EMISSION PATHWAYS TOWARDS A LOW-CARBON ENERGY SYSTEM FOR EUROPE - A MODEL-BASED ANALYSIS OF DECARBONIZATION SCENARIOS

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Overview

In the wake of increasing concerns about greenhouse gas emissions and the adverse effects of global warming, the scientific and policy debate about future energy scenarios is intensifying. Burning fossil fuels is the biggest driver for global greenhouse gas (GHG) emissions and therefore implies a fossil phase-out (IPCC 2014). Traditionally, energy system models relied on the trio of fossil fuels with carbon capture, nuclear energy, and renewables; the two former ones providing backup capacity in case of no wind and no sun. This pattern is now challenged by the availability of low-cost storage technologies and other flexibility options (such as demand-side management, high-voltage grid interconnections, etc.), providing the necessary flexibility to balance intermittent renewables (Gerbaulet and Lorenz 2017). The recent controversy about renewables-based energy scenarios highlights this issue, see Clack et al. (2017) and Jacobson, et al. (2017). In addition, recent trends show that neither nuclear nor carbon capture technologies are likely to play a major part in decarbonizing the electricity sector (Lorenz et al. 2016; Kemfert et al. 2017). The political urgency for reducing greenhouse gas-emissions is shown in the historical agreement of the 21st and 22nd Conference of the Parties in Paris and Marrakesh. As shown in the 450ppm scenario of the World Energy Outlook (IEA 2016), the effects of climate change can potentially be reduced to around two degrees compared to pre-industrial averages. This has a tremendous effect on the future outlook of the global energy system. Given the tense global situation, Europe has to play a major role in leading the transition towards a largely decarbonized energy system. Hence, there is a need to investigate the European energy system and its possible realizations towards a fully renewable future.

Methods

This paper presents different scenarios based on the regional distribution of the available CO2 Budget to keep the global mean temperature well below 2° Celsius. To analyze these scenarios, the "Global Energy System Model" (GENeSYS-MOD) by Löffler et al. (2017) is used. GENeSYS-MOD is a full-fledged energy system, originally based on the existing "Open Source Energy Modelling System" (OSeMOSYS) created by Howells et al. (2011). The model uses a system of linear equations of the energy system to search for lowest-cost solutions for a secure energy supply, given externally defined constraints on GHG emissions. In particular, it takes into account increasing interdependencies between traditionally segregated sectors, e.g., electricity, transportation, and heating. For our approach, we aggregated European countries into 15 geographic regions, calculating energy- and resource-flows to meet power, heat and transport demands. Final demands and demand profiles for our model stem from the 450ppm scenario of the IEA (2016), resulting in a primary energy demand for Europe of 23 EJ in 2050. The installed capacities in 2015 serve as a starting point for further investment, production, trade and salvage decisions which are calculated by the model. Several European limits of emitting CO_2 corresponding to common emission pathways (1.5°C, 2°C, BAU) are analyzed. These emission budgets incentivize the need for investments into RES. In the different scenarios, the available budget is then distributed to the various modeled regions. The share of this distributions is calculated by taking different key-indicators (e.g., GDP, Population, current CO_2 Emissions) into account and comparing the results to find a fair share of CO_2 emissions.

Results

As a result, in the base scenario, we were able to model a possible path towards a 100% renewable and climate-neutral global energy system in 2050. This implies the phase-out of fossil fuels, which happens at different rates for the power, heating and transportation sectors. The power sector is leading the change to renewable energies with as much as 45% of electricity generation in 2020, rising to over 90% by 2035. Current results indicate that the next ten years represent a strong turning point towards renewable power generation with only about 30% being produced by conventional energy carriers in 2025. Both the heating and transportation sectors experience a slower rate of change, depending on the regional setting. Based on the model calculations, the global energy system towards 2050 mainly relies on wind power (39%), solar power (27%) and biomass (24%). To a smaller degree, hydro, geothermal and concentrated solar power provide energy as well. Because the two main sources of energy, wind and solar power, provide energy in the form of electricity, we observe a strong sector-coupling of the power sector with both the heat and transportation sectors. In the heating sector, heat pumps and electric furnaces convert electricity into heat. In the transport sector, electricity is directly used in battery electric vehicles and electric rails as well as converted into hydrogen to provide mobility where a direct use of electricity is not possible (such as aviation or freight transport). The resulting costs for electricity generation are around 3.8 €ct per kilowatt-hour in 2050 which is below other calculations due to the fact that we do not consider infrastructure investments. A shadow price of around 32 € per ton of CO_2 is found, based on the set emission budget. Around 35% of the total investment costs occur in the last two modeled periods, 2045 and 2050.

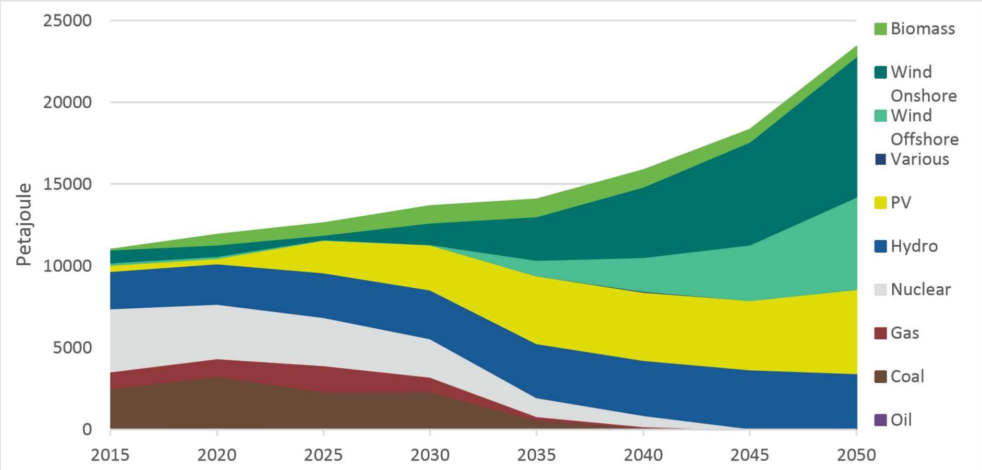

Figure 1: Development of European power generation in the base scenario (2°C without national budgets); Source: Own illustration

Conclusions

The paper provides two major contributions: model-based calculations indicate that decarbonization can be attained at the lowest cost by a combination of renewable energies (mainly solar and wind), storage, and some peak-shaving through demand-side management. Specific energy mixes will result, however, depending on the continent or the country that is analyzed. Second, by contributing a significant piece of modeling to the community, open-access with fully transparent code, data, and results, we contribute to the scientific debate and the transparency of analysis, thus strengthening the political debate with scientific substance.

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