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How can we facilitate the transition of the energy system?

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Abstract

The energy transformation to reduce CO_2 emissions have to use less amount of fossil fuels and their related technologies but will see an increase of carbon free technologies such as renewable electricity and heat generators. This paper analyzes how this transition in the energy sector (from to power sector to transport and heating) can be facilitated by an implementation of three key options: coal phase-out, imports and efficiency measures. By applying the techno-economic energy system model REMod-D, the “Energiewende” of the German energy system is studied. The paper concludes that these three key options play a significant part in shifting the energy sector as the implementation of these option can reduce the cost significantly. Furthermore it is shown that there is a beneficial influence on electricity and heat generation from renewables and on the change of vehicle concepts to reach the climate protection targets set until 2050.

1 Introduction

Efforts to reduce climate change until 2050 within the Paris Agreement for nationally determined contributions are challenges for all energy systems in the world [1]. Energy systems have to reduce their carbon footprint and therefore include a transformation from a mainly fossil fuel based system to a renewable energy based system within the next 35 years. This paper has the objective to compare in a scenario approach three key options which could facilitate the transition if they are carried out appropriately. With the energy system model REMod scenarios for the German energy system are modelled in order to analyse an integrated energy system coupling all sectors. The model optimizes transformation paths until 2050, detailed information can be found in [2]. The scenario approach in this paper includes a first scenario which does not force rapid progress in these three options (coal phase-out, energy efficiency, electricity imports). Then the three options are analysed in different scenarios separately (scenario 2 to 4). Finally, a last fifth scenario, called “Active”, is shown which combines the three elements. The basic assumption and the first scenario are also published in the report “Sector coupling – analysis and considerations on the development of an integrated energy system” published by Acatech [3].

2 Methodology

To evaluate potential structural options of the German energy system until 2050, a model-based analysis is carried out utilizing the simulation and optimization model REMod-D. The basic idea of the model REMod-D is a cost-based structural optimization of the transformation of the German energy supply system for all consumption-sectors – i.e. the sectors electricity, low-temperature heat (space heating and hot water), high-temperature (process) heat and transport. The purpose of these calculations is to determine a cost-effective transformation path from the current system to an energy system in 2050, with a total annual upper limit of permitted CO2 emissions across all sectors. The model calculations describe technically possible development paths of the energy system with all related system components (such as e.g. generators, converters, energy storages, networks and car parks) and optimize them in terms of minimizing the costs of the energy system based on assumptions and the analysis frame. A detailed model description is given in [4, 5].

The energy demand is divided into four utilization areas: transport, electricity, low-temperature heat and process heat. The calculations assume the so-called "single-node model" or "copper plate model", in which the distribution of electricity is not subject to any restrictions, meaning each unit produced and each unit demanded is available in the time step considered throughout Germany. However, the necessary costs for expansion or operation of the power grid are included in the cost accounting.

3 Scenario approach

Five different scenarios have been developed:

- a reference scenario (‘*basis scenario*’),
- three scenarios, each with one option (efficiency, coal phase-out or electricity imports)
- a final scenario including all three options (‘*active scenario*’).

The energy system analysis carried out in this paper for the timeframe until 2050, projections and assumptions for a wide range of parameters are necessary. This study uses the same assumptions as [3]. They are applied in all scenarios if not indicated otherwise. One key assumption is to reduce CO_2 emissions from the reference year 1990 to 2050. CO_2 emissions are reduced continuously to -85% compared to 1990, by taking immediate targets for 2030 and 2040 into account. Compared to the Basis scenario, each of the other scenarios has some specific additional assumptions as follows:

Energy efficiency scenario: Energy savings and efficiency measures reduce the base current load from 481 TWh to 360 TWh. This is in line with the target of the German government to reduce energy consumption for original power applications by 25% until 2050. Energy demand in industry decreases by 0.5 % annually. Solar thermal energy gains importance for low-temperature heat generation in buildings. For simplicity reasons, energy savings have not been connected to any cost item.

Coal phase-out scenario: Phase-out of lignite and hard coal power generation until 2040 (at the same time, CHP demand is reduced to decrease must-run conditions for these power plants) is expected.

Import scenario: European electricity network is expanded with an increase of capacity by the factor of 2 for all German interconnections with neighboring countries until 2050.

The last scenario connects all three options ("*Active scenario*") to show the impact on the system if all three options are in place.

4 Results of the analysis

Compared to today, electricity generation in Germany has to be increased to decarbonize all energy sectors by using renewable energy. This effect is mainly caused by the cross-sectoral demand increase of electricity, e.g. caused by new electricity demand in the heating and transport sector.
Electricity becomes the dominant energy carrier in each scenario considered here, as power from wind and solar power plants is the main renewable energy source available. Consequently, by 2050, the electricity system is based on high shares of renewable energy sources. The installed capacity of renewables, foremost wind power and solar PV are the main generation capacity, ranging from 350 GW to 500 GW depending on the scenario assumptions (**Figure 1**). Flexible power plants such as OCGT or CCGT running with natural gas are the backup technologies with an installed capacity between 66 GW to 120 GW which are operated in case of low wind speeds or low sun irradiance.

If some of key parameters are changed, this leads to significant changes in the power plant portfolio, see **Figure 1.**

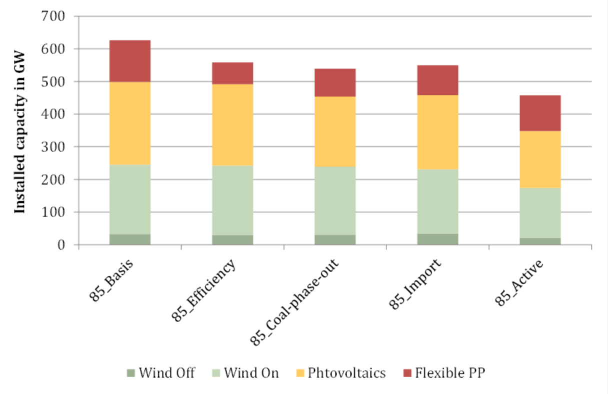

Figure 1: Installed capacity of power plants in Germany in 2050

Total annual power generation strongly depends on the scenario assumptions as **Figure 2** shows. However, compared to over 1000 TWh annual generation, the Active scenario with all options in place is able to reduce the total generation to about 800 TWh (of which 125 TWh are reduced by assumption in this scenario). This means a reduction of 20% only by pushing forward all of these three options. In this case, share of renewable energy is also only 79% compared to 84% in the reference case.

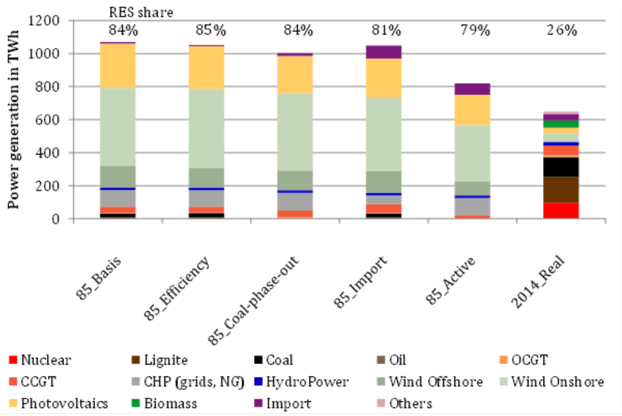

Figure 2: Electricity generation of all power plants and import/exports in 2050 compared with 2014

Following influences of each option can be derived:

- Efficiency measures reduce not only overall energy demand, but also high peaks in the hourly electricity demand.
- Coal phase-out directly and rapidly will decrease CO_2 emissions in the electricity sectors. This impacts the other sectors as more conventional fuels can be used in heating and transport.
- Electricity imports count as carbon free option to Germany as they have to be accounted for in the country of origin (however, it should be a target to also import electricity mainly from renewable sources). Therefore, imports decrease the need for electricity generation in Germany, and con-

sequently electricity generation from renewables and other sources.

When looking at the heating sector, today, oil and gas boilers as well as heating networks are used the most often to provide space heat and warm water. However by 2050, a shift to electric heat pumps (HP) and more heating networks (heat generated from CHP and HP) is suggested by the results to reduce CO_2 emissions (**Figure 3**). All in all, the share of electrical driven heating systems drastically increases in all scenarios (between 50-70 % by 2050), leading to an increasing electricity demand in the heating sector. A high peak electricity demand of heat pumps can be mitigated by making use of decentralized and centralized heat storages. They are used by the model in all scenarios. The high electricity demand by HP, however, is part of the reason why the back-up capacity of conventional power plants is still quite high in 2050 due to the constraint of security of (heat) supply during each hour of the year.

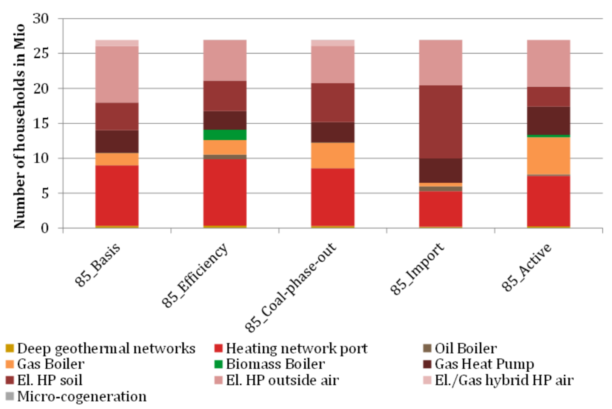

Figure 3: Distribution of heating technologies in the heating sector (private households) in 2050

The share of electrical driven heating systems drastically increases in all scenarios (between 50-70 % by 2050), leading to an increasing electricity demand in the heating sector. In the basis scenario and in the import scenario (due to the good availability of import electricity), the degree of electrification in the heating sector is high (see **Figure 4**). It continuously increases to almost 70%. Also in the Coal phase-out scenario and efficiency scenario, the degree sill accounts for 60%. Only in the Active scenario, all the elements lead to a lower share of under 50% created by electric heat pumps, deep geothermic and heat rods.

In this paper, a focus is set to the power and heating sector and no evaluation of the other results in transport and industry is given. But the impact in these sectors is similar and supports the overall message regarding the options to facilitate the energy transformation.

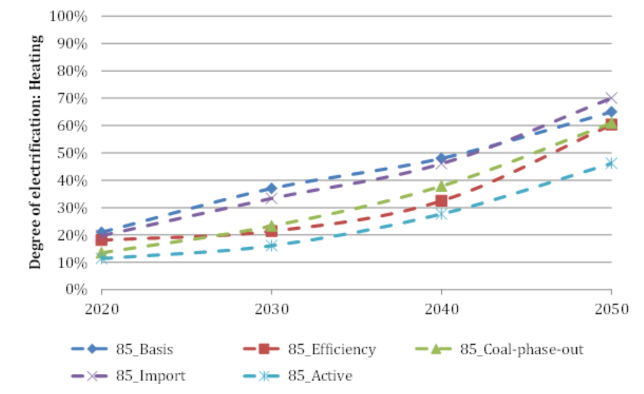

Figure 4: Degree of electrification in the heating sector

The different options have strong influence on the different sectors as showed above. But how is the influence on total system cost?

The implementation of the key elements decreases the total system cost as a sum from today to 2050. By 2050, the transformation is linked with about 6000 bn EUR in the Basis scenario (compared to 3800 – 4000 bn EUR in a business as usual scenario which is not displayed here). The effects of each element seem to be very complementary as the cost reduction of each element is added to the total reduction (see **Figure 5**). In the Active scenario, total system cost is reduced by 20% compared to the reference (~4700 bn EUR).

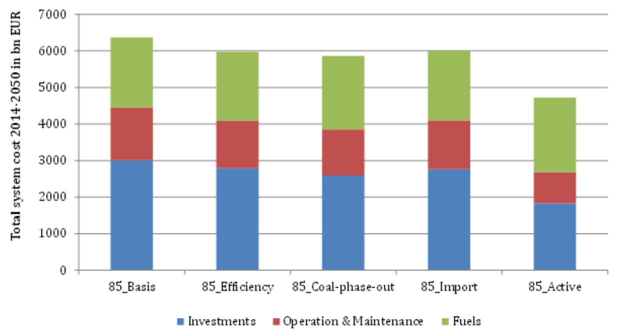

Figure 5: Cumulative total system cost from 2014 to 2050 in billion EUR

The analysis evaluates three options and shows that their implementation can be very beneficial. With the Active scenario can be highlighted that these options in place can offer many advantages from a technological and economic perspective compared to the scenarios without, with one or two option implemented. Combining these activities for energy efficiency, coal phase-out and imports, can potentially decrease some measurements in other fields, e.g. it reduces the need for renewable expansion to a certain level, but this level is much high compared to today also in the Active scenario. Also sector coupling is a result of an integrated energy system; the three options however, would facilitate or reduce also the requirements in the field of sector coupling. As a result, the total expenditures for the energy system can be reduced. The transition can be potentially facilitated and the acceptance of all stakeholders and involved parties increased. However, these options still will require huge policy efforts and support measures in order to be implemented, correctly, efficiently and on time.

If the temporal development path (of the Active scenario) is analyzed, it can be shown that renewables (mainly PV and onshore wind) have to continue to grow until 2050 whereas conventional flexible power plants remain stable at 95 GW but they shift to more power plants operated with natural gas. Between 2030 and 2035, already 200 GW of renewables are required to reduce the energy related CO_2 emissions by about 50% (by considering all energy savings and efficiency measures of this Active scenario).

At the same time, electric vehicles and heat pumps create new demand for electricity which uses also increasing shares of this electricity produced by renewables. In 2035, the number of electric vehicles has to reach around 15 Mio cars. In the long-term, almost 90% or 32 Mio cars are electric vehicles. The number of heat pumps grows at the same time to about 12 Mio applications, mainly in the residential building sector.

5 Conclusion

The three options analyzed in this paper have a very good potential to reduce the efforts for the energy transition (=facilitators of the transformation). Coal phase-out, energy efficiency and electricity imports can lower the effort and burden which come along with this transformation. Their implementation can therefore facilitate the energy transformation from a system perspective. However, their implementation can also add some complexity such as electricity imports can increase the coordination with neighboring countries in terms of capacity expansion of renewables and transmission lines.

6 Acknowledgement

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7 Literature

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