Achieving stringent climate targets: An analysis of the role of transport and variable renewable energies using energy-economy-climate models

Robert Pietzcker

Abstract

Anthropogenic climate change is threatening the welfare of mankind. Accordingly, policy makers have repeatedly stated the goal of slowing climate change and limiting the increase of global mean temperature to less than 2°C above pre-industrial times (the so-called “two degree target”). Stabilizing the temperature requires drastic reductions of greenhouse gas (GHG) emissions to nearly zero. As the global system of energy supply currently relies on fossil fuels, reducing GHG emissions can only be achieved through a full-scale transformation of the energy system. There are many possible paths to realize such a decarbonization, resulting in a variety of distinct energy-economy systems. Different transformation paths require different technologies and system changes, and will result in different socio-economic and environmental impacts.

This thesis investigates the economic requirements and implications of different scenarios that achieve stringent climate mitigation targets[1]. It starts with the analysis of characteristic decarbonization patterns and identifies two particularly relevant aspects of mitigation scenarios: deployment of variable renewable energies (VRE) and decarbonization of the transport sector. To investigate the role of renewable energies, we performed both a comparative study across seventeen integrated assessment models (IAMs) as well as a detailed deep-dive with the IAM REMIND. For the transport sector, we undertook a comparative study of five IAMs. Finally, we turned towards one of the most relevant questions for policy makers and analyzed the trade-off between the stringency of a climate target and its economic requirements and implications. All analyses are based on the improvement, application, comparison, and discussion of large-scale IAMs.

We started by developing the novel “mitigation share” metric and applying it to scenarios produced with REMIND. This metric allowed us to identify the relevance of specific technology groups for mitigation and to improve our understanding of the decarbonization patterns of different energy subsectors. It turned out that the power sector is decarbonized first and reaches lowest emissions, while the transport sector is slowest to decarbonize. For the power sector, non-biomass renewable energies contribute most to emission reductions, while the transport sector strongly relies on liquid fuels and therefore requires biomass in combination with carbon capture and sequestration (CCS) to reduce emissions.

The subsequent comparison of seventeen IAMs used by different research groups worldwide generally confirms the findings from the previous analysis: For most models, the deployment of renewable energy sources increases substantially with the stringency of climate policy. In most of the low stabilization scenarios that have a high likelihood of achieving the 2°C target, renewable energy becomes the

[1] “Stringent climate mitigation target” and “low stabilization scenario” in this thesis denote scenarios where the increase of global mean temperature is limited to 1.5–2.5 °C above pre-industrial times.

dominant source of electricity. Furthermore, the models with high renewable shares also show particularly high contributions from the VRE wind and solar. At the same time, the model comparison reveals large differences between actual technology deployment levels in the different models.

An in-depth investigation of the solar power technologies photovoltaics (PV) and concentrating solar power (CSP) in REMIND confirms the dominant role of these variable renewable energies for the decarbonization of the power sector. Recent cost reductions have brought PV to cost-competitiveness in regions with high midday electricity demand and high solar irradiance. The representation of system integration costs in REMIND is found to have significant impact on the competition between PV and CSP in the model: the low integration requirements of CSP equipped with thermal storage and hydrogen co-firing make CSP competitive at high shares of variable renewable energies, which leads to substantial deployment of both PV and CSP in low stabilization scenarios.

A cross-model study of transport sector decarbonization reveals a number of different decarbonization routes, as well as the need for future model improvement to ensure that all decarbonization options along the chain of causality are well represented. Our research confirms the earlier finding that the transport sector is not very reactive to intermediate carbon price levels: Until 2050, transport decarbonization lags 10–30 years behind the decarbonization of other sectors, and liquid fuels dominate the transport sector. In the long term, however, transportation does not seem to be an insurmountable barrier to stringent climate targets: As the price signals on CO2 increase further, transport emissions can be reduced substantially – if either hydrogen fuel cells or electromobility open a route to low-carbon energy carriers, or second generation biofuels (possibly in combination with CCS) allow the use of liquid-based transport modes with low emissions.

The last study takes up the fundamental question of this thesis and analyses the trade-off between the stringency of a climate target and the resulting techno-economic requirements and costs. We find that transforming the global energy-economy system to keep a two-thirds likelihood of limiting global warming to below 2°C is achievable at moderate economic implications. This result is contingent on the near-term implementation of stringent global climate policies and full availability of several technologies that are still in the demonstration phase. Delaying stringent policies and extending the current period of fragmented and weak action will substantially increase mitigation costs, such that stringent climate targets might be pushed out of reach. Should the current weak climate policies be extended until 2030, the transitional mitigation costs for keeping the 2°C target would increase three-fold compared to a world in which global cooperative action is decided on in 2015 and where first deep emission reductions are achieved in 2020. In case of technology limitations, the urgency of reaching a global climate agreement is even higher.

In this thesis, we performed a comprehensive analysis of stringent mitigation scenarios and their economic implications, with a special focus on VRE deployment and transport decarbonization. Based on extensive modeling work and global cross-model analyses, this thesis provides crucial insights and identifies strategies for achieving stringent mitigation targets.