Environmental Impacts of Germany's Future Energy System

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Overview

Achieving greenhouse gas (GHG) emission targets requires the design and operation of sustainable energy systems. The ongoing debate about future energy systems is increasingly supported by mathmatical models. However, future energy systems models require:

- Interconnections to neighbouring countries to consider import and export (Lopion et al. 2018)
- Spatial and temporal resolution to take fluctuating renewable energies into account (Kono et al. 2017)
- The consideration of environmental burden shifting (Laurent and Espinosa 2015)

In this work, we address these three requirements by combining Life Cycle Assessment and energy modelling with high spatial and temporal resolution. Thus, we present a temporally resolved energy model to determine fluctuating environmental impacts of electricity consumption in Germany.

In most regions, GHG emission reduction targets will likely result in rising shares of fluctuating electricity production by solar and wind. Considering fluctuating electricity sources, temporal resolution may increase insight about fluctuating environmental impacts over time.

To avoid burden shifting from global warming to other environmental impact categories like metal depletion or ecotoxicity, the search for sustainable design options of energy systems needs to consider various environmental impact categories (Rauner and Budzinski 2017). An established method to evaluate environmental impacts is Life Cycle Assessment as a method of systematic ecological evaluation.

The presented model integrates these three requirements to allow for the design of sustainable energy systems.

Methods

We formulate a two-stage synthesis optimization model to design and operate the future energy system in Germany while fulfilling total greenhouse gas emission targets.

The model optimizes the energy system operation at high temporal resolution considering the integration of fluctuating renewable power generation. The electricity sector is based on the electricity model ELMOD-DE (Egerer 2016). In addition, the transportation and heating sector (including industry) are considered in an integrated model to account for rising electricity demands in all sectors due to electrification technologies.

The optimally designed energy system is evaluated using Life Cycle Assessment. Comparative Life Cycle Assessment allows to compare environmental impacts holistically. We derive environmental impacts for the functional unit of 1 kWh electricity following the ReCiPe2008 method (Goedkoop et al. 2009). The environmental impacts are compared for a current and a future energy system.

Results

For pathways according GHG emission reduction targets, we determine the optimal design for a current and future energy system in Germany. The future energy system shows increasing interconnection between the electricity sector and the heat and transportation sector, mainly caused by heat pumps. For most environmental categories, impact decrease. However, we show a shift from operational impacts to impacts caused by the infrastructure.

In particular, we observe an increase in metal depletion, urban land occupation, and terrestrial ecotoxicity. The increases are mainly caused by the increased share of renewable electricity generation and the electrification of other energy services.

Conclusions

Life Cycle Assessment is crucial for the sustainability evaluation of energy system transitions. For the case study of Germany, we determine environmental trade-offs by determining environmental categories which gain further importance in future energy systems. The presented model allows to identify transition pathways towards a low-carbon society while avoiding problem-shifting to other environmental impacts.

References

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