SPATIO-TEMPORAL ANALYSIS OF SECTOR COUPLING PATHWAYS: COMBINING TOP-DOWN AND BOTTOM-UP APPROACHES FOR THE GERMAN CASE

Christina Kockel[1,*], Lars Nolting[1,*], Jan Priesmann[1,*], Aaron Praktiknjo[1]

[1] RWTH Aachen University,
Institute for Future Energy Consumer Needs and Behavior (FCN),
+49 241 80 49845, [christina.kockel; lnolting; jan.priesmann;apraktiknjo]@eonerc.rwth-aachen.de

[*] These authors contributed equally to this work

Overview

While technological potentials to reduce greenhouse gas (GHG) emissions are immense in the power sector, realizing reductions in other sectors such as transportation and heating requires more efforts. A strategy to propagate the potential GHG emission reductions from the power sector into other energy sectors is to use so-called sector-coupling technologies, see Ruhnau et al. (2019). Generally, demand for useful energy (e.g. mechanical energy for the transportation sector) can be supplied by means of different forms of final energy (e.g. gasoline, diesel, natural gas, electricity). However, depending on the chosen pathways for the provision of final energy, the demand coupled with the spatio-temporal availability of the respective final energy sources is associated with infrastructure requirements. Direct and indirect electrification are two strategies for implementing sector coupling by either directly using renewable electricity in end-user technologies (cf. Densing et al., 2016; Sugiyama, 2012), or by burning green fuels and gases (see e.g. McDowall and Eames, 2006; Welder et al., 2018). Direct electrification would shape the infrastructure towards transportation of electricity while indirect electrification relies on gas pipelines and road transport. Against this backdrop, we ask:

> *(1) How can demands for and supply of useful energy and final energy be estimated based on available data in a temporally and spatially highly disaggregated resolution?*
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> *(2) What impacts of sector coupling pathways on infrastructure requirements can be derived applying spatio-temporal analysis?*
>
> > *(2.1) To what extent can the internalization of integration costs and the efficient positioning of renewable energy plants reduce overall system costs?*
> >
> > *(2.2) How can suitable political frameworks for the efficient integration of renewable energies be defined?*

Methods

We analyze different sector coupling scenarios using a systemic, consumer-driven approach considering each stage of the energy balance (cf. Figure 1) and different end-consumer appliances, such as heat pumps, hydrogen fuel cells and battery electric vehicles. Subsequently, we derive the resulting final energy demand patterns. We then evaluate how different strategies for expanding infrastructure impact the economic efficiency using temporally and regionally resolved time series for energy demand and supply in Germany.[1]

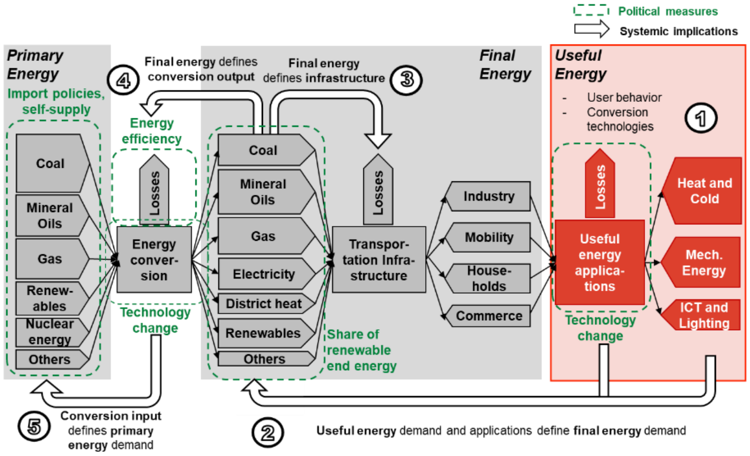

Figure 1: Systemic implications and political measures in energy balances of national energy systems

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[1] Germany represents an interesting case study as it focuses on expanding its share of renewable energies in the power sector (which has increased so far from 3.4% in 1990 to 37.8% in 2018 and is projected to increase even further) while having difficulties in decarbonizing the heat and transportation sector (renewable shares of 13.9% and 5.6%, respectively) (AGEE-Stat, 2019).

For our analysis, we model hourly and regionally resolved time series for useful and final energy demand and supply by combining *top-down* with *bottom-up* modeling methods. Here, we make use of comprehensive data sets stemming from publicly available data sources such as population and employment figures, land eligibilities for renewables, gross domestic production figures for eight industry and four commerce sub-sectors, energy intensity per sub-sector based on input-output tables, weather data, building characteristics and driving profiles per vehicle type. Top-down and bottom-up data is consolidated at interfaces in order to ensure the validity of our data sets.

Results

Applying our methodology as introduced above, we disaggregate useful energy demands, derive corresponding final energy demands, and spatially distribute renewable feed-in capacities (for a first excerpt, see Figure 2).

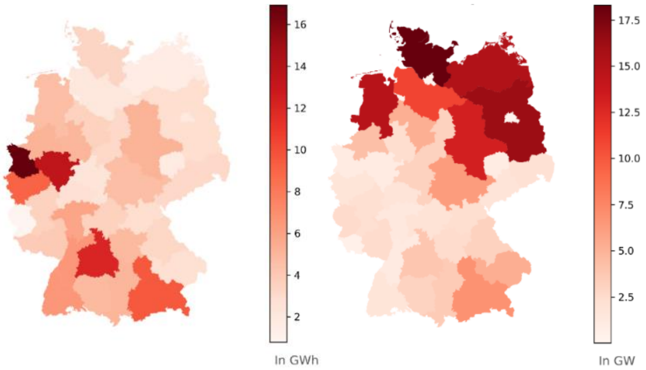

Figure 2: Yearly regional industrial electricity demand (left) and installed wind onshore capacities (right) in a future sector coupling scenario designed for 95% greenhouse gas reduction[2]

Conclusions

Based on our results, we draw conclusions and derive policy recommendations as follows:

(1) Sector coupling allows for the integration of renewable electricity in other sectors: both direct and indirect electrification scenarios increase the demand for (green) electricity as a final energy carrier. Thus, policy makers should consider additional needs for renewable capacities and ensure local acceptance beyond socio-political acceptance of renewable energies.

(2) Sector coupling pathways come with regionally different potentials for reducing greenhouse gas emissions and associated costs for end users. On an aggregated level, the implementation of sector coupling leads to infrastructure costs. The latter can have systemic effects that either align or contradict the regional effects. Policy makers should therefore consider regional differences in reduction potentials, cost, and local acceptance.

(3) The temporal analysis of electricity demand and renewable feed-in in sector coupling scenarios shows potential to reduce infrastructure needs by reducing peak loads through the use of flexible demand or storage capacities. Here, policy makers should create incentive mechanisms that make the flexible operation of sector-coupling technologies, such as heat pumps, profitable in order to avoid cost-intensive expansion of infrastructure.

(4) The spatial analysis of both electricity demand in sector coupling scenarios and the locations of renewable power plants reveals the potential to reduce infrastructure needs through the efficient allocation of renewable feed-in capacities based on future demand structures. Thus, policy makers should include the externality of integration costs of renewables by creating incentives to invest in capacities for renewable electricity close to sites with high electricity demands in sector coupling scenarios.

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[2] The currently displayed resolution of 38 regions will be further expanded to 401 regions in the full paper.