Overview of the European Commission's energy and climate policy-related modeling suite

European Commission

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Introduction

For well over a decade, the European Commission has been using computational models for system analysis of energy use and greenhouse gas emissions to support policy development in the Ministries of the 27 Member States of the European Union. The modeling tool kit consists of a series of interlinked models, combining different technical and economic methodologies and covering both energy systems models and macroeconomic approaches.

For example, energy system modeling has been used to define the targets for greenhouse gas emissions reduction, renewable energy deployment, and energy efficiency both for 2020 and 2030. The procedures of the European Union[1] require the European Commission to carry out an analysis of the costs and benefits for these policy initiatives, including an analysis of the investment needed for the energy transition.

Energy systems and greenhouse gas modeling

In particular, the modeling suite around the Price-Induced Market Equilibrium System (PRIMES) energy system model underpinned the quantitative analysis of the major energy and climate policies of the EU. To estimate energy demand, a macroeconomic computable general equilibrium model (CGE) model, General Equilibrium Model for Economy-Energy-Environment (GEM-E3) is used to disaggregate GDP and population projections in sectoral economic activity.[2] For energy models such as PRIMES, economic activity and population dynamics are necessary inputs to obtain projections for energy use and emissions. The PRIMES model is further coupled with models for non-CO_2 emission projections (the GAINS model), projections of land use, land-use change, and forestry (LULUCF) emissions and removals (the GLOBIOM/G4M model) and agricultural activity (the CAPRI model).[3]

Central to the modeling suite, the PRIMES model allows multiple policy targets to be handled via dual variables (shadow prices) associated with policy constraints (e.g., climate and energy targets).[4] This approach is useful for analyzing emissions reduction, energy efficiency, and renewables' targets simultaneously. The model also allows explicit modeling of carbon pricing and other specific energy and climate policies (for example, biofuels targets or the phaseout of specific technologies). It incorporates technology dynamics, such as how new, more efficient equipment gradually substitutes the old, changing the performance of the stock through the diffusion of successive generations of technology. This allows a detailed representation of technological progress and addresses behavioral choices. PRIMES provides detailed projections of energy demand, supply, prices, and investment, covering the entire energy system, including emissions from energy combustion and industrial processes up to 2050.[5]

Energy system models include a detailed description of technologies and technology development, whereas CGE modeling is often considered too static and not well suited to handle technological change. The PRIMES energy system model includes an extensive description of technology costs and performance, which can be integrated into CGE modeling to enable a robust impact assessment.[6] However, while the costs of several technologies are expected to decrease in the mid and long term, there is considerable uncertainty about these assumptions. To limit the uncertainty related technology evolution, these assumptions are based on published studies and checked with expert stakeholders.

1 See the Better Regulation Guidelines for details: https://commission.europa.eu/law/law-making-process/planning-and-proposing-law/better-regulation/better-regulation-guidelines-and-toolbox_en
2 Macroeconomic models, including GEM-E3 and E-QUEST, are also used to estimate the impact of policy measures on macroeconomic aggregates. See the sections below dedicated to these models.
3 For more details on these models, see https://climate.ec.europa.eu/eu-action/climate-strategies-targets/economic-analysis/modelling-tools-eu-analysis_en
4 The sectoral modules of PRIMES are described in more details in the EU Reference Scenario report (European Commission, 2021).
5 Projections are available up to 2070; however, such a long time horizon is rarely used in policymaking.
6 See, for example, the catalogue of technology assumption used for the 2040 Climate Target (European Commission, 2024) published online at 2040 climate target - European Commission (europa.eu).

Besides an extensive set of energy variables, the modeling suite allows to calculate greenhouse gas emissions and system costs. In particular, projections are available for system costs (both CAPEX and OPEX), annualized investments, fuel costs, power prices for final consumers, among other key indicators. The Impact Assessment of the 2040 Climate Target provides a recent example of an analysis of costs and investments (see in particular Section 6 of Part 1/5 and Section 2 of Part 3/5 in European Commission, 2024).

This modeling suite contributed to all major energy and climate policy initiatives for the European Union. Recent analyses include: the Fit-for-55 legislative package, the REPowerEU plan and the 2040 Climate Target.[7] The impact assessments of these proposals include extensive analyses of the socioeconomic impacts of the proposed measures. The coupling of the energy system and greenhouse gas modeling with various macroeconomic models allows us to assess changes in economic activity and employment by sector; energy expenditures for households or revenues from carbon pricing, thereby delivering a rich set of projections for energy and climate policy analysis.[8]

METIS is another energy system modeling software for the European electricity, gas, heat, and hydrogen sectors. It simulates *the short-term operation* of energy systems across the EU and neighboring countries.

The model allows the hour-by-hour simulation of Europe's energy systems for up to one year, considering uncertainties such as weather variations. It consists of a number of interconnected modules that can be easily adjusted or added to, depending on the scope of the system to study (e.g., electricity, gas, hydrogen, heat). The model can be used, for example, to analyze multi-energy systems integration, power and hydrogen network investments, energy infrastructure requirements, the climate-energy nexus, market price behavior, and design principles.

METIS was developed for the European Commission through several contracts, which also included a series of METIS studies. The Commission's Directorate-General for Energy and the Joint Research Centre (JRC) use the model to provide quantitative evidence for legislative proposals related to energy markets and infrastructure. It is one of the main tools within the Commission to assess dynamics (e.g., price shocks in relation to geopolitical events) and policy measures in short-term energy systems and markets.

METIS has recently been used to support legislative proposals and documents by the European Commission on the reform of the electricity market design (European Commission (2023)), power and gas infrastructure, and the Projects of Common Interest (PCI) process. It has also been instrumental in price-setting (Gasparella et al., 2023) and flexibility assessments (Koolen et al., 2023) in electricity markets, as well as in assessing the uptake of an EU hydrogen network.

The Commission regularly complements PRIMES and METIS with other energy system models. Prospective Outlook on Long-term Energy Systems (POLES), a global energy model, is used to obtain projections for the rest of the world. POLES is used to produce the Global Energy and Climate Outlook (GECO),[9] which is published annually by the JRC. This model is utilized, for example, in international climate negotiations. Policy-Oriented Tool for Energy and Climate Change Impact Assessment (POTEnCIA), serves as a European energy system model and is used as a complement to PRIMES, for instance, to check the robustness of results.

7 See European Commission (2020, 2022, and 2024).

8 An extensive description of technologies and emissions abatement options is needed to correctly estimate costs. PRIMES relies on a wide range of sources, including extensive sets of technology databases (JRC IDEES, ODYSSEE-MURE, ICARUS among others) to underpin the estimates. For more information, visit https://web.jrc.ec.europa.eu/policy-model-inventory/explore/models/model-primes/

9 For more details, see GECO at https://joint-research-centre.ec.europa.eu/scientific-activities-z/geco/geco-2023_en, POLES at https://joint-research-centre.ec.europa.eu/poles/model_en, and POTEnCIA at https://joint-research-centre.ec.europa.eu/scientific-tools-databases/potencia-policy-oriented-tool-energy-and-climate-change-impact-assessment-0_en

Macroeconomic models

Energy system and greenhouse gas modeling can be effectively combined with macroeconomic analysis to evaluate climate policy proposals.

The JRC operates the JRC-GEM-E3 model, which has been used to estimate the impacts of climate and energy policies on the macroeconomy (e.g., GDP and its components) and sectors (e.g., sectoral output, trade, employment). CGE models have a highly granular sectoral representation of the economy. Since energy and climate policies affect various sectors differently, these models are particularly well-suited to track the cross-sectoral impacts, providing a clearer picture of the macroeconomic effects throughout the economy. In order to capture fast changes in key sectors (e.g., the transition to renewables in the power sector, the roll out of electric vehicles in transportation, and the electrification of buildings), the CGE model is linked with the PRIMES model to incorporate information describing the transition in key sectors. The JRC-GEM-E3 model therefore serves to provide economy-wide context to the energy model scenarios, taking into account changes in aggregate investment, and it is well suited to cover interactions between sectors and regions (e.g., to assess leakage and international competitiveness aspects). In addition, post processing of JRC-GEM-E3 results can show distributional impacts including revenue recycling and labor market impacts by skill/occupation.

The European Commission's Directorate-General for Economic and Financial Affairs contributes with its in-house model, E-QUEST, a sectorally disaggregated dynamic equilibrium model designed to evaluate and quantify the macroeconomic effects of climate mitigation policies. E-QUEST (see Varga et al., 2022) is part of the family of energy-extended dynamic stochastic general equilibrium models (E-DSGE) used by other international organizations such as the European Central Bank and the International Monetary Fund, tailored for assessing climate policy scenarios.[10] For computational reasons, the sectoral disaggregation of E-DSGE models is significantly more limited than large-scale CGE and input-output models. The E-DSGE class of models is well-suited to undertaking (counterfactual) policy analysis. In particular, their explicit microfoundations and dynamic (forward-looking) optimization features enable the analysis of how households and firms respond to policy changes and expectations over time. This feature is crucial in the context of climate policy commitments, as investment decisions on the deployment of climate-friendly technologies are inherently forward-looking and heavily influenced by the projected profitability advantage of these technologies. To ensure consistent comparisons across macro-modeling outputs for EU climate policy assessments, E-QUEST also relies on the emissions trajectories generated by the PRIMES model under the reference scenarios.

E-QUEST has been featured in major climate policy impact assessments over the past five years. In the 2030 Climate Target Plan assessment (European Commission, 2020), E-QUEST highlighted the importance of effective recycling carbon tax revenue. Using this revenue to reduce distortionary taxes, such as a labor tax on low-skilled workers, or to subsidize clean technologies, can significantly mitigate the negative GDP effects of carbon pricing policies by 2030.

In the 2040 Climate Target Plan assessment (European Commission, 2024), E-QUEST demonstrated that while early implementation of climate mitigation policies incurs higher costs, it offers compelling reasons for achieving ambitious climate targets sooner. The simulations indicate that credible and ambitious policies can boost productivity gains through early investments, whereas delays and ambiguous signals lead to underinvestment in green technologies.[11]

In the context of rising energy prices, the assessments show that income policy measures—unlinked to current energy consumption—are more effective at reducing greenhouse gas emissions than fuel

10 See Carton et al. (2023) on the IMF's GMMET model and Coenen et al. (2023) on the ECB's NAWM-E model.

11 This analysis capitalized extensively on the forward-looking optimization feature of DSGE models, which is absent in recursive dynamic or static CGE models.

tax cuts. Fuel tax subsidies increase EU reliance on fossil fuel imports and counteract climate targets.[12]

These model applications demonstrate that DSGE models, often used by central banks and MoFs in EU member states for fiscal and monetary policy analysis, can be extended to incorporate energy and environmental aspects. Moreover, incorporating endogenous technological change and investment in research and development (R&D) is a critical area for future development of E-DSGE models, which are particularly important for assessing the effectiveness of climate policies. The forward-looking nature of R&D investment decisions makes E-DSGE models, with their dynamic framework, particularly well-suited to analyze these aspects compared to static or recursive dynamic CGE models.

This overview shows that the key aspect of the European Commission's analytical work in supporting policy is that it relies on a suite of models, which allows different aspects of specialized models to be covered in a consistent way. Multiple models are in use to structure the discussion around the main transmission channels, helping policymakers assess the trade-offs of various policies across multiple dimensions (see also Weitzel et al., 2019).

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