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ANALYSIS

Description of models and scenarios used to assess European decarbonisation pathways☆

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ABSTRACT

This study describes the models employed, the main scenario constraints and the energy and climate policy assumptions for a companion study on "European decarbonisation pathways under alternative technological and policy choices: A multi-model analysis". We describe the main characteristics, the coverage and applications of seven large-scale energy-economy EU models used in the aforementioned study (PRIMES, GEM-E3, TIMES-PanEu, NEMESIS, WorldScan, Green-X and GAINS). The alternative scenarios modelled and the underlying assumptions and constraints are also specified. The main European energy and climate policies assumed to be implemented in the Reference scenario are outlined. We explain the formula used for the decomposition of carbon emissions reduction achieved in the basic decarbonisation scenario relative to the reference. Detailed model results for the power generation mix and RES deployment in the basic decarbonisation scenario in the EU are also presented. We conclude the description of our modelling approach with a brief comparison of the strengths and weaknesses of the models used.

1. Introduction

In their study titled "*European decarbonisation pathways under alternative technological and policy choices: A multi-model analysis*" [1], Capros et al. explore the required energy system transformations and the associated costs incurred for the EU in order to meet the decarbonisation targets as specified in the EU Roadmap 2050 [2,3], i.e. the 80% GHG[1] emissions reduction target and the equivalent carbon budget by 2050. For this purpose the authors employ seven large-scale energy-economy models, namely PRIMES, GEM-E3, TIMES-PanEu, NEMESIS, WorldScan, Green-X and GAINS, which have been extensively used for the assessment of EU energy and climate policies, in order to simulate alternative EU decarbonisation pathways under technological limitations and climate policy delays. A multi-model inter-comparison analysis is undertaken with regard to decarbonisation strategies, energy system restructuring, associated energy system costs and further macro-economic implications incurred for the EU. The authors expand the model-based analysis provided in the EU Roadmap study [3] by using a variety of well-established energy-economy models for the EU, by considering alternative technological limitations and by combining climate policy delays with technological failures. The multi model analysis provides a thorough investigation of the costs of achieving the emissions reduction targets set by the EU and offers valuable insights for the design and formulation of robust energy and climate policies. The results show that the EU decarbonisation target is feasible with

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

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[1] Greenhouse Gases.

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currently known technological options at low costs. The model results also confirm the EU Roadmap priorities for 2050 on high energy efficiency improvements, extensive transport electrification and high RES,[2] CCS[3] and nuclear deployment. Decarbonisation targets are found to be achieved even in cases of technological limitations regarding CCS and nuclear technologies. Delaying emission reduction action until 2030 is found to have significant adverse effects on cumulative energy system costs for the period 2010–2050.

This paper complements in several ways the aforementioned study [1]. Towards this end the paper provides: i) a detailed discussion of the main characteristics of the seven energy-economy models used, including their methodological approaches, theoretical foundations, exogenous assumptions and sectoral and regional coverage, ii) a thorough analysis of the series of scenarios simulated with the aforementioned large-scale models, iii) an extension at a considerable level of detail of the Reference scenario design and the main energy and climate policy assumptions simulated, iv) a presentation of the methodological approach used to decompose carbon emissions reductions in the decarbonisation scenarios relative to the reference and v) an enhancement of the discussion on modelling approaches employed in Ref. [1] with the comparative analysis of the main strengths and weaknesses of the alternative models used.

In this way the paper aims at adding in a systematic way to methodological approaches and simulation alternatives used to model EU energy and climate policies. The thorough review of the methodological approaches of the seven EU energy-economy models is carried out for the first time at such an extent with the aim to improve the transparency of the models used, to enhance the understanding of the model structures and differentials and thus to facilitate future modelling of the energy-economy system. The Reference scenario serves as the benchmark against which the alternative scenarios are studied and compared. The specification of the Reference scenario includes a very detailed assessment of the various energy and climate policies that are already firmly decided by the EU and the member states. The detailed presentation of the series of decarbonisation scenarios complements the discussion on energy and climate policies in the EU and can provide the basis for the future design of similar scenarios for exploring alternative European decarbonisation pathways under technological limitations and climate policy delays.

The remainder of the paper develops as follows: Section 2 describes the models employed in Ref. [1]. Section 3 presents the detailed specifications for the series of the alternative scenarios simulated. Section 4 summarizes the main EU energy and climate policies implemented in the Reference scenario. The methodology used for emissions reductions' decomposition is presented in Section 5, while Section 6 discusses the model results for the EU power generation mix and RES penetration in the basic decarbonisation scenario. Last section compares the strengths and weaknesses of the models used in the study and concludes.

2. Description of models

The following subsections summarize the main characteristics and applications of the seven large scale EU energy-economy models employed in Ref. [1].

2.1. The PRIMES model

The PRIMES model [4] has been extensively used for energy and climate policy analysis providing key input for benchmark studies of the European Commission [2,3,5]. Other model applications include studies of Refs. [6–8].

PRIMES is a modelling system that simulates a market equilibrium solution for energy supply and demand for the current 28 EU member states until 2050 by five-year periods. The model determines the equilibrium by finding the prices of each energy form such that the quantity producers find best to supply matches the quantity consumers wish to use. The equilibrium is static (within each time period) but repeated in a time-forward path, under dynamic relationships. The model is organised in modules which interact via the exchange of fuel quantities and prices, leading to the overall equilibrium of the energy system.

The model is organized in sub-models (modules), each one representing the behaviour of a specific (or representative) agent, a demander and/or a supplier of energy. The agent's behaviour is modelled according to microeconomic foundation: the agent aims to maximise its benefit (profit, utility, etc.) from energy demand and/or supply, under constraints that refer to activity, disposable income, comfort, energy equipment, technological options, environment or fuel availability. The agent is assumed to be a price-taker as energy demander and a price-maker as energy supplier, depending on assumptions about the prevailing market competition regime. All economic decisions of the agents are dynamic and concern both operation of existing equipment and investment in new equipment. The agent's investment behaviour consists of building or purchasing new energy equipment to cover new needs, or retrofitting existing equipment or even for replacing prematurely old equipment for economic reasons. Microeconomic foundation is a distinguishing feature of the PRIMES model and applies to all sectors. Although the decision is assumed to be economic, many of the constraints and possibilities reflect engineering restrictions. The model thus combines economics with engineering, in order to ensure consistency. PRIMES is more aggregated than engineering models and far more disaggregated than econometric (or reduced form) models.

All formulations of agent behaviour consider explicit energy technologies, either existing or expected to become available in the future. The technology selection decisions depend on technical-economic characteristics of these technologies, which change over time either autonomously (exogenous) or because of the technology-selection decisions (learning and scale effects). The agent's investment behaviour, the purchasing of durable goods and the energy saving expenditures involve capital investment, which enter the economic calculations as annuity payments for capital. Annuity payments depend on a (real) interest rate which is assumed to be specific to each agent (sector). Energy prices are calculated from supply costs, fossil fuel import prices and infrastructure costs depending on assumptions about the prevailing market competition regime and price regulations. The prices influence energy demand and so the model simulates a closed loop between energy demand, supply and prices. The model incorporates alternative policy instruments that influence energy demand, supply and prices, such as: taxes and subsidies, tradable certificates, tradable emission allowances, emission limitation standards, energy efficiency performance standards, obligations (e.g. for renewables, CHP,[4] etc.) and technology push mechanisms (e.g. promotion of energy savings). Final energy demand in PRIMES comes from three main sectors: industry, domestic (which includes households, services and agriculture) and transport (both private and public transport are included). Within these broad categories the model identifies a variety of subsectors and explicit specific energy uses.

PRIMES includes 72 different plant types per country for the existing thermal plant types, 150 different plant types per country for the new thermal plants and 30 different plant types per country for intermittent

[2] Renewable Energy Sources.

[3] Carbon Capture and Storage.

[4] Combined Heat and Power.