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# Modelling the Impact of Energy and Climate Policies

Daniel Huppmann and Franziska Holz

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**Daniel Huppmann | dhuppmann@diw.de| Department of Energy, Transportation, Environment at DIW Berlin**
**Franziska Holz | fholz@diw.de| Department of Energy, Transportation, Environment at DIW Berlin**

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Climate change mitigation and the transformation to a global low-carbon economy is a pressing issue in policy discussions and international negotiations. The political debate is supported by the scientific community with a large number of projections, pathway simulations and scenario analyses of the global energy system and its development over the next decades. These studies are often based on numerical economy-energy-environment-climate models.

This DIW Roundup provides an overview of the model types used in the academic arena to evaluate and quantify the potential impacts of energy and climate policy measures. Their aim is to translate specific mitigation pathways into an economic and socio-political assessment, in order to identify trade-offs between different mitigation options. Since no single modelling framework can adequately capture all relevant aspects, a comprehensive assessment requires a mix of models and approaches.

There are numerous policy initiatives that aim at reducing global warming and mitigating its adverse impacts. The European Union (EU) defined its "2030 framework for climate and energy policies", seeking to reduce greenhouse gas (GHG) emissions by 40 % in 2030 relative to 1990, increase the share of renewable energy to 27 % and improve energy efficiency by 27 % (EC, 2014). The US government also recently announced its energy strategy to reduce GHG emissions from the power sector, while several US states already launched their own emission cap-and-trade systems (http://www.whitehouse.gov/energy/). The UN Climate Change Summit in September 2014 in New York aimed to raise political momentum towards a comprehensive climate agreement at the 2015 summit in Paris as a successor to the "Kyoto Protocol" (http://www.un.org/climatechange/summit/).

In its most recent Assessment Report, the Intergovernmental Panel on Climate Change (IPCC, 2014, AR5) provides a comprehensive overview and compilation of the state-of-the-art of climate change science – and thereby touches upon the role of energy in a carbon-constrained world, since combustion of fossil fuels is currently causing the lion's share of global GHG emissions. It is beyond serious discussion that urgent action to mitigate global warming is required.

## Assessing the impact of policy measures requires numerical models

Limiting global warming to a certain range or threshold requires a substantial reduction of GHG emissions. Since energy consumption is the main driver of emissions and the power sector offers "low-hanging fruits" for decarbonisation, many studies focus on these areas for mitigation. The transition of the energy system towards a low-carbon – or even no-carbon – economy is of paramount importance.

Climate and energy policy interventions have many interdependencies and affect the economy and society at many levels, ranging from macro-economic effects to detailed technical-engineering or sector-specific considerations. Numerical models are therefore helpful to evaluate and quantify the impact of climate and energy policy measures. All such models critically hinge on various implicit and explicit assumptions, for example on the availability and costs of technologies in the future or the discount rate used to value future damages and benefits. There is an on-going debate in the academic community on the appropriateness of economy-energy-environment models (sometimes referred to as E3, with "climate" conceptually included in the "environment") given the caveats and critiques (Rosen and Guenther, 2014; Pindyck, 2013). Nevertheless, numerical models can at least illustrate pathways and trade-offs between different mitigation options. Their findings can thereby serve as useful reference in international negotiations and as benchmarks for national policy targets.

Projections and scenario analyses allow policy-makers to evaluate the trade-off between different policy options. These studies aim to translate different emission pathways, such as those presented in Figure 1, into an economic and socio-political assessment. One typical research question concerns the timing of policy intervention: early action implies relatively low costs while a delay of global concerted mitigation policies imposes a much higher burden. No meaningful mitigation policy, in contrast, increases the risk of catastrophic effects from climate change. Along a similar rationale, scenario analyses allow to gauge the impact of the availability (or non-availability) of specific low-carbon technologies (e.g., carbon capture and sequestration, CCS) on the cost of climate change mitigation action. Söderholm (2012) discusses the meaning and interpretation of economic costs in the energy and climate policy context in more detail.

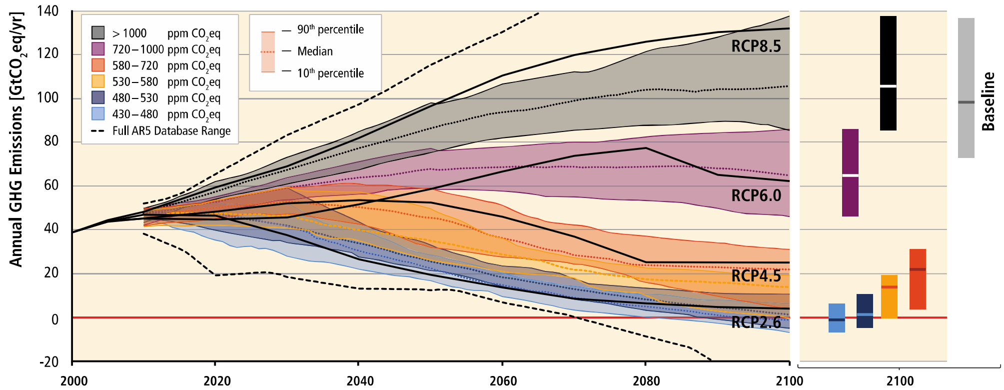


Figure 1: IPCC AR5, WG 3, Summary for Policymakers, page 11 (SPM.4):
Pathways of global greenhouse gas emissions in baseline and mitigation scenarios (emissions measured in Gigatons of carbon dioxide equivalents, $GtCO_2eq$; scenarios are grouped by the Representative Concentration Pathway, RCP, identified by the approximate radiative forcing in 2100 relative to 1750, and by the relative concentration of GHG in the atmosphere in parts per million, ppm)

Numerical modelling is also helpful in providing a quantification of "co-benefits" from climate change mitigation and low-carbon policies. Co-benefits are positive effects for the economy or society arising as a by-product of energy and climate mitigation interventions. For example, increasing domestic renewable energy production reduces the import dependency on fossil fuels from politically unstable regions; improving the efficiency of coal power plants not only lowers carbon dioxide emissions and thus mitigates global warming, but also improves air quality in the vicinity of the plant and thereby improves the health of the local population. These effects are difficult to quantify in monetary terms, but numerical models help to illustrate the trade-offs faced by policy-makers when weighing various policy options.

### Modelling the energy system – the devil is in the details

Numerous models were developed over the past decades to analyse the economy-energy-environment-climate complex. The broad range of approaches commonly used is a reflection of the many disciplines that work in this research area, from geophysicists and climate scientists to economists and engineers. In this Roundup, we do not attempt to provide a comprehensive list of models. Rather, we illustrate the most common approaches from an economist's perspective, explain the typical research question for which they are applied, and provide a few exemplary academic references.

There is an inherent trade-off in modelling the energy system, whether on a global scale or with a national focus: a broad research question requires an elaborate model, but the mathematical scope and computational capacity put a limit on the complexity that is practicable in real-world applications. At the same time, many questions with regard to energy – in particular infrastructure requirements – can only be adequately tackled if accounting for operational or seasonal detail. Researchers therefore set different priorities and models vary with respect to spatial disaggregation, the time horizon under consideration, and the level of detail in the representation of fuels and technologies (e.g., in power generation), as well as the characterization of technological progress over time. They also treat different variables as endogenous (determined by the model) or exogenous (taken as a given parameter from some external source or assumption).

The numerical modelling approaches can be broadly classified into four categories, although the distinction is not clear-cut and there is some overlap. The standard approach to investigate shifts and effects from policy changes within the economy are *computable general equilibrium* (CGE) models. The CGE approach is derived from a micro-economic formulation of representative economic agents maximizing their welfare. It uses elasticities of substitution between different inputs to production (e.g., capital and labour) as well as on the consumption side; hence, it is sometimes referred to as "top-down" modelling. Several CGE models specifically include energy as an input factor as well as a representation of emissions and climate policy (e.g., GEM-E3, Capros et al., 2013; GTAP-E, McDougall and Golub, 2007, Kemfert and Truong, 2007; MIT-EPPA, Jacoby, Reilly et al., 2006).

A drawback of using elasticities is that if an input or technology is not used in the base year, such models are rather inert. Therefore, they cannot easily result in large future penetration rates of these inputs even when economic considerations would warrant it. This is a significant disadvantage when modelling potentially "game-changing" technologies. There is also some controversy in the academic arena regarding the applicability of models based on micro-economic foundations. Hence, other approaches to represent the economy include models derived from (Keynesian) macro-economic considerations and econometric models built upon an empirical assessment of the correlation between important variables of the economy- energy-environment complex (e.g., E3ME, Pollitt, 2014; NEMESIS, Capros et al., 2014).

*Integrated assessment models* (IAM) such as REMIND (Leimbach et al., 2010) and ETSAP-TIAM (Loulou and Labriet, 2008) combine a representation of the economy with a more detailed environment and climate module. The term Integrated Assessment Model is used for a wide range of modelling approaches in the academic community, making it difficult to provide a generally valid definition of such models. These models typically have a global and long-term scope and explicitly capture the interaction between economic activity, the energy sector, and climate, including such aspects as the indirect emissions caused by land use change. Some IAMs also include the long-term evolution of climate and the atmospheric concentration of GHG, for example using a system dynamics approach.

In both IAM and CGE models, the energy sector can be embedded in the broader economy, thereby allowing for well-founded welfare analyses specifically including the interaction between economic activity and energy prices (Capellán-Pérez et al. 2013, Silva et al., 2010). However, due to the aggregation necessary to numerically solve such models, many details have to be omitted.

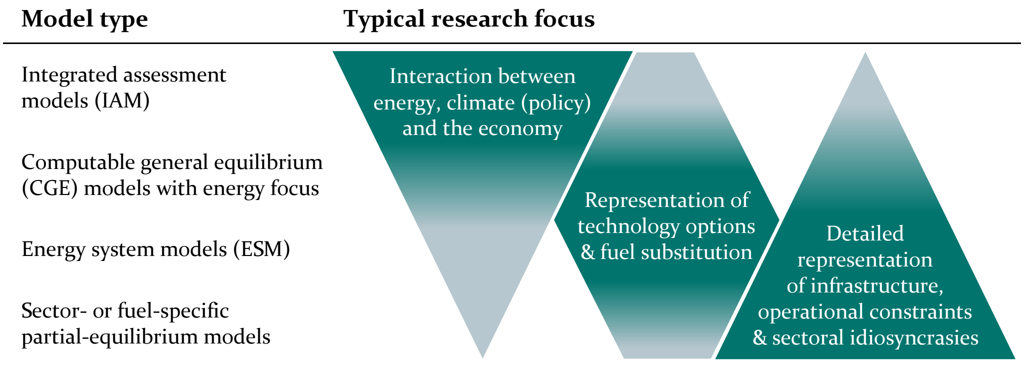


Figure 2: Illustration of the different modelling approaches and the respective typical research focus

*Energy system models* (ESM) – in contrast to CGE and IAM – abstract from other sectors of the economy and focus only on the energy sector. Because they neglect this interdependence and take many economic values such as interest rates or GDP growth as given parameters, they are called "partial-equilibrium" models. Their limited focus allows for a more detailed analysis of technical-engineering aspects. Examples include the PRIMES model used by the European Commission (EC, 2011) and the many applications based on TIMES-MARKAL (see http://www.iea-etsap.org). Such models are usually built up from the technical and operational considerations of the energy sector; therefore, this is often referred to as a "bottom-up" approach.

Lastly, *sector models* only cover one particular fuel – such as natural gas – or sector, for example power generation. This focus allows for the inclusion of a high level of detail with regard to market characteristics, infrastructure constraints (e.g., flow of electricity in a network), or variability over time. This is of particular relevance when considering the intermittency and limited predictability of renewable energy sources. Such models also allow investigating the infrastructure requirements for a achieving a certain low-carbon path, for example with a high penetration of renewable energies such as off-shore wind (cf. Egerer et al., 2013).

Furthermore, some models in this area of research have a detailed representation of the market structure and strategic behaviour by certain dominant players. Several studies recently used such models to investigate the Russian-Ukrainian natural gas crisis and the relevance of different infrastructure options (i.e., pipelines vs. Liquefied Natural Gas, LNG) on the European security of supply (e.g., Richter and Holz, 2014). These models are consequently the natural choice to investigate issues such as energy import dependency with regard to a particular fuel.

## Evaluating policy measures requires a mix of models

Climate and energy policy interventions have substantial impacts, ranging from macro-effects due to the interdependence between energy prices and economic activity to rather local and technical issues, for example the efficient operation of the domestic electricity grid in the face of variable renewable feed-in. Models covering the interaction between climate, energy and the economy are helpful to evaluate and quantify the impact of policy measures on the global macro-economic level. At the same time, detailed and focused approaches are necessary to ensure that the energy system resulting from a set of measures actually "works". Furthermore, political considerations such as an unacceptably high import dependency or welfare reallocation between different stakeholders must be evaluated with regard to national or regional priorities.

Since computational limits impose practical bounds on model scale and complexity, no model can credibly answer all relevant questions with regard to impact assessment. Researchers therefore either use a mix of models, where the results from a macro-economic model are checked for political and technical-economic feasibility by using more focused approaches, or they build hybrid models that combine aspects of different model types to answer specific research questions. Academic model comparison exercises such as the "Energy Modeling Forum" (http://emf.stanford.edu/) are important for the scientific community to better understand the advantages and caveats of different approaches and to gauge the sensitivity of numerical results and policy recommendations with regard to model formulations, input data and assumptions.

As a last remark, it must be said that climate and energy is a highly controversial policy area due to the large shifts and rent reallocations caused by the transformation of the energy system. In addition, projections regarding the global climate and regional impacts of global warming are inherently uncertain. The scientific community cannot provide "the optimal solution" (cf. Schellnhuber and Edenhofer, 2012). Rather, it can show scenarios and potential pathways, which serve to illustrate the trade-off between conflicting goals, and it can quantify expected risks and benefits in economic terms. The final decision, however, ultimately lies with policy-makers and the society at large.

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DIW Berlin – Deutsches Institut
für Wirtschaftsforschung
Mohrenstraße 58, 10117 Berlin

Tel. +49 (30) 897 89-0
Fax +49 (30) 897 89-200
http://www.diw.de

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