributes to longer-term efforts to decarbonize national economies and meet the sustainable development goals.

In this critical moment, avoiding one-way decisions to strengthen the status quo is as important as combining the decarbonization challenged with economic recovery. Policy makers need to resist strong pressure for subsidizing fossil fuels. This includes tax incentives for diesel fuel, subsidies for fossil-fueled gas power plants for combined heat and power generation and subsidies for fossil natural gas infrastructure, e.g. in the Projects of Common Interest (PCI) program. The European Green Deal has to be a “real deal” to be sustainable, both for climate neutrality and economic recovery.

1 Introduction

1.1 European Green Deal must become a real deal

The European Green Deal (in the following: EGD) has been developed before the economic corona-pandemic to “put Europe on a pathway to a sustainable future, while leaving no one behind”. The objective of the EGD is to place Europe on the trajectory of a climate neutral, circular economic system. Aspects of a fair distribution of profits and burdens play a special role, which is also made clear by the reference to an "inclusive approach" of the EGD. The focus of the EGD is thus on measures that strengthen the importance of environmental and climate protection for the innovative and economic power of the EU and its member states on the way to climate neutrality. This level of ambition is divided into sub-areas, such as "sustainable transport", "clean, reliable and affordable energy", a "green agricultural policy" including "farm-to-fork consideration", etc. Further sub- and sub-objectives complete the complex structure of the EGD.

The corona pandemic has considerably increased the importance of the EGD: on the one hand, there is a synergy between stimulus packages and sustainable technologies, such as renewable energy, neglected for many years. On the other hand, however, it must also be prevented that, under the impact of the political and economic crisis, the conventional stakeholders of the outdated fossil and fissile energy system become the brake on sustainable development through subsidies. The recent example of extensive subsidies for the fossil natural gas industry represents a first low point in the "green" deal here, raising doubts about the seriousness of the package.

This study analyzes selected areas of the EGD critically, that could contribute significantly to the path towards climate neutrality, including the electricity generation sector, transportation, and industry. The study was written by a team of researchers at the German Institute for Economic Research (DIW Berlin), Berlin University of Technology (TU Berlin), and the Research Group “CoalExit”[5] – and combines research streams from an ongoing European H2020 project

[5] Additional support was gained through input of Philipp Herpich, Paula Walk and Paola Yanguas Parra.

("OpenEntrance") and two project for the German Federal Ministry of Education and Research ("CoalExit" and "Future of Fossil Fuels – FFF").[6]

The study analyses and further analyses presented in the report show that a tightening of the sectoral measures of the EGD are necessary to achieve decarbonization. Furthermore, an explicit institutional framework is needed to actively involve those actors that would be weakened by the measures in order to reap the benefits of pan-European solutions. The modelling also shows the macroeconomic benefits of rapid decarbonization in the form of saved raw material imports and lower investment and operating costs of the energy system. However, the study also highlights the dangers of hasty measures for economic recovery that contradict the objectives of the EGD: The European Green Deal has to be a "real deal" to be sustainable, both for climate neutrality and economic recovery.

1.2 Structure of the study

After this introduction, the rest of the study is structured in the following way: Section 2 lays out the approach of the study, the energy system modelling suite, and the macro-indicators derived from there. Section 3 then focusses on the link between the European Green Deal (EGD), climate neutrality, and economic recovery. In particular, we derive the conditions under which an ambitious climate pathway – in line with the Paris climate agreement and EU climate neutrality by 2050 – can be combined with investments and structural measures for a Green Deal as an economic stimulus after the crisis. In Section 4 we discuss the implications for different sectors, mainly electrictiy, but also transport and industry: Climate neutrality requires a high degree of sector coupling that raises electricity demand, as well as the flexibility needs in what becomes a fully renewables-based system. The combination of top-down and bottom-up modeling explains how these decarbonized systems can still provide supply security: The lights do not go out, and it stays warm, too. Section 4 also takes a closer look at the evolution of the energy ix over the next three decades: Climate neutrality implies the medium-term exit of coal, fossil gas, and fossil oil that are gradually replaced by renewable energies;

[6] Links to the individual project-websites: OpenEntrance: https://openentrance.eu/; CoalExit under grant number 01LN1704A: https://www.coalexit.tu-berlin.de/; FFF under grant number 01LA1810A: https://www.diw.de/fff.

the cost optimal pathway does not contain any nuclear power investments anymore. Hydrogen enters modestly into some market segments, but only in connection with regional renewables-based production. Section 5 addresses important issues linked with solidarity and the "Just Transition Fund" (JTF) as a part of the EGD, which offers perspectives for local restructuring, but also potential dangers of being misused to maintain fossil production structures alive. Section 6 concludes.

2 Methodology

2.1 Modeling a Paris-compatible energy system top-down ...

We use an integrated modeling approach for the energy and climate analysis. The Global Energy System Model GENeSYS-MOD is used to analyze scenarios for achieving climate targets in the European context. The model calculates cost-minimal development paths for the electricity, transport, and heating sectors, thus excluding parts of the agricultural sector and non-energetic use of resources in industry. A pathway from 2015 to 2050 is calculated with every year being represented by almost 20 time-slices, which serve to highlight seasonal and daily differences in generation and demand. The respective scenario's energy and technology mix composition depends on how the parameters, in particular the assumed carbon prize and technology development, are chosen. In the "Paris" scenario, decarbonization of the whole energy system by 2040 is modeled in comparison to a "business-as-usual" (BAU) scenario where less ambitious targets and projections are implemented. The "Paris" scenario was developed and quantified in the process of the Horizon-2020 project "openENTRANCE",[7] while the BAU scenario stems from earlier work with GENeSYS-MOD (see Oei et al. (2019) for reference). Therefore, the temporal and regional disaggregation of Europe differs slightly between the two scenarios, which, however, does not affect the overall findings in a significant way. See Box 1 for a more detailed description.

[7] The "Paris" scenario is based on the "societal commitment" scenario developed in the current EU Horizon 2020 project "Open Entrance", see for details (Auer et al. 2020). The project openENTRANCE has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No. 835896. The results shown here do not reflect concrete project output from that project though.

Box 1: The Global Energy System Model (GENeSYS-MOD)

Compliance with climate targets is analyzed using the Global Energy System Model (GENeSYS-MOD). The model is based on the well-established Open Source Energy Modelling System (OSeMOSYS), an open-source software for long-term energy system analyses. OSeMOSYS is continually developed by a number of researchers worldwide in a decentralized manner and is used in countless scientific and policy advisory publications. Based on this model, GENeSYS-MOD was developed for the present analysis. The objective function of the model covers the total cost of providing energy for the electricity, transport, and heating sectors in Europe. The model result is a cost-minimal combination of technologies to fully meet energy demand at all times. Climate targets can be represented by a budget approach or a CO_2 price.

Since the availability of wind and solar energy fluctuates with the weather conditions, a temporal and spatial balance is necessary in order to be able to cover the energy demand at any time. For this purpose, several technologies for storage and sector coupling are implemented in the model. Above all, lithium-ion batteries serve to balance temporal fluctuations in energy supply and demand. In addition, the coupling of the electricity sector with the heating and transport sectors enables them to decarbonize by using electricity from renewable sources. This optimization is carried out throughout the EU-27 countries plus the UK, Norway, Switzerland, Turkey and the Balkan region.

It is possible to exchange fuels and electricity between the regions, but not heat. In order to keep the complexity of the model calculable, aggregation is also carried out on a temporal level. In the course of the analysis, all hours of a year are summarized in 20 time slices, which represent seasonal and daily fluctuations of demand and the availability of renewable energies. The years 2020 to 2050 are considered in integrated five-year steps, assuming full knowledge of future developments in demand, costs and availability of renewable energies. The calculations are mainly based on cost estimates from 2018; however, the results could underestimate the potential of renewables due to unexpected, rapid cost decreases in solar energy. On the other hand, the calculations do not sufficiently consider a part of the integration costs of renewables due to the lower regional and temporal resolution, which leads to some overestimation of the potentials of fluctuating renewables.

Source: Oei et al. (2019, 367).

The chosen scenario is based on the “Societal Commitment” storyline from the “openEN-TRANCE” project. High societal engagement and awareness of the importance to become a low-carbon society characterizes this storyline. Individuals, communities, and the overall public attitude supports strong policy measures to accelerate the energy transformatio. Hence, “green” government initiatives drive and direct ambitious measures in decarbonizing the energy and transport sectors. However, the pathway assumes that no technological breakthroughs occur and there Is lack of major achievements in technology development. The key driver of this storyline is that society as a whole embraces cleaner and smarter life styles with public sector working with and supporting grassroots initiatives.

This storyline mainly describes a prudent society characterized by a sustainable life style and behavioral changes, which includes a significant reduction of energy use for delivering energy and transport services, the implementation of a circular (and partially sharing) economy as well as the exploitation of digitalization potentials to support individual and local service needs. While not all of these characteristics can be translated into an energy system model, the overarching storyline substantially drives the assumptions and parameters of the computations.

2.2 … and bottom-up

The top-down results are translated into hourly load curves to ensure that in the transformed energy system supply can always match demand. The study therefore provides a (soft) model coupling between GENeSYS-MOD and a more detailed model of the European electricity and gas sector created by the anyMOD framework. Within the latter supply and demand for electricity are modeled with an hourly resolution for the entire year (see Box 2 for a more detailed description). The final demand for electricity and synthetic gases from various applications and sectors determined by GENeSYS-MOD serves as an input to this second step. Since the more detailed analysis is limited to the pathway from 2030 and 2040, capacity investment until 2030 is also based on GENeSYS-MOD results. Figure 1 provides an overview of the modelled technologies, energy carriers and how they are connected. In the figure, grey dots correspond to technologies and colored squares to energy carriers. An incoming arrow indicates that an energy carrier is required as an input by the technology. Accordingly, an outgoing arrow means the technology generates the corresponding carrier.

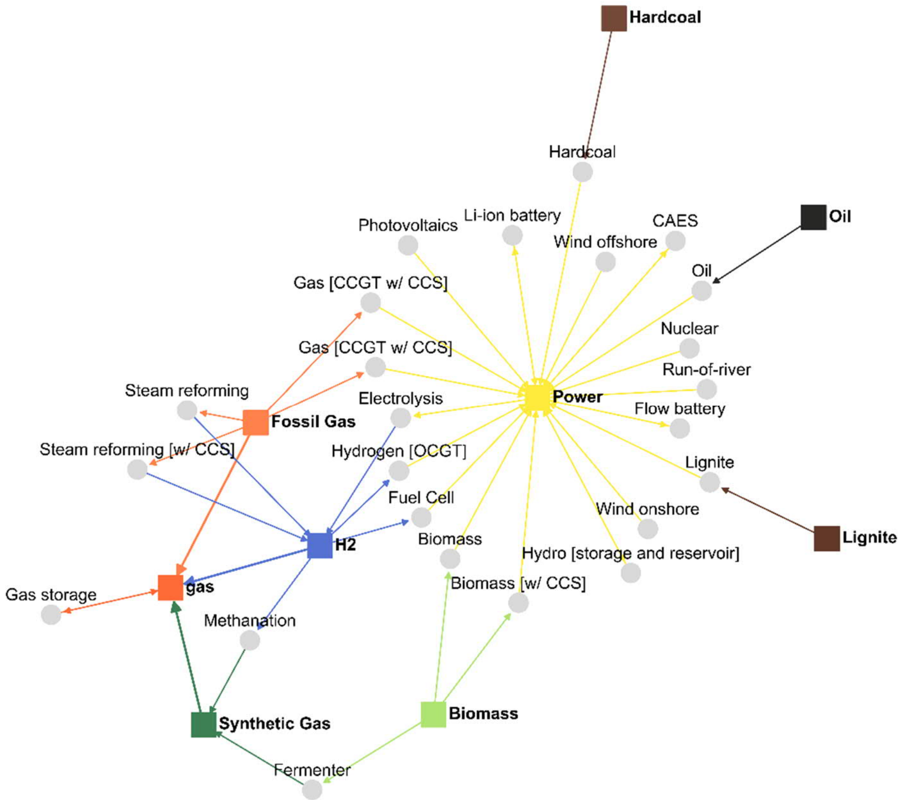

Figure 1: Overview of modelled energy carriers and technologies in the anyMOD framework
Source: Own illustration.

Box 2: The anyMOD modeling framework

The anyMOD framework was developed to address the challenges the challenges of modelling energy systems with high-shares of sectoral integration and intermittent renewables (e.g. wind and solar).[8] In particular, it is aimed at modelling capacity expansion with multiple periods. In contrast to existing tools, the framework pursues a novel approach based on graph theory. Organizing sets in rooted trees enables two features that facilitate modelling systems with high shares of renewables and sector integration:

- The level of temporal and spatial detail can be varied by energy carrier. As a result, model size can be reduced without reducing the level of detail applied to fluctuating renewables. In addition, flexibility inherent to the system can be accounted for.

[8] The development of anyMOD has received funding from the European Union's Horizon 2020 research and innovation program in the OSMOSE project under grant agreement No 773406; the results shown here do not reflect concrete project output from that project though.

- Substitution of energy carriers can be modelled in the respective context: conversion, storage, transport, or demand. This achieves a more comprehensive representation of how technologies and energy carriers can interact in an integrated energy system. In addition, an accurate representation of technological advancement, endogenous decommissioning and internal storage of generated carriers, are been implemented.

anyMOD is freely available here: https://github.com/leonardgoeke/anyMOD.jl. It is implemented in the open source language Julia and can be used with open solvers. To ensure accessibility, anyMOD does not require extensive programming skills and enables model development using version control to facilitate collaboration and increase transparency.

Source: Göke (forthcoming).

2.3 Translation into macro-parameters

The translation of the earlier described storyline into parameters for the energy system model is characterized by the following main features: i) energy service demand across all sectors decreases between 2015 and 2050, being driven by societal awareness and behavioral change (power, buildings, and transportation sector) and policy incentives (industry and transportation sector; ii) society's willingness to invest into the sustainable transformation of the energy system; iii) simulation of the sharing nature of society, especially in the transportation sector; and iv) decreasing fossil fuel prices due to lowered demand which is accompanied by a high carbon price, caused by the widespread recognition of environmental externalities caused by greenhouse gases.

The models are also used to extract additional macroeconomic indicators, such as energy system costs, trade-balance effects from reduced fossil fuel imports, etc. For the emissions pathways, the results are also compared to a "business-as-usual" pathway, with current objectives that are clearly not Paris-compatible. A particular focus is placed on the year 2040, also to reap synergy effects with the ongoing PAC-modeling exercise.[9]

[9] The PAC project – "Paris Agreement Compatible Scenarios for Energy Infrastructure"– has been established to develop a future energy scenario for Europe which is compatible with the Paris Agreement. The scenario, under development by civil society organizations, shall guide European energy infrastructure planning and help to ensure that we are planning and building the infrastructure necessary for a future low carbon, renewables-based energy system, see https://www.pac-scenarios.eu/.

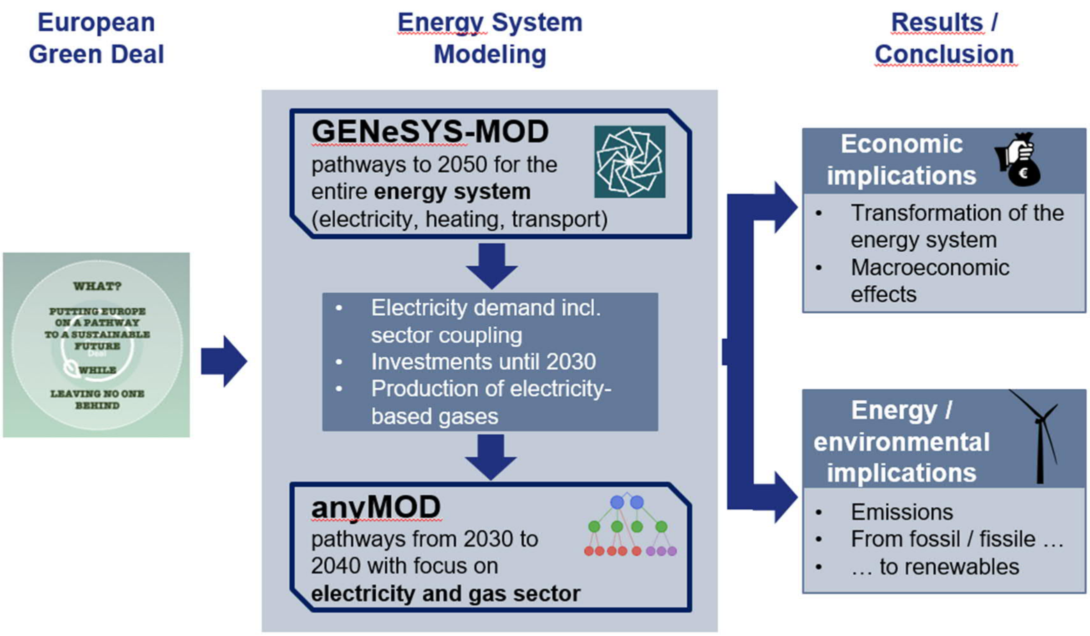

Figure 2: Approach and methodology
Source: Own illustration.

3 Climate neutrality and economic recovery

3.1 Reduced demand, reduced emissions, and enhanced sector coupling

The results of the "Paris" scenario show an ambitious pathway towards the decarbonization of the energy system. Fossil fuels are being phased out at a significant rate and being replaced by renewable generation technologies, mainly being wind and photovoltaics (Figure 3). Therefore, high degrees of electrification are required across all sectors with fuels produced through electricity (e.g. hydrogen, H_2) complementing where direct electric solutions are not available. This leads to an overall reduction of primary energy demand since electricity-based technologies usually offer higher efficiencies than the combustion of fossil fuels. Fossil gas remains as the last fossil energy carrier until as late as 2040, while wind onshore gains significantly in importance in early years and is complemented by increasing amounts of solar photovoltaics. Hydropower and biomass stay relevant across all periods, though their role does not change meaningfully since their potentials are already today almost being completely used.

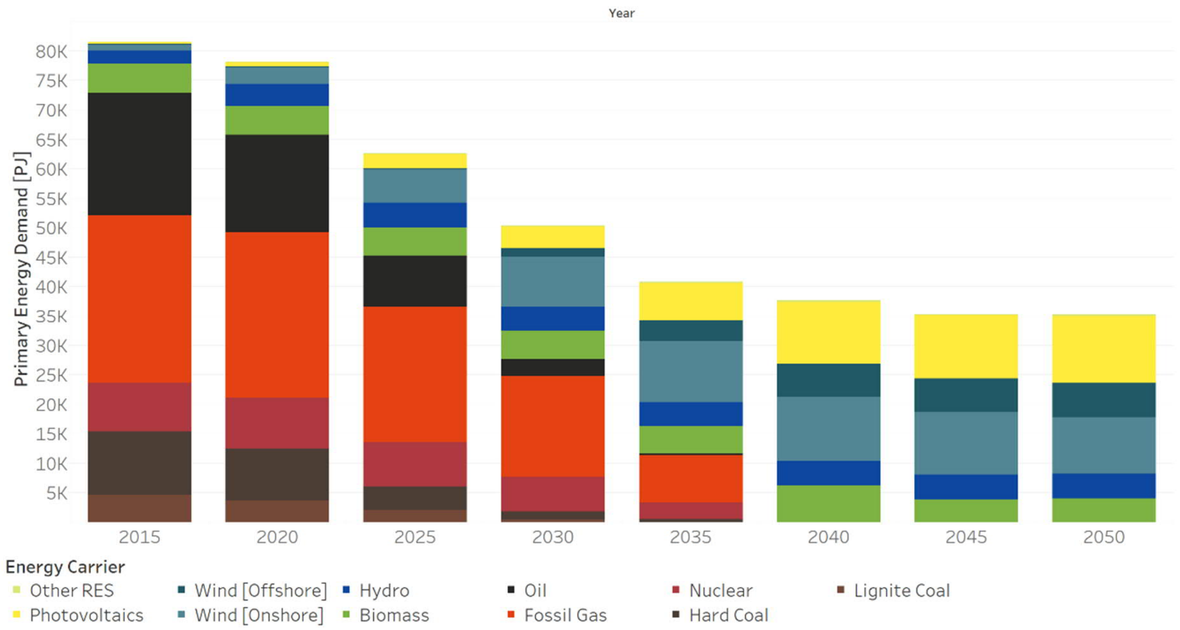

Figure 3: Primary energy demand in Europe in the climate scenario „Paris“ (2015 - 2050)
Source: Own illustration.

As a result of all the previous points, emissions decrease drastically until 2040, with the electricity sector leading the way and being followed by the industry, buildings, and transportation sector (Figure 4).

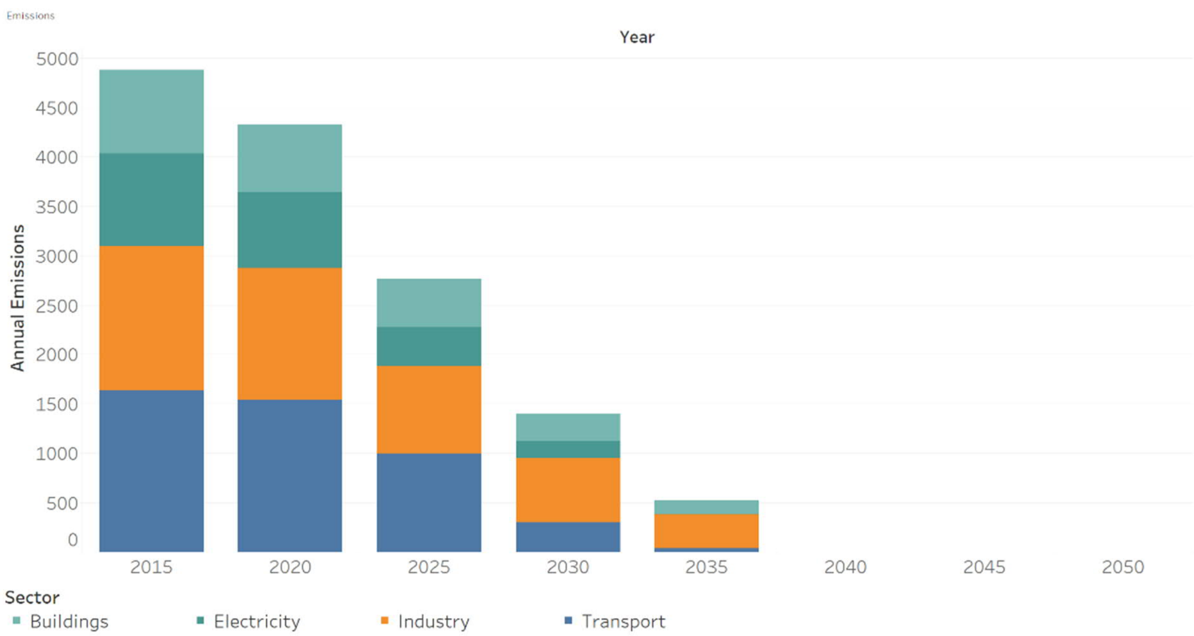

Figure 4: CO_2-emissions in the climate scenario „Paris”
Source: Own illustration.

This high degree of electrification, consequently, leads to significantly higher amounts of electricity required. Especially hydrogen production, which is mainly being produced through electrolysis, and its subsequent combustion or usage in fuel cells consumes high amounts of energy over the entire process and is merely being used in situations where electric technologies are not an option. As a result, electricity production more than doubles until 2040, with wind and solar photovoltaic being the main contributors (Figure 5). Capacity expansions of said technologies increasingly take over starting in 2025, with significant additions of storage capacities being added after 2030. In contrast, no additional fossil generation capacities are required in the process of decarbonizing the energy system and existing ones are being used until their lifetime expires (see Figure 6).

Even though the overall trend of increased electrification and higher amounts of renewable technologies in the power sector are mirrored in the BAU scenario, the effects are not nearly as high as in the "Paris" scenario. As a result, while the increase in electricity production is not as high (about 65% higher in 2050 than in 2015), significant amounts of fossil fuels are present until 2050 in the BAU scenario. In addition, the existence of fossil generation in later periods leads to less need for offshore wind capacities and storages to balance out the fluctuating generation pattern of solar photovoltaic and, to a lesser degree, onshore wind.

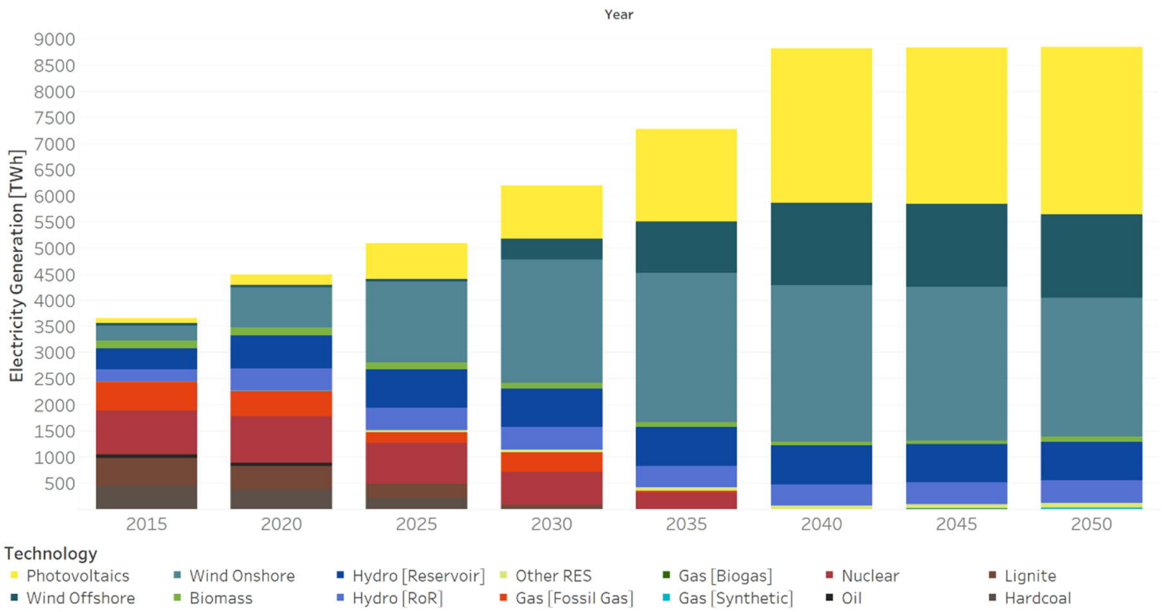

Figure 5: Electricity generation Europe until 2050 (in energy terms)
Source: Own illustration.

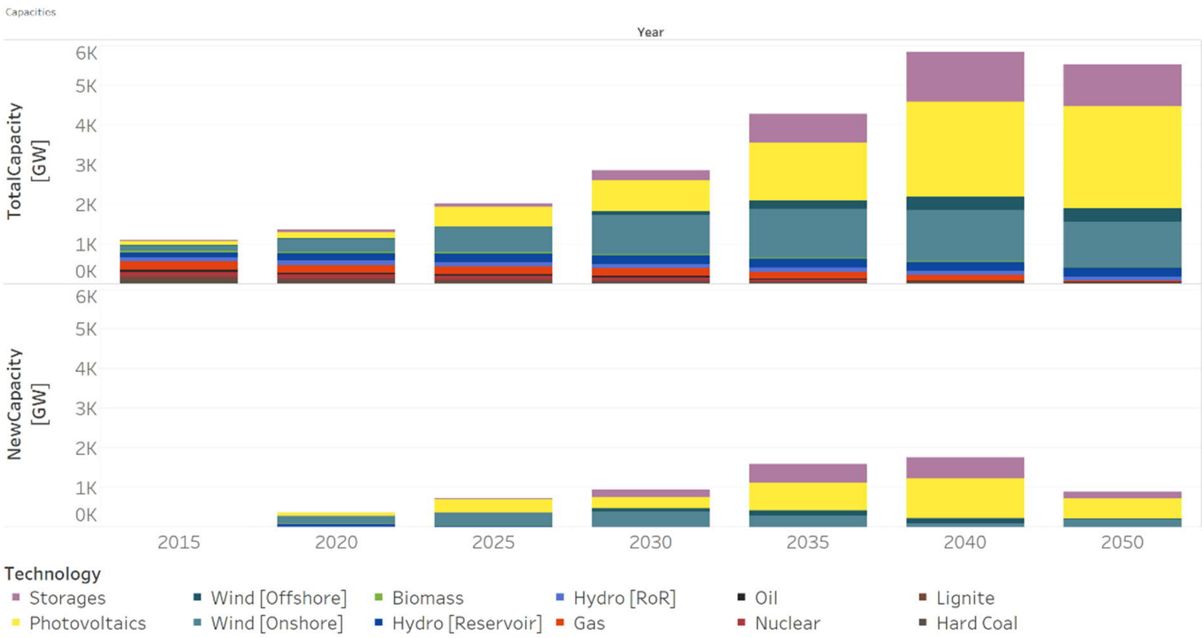

Figure 6: Electricity generation capacities Europe until 2050 (absolute values (above), and period-on-period changes (below)

Source: Own illustration.

In order to decarbonize the industry, building, and transportation sectors, all of which currently heavily rely on fossil fuels, sector coupling and the subsequent electrification of heating and transport technologies play a major role in the “Paris” scenario. In most cases, suitable technologies are already present today and their large scale adoption leads to a shift from fossil fuels to electricity in the respective sectors. Examples are ground- and air-sourced heat pumps in the buildings sector, electric trains, steam boilers in the industrial sector, and, to a lesser degree, battery electric vehicles (BEVs). Therefore, all of the named technologies play important roles in the future energy system, providing clean energy services at affordable costs. In some cases, however, these solutions cannot substitute their fossil counterparts, either because higher temperatures are required in the industrial sector, the location and characteristics of a building do not favor heat pumps, or the required battery size for road freight transportation would reduce the vehicle’s performance. In these cases, hydrogen or biomass and biofuels complement the mentioned direct electric technologies. As a result, across all sectors, fossil gas, coal, and oil are constantly being phased out and replaced by their clean counterparts. The pathways for the different sectors are illustrated from Figure 7 to Figure 10.

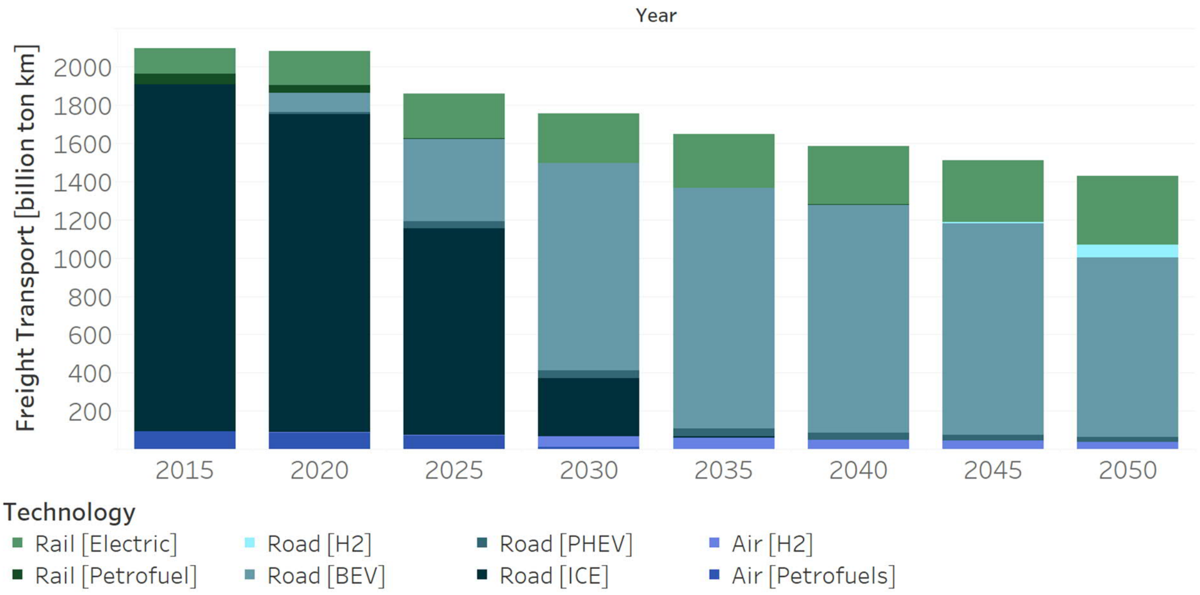

Figure 7: Energy demand for passenger transport (until 2050, by technology and fuel)

Source: Own illustration.

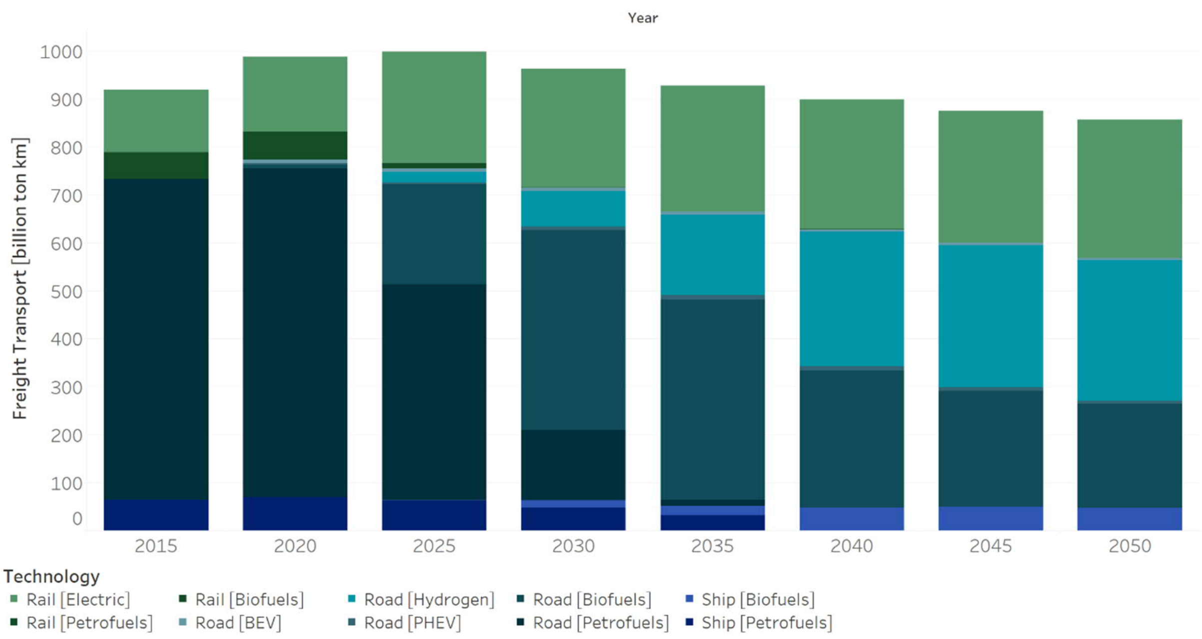

Figure 8: Energy demand for freight transport (until 2050, by technology and fuel)

Source: Own illustration.

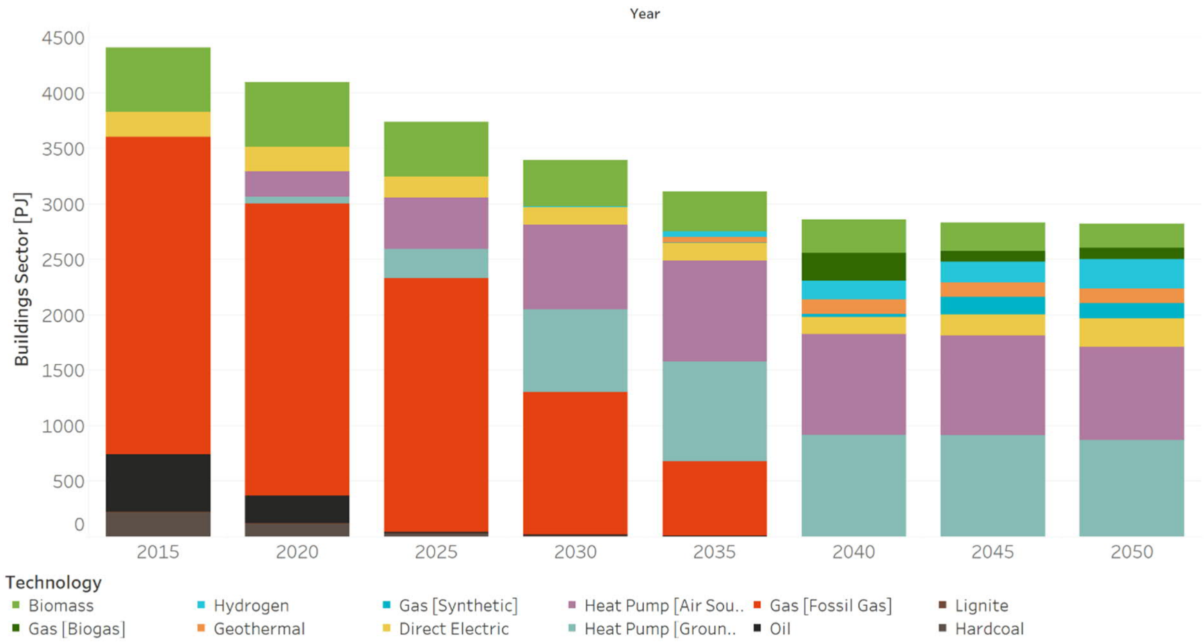

Figure 9: Energy demand for low-temperature heating (until 2050, by technology and fuel)

Source: Own illustration.

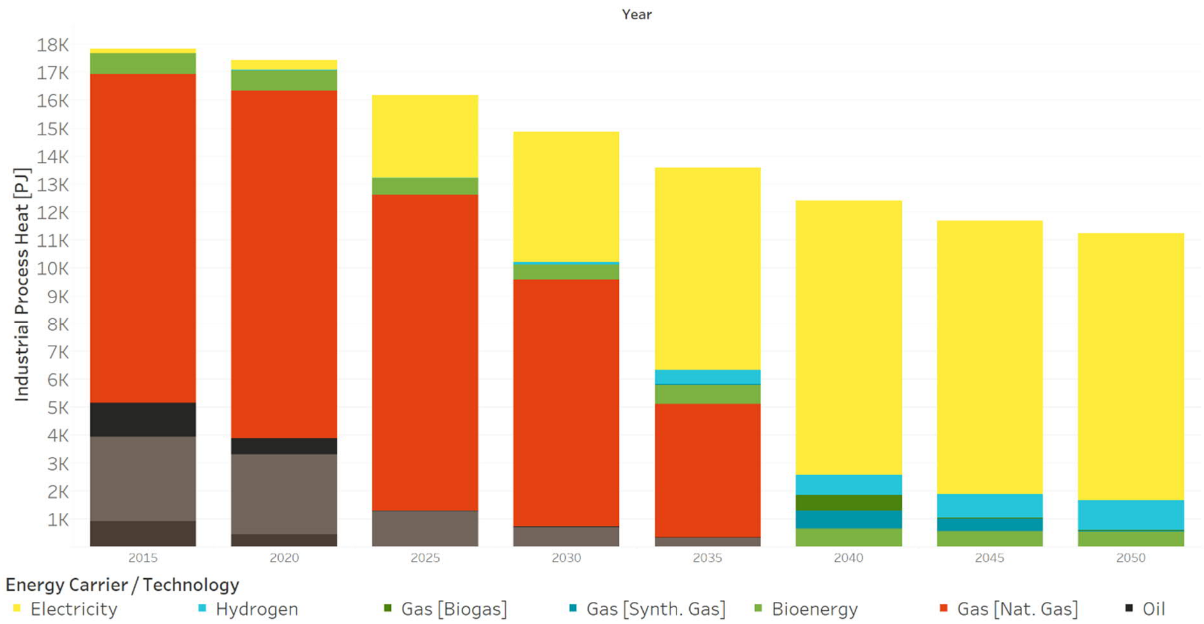

Figure 10: Energy demand for high-temperature heating (until 2050, by technology and fuel)

Source: Own illustration.

3.2 Macro-effects

3.2.1 Protecting the climate is the cheapest option

Apart from the overall configuration of the energy system, a special emphasis has to be put on the emission development during the modeling period. Therefore, the "Paris" scenario is compared to the BAU scenario and complemented by a third scenario (called "Moderate") which was also calculated in the openENTRANCE project. This thirst scenario shows less ambitious targets than the "Paris" scenario and technology, society, and policy related assumptions are less stringent. Figure 11 shows the annual as well as the cumulative emissions for the three different scenarios.

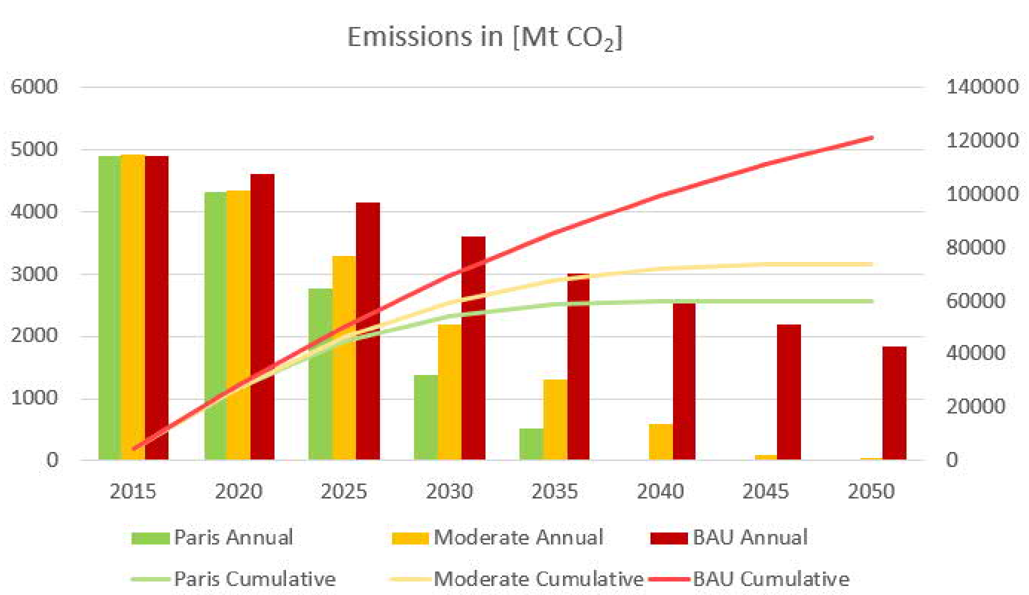

Figure 11: Annual CO_2-emissions (left) and cumulative emissions (right) in the "Paris" scenario, compared to the moderate and the BAU scenario[10]

Source: Own depiction based on Auer et al. (2020) and Oei et al. (2019).

In the BAU scenario, yearly emissions will sink by only approximately 38 percent in comparison to 1990 by 2030. This means that the Paris climate target will not be met, as the cumulative emissions will cause far too much warming by 2050. In the Paris scenario, however, an emission reduction of about 75 percent by 2030 achieves the remaining CO_2 budget set for Europe

[10] Since the BAU scenario included a different set of regions as well as reduced sectoral detail, the values were scaled to the other two scenarios.

to be below the 2° C target. The moderate scenario, while also achieving almost climate neutrality by 2050, surpasses the 2° C target but is still below the BAU scenario by a substantial amount.

As illustrated, pursuing the climate goals leads to a substantial amount of CO_2 reduction until 2050. By 2030 annual emissions in the Paris scenario amount to only 40 percent of the emissions in the BAU scenario. Cumulative, 15 Gt of CO_2 emissions can be avoided until 2030, almost 40 Gt until 2040 and more than 60 Gt until 2050, corresponds to savings in environmental and climate costs of over 10,000 billion euros by 2050, since every ton of CO_2 not emitted causes costs of 180 euros on a global level.[11] Achieving these climate targets would entail additional system costs of 222 billion euros; this corresponds to approximately 3.3 percent of the total energy system costs and is well below the environmental and climate costs avoided. The system costs can increase further due to the integration costs of renewables, which are not included in the model. The analysis also focuses on climate impacts from CO_2 emissions and neglects additional emissions as well as the environmental and health costs of other pollutants (including nitrogen oxides, sulphate dioxide, mercury, and particulate matter) arising from fossil fuel combustion.[12]

Another significant effect of an on renewable generation based energy system is the reduction of imports of fossil fuels from other regions in the world. Comparing the Paris scenario with the BAU scenario, 280 billion euros are saved until 2030 which otherwise would go into fossil resource imports and extraction. This number increases to 1,426 billion euros and 1,859 billion euros until 2040 and 2050, respectively, which significantly reduces the EU's import dependency.

3.2.2 Significant investments in renewables needed

Electricity demand will rise over the next decades as additional electricity demand outstrips the efficiency gains from sector coupling (transport and heating). Coal-powered electricity in

[11] The global environmental, climate, and health costs caused by the emission of carbon dioxide are calculated. Cf. Umweltbundesamt, *Methodenkonvention 3.0 zur Ermittlung von Umweltkosten - Kostensätze Stand 02.2019* (Dessau-Roßlau: 2019) (in German; available online).

[12] Further studies which calculate the pollutant costs of energy production include Sanbag et al., *Last Gasp: The coal companies making Europe sick* (2018) as well as CAN Europe et al., *Europe's Dark Cloud. How coal-burning countries are making their neighbours sick*, (Brussels: 2016).

Europe is declining continuously; gas use is also falling sharply. By 2040, almost all electricity will be generated by a combination of photovoltaics, onshore wind power, and hydropower. This results in high investments into renewable generation capacities, mainly wind (on- and offshore as well as solar photovoltaics) which accumulate to 3202 billion euros until 2040. An additional 183 billion euros are required to build storage capacities which are required to balance out the fluctuating nature of renewable generation. These costs are, however, offset by the very low operating costs of renewable power generation technologies which, in combination with efficiency improvements, make them the superior option compared to fossil alternatives.

4 Energy economic implications

4.1 A climate neutral energy mix

In the following, modelling results presented above are used as a starting point to analysis how decarbonization can be achieved in the gas and more importantly the power sector. Building on the final demand for electricity and gas computed within Section 3.1, a pathway from 2030 to full decarbonization in 2040 is modelled. To account for the intermittency of wind and solar generation, for the power sector an hourly resolution is applied now.[13]

4.1.1 Sector integration increasingly shapes demand for electricity

Since non-electric options to decarbonize the heat and transport sector are limited, a substantial increase in demand for renewable electricity from these sectors can be observed. This is displayed in Figure 12. While conventional demand for electricity slightly decreases, electric heating technologies, in particular for industrial applications, but also for residential heating cause a steep increase in overall demand. E-mobility and production of green hydrogen via electrolysis create additional demand. Hydrogen trading is limited to Europe.

[13] When considering the modelling results, one should be aware that these are solely driven by system costs. This means other solutions that parts of the general public might prefer, for example less wind but more solar capacities, are conceivable, too. Such alternative solutions and the normative questions they imply are beyond scope here and not explicitly discussed, but the trade-offs and adverse effects they come with are briefly picked up on at the end of this Section.

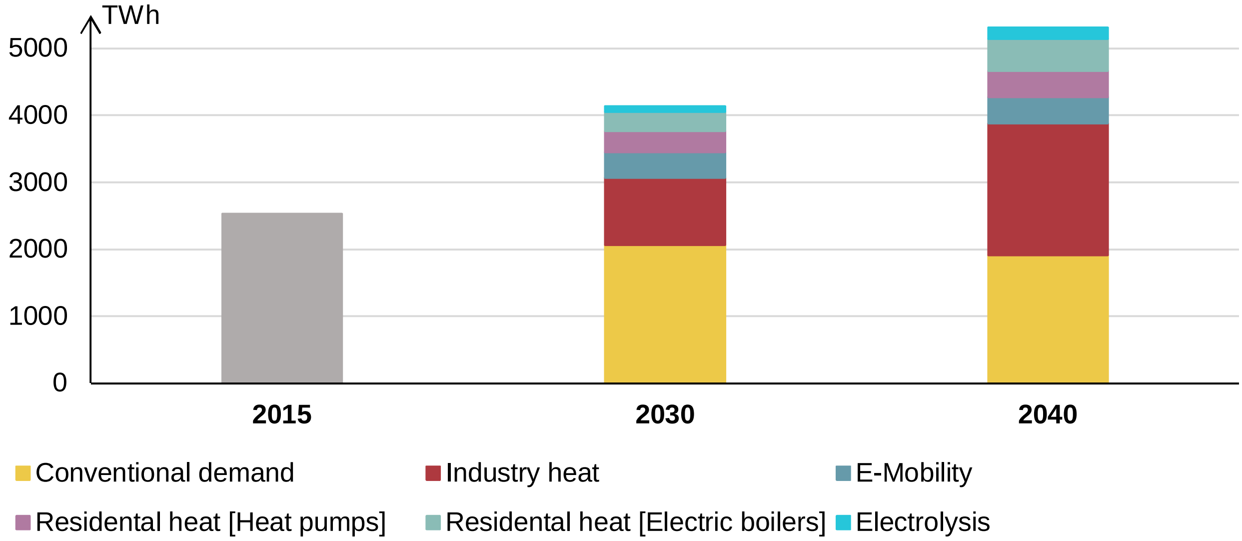

Figure 12: Electricity demand of EU27[14]
Source: Own illustration.

The shifts in demand do not only affect total quantities, but also the shape of the demand curve. For the case of Germany, the average of daily demand in 2040 is plotted in Figure 13. Since heating demands peak during the winter, in additional to the overall increase, seasonal variations become more pronounced.

[14] Excluding Malta and Cyprus.

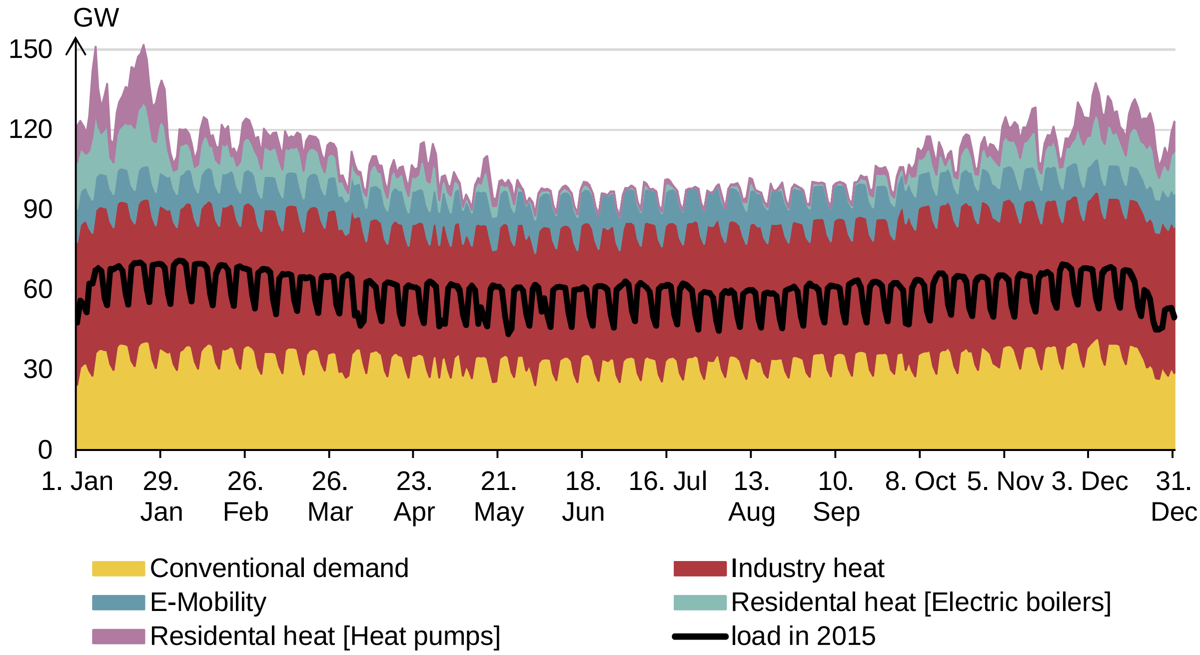

Figure 13: Demand for Germany in 2040
Source: Own illustration.

4.1.2 Transnational exchange enables high shares of wind and solar generation

This change in demand greatly effects the entire system. Providing the corresponding renewable electricity requires extensive expansion of renewable capacities, as displayed in Figure 14. As a comparison, today these capacities roughly amount to 300 GW.

The results show that wind onshore and photovoltaics cover the greatest share of demand. Due to limited potential, run-of-river capacities remain at current levels. Only in 2040 a substantial amount of wind offshore is deployed amounting to 180 GW.

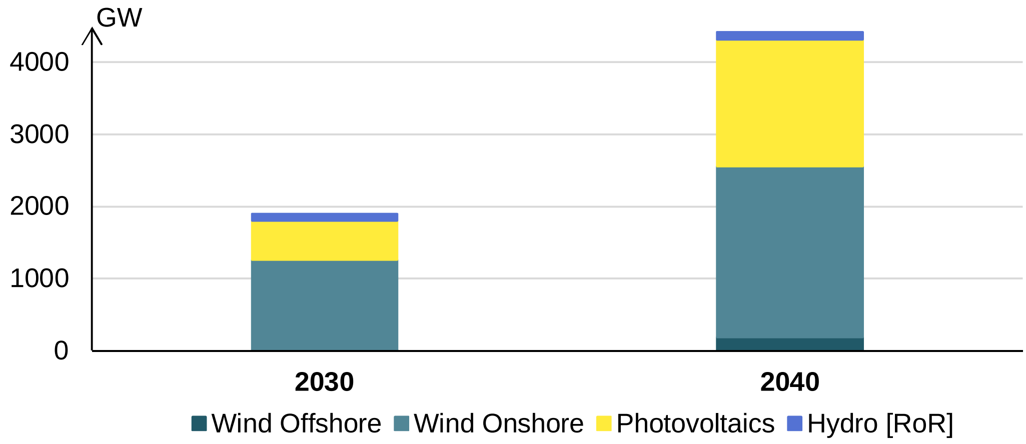

Figure 14: Installed capacities of intermittent renewables in the EU27
Source: Own illustration.

Since renewable electricity is not necessarily demanded where it is generated, modelling includes a stylized representation of electricity exchange. Results suggest that decarbonization does not only require substantial investment into renewable energy itself, but also to strengthen and extend the transnational exchange of electricity within Europe. More detailed modelling is required to deepen the insights into this important topic.

The gas grid and infrastructure are modelled analogously to power, but results are opposed. Although the grid is assumed to equally transport hydrogen, about 90% of today's capacities are decommissioned.

4.1.3 How the flexibility needs of a fully renewable system can be met

While power girds allow to shift generation between regions, storage allows shifting between different periods. Therefore, they are a key option to provide a renewable system with the required flexibility. Figure 15 gives an overview of the most important non-intermittent capacities installed in 2030 and 2040. It is important to note that due to the chosen approach capacities for Lithium Ion batteries are likely to be overestimated. Since demand for electricity from the mobility and heat sector is treated as a fixed input and therefore inflexible, these batteries are heavily used to shift generation within a day. However, if for example electric vehicles are loaded more flexible, demand is shifted instead and battery investment can be reduced. Beside such short-term flexibility, the requirement for seasonal flexibility arising from the seasonal fluctuations of demand outlined in Section 4.1.1 are met by hydrogen turbines fueled with hydrogen created via electrolysis. In addition, electrolysis and methanation provide synthetic fuels to be used outside of the power sector as discussed in section 3.1.

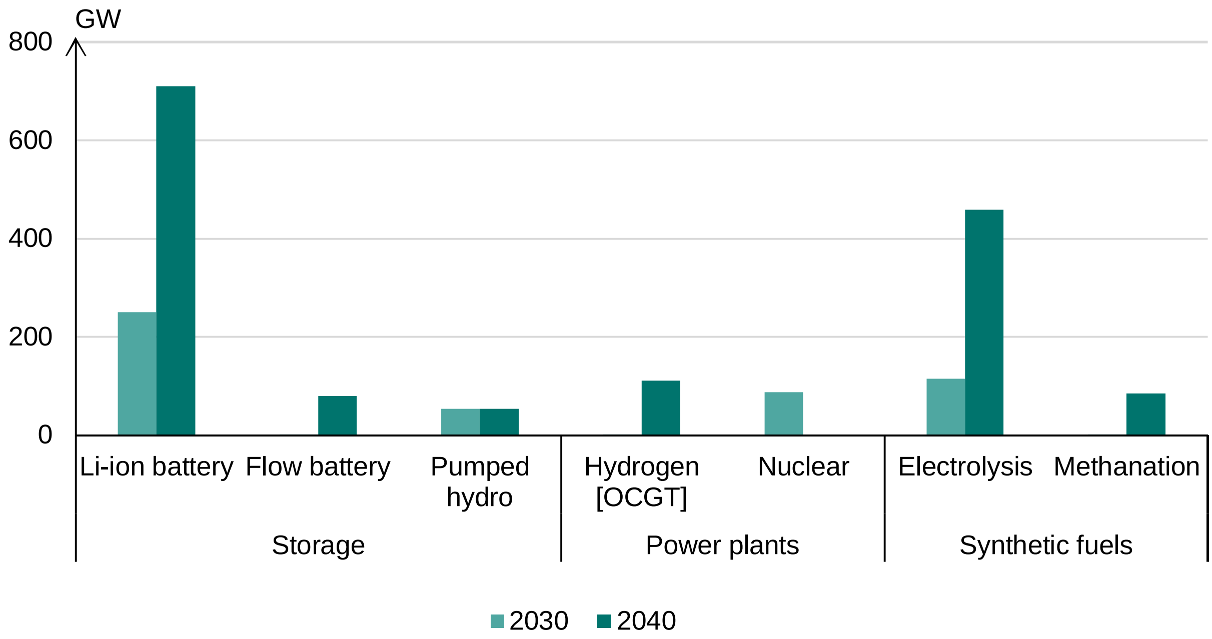

Figure 15: Capacities for non-intermittent technologies in EU27
Source: Own illustration.

4.1.4 Country foci: Hourly dispatch in France and Poland

To provide a better understanding of the interplay between renewables and non-intermittent technologies exemplarily the hourly profile of electricity demand and generation between the 17th and 23th of January, the week demand peaks, are shown next for two important countries, France and Poland.

France

In Figure 16 and Figure 17 generation and demand for electricity in the mentioned week is plotted for France, respectively. A close correlation between photovoltaics and Li-ion batteries that step-in whenever solar generation is low can be observed. Throughout the whole week France is importing electricity. As can be seen in Figure 17, with France being locate in the center of Europe a considerable share of these imports is exported again leading to much smaller net imports. Since demand peaks within the plotted time-frame, storage technologies are mostly discharged during this period.

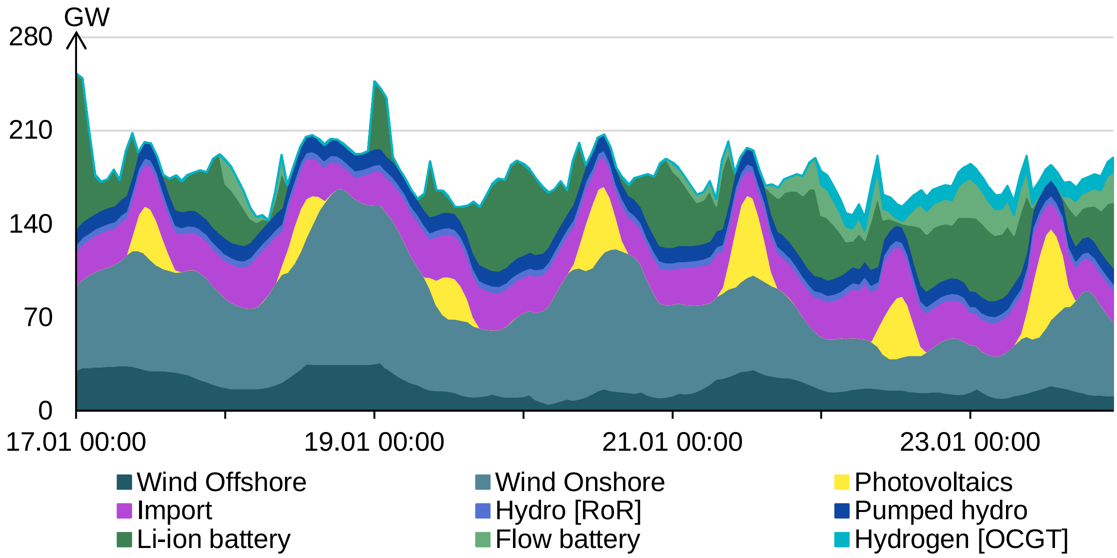

Figure 16: Generation from 17.01 to 23.01 for France in 2040

Source: Own illustration.

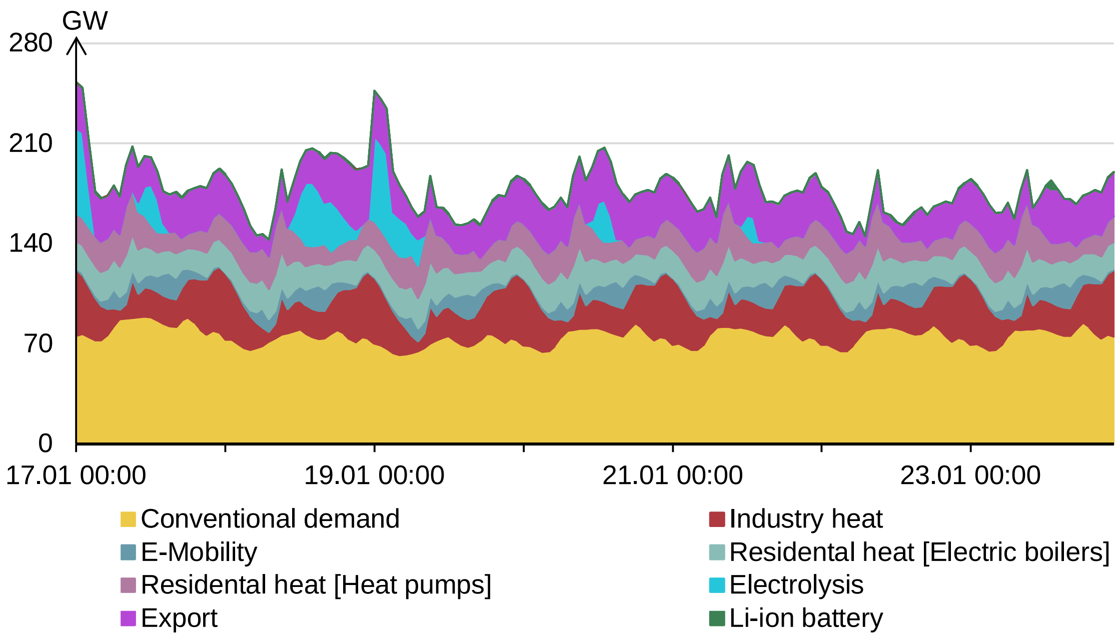

Figure 17: Demand from 17.01 to 23.01 for France in 2040

Source: Own illustration.

Poland

For Poland generation within the same week is displayed in Figure 18. Generally, generation displays pattern similar to France, but towards the end of the week hydrogen fueled turbines need to be used to satisfy demand.

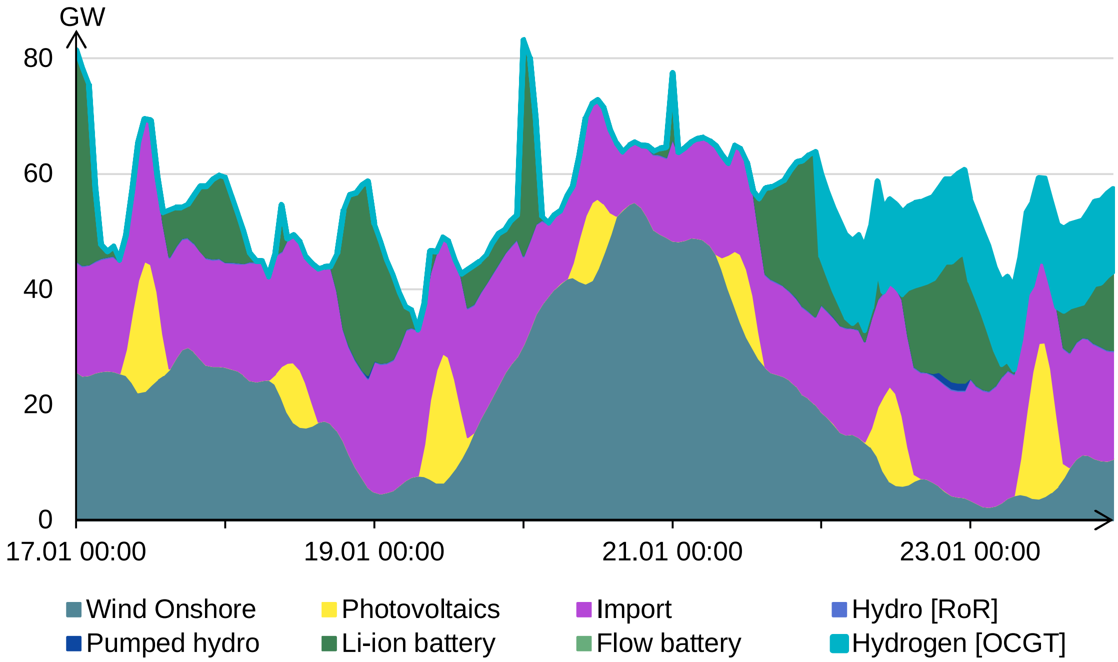

Figure 18: Generation from 17.01 to 23.01 for Poland in 2040
Source: Own illustration.

The renewable system outlined here is only one conceivable option and was derived based on system costs. If, deviating from this, instead of wind solar should provide a greater share of electricity also the flexibility needs of the system change. Since solar generation pre-dominantly occurs during the summer, more generation has to be shifted towards winter via creation and re-fuelling of synthetic fuels like hydrogen. Similarly, increasing the level of exchange between regions will facilitate meeting the electricity demand and is likely to reduce the required investments into batteries and renewable capacities.

4.2 Natural gas exit: From a “clean” to a “dirty” fuel

The model analysis confirms that decarbonizing the European energy system implies the end of fossil fuels. This is quite evident for the case of coal, with almost all EU countries having decided coal exit strategies (see next section). By contrast, this evidence is not yet common sense in the fossil natural gas industry, neither in the fossil oil industry. The above model analysis makes it quite clear that under Paris-compatible climate targets, there will be no sweet spot anymore in the 2040s, neither for coal, nor for fossil natural gas or fossil oil. The transportation sector, traditionally supplied by petrofuels, is able to convert its demand to electricity and some biofuels, plus some hydrogen. Heating, formerly a stronghold for fossil natural gas, can also be converted to renewable-based solutions, with only a very minor share for synthetic fuels.[15]

4.2.1 The old narrative: A "clean" bridge fuel ...

Natural gas has a brief, yet illustrious role in the European energy systems. Synthetic "town gas" had lost its dominant role in lighting to electricity in the late 19th century, and gas was almost completely absent from energy conversion in the first half of the last century. It was only after the discovery of large natural gas fields in the North Seat that natural gas found its way into the energy mix of some European countries, such as the UK, the Netherlands, and Germany, from the 1960s/70s onwards. With the liberalization and completion of the European Single Market, spearheaded by the UK in the 1980s, that natural gas gained a more significant share of the electricity market. Yet, the share of natural gas in European primary energy production and consumption between 1990 and 2016 never exceeded 22.2% (2000) and 25.4% (2010), respectively (in 2017 it was 13.6% and 23.8%, respectively) (Eurostat 2019).

The need for deep decarbonization of the European energy system has for a long time not been identified as an existential threat by the industry. Rather, the European natural gas industry has joined international narratives of a "golden age" of natural gas, as expressed in IEA's (2011) World Energy Outlook, as an integral part of the low-carbon transformation. In a paper that belongs to this past era, Neumann and von Hirschhausen (2015, 3) describe this narrative of natural gas as a "transformation fuel": "Cleaner than coal, more flexible than oil in power generation, it can serve as a backup to renewables", an ideal transformation fuel." Thus, even against the evident decline of natural gas consumption in the EU 27 after 2010, the European Commission's EU reference forecasts continued to be optimistic about European

[15] This section includes material from von Hirschhausen and Praeger (forthcoming).

production and consumption (EC 2013; 2016). The assessment was accompanied by even more optimistic growth perspective by the industry itself, Eurogas.[16]

Consequently, in the EU Reference Scenarios natural gas plays an important role in the energy mix up to 2050, though it is somewhat diminishing over the past exercises. Figure 19 shows the total energy mix in the most recently available and fully documented 2016 Reference Scenario (EC 2016). Even though one observes a slight decrease, natural gas maintains a strong share in the energy mix of the gross inland consumption, from 16,114 PJ (or: 14% of total primary energy production) in 2020 over 15,546 PJ and 15,853 (or: 11% and 8% of total primary energy production) in 2030 and in 2050, respectively.

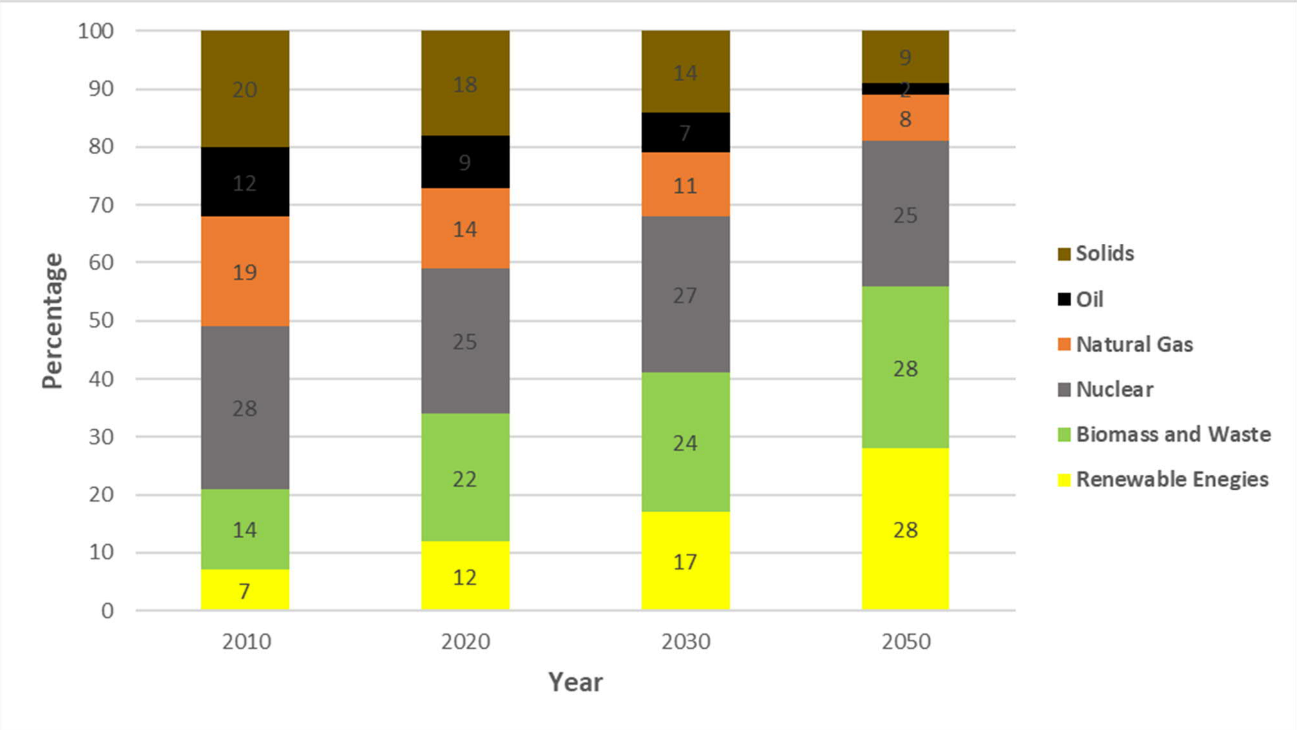

Figure 19: Mix of total primary energy production in the EU Reference Scenario 2016
Source: EC (2016)

4.2.2 ... becomes “dirty” under tight carbon constraints

Environmental groups, such as Muttit et al. (2016) and Stockman et al. (2018) as well as concerned scientists, such as Howarth (2014b; 2015; 2019), Shindell et al. (2009), Nisbet et al. (2019), Hughes (2011), Cremonese and Gusev (2016) and Alvarez (2018) had already identified

[16] See regular forecasts and other publications by Eurogas https://eurogas.org.

the potential danger of large-scale use of natural gas to true decarbonization early on. Yet it has taken professional industry analysts relatively long to come to grips with the incompatibility between strong climate ambition and continued natural gas use. Among the early warning signs about the decline of natural gas in the wake of deep decarbonization, Aoun and Cornot-Gandolphe (2015, 83) suggested that while the industry was looking for the golden age, "the gas market has to deal with a new operating context, dominated by uncertainty over the evolution of supply and demand."

Methane (CH_4), which is emitted directly to the atmosphere trough leakages and vents (upstream and midstream emissions), has a particularly higher damaging effect on the climate than CO_2, as it has the ability to retain heat more effectively in the atmosphere. Methane has different CO_2 equivalents, or global warming potentials (GWP),[17] depending on whether one uses a 20-year perspective, or a 100-year perspective.[18] The IPCC Fourth Assessment Report (AR4) worked with a GWP_{100} of 25 (Strogies and Gniffke 2019, 89), whereas the Fifth Assessment Report" (AR5) (Myhre et al. 2013, 56) raised the values to GWP_{100} of 34, and GWP_{20} of 86 (mainly due to the inclusion of gas-aerosol-interactions.[19] Yet many countries still use the old value in the NDC reports. Current climate policies use the (low) GWP_{100} value. However, if one takes climate change and the corresponding need for decarbonization serious and does not rely on future CO_2-free technologies (such as CCTS, see below), then one has to use the 20-year perspective due to the perturbation lifetime of methane, leading to substantially higher CO_2-equivalents of the methane emissions.

Recent changes in the amounts of methane in the atmosphere are alarming, since the quantity of methane doubled in the time from 2014 to the end of 2018, compared to observed values in 2007 (the start of observing increasing CH_4 levels) (Fletcher and Schaefer 2019). Depending

[17] The global warming approach (GWP) "compares how much larger the integrated global warming from a given mass of methane is over a specified period of time compared to the same mass of carbon dioxide." (Howarth 2014a, 53).

[18] Methane has only a short atmospheric lifetime of about a decade (with a peak after 12 years and over 80% of the effect exhausted after 40 years) whereas CO_2 has an effective influence on atmospheric chemistry for a century or longer (Howarth 2014a, 52). After approximately a decade, methane decays to additional CO_2 in the atmosphere, which is mostly absorbed by the oceans and the terrestrial biosphere but partly remains up to a hundred years as additional CO_2 in the atmosphere and further contributes to the warming of the planet (Lorenzo Cremonese and Alexander Gusev 2016). In addition to global warming, methane also contributes to the formation of ground-level ozone, which has negative health impacts on the human organism and agricultural systems (Drew T. Shindell 2015).

[19] Other publications even suggested a GWP_{20} value of 105: (D. T. Shindell et al. 2009; Hughes 2011; Howarth, Santoro, and Ingraffea 2011).

on the origin of the gas, e.g. shale or conventional natural gas, coal (surface mining, vs. deep mining) and other energy sources, gas turns out to be more climate damaging than both coal and oil in many cases. Howarth (2014a; 2015) provides a range of estimates of the greenhouse gas footprint indicating that taking into account the entire value chain, shale and conventional natural gas have higher CO_2 equivalents per MJ than coal or diesel oil for heat generation and electricity production, respectively. Thus, instead of treating natural gas as clean, it needs to be treated as "dirty".

4.2.3 Methane can not decarbonize …

Can the fossil natural gas industry still be saved, e.g. by referring to other gases as substitute? This narrative of the "decarbonized green gas" is now increasingly adopted and implemented by the gas industry to justify the continuation and expansion of fossil natural gas infrastructure such as fossil natural gas-fired power plants, pipelines and LNG-terminals, and to maintain old, centralized energy supply systems and related business models. The narrative of decarbonizing the fuel itself and step-by-step displacing fossil natural gas by hydrogen-blended or decarbonized gases, while relying on established and existing infrastructure and business models, was established and successfully implemented in pathways strategies for reaching 80-95% GHG reductions or even "climate neutrality".

Such attempts can be observed, among others, in the calculations of the latest dena-study scenarios (dena 2018) for meeting the German climate targets[20], which states by far the highest shares of synthetic methane until 2050. However, when calculating the energy- and processed-based emissions, upstream emissions[21] are not included. Further, the CO_2-factor for imported synthetic fuels is considered as 0 and thus, emissions from synthetic fuels (production and transportation) are outsourced and not included, because they are considered as CO_2-neutral. Even if (not yet existing) direct air capture (DAC) is used for the provision of the CO_2, needed for the methanation, direct methane emissions to the atmosphere from leakages and process-based ventilations will remain. A report by the Energy Watch Group which used updated values for methane emissions from Howarth (2019) has shown that the methane

[20] 80-95% emission reduction in 2050 compared to 1990

[21] E.g. methane emissions from production and transportation threw leaks (both, fossil and synthetic methane).

emissions in the natural gas system have been drastically underestimated and that fossil natural gas does not contribute to climate protection (Traber and Fell 2019).[22] This also implies that the use of methane, whether it is from fossil natural gas or synthetic is not compatible with effective climate protection because upstream- and downstream emissions will remain.

4.2.4 ... and gas has no color

The debate about "decarbonized" gases and their role in the future energy system is often very vague. The reason for this is that there is often no clear distinction between hydrogen, synthetic methane or hydrogen blended fossil natural gas when dealing with the term "green gases". However, the gases differ significantly in terms of both use and production as well as their impact on the climate. Figure 20 shows an overview of energy gases, including their extraction and production. Hydrogen, as the basis for synthetic methane, is produced from fossil hydrocarbons (mainly via steam reformation of natural gas) or by electrolysis of water (with fossil or renewable electricity). Methane, the main component of fossil natural gas, has its origin in natural gas reserves or can be produced by methanation of hydrogen or by the fermentation or gasification of biogenic substances. When the term "green gas" is used by decisions-makers and in future strategies, they mainly consider both, methane and hydrogen, which are synthesized via electrolysis and subsequent methanation with the use of renewable energies and is therefore framed as "green".[23]

Another method with the attempt to decarbonize gas is the so called "blue hydrogen". For this, fossil natural gas is reformed (or thermal cracked in the future) and the resulting CO_2 is (not completely) captured and injected into old offshore gas fields (Steffen Bukold 2020). This process is also known as CCTOS (Carbon Capture, Transport, and Offshore Storage) (Kim et al. 2016; Cumming et al. 2017). The discussion about the "50 shades of gas" is misleading, and often misused to argue for a dominant role for the incumbent natural gas industry. We suggest to refrain from this taxonomy, and to rely on a technical description of the origin and the processes of the gas in question.

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[22] According to the estimates of the Energy Watch Group, three to 4.5 percent of the gas is lost in fracking gas, while other researchers consider a loss of six percent possible. It is only more climate-friendly than coal piles if less than 3.2 percent of the gas escapes.

[23] This two-step procedure is referred as Power-to-Gas (PtG) process (Götz et al. 2016). In a third process, the synthetic gas can be converted to a liquid fuel by Fischer-Tropsch synthesis, known as Power-to-liquid (PtL).

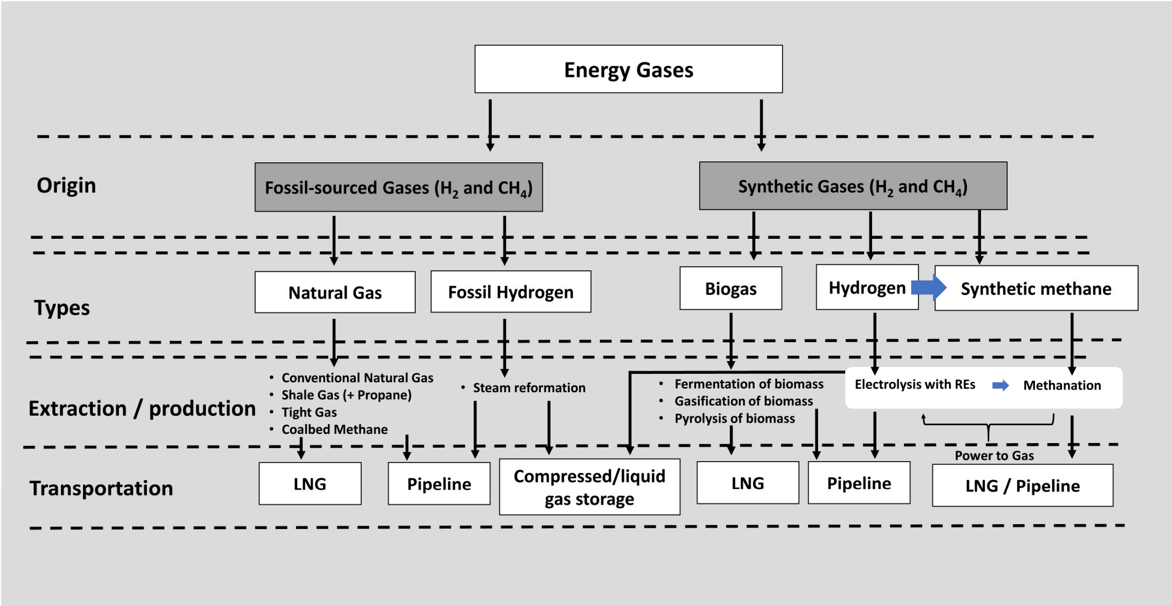

Figure 20: Overview of energy gases
Source: Own illustration

4.2.5 The carbon capture (CCTS) illusion

Carbon capture, transport, and storage (CCTS) is very expensive, not fully carbon free, and offers no technical neither an economic solution to save the fossil gas industry. This assessment is not shared by the industry currently, but needs to enter the EGD discussion on decarbonization. In fact, the CCTS illusion consists of hoping for a technology that is neither technically nor economically available to us. Since the beginning of this century, hopes in CCTS (Carbon Capture Transport and Storage) have been highly traded for the solving of our problems with fossil fuel CO_2 emissions while not making any notable progress in reality. A decade ago, we have identified the first decade of the 21st century as a “lost decade” (von Hirschhausen, Herold, and Oei 2012). This exercise can now be repeated for the second decade of the 21st century: Until today, the step from small-scale pilot projects to large-scale demonstration plants never succeeded.

Table 1 provides an overview of failed CCTS projects in Europe. The failure of the technology is confirmed, world-wide, by regular accounts of unsuccessful projects, e.g. by the Global CCS Institute (GCCSI 2018).

Table 1: (Failed) CCTS projects in Europe

Project	Jänschwalde	Porto-Tolle	ROAD	Belchatow	Compostilla	Don Valley	Killingholm (C-GEN)	Longannet Project	Getica	ULCOS	Green Hydrogen
Country	DE	IT	NL	PL	ES	UK	UK	UK	RO	FR	NL
Technology	Oxyfuel	Post	Post	Post	Oxyfuel	Pre	Pre	Post	Post	Post	Pre
Storage	Aquifer	Aquifer	Oil-/ gasfield	Aquifer	Aquifer	EOR	Aquifer	EOR	Aquifer	Aquifer	EGR
Capacity [MW]	250	250	250	260	320	650	450	330	250	Steel	H_2
Plan in 2011	2015	2015	2015	2015	2015	2015	2015	2015	2015	2016	2016
Status in 2018	canceled 2011	canceled 2014	canceled 2017	canceled 2013	canceled 2013	canceled 2015	canceled 2015	canceled 2011	canceled 2014	canceled 2012	canceled 2012
	White Rose (UK Oxy)	Peel Energy	Peterhead	Teesside (Eston)[24]	Eemshaven	Pegasus	Maritsa	Mongstad	Caledonia Clean Energy[25]	Norway Full Chain CCS	
Country	UK	UK	UK	UK	NL	NL	BG	NO	UK	NO	
Technology	Oxyfuel	Post	Post	Various	Post	Oxyfuel	Post	Post	Post	Various	
Storage	Aquifer	Oil-/ gasfield	Oil-/ gasfield	Aquifer	EOR	Oil-/ gasfield	Aquifer	Aquifer	Aquifer/EOR	Aquifer	
Capacity [MW]	430	400	400	0.8 Mtpa	250	340	120	630	3 Mtpa	1.3 Mtpa	
Plan in 2011	2016	2016	2016	2016	2017	2017	2020	2020	-	-	
Status in 2018	canceled 2016	canceled 2012	canceled 2015	mid 2020s	canceled 2013	canceled 2013	canceled 2013	canceled 2013	2024	2022	

Source: Own illustration.

[24] Power plant with CCTS canceled in 2014, now industrial park collective.
[25] Formerly Captain Clean Energy.

4.3 Nuclear power is expensive and not ”clean“

4.3.1 Nuclear power as the “big elephant” in the EGD

Nuclear power is almost completely absent from the “European Green Deal”, but it is the big elephant in the room with respect to decarbonization. Since the very beginnings of the European Union, nuclear power has been one of the pillars of energy supply. EURATOM, the Agency promoting nuclear power in Europe and internationally, is as old as the European Economic Community (EEC). The Treaty establishing the European Atomic Energy Community signed in Rome in 1957, was intended to promote international cooperation concerning atomic energy as a basis for modernization and industrialization.[26]

Since that time, there is a compromise in the European institutions not to challenge the role of nuclear power in some countries' energy mix. Very roughly speaking, this compromise consists of a “triade”, three pillars that make up the European “low-carbon” energy mix (Mendelevitch et al. 2018):

- A major role for <u>nuclear power</u> in the electricity mix, to cater to the political preferences of the European nuclear powers (UK and France) and some “followers”, mainly in Central and Eastern Europe, e.g. the Czech Republic and Hungary,
- some remaining <u>fossil fuels</u>, mainly to cater to Central and South Eastern countries hanging on to coal and natural gas (biggest importers are Germany, Italy, Netherlands, France and UK) and - in order to justify this - the ex-nihilo introduction of carbon dioxide removal technologies, here concretely carbon capture, transport, and storage (CCTS), in its pure form, and extended to bioenergy (BE-CCTS),
- a certain share of <u>renewable energies</u>, to cater to the ambitions of countries wanting to rely largely on renewable energy sources, such as Denmark and Germany.

The compromise also includes to remain silent about the bad economics, the dangers, and the unresolved issues of the back end of nuclear power, i.e. the decommissioning of nuclear power plants, and the intermediate and long-term storage of radioactive nuclear waste. Thus,

[26] See. Euratom Treaty, http://europa.eu/eu-law/decision- making/treaties/pdf/consolidated_version_of_the_treaty_establishing_the_european_atomic_energy_community/consolidated_version_of_the_treaty_establishing_the_european_atomic_energy_community_en.pdf.

the "Clean Energy Package" (European Commission 2018) - the continuation of the long-term EU climate protection strategy - not only contains significant service life extensions but also recommends building over 100 new nuclear power plants by 2050. As the climate debate is picking up speed, attempts to get nuclear power classified as a "clean" source of energy, e.g. in the taxonomy for sustainable finance, are intensifying.

Hélas, nuclear power is uneconomic, and it is not "clean". Even ignoring the expense of dismantling nuclear power plants and the long-term storage of nuclear waste, nuclear power is uneconomic, and therefore not part of any energy mix for decarbonization. In addition, nuclear power is not "clean", due to radioactivity, which endanger humans and the natural environment for over one million years; it also harbors the high risk of proliferation. In this subsection, we explain the current status and the perspectives of nuclear power in the EU, and why it needs to be part of the EGD debate.[27]

4.3.2 Status Quo

In 2018, nuclear power plants generated around 762 000 GWh or 28 % of the (gross) electricity produced in the EU-27; the by far largest producer in 2018 was France, with a 54.2 % share of the EU, followed by Germany (10.0 %), Sweden (9.0 %) and Spain (7.3 %). These four Member States produced 80.5 % of the total amount of electricity generated in nuclear facilities in the EU-27.[28] The UK, one of the two founding nations of nuclear technology in Europe, also still operates a large number of plants. Figure 21 shows the nuclear share as well as nuclear generation in the EU-28 between 1965 and 2015. Both, the nuclear share and electricity generation from nuclear reactors rose sharply between the 1980s and mid-1990s; the nuclear share peaked in 1997 with a third (33 %) of electricity generation coming from nuclear reactors, while nuclear generation peaked in 2004 with around 1,000 Terrawatt-hours. Since then nuclear production declined by 15 % to 857 TWh in 2015.

In mid-2020, 13 countries use a total of 108 reactors for electricity generation in the EU-27 in 2019 (see Table 2). More than half (57) of the EU reactors are operated in France: The country has by far the largest nuclear share (71 %), followed by (in that order) Slovakia, Hungary, and

[27] This section includes analysis on nuclear power form Wealer (2018), Wealer, et al. (2019), and Wealer, et al. (2020).

[28] Eurostat. 2020. "Nuclear Energy Statistics". https://ec.europa.eu/eurostat/statistics-explained/index.php/Nuclear_energy_statistics#Nuclear_heat_and_gross_electricity_production, 19 May 2020.

Belgium. These four Member States produce nearly half of their electricity production with nuclear sources. A total of nine countries rely around one third on nuclear power.

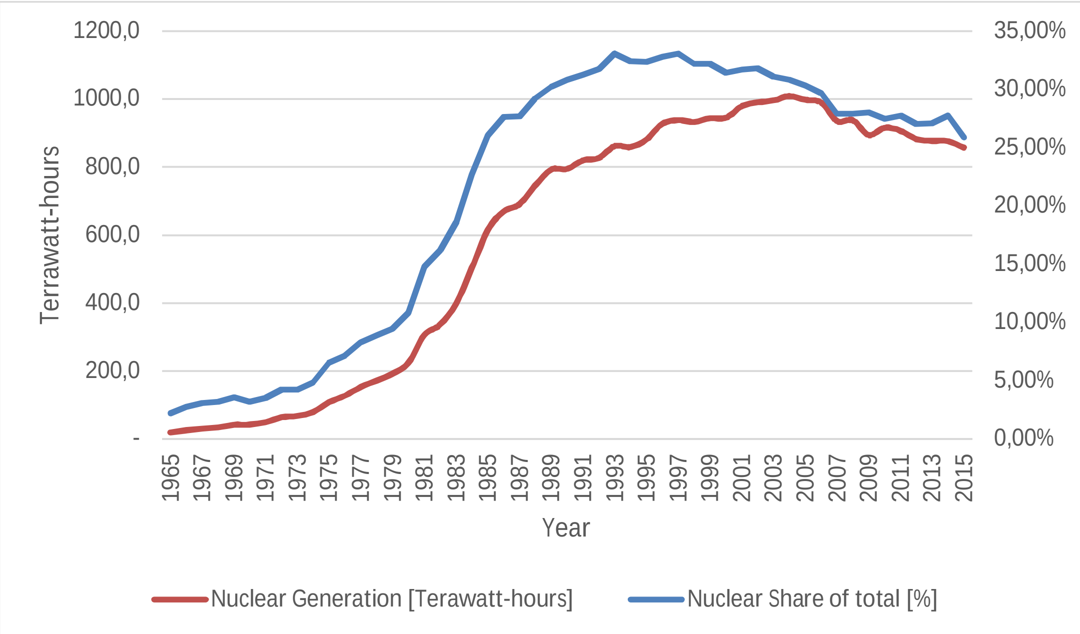

Figure 21: Nuclear generation and nuclear share in the EU-28, 1965-2015.
Source: Own depiction based on World Bank (2019) and BP (2019).

Table 2: Operational nuclear fleet in EU-27 in 2019, ordered by nuclear share

Country	Capacity in GW (NPPs)	Average age of the fleet in years	Nuclear share
France	62.2 GW (57)	35	70.6 %
Slovakia	1.9 GW (4)	28	53.9 %
Hungary	1.9 GW (4)	35	49.2 %
Belgium	5.9 GW (7)	40	47.6 %
Bulgaria	1.9 GW (2)	31	37.5 %
Slovenia	0.7 GW (1)	39	37.0 %
Czech Republic	3.9 GW (6)	29	35.2 %
Finland	2.8 GW (4)	41	34.7 %
Sweden	7.7 GW (7)	39	34.0%
Spain	7.1 GW (7)	35	21.4 %
Romania	1.3 GW (2)	19	18.5 %
Germany	8.1 GW (6)	34	12.4 %
Netherlands	0.5 GW (1)	47	3.2 %
	106 GW (108)	~ 35 years	

Source: Own depiction based on IAEA PRIS Database.

The European nuclear power fleet is outdated. The current reactor fleet in the EU-27 consist of reactors of the second generation, which were designed for 30 to 40 years of operation. As of 2019, the average age of the reactor fleet in the EU-27 was 35 years. Taking 40 years of lifetime into account, the installed power would drop sharply in the next decades (see Figure 22): As early as 2025, installed power would decrease by 50 percent to 54 GW. And ten years later, nuclear energy would feed only around 14 GW into the European grid. The remaining nuclear power plant operators would primarily be located in Eastern Europe: the Czech Republic, Romania, and Slovakia (Wealer et al. 2019).

Currently, there are two countries with ongoing construction projects (France, Flammanville) and Finland (Olkiluoto), and two countries with beginning projects (UK (Hinkley Point C), and Slovakia (Mochovce)). A few other countries are considering the construction, e.g. the Czech Republic and Hungary. Lifetime extensions are discussed, too, mainly in France.

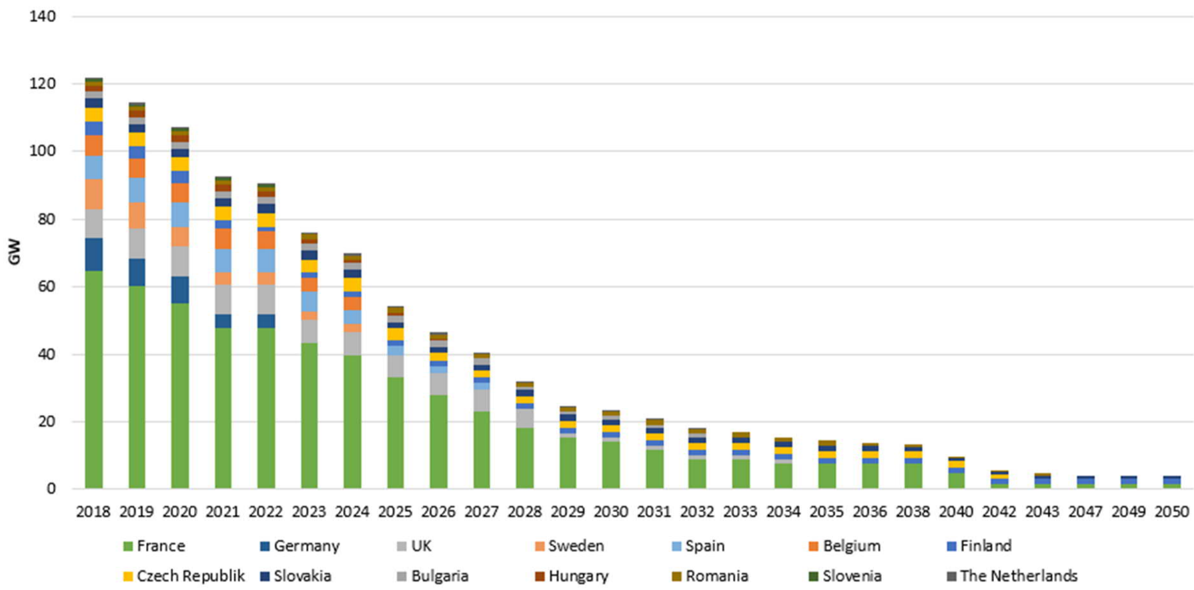

Figure 22: Operational nuclear capacity in the EU-28, 2018-2050
Source: Wealer et al. (2019).[29]

[29] The current shutdown dates of nuclear power plants that were connected to the grid after 1978, and are therefore over 40 years old, were considered. Belgium: Doel-3 in 2022, Tihange-2 in 2023, Doel-1/2/4, and Tihange-1/3 in 2025. Netherlands: Borssele in 2033. Sweden: Ringhals-2 in 2019, Ringhals-1 in 2020. The UK: Hinkley-Point B-2, Hunterston B-1, Hunterston B-2 and Hinkley-Point B-1 in 2023, Hartlepool A-1/2, Heysham A-1/2 in 2024, Dungeness B-1/2 in 2028, Torness-1/2, Heysham B-1/2 in 2030, and Sizewell B in 2035. Finland: Loviisa in 2021. Germany: by 2022 (2019/21/22).

4.3.3 Building new nuclear plants is uneconomic …

When nuclear power for electricity generation was introduced in the late 1950s resp. early 1960s, government, industry, as well as academics were quite enthusiastic that nuclear power would become rapidly economic in the following decade and become the major energy source for electricity generation. However, this wishful thinking abided already in the 1960s, where the costs of nuclear power remained a multi-fold of other conventional generation; this has not changed until today. Two important studies on nuclear power came from the MIT (2003) and the University of Chicago (2004), respectively, both arguing that nuclear power was not cost competitive with other fossil fuels at the time; these studies were regularly updated (MIT 2009; 2018; University of Chicago 2011). Joskow and Parsons (2009), Rothwell (2011) Linares and Conchado (2013) have provided updates, too, with detailed calculations, though confirming the earlier findings. Davis (2012) provides a broad survey of the literature, including own estimates.

Today, conditions for investing into new nuclear plants have further worsened. Economic analyses suggest that investing in nuclear power plants is not profitable, i.e. expected net present values are highly negative, mainly driven by high construction costs, including capital costs, and uncertain and low revenues. Investing in a nuclear power plant today is likely to yield losses of several billion € (Wealer et al. 2020).

The levelized costs of electricity (LCOE) metric is defined as the long-term breakeven price an investor should receive to cover all costs. In other words, given the power output over the technology's lifetime, the LCOE equals the price of electricity in order to break even. Figure 23 shows the model results for the distribution of LCOE: In four representative scenarios, the mean levelized costs are between around 91 USD_{2018}/MWh and 222 USD_{2018}/MWh, about three to five times the cost of solar or wind energy.

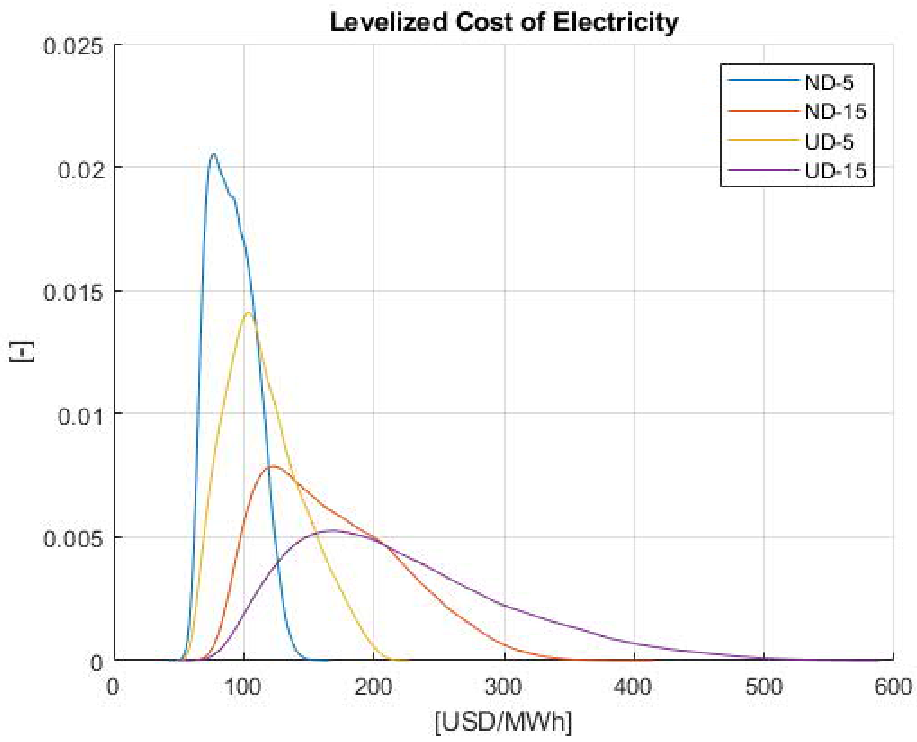

Figure 23: Levelized costs of nuclear power
Source: Wealer et al. (2020, 19).

4.3.4 … and the focus should be on decommissioning and storing nuclear waste

The real challenges of nuclear power today are the decommissioning of closed-down plants, and the safe intermediate and long-term storage of radioactive nuclear waste. With respect to decommissioning, Europe has 103 closed down nuclear reactors, but only five of them have been decommissioned (Schneider et al. 2019, Chapter "Decommissioning Report"). The first nuclear countries, France and the UK, have not yet decommissioned any of their legacy plants. They are making plans to push this problem well into the 22nd century. There are different modes of financing the decommissioning, but all of them are based on vague estimates, and run the risk of underestimating the real costs considerably.

The challenges of nuclear waste are even much higher. As of today, no European country, and no country world-wide, has found a way to store high-level nuclear waste safely for over a million of years (Table 3). Finland is the only country to have started the construction of a deep geological depository, to be finished by the mid-2020s. Recent analysis of the European Commission confirms that managing the radioactive waste will be more costly than initially planned.[30] In 2019, these estimates amounted to € 422 – 566 billion, about €100 billion more than estimated just three years ago.

Table 3: Country programs for repositories for high level waste (2019)

Country	Waste type	Host rock	Site selection status	Underground Research Laboratory	Construction permit	Time frame to repository license
BELGIUM	SNF, HLW, TRU	clay, unconsolidated	appointed	Hades		not scheduled
CANADA	SNF, HLW, TRU	crystalline	deferred*	none		not scheduled
CHINA	HLW, TRU	crystalline, clay	ongoing?	Beishan		not scheduled
CZECH REPUBLIC	HLW	crystalline	1990-2015 (est.)	none		2065 (est.)
FINLAND	SNF	Crystalline	appointed (1985-2000)	Onkalo RF	2018	2024 (est.)
FRANCE	HLW, TRU	clay, consolidated	appointed	Bure, Tournemire	2020 (est.)	not scheduled
GERMANY	SNF, HLW, TRU	salt, clay, Crystalline	2017-2031 (est.)	none		2050 (est.)
HUNGARY	SNF, TRU	clay	1995-2030 (est.)	Pécs		not scheduled
JAPAN	HLW, TRU	crystalline, sediments	2010-2030 (est.)	Honorobe Mizunami, others		not scheduled
THE NETHERLANDS	SNF, HLW	open	deferred	none		storage >100 years
SPAIN	SNF, HLW	salt, clay, Crystalline	deferred	none		not scheduled
SWEDEN	SNF (HLW)	crystalline	appointed (1980s-2009)	Äspö	ongoing (deposited 2011)	not scheduled
SWITZERLAND	SNF, HLW, TRU	clay, consolidated	2008-2030 (est.)	Mont-Terri		2060 (est.)
UNITED KINGDOM	HLW, TRU	not specified, different UK-country policies	2008	none		not scheduled
USA	TRU-wastes	salt	appointed (1972-1988)	none	repository in operation (1998/2000)	
	SNF, HLW	tuff (other)	deferred	none		not scheduled

Source: Own compilation based on official country reports
Notes: *on voluntary basis. est. = estimated; HLW = high-level waste; SNF = spent nuclear fuel; TRU = transuranic waste

Source: Besnard et al. (2019).

30 https://ec.europa.eu/transparency/regdoc/rep/1/2019/EN/COM-2019-632-F1-EN-MAIN-PART-1.PDF.

5 Solidarity required: Just transition

5.1 Burden sharing among member states

The tightening of the EU climate protection targets within the framework of the Green Deal has different effects on individual member states which must be taken into account in managing the upcoming transition. The model results for individual member states can be seen in Figure 24. They show a country-specific generation mix for 2020, with still high shares of fossil fuels and nuclear power, which shifts to 100% renewables by 2040. It is clear that countries with a high initial fossil and/or fissile (nuclear) endowment are hit particularly hard. Further factors to consider are the economic strength or weakness and the level of historical emissions of regions. Country-specific measures and transfer schemes are therefore needed, complementing the uniform CO_2 price for all countries within the European Emission Trading System (ETS).

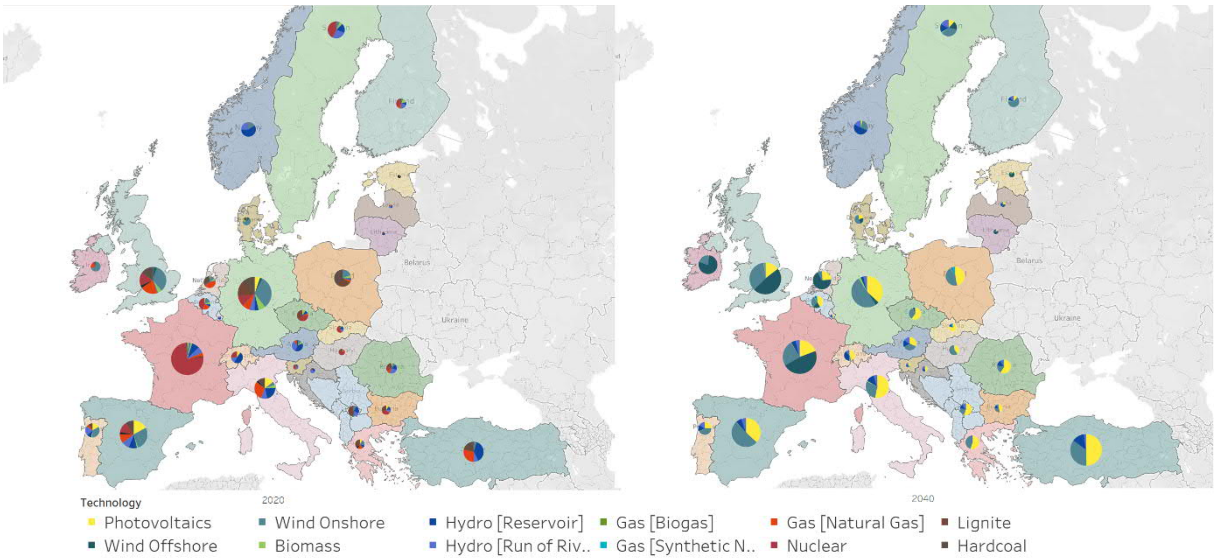

Figure 24: Change of generation mix in Europe by country from 2020 (left) to 2040 (right)
Source: Own illustration.

Recent news - such as announcements by Greece, currently still dependent on coal, to phase it out by 2028 - shows that the necessary energy transformation can be successful.[31] Greece joins a rising number of European countries that have decided upon a coal phase out before 2030, as can be seen in Figure 25: The figure displays the year when a coal phase-out decision was taken (upper left figure) as well as the aimed at phase-out year (upper right figure). Taking into consideration the remaining share of coal in that year, an annual reduction until the phase-out can be calculated within each country (bottom left figure). These relative reductions of coal, however, underestimate the challenges for countries with big remaining coal fleets, such as Greece, Germany or Spain. The bottom right figure therefore also includes the relative reduction of electricity being produced by coal (e.g. for Germany reducing the share of ~40% electricity by coal within 20 years amounts to a 2% annual reduction). A just transition also for these regions can benefit from lessons learned of past transitions which will be analyzed in more detail in the following sub-sections.

[31] Cf. Svetlana Jovanovic, "Greece seeks to phase out coal by 2028, Ptloemaida V prospects unclear," *Balkan Green Energy News* (2019) (available online).

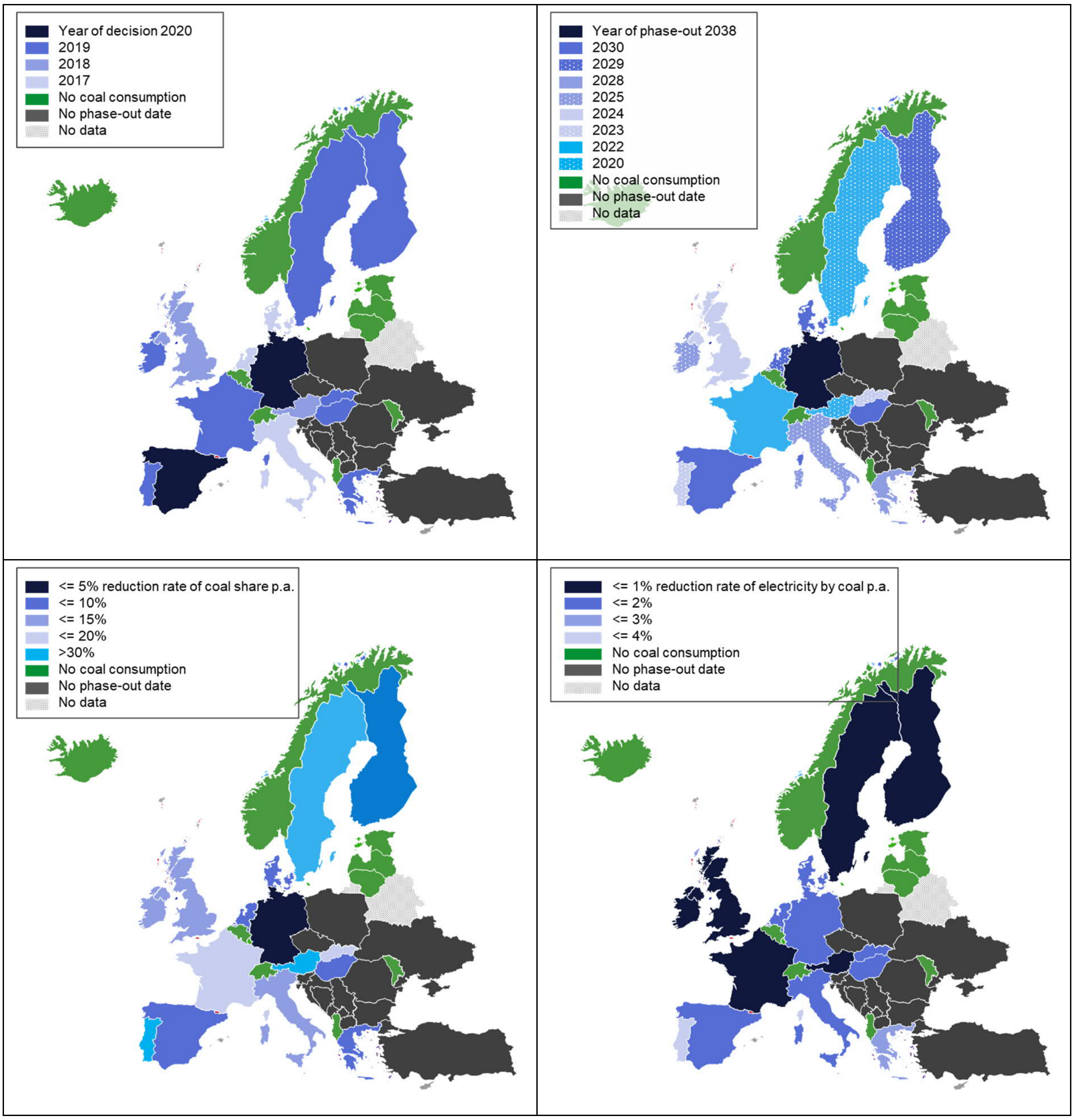

Figure 25: Ongoing plans for a European coal phase-out

Source: Own illustration.

5.2 The ongoing example of a coal-phase out in Germany

5.2.1 50 years of restructuring

The Ruhr and Saarland experienced a 50-year-long, predominantly economically driven decline of their coal industries. Since 1960, many different structural and societal policy measures at the national and state levels were sought to regulate – typically to slow down –

the rate of necessary structural changes. The decision that most prolonged German hard coal production was to support the mining companies with public subsidies. It also meant that none of the former workers were left behind, thus securing a claim for a just and in-time transition. On the other hand, insufficient measures were taken for the creation of new potential for upcoming generations and more sustainable industries. Further, the shift to imported hard coal for power plants ignored the global climate, social, and environmental effects of burning coal. In this respect, the hard coal mining phase-out in both regions failed to achieve a just and in-time transition. Nevertheless, this analysis provides some transferable lessons on how regional resistance and structural change can be addressed in the future. (Oei, Brauers, and Herpich 2019)

The main lessons of the two case studies with resulting recommendations are:

- Refrain from subsidizing the coal industry: Instead, the formal and informal political influence of the coal companies must be weakened in order to overcome the lock-ins, thus enabling economic reorientation. Currently, G20 states are still spending around US$39 billion on coal production each year (Climate Transparency 2019); in line with the PPCA commitments, these should be abolished.
- Take into account long-term effects and impacts beyond the local communities in decision making: The aim of leaving no one behind was not fully met, as future generations within the region as well as international actors (to account for climate and environmental justice effects along the entire value chain) were not included in the transition's decision making processes.
- Listen to external independent advice in addition to the incumbent coal regime: An earlier phase-out, as recommended by academics, would have been less expensive, caused less environmental devastation, and most likely resulted in a faster recovery of the regions.
- Diversification can minimize the risk as no "silver bullet" exists: It is difficult to attract and predict the success of new industries. The Saarland was more successful earlier on; however, its new dependence on the automotive industry creates the next threat. In contrast, the Ruhr economy transformed slower but is now more diversified.

- Participation enables locally adapted solutions and higher acceptance: The involvement of local stakeholders is important for identifying strengths and weaknesses of the regions in terms of adjusting, developing, and implementing local strategies.
- Encourage cooperation through crossing borders: Appropriate structures must be created to enable a joint post-carbon strategy for entire mining regions, independent from administrative federal or national borders. Political institutions focused on social, labor, spatial, and energy planning must combine efforts, facilitating the establishment of an integrated, coherent policy mix.

The two cases examined involve relatively wealthy, old, industrial regions in a central European location, with relatively high population densities and proximity to supra-regional conurbations. This is a major advantage for the promotion of projects and the establishment of companies, which does not apply to all mining regions. The transition of both regions is not solely attributable to declining coal production; the diminishing importance of the steel industry also played a role. (Oei, Brauers, and Herpich 2019)

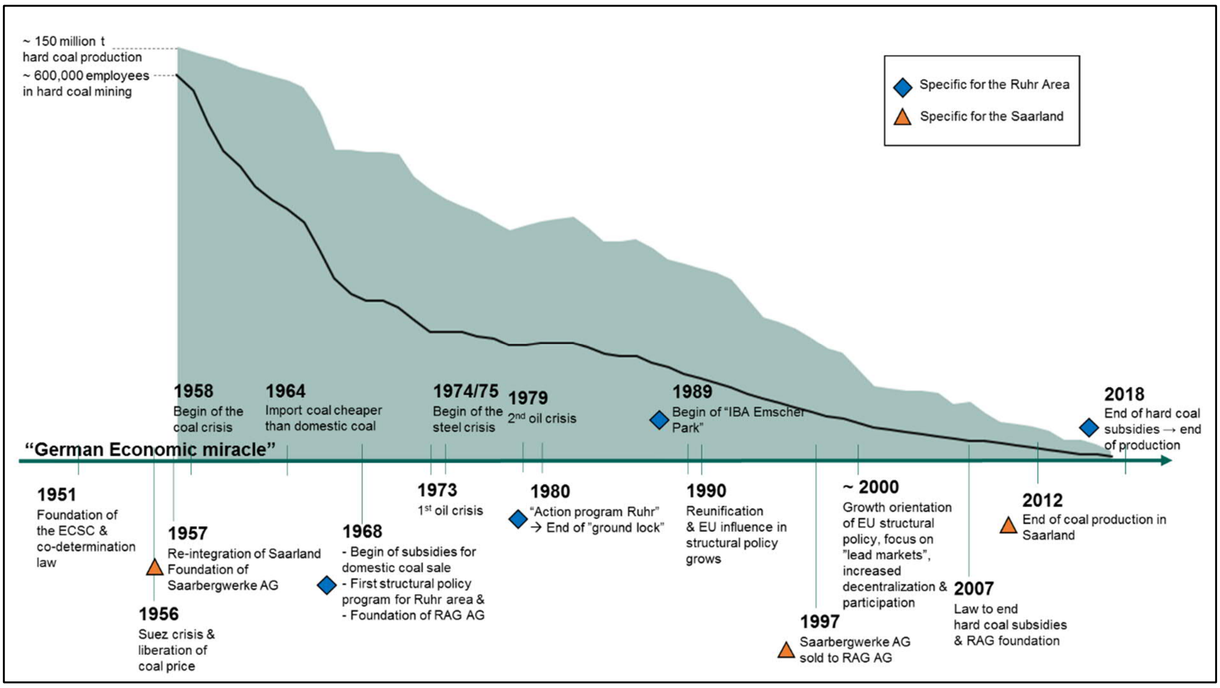

Figure 26: The phase-out of hard coal mining in Germany
Source: Oei, Brauers, and Herpich (2019).

5.2.2 Remaining issues

Apart from the hard coal phase-out which is mostly terminated, also challenges remain for Germany's lignite regions: When comparing the two biggest remaining lignite regions in Germany, it becomes eminent that the challenges for the Rhineland and Lusatia differ a lot – also due to their different evolvement in the past. For Lusatia, the upcoming coal phase-out is going to be the second major externally imposed transition within a much shorter period. This makes the situation more difficult economically and emotionally, especially since a considerable part of the population is going to have experienced both transitions. It is therefore even more important to manage the coal phase-out in a structured and just way in order to minimize the impacts on the affected population. By learning from previous energy transitions and considering resource peaks and the risks of climate change, future transitions may be achieved in a much faster and more coordinated way.

The phase-out date of 2035-2038 suggested by the German coal commission in its final report lays down a timeframe of 20 years to manage the coal phase-out. The commission acknowledges the need for measures to support the structural change in the lignite regions, suggesting measures to improve infrastructure, research and development, and the expansion of renewable energies. In order to finance these measures, the regions are going to receive a total amount of 40 billion € over the next 20 years from the federal budget. If deployed in a sensible way, these funds can be a chance towards a sustainable structural change and a just transition within the regions. Therefore, the commission's recommendations need to be swiftly transposed into federal law, as scheduled, in order to create planning certainty for the regions and prevent them from maladaptation to dysfunctional circumstances. In order to efficiently allocate the funds and measures in the Structural Enhancement Act, the differences between the two regions should be considered, keeping in mind the increased difficulties that Lusatia faces compared to the Rhineland. Among the most important measures, especially in the structurally weak region of Lusatia, are the expansion of digital and transportation infrastructure as well as the promotion of research and development and the improvement of soft location factors. In both regions, the structural support should be deployed towards the fostering of innovation in order to be as adaptable as possible and well equipped to handle future disturbances. (Stognief et al. 2019; Oei et al. 2020)

5.3 Lessons learned from the decline of "king coal" in the UK

The UK is one of the few European states where coal played an important role in the energy sector, but which nevertheless announced a coal phase-out by 2025 already in 2015 and is a founding member of the Powering Past Coal Alliance.[32] Coal's share in the electricity mix declined from 80% in the 1980's to 40% in 2012 reaching 2% in 2019.[33] When coal mining became uneconomic, state support was withdrawn in the 1980's, other than for example in Germany (Oei, Brauers, and Herpich 2019). The resistance of miners to close mines was oppressed – not for climate but other political reasons. Having to import coal lowered opposition to reducing coal's importance in the power sector in the following decades.

A focus on environmental protection and climate change by the government during the 2000s led to the implementation of crucial policies like the Carbon Price Floor (CPF) and the Emissions Trading Scheme (EPS). Together with EU emission reduction targets the policies weakened the coal industry's business. The EPS prevented new coal-fired power plants from being built, the CPF made electricity generation by coal less competitive and air pollution regulations forced older power plants to be closed. This coincided with a point in time when due to the age of coal-fired power plants a decision between either major investments or a shutdown was necessary. The policies incentivized incumbents to change their strategy, and to invest in renewables, and natural gas projects instead of further holding on to coal being their main business model. Another driving force were NGO campaigns influencing public opinion on climate change, which facilitated a competition between parties for 'green' policies and the implementation of the aforementioned policy instruments.

[32] Boris Johnson announced in early 2020 to move the coal phase-out forward to 2024.

[33] Department for Business, Energy & Industrial Strategy. 2018. „Historical coal data: coal production, availability and consumption". https://www.gov.uk/government/statistical-data-sets/historical-coal-data-coal-production-availability-and-consumption; ———. 2019. „Supply and Consumption of Coal". www.gov.uk. 2019. https://www.gov.uk/government/statistics/solid-fuels-and-derived-gases-chapter-2-digest-of-united-kingdom-energy-statistics-dukes.

Several lessons can be learned from the UK case study:

- Supporting renewables is not enough to achieve climate targets aiming at GHG neutrality. The UK partly shifted from coal to gas.
- Opportunities for change exist whenever larger investment decisions for plants or mines need to be taken. Enforcing stringent climate and environmental regulation for new investments, as done in the UK, can prevent stranded investments. Missing such points in time can lead to ongoing legal debates regarding potential compensation payments, as currently being discussed in Germany.
- Weakening the existing coal regime as well as showing them alternative business models enables change.
- Phasing-out coal is not only about the replacement of coal with renewable energies within the energy system. For coal mining countries, such as the UK and Germany, the biggest challenge actually lies within the needed adjustments for the mostly regional dependent economies (Stognief et al. 2019).

5.4 Overall lessons learned from the past

Some overarching policy recommendations to be drawn from these past experiences show that supporting renewable energies is not sufficient to enable a coal phase-out in line with (inter-) national climate targets. This is depicted in the struggle of the German government to implement the agreement of the coal commission. The result becomes visible in the achieved compromise which is not even in line with the Paris Agreement, nor Germany's climate targets and slower than citizens' preferences (Rinscheid and Wüstenhagen 2019). A main reason for this were successful continuing opposition of incumbents – while the UK somehow managed to foster a more rapid phase-out (see Figure 27). That supporting renewables is not enough to achieve climate targets aiming at GHG neutrality is also visible in the UK partly shifting from coal to gas. Other countries, e.g. Poland, on the other hand have barely started the discussion upon coal. Table 4 therefore displays the different economic and socio-political environments of the coal regimes in the UK, Germany and Poland as well as their responses which explain the different outcomes.

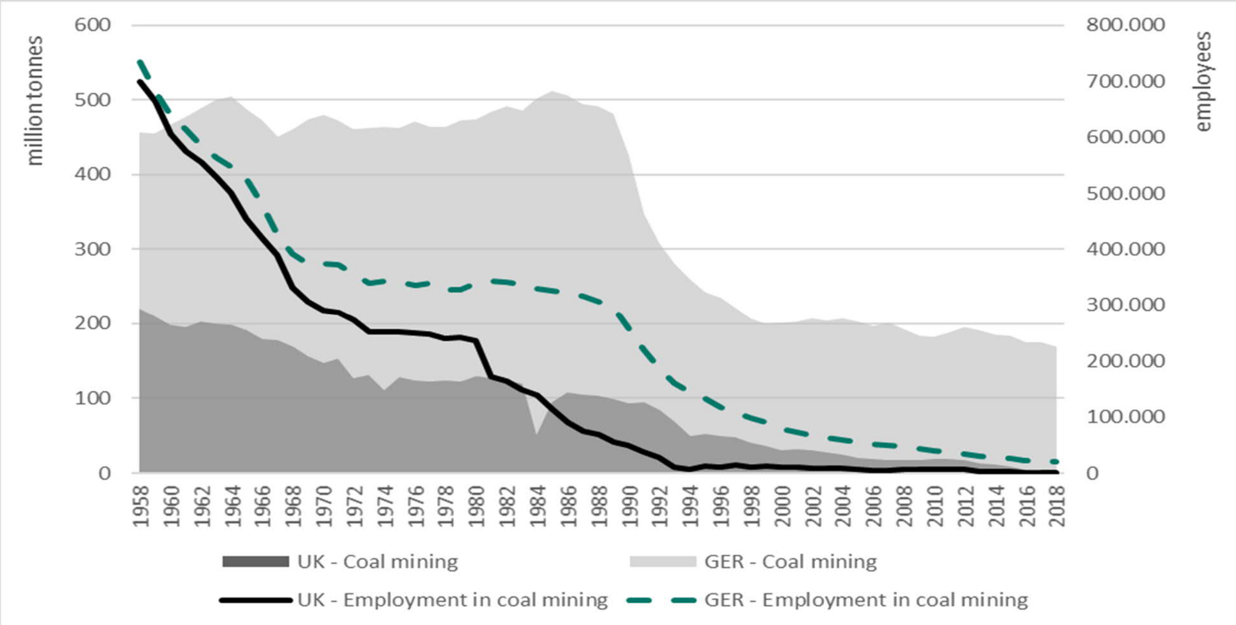

Figure 27: Coal mining and number of direct employees in the UK and Germany from 1957-2018[34]

Source: Own illustration.

Weakening the existing coal regime as well as showing them alternative business models enables change. Margaret Thatcher's political actions reduced the influence of the unions, but also resulted in other negative socio-economic consequences for mining regions still visible today. In Germany, the entrance of new renewable energy actors reduced profits for the incumbents and consequently forced their strategic reorientation.

Opportunities for change exist whenever larger investment decisions for plants or mines need to be taken. Enforcing stringent climate and environmental regulation for new investments, as done in the UK, can prevent stranded investments. Missing such points in time can lead to

[34] Sources: Own depiction based on Department for Business, Energy & Industrial Strategy. 2018. „Historical coal data: coal production, availability and consumption". https://www.gov.uk/government/statistical-data-sets/historical-coal-data-coal-production-availability-and-consumption; ———. 2019. „Supply and Consumption of Coal". www.gov.uk. 2019. https://www.gov.uk/government/statistics/solid-fuels-and-derived-gases-chapter-2-digest-of-united-kingdom-energy-statistics-dukes; Statistik der Kohlenwirtschaft e.V. 2018a. „Braunkohle im Überblick". Statistik der Kohlenwirtschaft. 2018. https://kohlenstatistik.de/; ———. 2018b. „Datenangebot Statistik der Kohlenwirtschaft". 2018. https://kohlenstatistik.de/4-0-Download.html; ———. 2019a. „Beschäftigte der Braunkohlenindustrie in Deutschland". https://kohlenstatistik.de/wp-content/uploads/2019/10/B-11-19.pdf; ———. 2019b. „Steinkohle". Statistik der Kohlenwirtschaft. 2019. https://kohlenstatistik.de/downloads/steinkohle/, DIW Berlin et al. (2018) and own calculations.

ongoing legal debates regarding potential compensation payments, as currently being discussed in Germany.

Phasing-out coal is not only about the replacement of coal with renewable energies within the energy system. For coal mining countries, such as the UK and Germany, the biggest challenge actually lies within the needed adjustments for the mostly regional dependent economies. Past experiences show lessons of hardly managing (UK) or to passively delaying (Germany) this process. Current debates of the EU Green Deal try to reflect this by focusing on a "just transition" for all regions that will be affected by upcoming phase-out pathways. Solutions hereby strongly depend on regional contextual factors and therefore have to be adopted individually, as no single blueprint for a socially acceptable coal phase-out exists. The Just Transition Fund can be a helpful vehicle to enable such a transition from fossil fuel based economies towards renewable energy system (see Figure 28):

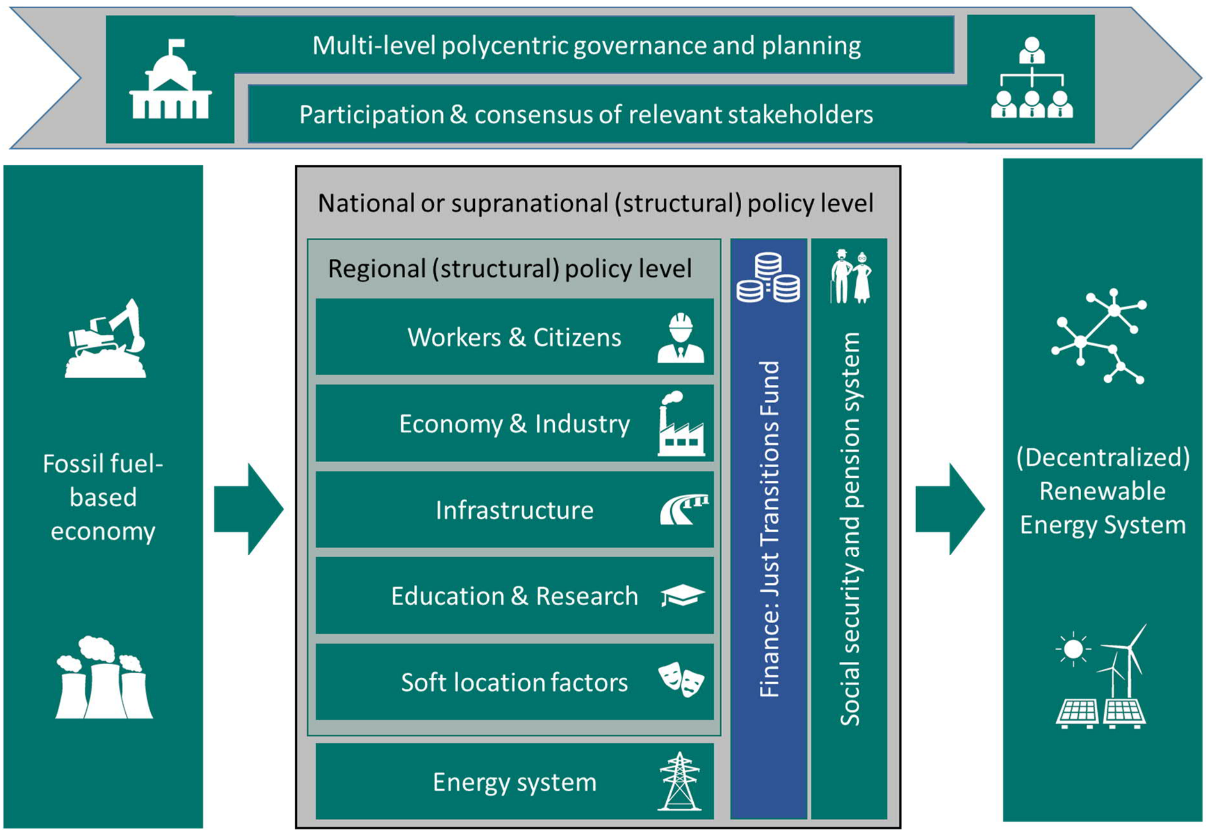

Figure 28: Managing a just transition from a fossil fuel based to a renewable energy system through the help of a just transition fund

Source: Own illustration.

Table 4: The economic and socio-political environment of the coal regimes in the UK, Germany and Poland as well as their responses

		UK	Germany	Poland
Socio-political environment	Civil society	NGO campaigns influenced public opinion on climate change, especially in the 2000s	Historically strong civil society, but focus more on nuclear phase-out until 2011	Comparatively little political influence civil society as well as low concerns about climate change
	Government	Policies like carbon price floor and emission performance standards restricting coal use for electricity generation Liberal market economy → focus on market approaches, preference on cost-efficiency and large-scale technologies Close policy networks between government and incumbent industries, but not new market entrants; limited stakeholder engagement	Regional and national governments preserving coal mining to protect jobs Feed-in-tariff supported new market actors to invest in renewables Coordinated market economy → close connections not only between industries and government, but also between government and unions as well as civil society	Policies focused on protecting coal mining and coal-fired power plants Managed closure of most inefficient mines, but with main goal to protect the remaining ones Few political incentives for investments in renewable energies Coordinated market economy → close connections between industries, government, and unions, limited influence civil society
	Unions	Miners unions lost influence in 1980's due to Thatcher's policies	Strong miners and energy intensive industries unions	Strong miners unions

Economic environment	Coal infrastructure	Necessary investment decisions due to old infrastructure End of domestic mining due to low coal import prices, and end of mining subsidies	Coal infrastructure with broad age structure, domestic coal mining for a longer period (due to hard coal subsidies and lignite deposits)	Relatively old coal infrastructure with broad age structure, domestic coal mining for a longer period (due to hard coal subsidies and lignite deposits)
	Energy Market	Availability of domestic natural gas production	Simultaneous nuclear phase-out, little domestic natural gas production	Little natural gas consumption due to energy security concerns regarding Russia, no nuclear power
		Technologically advanced renewables and falling prices		So far little investments in renewables expect for biomass and until 2017 onshore wind
External strategies of coal regime	Political influence	Successful lobbying: E.g. capacity markets and cap on the carbon price floor Fostering concerns that ending coal would lead to rising electricity prices and black-outs	Successful lobbying: E.g. hard coal mining subsidies since the 1950s and lignite capacity reserve payments Criticizing renewables as 'over subsidised', and highlighting energy security and job losses concerns	Successful lobbying: continuous support for coal mines and power plants, direct influence due to public ownership Highlighting energy security concerns, economic dependence coal regions, as well as high costs of RES
Internal strategies of coal regime	Strategic (re-) orientation	Investments in large-scale renewables and natural gas	Little reorientation, effort to keep the old business model as long as possible	Little reorientation

6 Conclusions

This study analyzes selected areas of the European Green Deal critically, that could contribute significantly to the path towards climate neutrality, including the electricity generation sector, transportation, and industry. The robust analyses throughout several projects presented in the study show that a tightening of the sectoral measures of the EGD are necessary to achieve decarbonization. Furthermore, an explicit institutional framework is needed to actively involve those actors that would be weakened by the measures to transform their existing business models for sustainable solutions in order to reap the benefits of pan-European solutions. A rapid decarbonization of the European energy system can therefore result in macroeconomic benefits in the form of saved raw material imports and lower investment and operating costs of the energy system – as shown by the presented modelling results. However, the study also highlights the dangers of hasty measures for economic recovery that contradict the objectives of the EGD.

The reference benchmark of the EGD must be climate neutrality, and coherence with the 2015 Paris climate agreement for a pathway limiting the increase of the global mean temperature to far below 2°, and if possible to 1.5°. Significant increases in energy efficiency and energy savings through behavioral change can lead to a reduction of primary energy demand by about 50% by 2050 (basis: 2015). Even under these optimistic assumptions, an increase of the greenhouse gas emission reductions ("ambition level") is necessary for 2030 and 2040, to reach climate neutrality. An appropriate target for 2030 is in the range of 60% to 65% reduction (basis: 1990), instead of the "business-as-usual", i.e. only a 40% reduction target for 2030.

Despite declining final energy consumption, the trend towards electrification is increasing the demand for electricity, which is likely to more than double between 2020 (approx. 4,000 terrawatt-hours, TWh) and 2050. The declining shares of fossil and fissile power generation will be replaced mainly by onshore wind and solar photovoltaic capacities. Offshore wind plays a certain role, especially in the countries bordering the North Sea. At the end of the period, in the 2040s, 100% of supply will be secured by renewable energies.

Some progress can be observed at the national level to end the use of coal, though these programs need to be accelerated to phase out coal by the early 2030s the latest. Focus now needs to shift on phasing out fossil natural gas, the climate effects of which have been largely underestimated thus far. Nuclear power is expensive, dangerous, and has unresolved issues of storing radioactive waste; according to model results, no more nuclear power plant would be constructed beyond 2020.

The "Paris"-climate scenario can be designed in a cost-efficient manner, and become an important element of the economic recovery process. Although the energy system costs increase slightly with respect to the business as usual (BAU, ~ € 200 billion), these costs are by far outweighed by avoided costs: Being in line with the Paris agreement saves 15 Gigatons (Gt) of CO_2 until 2030, and more than 60 Gt of CO_2 by 2050. This is worth more than € 10 trillion in terms of avoided environmental and climate damage. Another important macroeconomic effect comes from investments into renewable energies and storage facilities, in the range of € 3,000 billion. Note that over two thirds of these investments could be financed through savings of fossil fuel imports (~ € 2,000 billion). This would also substantially reduce the EU's import dependency.

Solidarity is an integral part of the EGD ("leaving no one behind") and has to play out at the national and at sub-national levels. At the national level, the tightening of the EU climate protection targets within the framework of the Green Deal has different effects on individual member states; this must be taken into account in implementation. At the local level, the "Just Transition Fund" (JTF) has an endowment of € 7.5 bn. that – in conjunction with the regional fund and the social cohesion fund – is supposed to leverage significant amounts of public and private funding to foster structural change. Particular care must be taken to ensure that the funds are not misused for the de facto stabilization of fossil development paths, e.g. by placing money for CO_2 capture technologies.

In this critical moment, learning from lessons of past transitions, avoiding one-way decisions to strengthen the status quo is as important as combining the decarbonization challenged with economic recovery. Policy makers need to resist strong pressure for subsidizing fossil fuels, or fossil fuel use. This includes tax incentives for diesel fuel, subsidies for fossil-fueled gas power plants for combined heat and power generation and subsidies for fossil natural gas infrastructure, e.g. in the Projects of Common Interest (PCI) program. The European Green Deal has to be a "real deal" to be sustainable, both for climate neutrality and economic recovery.

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