MODELING A GLOBAL ENERGY SYSTEM BASED ON 100% RENEWABLES

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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-emissions and therefore implies a fossil phase-out (IPCC, 2014). Traditionally, energy system models trying to reach the two degrees target relied on the trias 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. Recent trends, however, contradict several of the underlying assumptions: This includes the unexpected cost decrease of renewable energies and storage technologies, as well as other flexibility options (such as demand-side management, high-voltage grid interconnections, etc.) providing the necessary flexibility to balance intermittent renewables (Edenhofer et al., 2012). 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). 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, 2015), 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. Even though the 450ppm scenario gives an impression of trends and demands, it fails to reach the limits set by the Paris Agreement. In fact, the declared goals can reasonably only be achieved with a fully decarbonized energy system by 2050. Hence, there is a need to investigate the global energy system and its possible realizations towards 100% renewable energies.

Methods

We set up a linear cost-minimizing optimization model, calculating the pathway from 2015 to 2050 in 5 year steps. The model is based on the existing Open Source Energy Model "OSeMOSYS" (Howells et al., 2011; Welsch et al., 2012), which has been expanded and modified. For our approach, we aggregated countries into 10 geographic regions, calculating energy and resource flows to meet power, heat and transport demands. A particular focus is set on the calculations for Europe and North America. Final demands and demand profiles for our model stem from the 450ppm scenario of the IEA, resulting in a primary energy demand of 290 EJ in 2050. Time is being disaggregated into multiple time slices, modeling multiple seasons and day/night cycles. The installed capacities in 2015 serve as a starting point for further investment, production, trade and salvage decisions which are calculated by the model. A global limit for CO_2 emissions incentivizes the need for these investments.

Results

As a result, 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 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 CO2 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.

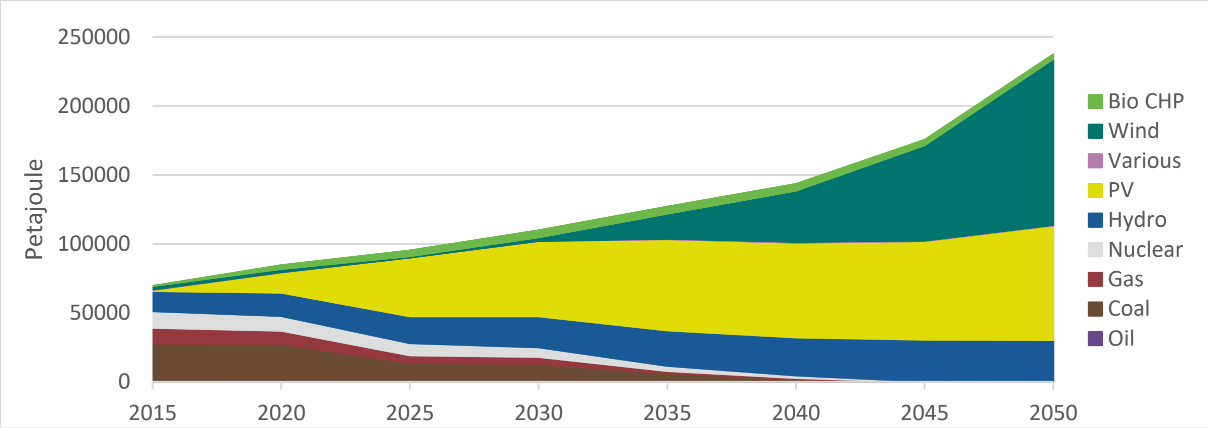

Figure 1: Global Power Generation; Source: Own illustration

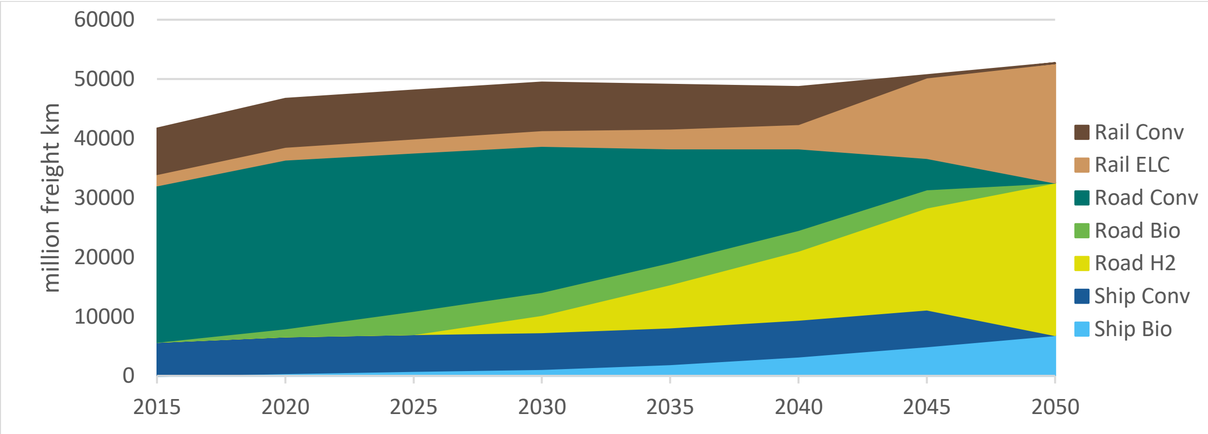

Figure 2: Global Freight Transport; Source: Own illustration

Conclusions

The paper provides two major contributions: model-based calculations indicate that decarbonization can be attained at 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 modelling 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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