RENEWABLES EXPANSION AND SUPPORTING INFRASTRUCTURES FOR A NET-ZERO ENERGY SYSTEM TRANSITION OF GERMANY BY 2050

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Overview

We analysed transition pathways for the energy system in Germany under a pre-defined carbon budget to comply with the global “well below 1.5°C” target, reaching net-zero by 2050 [1]. The energy system is modelled under a cost optimization approach with consideration of future energy and electricity demands from various end-use sectors (industry, households, transport, commerce, trade and services). Our analysis is focused on Germany, which is divided into 10 regions with 12 additional nodes representing its neighboring countries. Our approach focuses especially on capacity expansion of renewables as well as of supporting infrastructures for the generation, storage and transport of electricity, hydrogen and synthetic methane. Future capacities of 90 technologies are calculated in an hourly resolution for the scenario years of 2020, 2030, 2040 and 2050. The results show interactions among the utilization of renewable energies and the balancing of fluctuating generation and demand. As the optimization of the power system highly depends on several key assumptions, such as fuel costs, availability of renewable resources and power import dependency, we also test four sensitivity cases for the power sector. The sensitivity analysis focuses on the variations of minimum domestic power generation shares from 90% in the base scenario to 80% in the high-import scenario or even 95% in the low-import scenario, assumed maximum PV generation potentials and lower biomass cost assumptions.

Methods

We applied the energy system optimization model REMix, which consists of two parts: EnDat which provides the temporal load and the feed-in renewable energy profiles for each model region, and REMix-Optimo which optimizes the expansion and operation of the energy system. REMix minimizes the total system cost from a central economic planner’s point of view. Our myopic approach optimizes capacities in each model run, which are then passed on to the next scenario year, while technology components that exceed their lifetimes are decommissioned. The total system cost includes the operation, fuel and CO_2 certificate costs and investment costs for built capacities, which are modelled endogenously. The proportional capital costs of the installed capacities are calculated from technology investment costs, fixed operation and maintenance costs, amortization times and interest rates. A detailed model description can be found in [2,3]. In our study, we consider sector coupling among the power, heat, transport, industry and gas sectors. The gas sector comprises gas production, usage, storage, imports and transmission. Synthetic gas can be produced through electrolysis and methanation powered by renewable energy. Additionally, we included two model constraints to the optimization: upper limits for CO_2 emissions, and a minimum of remaining CHP capacities for biomass. Considering the input data for the technological and economical parameters, the weather and load profiles from EnDAT and the additional model constraints, REMix optimizes the energy system and provides the optimized expansion and dispatch of the energy system infrastructure, the total system costs and the annual CO_2 emissions as outputs.

Results

Our results show that renewables especially solar and wind would be the main pillars of domestic renewable power generation in the future but with significant regional uneven distributions. Most of the photovoltaic would be installed in the south and southwest of Germany while wind plays a major role in the north and northeast. Other than that, grid expansion is also necessary to realize such a power supply system based on variable renewable energies. Within Germany, total grid transfer capacity in the base scenario needs to triple from 2020 to 2050. In addition to new infrastructure for power exchange, the results reveal that significant installations of both production and transport capacity for hydrogen will be required. A massive deployment of 26 GW of electrolyzer capacity would be needed in Germany within the next decade, increasing to 96 GW by 2050. Hydrogen production would be focused in the northern regions of Germany where electrolysis could be used to balance the offshore wind fluctuations. To be on track with the carbon budget, an early construction of a hydrogen transport network would also be required. The transport capacities need to reach up to 23 GW in 2030 and 33 GW in 2050 in order to connect the central electrolyzer capacities and cavern storage in the north with 50% or 27 GW in Lower-Saxony to the demand centers in the south and west. The above discussed energy system also requires substantial investment in renewable energy technologies and related infrastructures. The highest system costs of 65 billion € occur in 2030 and would decline to around one third in 2050. This is accompanied by a shift from fuel costs, which are with 64% the main component in 2020, to investment costs, which represent with 46% the largest share in 2050. Each decade would require 10-14 billion € investment in low carbon technologies and supporting infrastructures. Replacing fossil fuels could significantly reduce CO_2 emissions costs, which cover one fourth of total system costs in 2020. At the same time, the power import costs would account for up to 26% of system costs in 2050, replacing partially today's fuel imports. The sensitivity analysis shows that setting the share of domestic power generation from 95% to the minimum of 80% leads to the highest variants. The resulting power exchange in Germany could vary by up to 115 TWh net import (under the 80% of minimum domestic power generation shares) to 52 TWh net export (under the 95% of minimum domestic power generation shares) by 2050 compared to the base scenario. Limiting the utilization of photovoltaic may promote the exploration of wind energy but could also lead to 17% more power import in 2040. The total system costs vary the most in 2050. Allowing 10% more power import could reduce total system costs by 9% in Germany and vice versa. The reason is that the domestic investments and operation costs are higher than power import costs. Exploring only half photovoltaic potentials would increase total system costs by 4%. The reduction of biomass fuel price barely influences the total system costs.

Conclusions

In this study, we modelled an exemplary future energy system for Germany which complies with a carbon budget for the 1.5°C-climate target and also minimizes total system costs. We found that the results on capacity expansion depends heavily on system assumptions. For example the development of power demand due to efficiency improvement and electrification from various end-use sectors, the available renewable energy potentials, cost and efficiency assumptions of emerging technologies. The optimization results for grid expansion strongly depend on the portfolio of installed renewable power generation plants and their spatial distribution. In order to integrate the regionally varying energy sources of wind and solar into the German energy system at the lowest possible cost, an expansion of the grid is necessary. In addition, an expansion of the grid to neighboring countries is required so that electricity could be imported at lower cost. The expansion of the power grid, which is a key infrastructure component with a long life time as well as relatively high capital costs, should be planned in advance over the long term to avoid possible "lock-in" effects. The regional and cross-border exchange of electricity thus requires a more flexible electricity trading system with consideration of geographical influences so that regional generation peaks resulting in less curtailment. The hydrogen produced from renewable electricity and partially imported serves as an energy source for sectors that are difficult to decarbonize, either directly or via downstream products such as synthetic fuels. The gas infrastructure identified from the optimization analysis also can be used for the needed sector coupling between the power, heat and the transportation sectors.

References

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