



Simulating climate and energy policy with agent-based modelling: The Energy Modelling Laboratory (EMLab)

Emile J.L. Chappin ^{a, b, *}, Laurens J. de Vries ^a, Joern C. Richstein ^{a, c},
Pradyumna Bhagwat ^{a, d}, Kaveri Iychettira ^a, Salman Khan ^a

^a Delft University of Technology, Faculty of Technology, Policy and Management, Jaffalaan 5, 2628 BX Delft, The Netherlands

^b Wuppertal Institute for Climate, Environment and Energy, Döppersberg 19, 42103 Wuppertal, Germany

^c DIW Berlin, Mohrenstrasse 58, 10117 Berlin, Germany

^d Florence School of Regulation, RSCAS, European University Institute, Il Casale, Via Boccaccio 121, I-50133, Florence, Italy

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ABSTRACT

We present an approach to simulate climate and energy policy for the EU, using a flexible and modular agent-based modelling approach and a toolbox, called the Energy Modelling Laboratory (EMLab). The paper shortly reviews core challenges and approaches for modelling climate and energy policy in light of the energy transition. Afterwards, we present an agent-based model of investment in power generation that has addressed a variety of European energy policy questions. We describe the development of a flexible model core as well as modules on carbon and renewables policies, capacity mechanisms, investment behaviour and representation of intermittent renewables. We present an overview of modelling results, ongoing projects, a case study on current reforms of the EU ETS, and we show their relevance in the EU context.

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1. Introduction

We face inherent uncertainties regarding how our energy infrastructures can be shaped towards our policy objectives of a sustainable, affordable and secure supply of energy. While policy objectives are becoming more ambitious and firm, i.e. the COP21 agreement in Paris, it is yet unclear what would constitute the best set of policies for an effective and efficient transition. We cannot just rely on targets and we cannot expect the market to act by itself (Stern, 2006). The question is how to intervene in the complex dynamics of our energy infrastructures (Chappin and Dijkema, 2015).

In this paper, we present an agent-based modelling approach for designing and evaluating energy and climate policy. We do so with modular approach aiming to represent much detail of European electricity systems (cf. a complicated model as described in (Sun et al., 2016)). Therefore, the core objective of this paper is to illustrate how agent-based modelling can support energy and climate policy

analysis. We focus on our model of the decarbonisation of the power sector, in particular on how energy and climate policy affects investment in electricity generation. The effects of policies, such as the European emissions trading scheme (Zhang et al., 2011), are core to the analysis. The Energy Modelling Laboratory (EMLab) was developed to complement existing approaches in analysing policies for improving the EU emissions-trading scheme (EU ETS). This includes national CO₂ price restrictions, the interaction of the EU ETS with national renewables policies and policy schemes for maintaining security of electricity supply under large scale renewables deployment. At the end of the day, we aim to contribute to the methodological question of how to model the impacts of interventions in complex dynamic systems.

The decarbonisation of the power sector requires large investments. These investments are risky: they are capital intensive, the regulatory framework is in flux and the costs of resources such as fuel and CO₂ are uncertain. The long lead times of investments (due to permitting and construction times) and the long life cycles of power sector assets create a delayed response and a physical path dependence. As a result, the power system is never in a long-term economic equilibrium. Imperfect behaviour of actors, such as investor and consumer risk aversion complicates the sector

* Corresponding author. Delft University of Technology, Faculty of Technology, Policy and Management, Jaffalaan 5, 2628 BX Delft, The Netherlands.

E-mail address: e.j.l.chappin@tudelft.nl (E.J.L. Chappin).

dynamics. Policy instruments may affect the objectives of other instruments; for example, renewable energy support affects generation adequacy as well as CO₂ policy. These instruments may also create spill-over effects into adjacent markets with which electricity is exchanged, e.g. in the form of cheap exports and/or price volatility.

These factors need to be modelled in order to analyse the expected effectiveness of policy interventions. A policy that is aimed at stabilizing the system such as a capacity market or the Market Stability Reserve in the European Emission Trade System cannot be modelled with an equilibrium model. Such a model would assume the problem away, rendering an intervention by definition useless. Compound effects of multiple instruments, risk aversion of actors, physical path dependence and cross-border effects are also difficult to model with conventional models. Agent-based modelling can handle these aspects more easily. In this paper, focus on how to design an ABM that is suited for answering these types of questions.

The structure of this paper is as follows: we illustrate the modelling questions that matter for the energy transition and outline the complementarity of agent-based modelling to current approaches (section 2), we describe the modelling laboratory (section 3), the main research projects and results were obtained with using it (section 4), supported by a case study about the improved proposal for the Market Stability Reserve (section 5) and end with conclusions (section 6).

2. Modelling policies for the energy transition: existing approaches, challenges and the need for an agent-based toolbox

Currently the policy objective in Europe is to decarbonize the electricity sector in the next decades. In this section, we highlight the challenges for energy and climate policy modelling, we introduce three dimensions to analyse existing modelling approaches, we shortly review the existing approaches and the need for an agent-based toolbox. We start from the desire to explore what the likely consequences are of (proposed) energy and climate policies with respect to achieving the policy objective(s) of energy saving, renewables and CO₂ reduction. At the same time the energy and climate goals shall be in line with preserving affordability and security of energy supply. Numerous climate and energy policy instruments are needed to drive these radical changes; the most important climate policy in Europe is the EU emissions-trading scheme (EU ETS). The ongoing efforts to improve the performance of the EU ETS (Richstein, 2015), and the debate around the German 'Energiewende' (Buchan, 2012) illustrate the huge challenge of getting the 'right' policies in place for achieving the said objectives.

2.1. The need for policy modelling

For the case of climate and energy policy, it is difficult to determine without modelling what the side effects of policies are, because of the following sources of complexities in the system:

- **Cross-policy effects.** The performance of various policies may be affected because they interact with others, for instance renewables policies interact with decarbonisation policies, because renewables are also options that reduce carbon emissions.
- **Cross-border effects.** The various physical infrastructures and markets of European countries are linked, which means that cross-border effects of neighbouring countries may influence policies in place and should be considered.

- **Imperfect foresight.** Substantial reductions in CO₂ emissions need to be achieved by investments in low carbon technologies. Investments are made by heterogeneous actors, each deciding on the basis of their own preferences, on the basis of interactions with others, on the basis of their own belief system of the policies in place. Decisions to reduce energy consumption or invest in low carbon technologies are, therefore, not based on perfect forecasts and only financial reasons.
- **Lumpiness of investment.** Furthermore, investment decisions are highly capital intensive, so each individual decision matters: any investment made influences additional opportunities to invest.
- **Differences in actor behaviour.** In reality, significant differences exist between actors with respect to their preferences and assets (Groot et al., 2013). These differences affect their investment decisions.
- **Path dependence.** Climate and energy policies essentially target long-term changes in large-scale systems. All effects that play out dynamically over time need to be taken into account in order to have a realistic analysis of any of the policies. Over the course of decades, unwanted side effects may emerge out of the decisions made over time. In the long run, path dependency creates lock-in effects (Chappin and Dijkema, 2015), which, in turn, could make the energy transition costly and slow.

In order to explore the possible effects of energy and climate policies, these complexities need to be somehow explored.

2.2. Framework for energy policy modelling traditions

Modelling traditions differ with respect to the methodology and logic with which they evaluate policy instruments. We distinguish the approaches among the three dimensions in Fig. 1: how models deal with time (x-axis) because of the strong path dependence of investments, how they deal with scope (y-axis) because decarbonisation involves strong interdependencies between different subsystems and depends on many factors, and how they deal with uncertainty (z-axis) because large investments are strongly dependent on uncertain future developments.

With respect to the **time horizon and resolution**, some models are used to study today's energy systems and evaluate their dynamics with a focus on short time scales. These models thus focus on how to get the energy transition going, rather than the structural changes that need to follow along the way. For instance, what can we expect from the CO₂ price in the near future and what investment incentive for low carbon technologies can we expect. This can lead, for instance to an estimation of the need for or the cost of a policy instrument in the short to medium term. Models those are strong at representing today's energy systems often have a high resolution, and contain a large amount of data, which limits their scope to the short and medium term.

At the other end, modelling studies can simulate a possible future end-state of an energy system. These essentially are similar to the short and medium time scale questions, but placed in the future. Simulations include technological choices under ideal, minimal societal cost conditions and determine the technological composition of the energy system in a particular future year. This results in visions on the energy mix in the next decades after the energy transition, and how a hypothetical energy system may function: what dynamics of the system can be expected, what electricity prices may be, how welfare may be distributed. It also allows a reference for parts of the system, such as the business case for energy storage, demand response, or grid expansion.

In between are the models that deal with energy transition pathways, which need to consider long-term dynamics. Typical are

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