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The impact of climate change on the European energy system ☆

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HIGHLIGHTS

- Expanded coverage of climate change impacts on European energy system.
- Demand side impacts are larger than supply side impacts.
- Power from fossil and nuclear sources decreases, renewable energy increases.
- Impacts are larger in Southern Europe than in Northern Europe.
- Synergies exist between climate change mitigation and climate change adaptation.

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ABSTRACT

Climate change can affect the economy via many different channels in many different sectors. The POLES global energy model has been modified to widen the coverage of climate change impacts on the European energy system. The impacts considered are changes in heating and cooling demand in the residential and services sector, changes in the efficiency of thermal power plants, and changes in hydro, wind (both on- and off-shore) and solar PV electricity output. Results of the impacts of six scenarios on the European energy system are presented, and the implications for European energy security and energy imports are presented.

Main findings include: demand side impacts (heating and cooling in the residential and services sector) are larger than supply side impacts; power generation from fossil-fuel and nuclear sources decreases and renewable energy increases; and impacts are larger in Southern Europe than in Northern Europe.

There remain many more climate change impacts on the energy sector that cannot currently be captured due to a variety of issues including: lack of climate data, difficulties translating climate data into energy-system-relevant data, lack of detail in energy system models where climate impacts act. This paper does not attempt to provide an exhaustive analysis of climate change impacts in the energy sector, it is rather another step towards an increasing coverage of possible impacts.

1. Introduction

Climate change can affect the economy via many different channels in many different sectors. The energy sector may be one of the sectors of the economy most affected by climate change. Different climate impact categories were studied by Anthoff et al. (2011) in the estimation of the social cost of carbon, it was found that energy for cooling buildings and agriculture are the sectors with the highest marginal impacts.

Ciscar and Dowling (2012) showed that the field of analysis of climate change impacts on the energy system is in its infancy, and significant variation in results have been seen depending on the type of model used, the climate runs analysed, and impacts covered. Results are available from economic integrated assessment models (IAMs) which can be considered top-down models, and energy or climate IAMs using a bottom-up approach. Following is a brief summary of relevant literature.

The GRACE CGE model (an economic IAM) was used by Aaheim et al. (2009) to estimate climate impacts in Europe. They concluded that total energy demand fell as a result of climate change in Europe. While oil and gas demand fell (in a range from 1% to 10%) in all the eight European areas considered in the study, electricity demand in Southern Europe and the Iberian peninsula regions increased, due to higher cooling demand.

☆The views expressed are purely those of the authors and may not in any circumstances be regarded as stating an official position of the European Commission.

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Aaheim et al. (2009) used top-down modelling where they incorporated the findings of empirical literature in an IAM. The sector-specific, bottom-up modelling of van Vliet et al. (2012) focussed on the electricity generation sector, and consisted of a "physically based hydrological and water temperature modelling framework" to find "a summer average decrease in capacity of power plants of 6.3–19% in Europe … depending on cooling system type and climate scenario for 2031–2060."

Looking at building energy demand, Isaac and van Vuuren (2009) used a bottom-up approach by applying heating and cooling degree days in combination with a model employing output from the TIMER global energy model. They found that energy use for residential heating under a +3.7 °C scenario decreased by 25% in Continental Europe and part of Atlantic Europe between 2000 and 2050, and remained stable for the rest of Europe, while decreases from 18% to 43% were shown for 2050–2100. Cooling demand increased by 260% in Continental Europe and part of Atlantic Europe between 2000 and 2050 and by more than 4000% in the rest of Europe, after 2050 the increase slowed to 74–118%.

The size and complexity of the energy system offers many possible points where a wide variety of climate change impacts could act. Most studies investigating the impact of climate change on the energy system have concentrated on the impact of changes in heating and cooling demand, as found by Ciscar and Dowling (2012) in a review of how integrated assessment models (IAMs) have estimated climate impacts in the energy sector. There are many climate-induced impacts on the energy sector that remain unanalysed. This paper adds to the literature by extending the coverage of climate impacts on the energy sector. The impact of four climate scenarios on the European energy system is analysed using the POLES energy model. The POLES model (Prospective Outlook on Long-term Energy Systems) is a global partial equilibrium simulation model for the development of energy scenarios until 2050 housed in the European Commission's Joint Research Centre. The climate impacts analysed include changes in heating and cooling demand in the residential and services sector, changes in the efficiency of thermal power plants, and changes in hydro, wind (both on- and off-shore) and solar PV electricity output. This paper presents a brief description of the POLES model and the modifications completed for this analysis. Then results of the impacts of six scenarios on the European Energy system are presented with the implications for European energy security and energy imports are presented. This analysis was performed as a part of the European Commission's PESETA 2[1] project.

Whilst the climate impacts captured in this analysis go further than the current literature, there remain many more impacts that cannot currently be captured due to a variety of issues including: lack of climate data, difficulties translating climate data into energy-system-relevant data, and lack of detail in energy system models where climate impacts act. This paper does not attempt to provide an exhaustive analysis of climate impacts in the energy sector, it is rather another step towards an increasing coverage of possible impacts.

2. POLES description

The POLES[2] (Prospective Outlook for the Long-term Energy System) model is a global sectoral simulation model for the development of energy scenarios until 2050. The dynamics of the model is based on a year-on-year simulation process of energy demand and supply with lagged adjustments to prices and a feedback loop through international energy prices. The model is developed in the framework of a hierarchical structure of interconnected modules at the international, regional and national level. It contains technologically-detailed modules for energy-intensive sectors, including power generation, iron and steel, the chemical sector, aluminium production, cement making, non-ferrous minerals and modal transportation sectors (including aviation). The final energy demand in these sectors combines an income or activity variable elasticity, price elasticities, autonomous technological trends and, when necessary, saturation effects. Inter-fuel substitution equations also take into account both the rigidities of existing equipment flexibility and the flexibility of inter-fuel substitution for new equipment. Each demand equation combines, technological trends. The model delivers detailed energy balances. Emissions of all Kyoto gases are calculated for the sectors covered by the model.

The development of the model and of the corresponding scenario studies are used to produce detailed world energy system scenarios allowing the analysis of strategic areas for emission control policies, technologies development, marginal abatement costs for CO_2 emissions and the impacts on international markets and price feedback.

The POLES model breaks down the world into 47 regions, of which 31 correspond to countries and 16 correspond to countries aggregates. The model consists of four main modules for each region:

- Final energy demand by main sectors
- New and renewable energy technologies
- Electricity and conventional energy and transformation system
- Primary energy supply

This structure allows for the simulation of a complete energy balance for each region. Horizontal integration is ensured in the energy markets module of which the main inputs are the import demands and export capacities of the different regions. According to the principle of recursive simulation, the comparison of import and export capacities for each market allows for the determination of the variation of the price for the following period of the model. Combined with the different lag structure of demand and supply in the regional modules, this feature of the model allows for the simulation of under- or over-capacity situations, with the possibility of price shocks or counter-shocks similar to those that occurred on the oil market in the seventies and eighties.

The new and renewable energy module of the POLES model recognises the difference between technical and economical potentials, the time-constants which characterise the diffusion processes, and introduces elements such as "learning-curves" and "niche-markets" which allow for the dynamic development and diffusion of these technologies. Investment and dispatching decisions in the power generation sector are made based on minimising lifetime costs. The model makes these decisions using construction costs, fuel and maintenance costs, plant efficiencies, technical and economic potentials of renewables, endogenous electricity load-curves, plant lifetimes, must-run and merit-order technology groupings, and dynamic cost improvements via learning curves.

The electricity load-curve is endogenous and deduced from sectoral demand in the final demand module, through the use of load coefficients for two typical days of the year (summer and winter). Then the production corresponding to the different blocks of the load curve are calculated by taking into account the plant's variable costs and capacity constraints. In the end of the process, average full-costs for the satisfaction of baseload demand (relevant

[1] The objective of the PESETA project (Projection of Economic impacts of climate change in Sectors of the European Union based on bottom-up Analysis) is to make a multi-sectoral assessment of the impacts of climate change in Europe for the 2011–2040 and 2071–2100 time horizons. For more information go to: http://peseta.jrc.ec.europa.eu/

[2] For a more detailed description of the POLES model than that provided in this paper go to: http://ipts.jrc.ec.europa.eu/activities/energy-and-transport/documents/POLESdescription.pdf

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