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Comparing policy routes for low-carbon power technology deployment in EU – an energy system analysis

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ABSTRACT

The optimization energy system model JRC-EU-TIMES is used to support energy technology R & D design by analysing power technologies deployment till 2050 and their sensitivity to different decarbonisation exogenous policy routes. The policy routes are based on the decarbonised scenarios of the EU Energy Roadmap 2050 combining energy efficiency, renewables, nuclear or carbon capture and storage (CCS). A "reference" and seven decarbonised scenarios are modelled for EU28. We conclude on the importance of policy decisions for the configuration of the low carbon power sector, especially on nuclear acceptance and available sites for new RES plants. Differently from typical analysis focussing on technology portfolio for each route, we analyse the deployment of each technology across policy routes, for optimising technology R & D. R & D priority should be given to those less-policy-sensitive technologies that are in any case deployed rapidly across the modelled time horizon (e.g. PV), but also to those deployed up to their technical potentials and typically less sensitive to exogenous policy routes. For these 'no regret' technologies (e.g. geothermal), R & D efforts should focus on increasing their technical potential. For possibly cost-effective technologies very sensitive to the policy routes (e.g. CSP and marine), R & D efforts should be directed to improving their techno-economic performance.

1. Introduction

The power sector is a large player in energy related CO_2 mitigation and thus has been an important target within several European Union (EU) energy and climate policy initiatives. The key EU policy initiatives are summarised in Table 1. Correspondingly, the possible long term future layout of a low-carbon EU power sector and its technology mixes have been widely covered in scientific literature by using a number of models. For instance, Capros et al. (2012a) and Capros et al. (2012b) used the PRIMES partial equilibrium energy system model to assess the decarbonisation of the EU energy system until 2050. They conclude that it is feasible for the EU power sector to reduce its CO_2 emissions by 98% with respect to1990 levels by replacing coal and gas power plants with renewable energy resources (RES) based electricity (notably wind and solar PV) and carbon capture and storage (CCS) gas plants. This would be accompanied by an increase in electricity prices of 1.7–8.7% compared to a non-decarbonised scenario. A more recent study (Capros et al., 2014) performed a multi model analysis with partial and general equilibrium models to explore the required energy system transformations to reduce GHG emissions in 2050 to less 80% than 1990 levels. The authors conclude that decarbonising the EU power sector is a cost effective strategy to meet such a stringent emission cap, achievable via an increase in the share RES electricity, nuclear and CCS.

Similarly, an analysis of the Roadmap for moving to a low-carbon economy in 2050 undertaken with the general equilibrium model PACE (Hübler and Löschel, 2013) conclude that the electricity sector is crucial for decarbonisation but would lead to estimated increases in electricity prices between 18–67% in 2050 from 2005 values. Partial multi-region electricity sector models have also been used to develop decarbonised scenarios for the EU, such as Haller et al. (2012) concluding that a near complete decarbonisation can be achieved at "moderate costs" via solar PV, CSP and wind with expansion in transmission capacity within the EU. Jägemann et al. (2013) used an optimization model for the electricity sector to evaluate the economic implications of alternative energy policies for the EU's power sector, in particular assessing the implications of a nuclear phase out, CCS deployment and targets on the share of RES electricity, focusing on the synergies and competition among the three. At global level, the IPCC AR5 (Pachauri and Meyer, 2015) compares global climate mitigation pathways for the power sector and assesses mitigation cost increases in scenarios with limited availability of the following low-carbon technologies: CCS, solar/wind, bioenergy and nuclear, concluding that total discounted mitigation costs in 2015–2100, increase from 6% to 138%

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Table 1
Overview of key EU policy initiatives on energy and climate change with relevance to the power sector.

Policy initiative	Short description and role of power sector
Directive 2001/77/EC	National targets for increasing the electricity produced from renewable energy sources (RES) (European Communities, 2001).
Directive 2003/87/EC **Directive 2009/29/EC**	Important role of the power sector played within the EU greenhouse gas (GHG) emissions allowance trading scheme (EU ETS) including a possibility for free allocation of allowances in the first two phases (European Communities, 2003) and for transitional power plants in the current phase (European Communities, 2009a).
Directive 2009/28/EC	Special consideration of RES electricity in transport within the directive on the promotion of use of final energy from RES (European Communities, 2009b).
COM(2011) 112 final	The highest sectoral reductions for power sector CO_2 emissions (less 93–99% in 2050 compared to 1990) in the Roadmap for moving to a competitive low-carbon economy (European Commission, 2011b).
COM(2011) 885 final	The important role of the power sector in long term satisfaction of final energy demand and CO_2 mitigation in EU is clearly stated in the Energy Roadmap 2050 (European Commission, 2011a).
COM(2014) 15 final	The policy framework for climate and energy in the period 2020–2030 (European Commission, 2014) highlights that ensuring competition in integrated electricity (and gas) markets is necessary to implement energy policy objectives in a cost-efficient manner.

relative to default technology assumptions. Limited CCS has the biggest impact in mitigation costs increases, followed by limited bioenergy, nuclear phase out and limited solar/wind. All the authors seem to agree that the EU power sector will have to undertake major changes to meet strict decarbonisation targets and that the future portfolio of the EU power technologies will vary depending on factors such as climate policy decisions, electricity technology characteristics and sector policies (Jägemann et al., 2013).

In support to the EU decarbonisation objectives in this field of research, the EU Strategic Energy Technology Plan (SET Plan) (European Commission, 2007) established an energy technology policy for Europe aiming to accelerate the development and deployment of cost-effective low-carbon technologies. The SET Plan covers electricity generation technologies, such as RES, sustainable nuclear fission and advanced fossil fuels. Furthermore, it addresses electricity grids, smart cities, hydrogen and fuel cells, energy efficiency, and low-carbon industrial processes across a range of sectors. Under the 2020 climate & energy policy package, the SET Plan has increased EU-wide R & D investments in energy technologies from €3.2 to €5.4 billion per year (European Commission, 2014), but according to the 2030 climate & energy policy framework the EU will have to step up its efforts on research and innovation policy to support the post-2020 climate and energy framework. For this purpose, it is necessary to reflect on how and with which priorities R & D investments should be allocated (European Commission, 2014).

This paper takes into account this call for priority setting regarding energy technologies and goes beyond current literature by comparing how different ‘exogenous policy routes’ for decarbonisation affect the deployment of the SET Plan power sector technologies across scenarios. The EU Energy Roadmap 2050 (European Commission, 2011a) used decarbonised scenarios to explore “routes towards decarbonisation of the energy system” that combine “four main policy directions to decarbonisation”: energy efficiency, renewables, nuclear or CCS. Similarly, in the context of this paper, ‘exogenous policy routes’ are exogenous assumptions introduced into the modelling exercise as decarbonised scenarios reflecting energy policy topics affecting power decarbonisation, akin to the scenarios of the EU Energy Roadmap 2050. However, whereas the EU Energy Roadmap 2050 and current literature typically present results as portfolios of low-carbon power technologies for each decarbonised scenario (Capros et al., 2012a, 2014), this paper also looks into the technologies' cost-effectiveness across scenarios. This is useful for assessing how the assumed ‘policy routes’ affect the interplay between low-carbon power technologies thus informing energy technology policy-making and identifying ‘no-regrets’ options. The former approach (Capros et al., 2012b, 2014) is possibly more adequate for supporting less technology specific climate mitigation targets. In addition, long-term energy system modelling exercises are subject to uncertainty from assumptions and from the definition of boundary conditions. Thus, understanding how sensitive the results are to the scenarios' design assumptions is as vital as analysing the interplay of technology substitution.

For this analysis, the energy system model JRC-EU-TIMES for the EU28 from 2005 till 2050 is used to model in total eight scenarios, one of which is used as reference (Current Policy Initiatives scenario, hereafter named CPI) and includes the 20-20-20 policy targets. All other seven scenarios are decarbonised scenarios since they all have a CO_2 reduction cap of 85% below 1990 values in 2050. The CAP85 scenario only has this CO_2 reduction cap. The other six decarbonised scenarios were designed to reflect ‘exogenous policy routes’ assumptions in addition to the CO_2 cap. The assumptions direct the model towards different technological routes for decarbonisation as follows: smaller contribution of CCS (DCCS); higher social acceptance and facilitated permitting of RES plants (HRES); higher social acceptance of nuclear plants (HNUC); stricter and more effective end-use energy efficiency requirements (LEN); lower biomass availability for the energy system following concerns with nature conservation and food production (LBIO); and higher concerns with ensuring the reliability of transmission and distribution, reducing the share of intermittent variable solar and wind electricity (LSW). The CAP85 scenario is left without a policy route other than carbon mitigation to serve as a benchmark for comparing technology deployment in a long-term decarbonisation context. The paper is structured as follows: in the following section methods and assumptions underlying the modelling are detailed. Section 3 and Section 4 respectively present results and discuss its limitations, while Section 5 concludes.

2. Methods

2.1. Overview of the JRC-EU-TIMES model

JRC-EU-TIMES is a linear optimization bottom-up energy system model generated with the TIMES model generator from Energy Technology Systems Analysis Program (ETSAP) of the International Energy Agency (Loulou et al., 2005a, 2005b). The spatial coverage of JRC-EU-TIMES is the EU28 energy system plus Switzerland, Iceland and Norway (hereafter referred to as EU28+), where each country is specifically modelled. Timewise, the model covers the period from 2005 to 2050 and each year is divided in 12 time-slices that represent an average of day, night and peak demand for every one of the four seasons of the year. More information on the model, including a detailed description of its inputs, can be found in Simoes et al. (2013).

The equilibrium is driven by the maximization (via linear programming) of the discounted present value of total surplus, representing the sum of producers and consumers surplus, which acts as a proxy for welfare in each region of the model. The maximization is subject to constraints, such as: supply bounds for the primary resources, technical constraints governing the deployment of each technology, balance constraints for all energy forms and emissions, timing of investment payments and other cash flows, and the satisfaction of a set of exogenous demands for energy services in the modelled sectors of the economy, namely: industry; residential; commercial; agriculture; and transport. These demands drive the activity of the primary energy supply and electricity generation sectors, which are endogenous to the model.

As a partial equilibrium model, JRC-EU-TIMES does not model the economic interactions outside of the energy sector, although it considers price elasticities of the energy service demands. JRC-EU-TIMES also does not consider non-rational aspects that condition investment in new and more efficient technologies.