Modelling the transition to a low-carbon energy supply

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A transition to a low-carbon electricity supply is crucial to limit the effects of climate change. Reducing carbon emissions could help prevent the world from reaching a tipping point where runaway emissions are likely. Runaway emissions could lead to hot extremes in most inhabited regions, with the possibility for drought in some regions and heavy precipitation in others.

However, the movement to a low-carbon energy supply can not happen instantaneously due to the existing fossil-fuel infrastructure, and the requirement to maintain an energy supply. Therefore, a low-carbon transition is required. However, the decisions various stakeholders should make over the coming decades to reduce these carbon emissions are not obvious. This is due to many long-term uncertainties, such as electricity, fuel and generation costs, human behaviour and the size of electricity demand. In addition, the electricity generators invested in are controlled by many heterogeneous actors in many markets around the world. These markets are known as decentralised electricity markets. Decentralised electricity markets stand in contrast to centralised control markets, where a central actor, such as a government, invest and control the market. Therefore a well choreographed low-carbon transition is required.

To account for these long-term uncertainties in decentralised electricity markets, energy modelling can be used to aid stakeholders better understand the energy system This allows for decisions to be made with more information. Energy models enable a quantitative analysis of how an electricity system may develop over the long term. Simulations are powerful tools to deal with the complexity of these models.

In this thesis, a novel agent-based simulation model, ElecSim, is created. ElecSim adopts an agent-based approach to simulation where each generation company within the system is modelled with its behaviour. This allows for fine-grained control and modelling of these generation companies. Thus allowing ElecSim to be used to investigate the following significant challenges in moving towards a low-carbon future:

1. Devising a carbon tax can be challenging due to multiple competing objectives, and the inability for an iterative learning approach. In this work, we used ElecSim to model multiple different carbon tax policies using a genetic algorithm.

2. Many decentralised electricity markets have become oligopolies, where a few generation companies own a majority of the electricity supply. In this thesis, we used reinforcement learning and ElecSim to find ways to ensure healthy competition.

3. Predicting short-term electricity demand is a core challenge for electricity markets. This is so that electricity supply can be matched with demand. In this work, various methodologies were used to predict demand 30 minutes and a day ahead. In addition, an exploration of the impact of poor predictions on the long-term electricity market was carried out.

This requires a number of core challenges to be addressed to ensure ElecSim is fit for purpose. These are:

1. Development of the ElecSim model, where the replication of the pertinent features of the electricity market was required. For example, generation company investment behaviour, electricity market design and temporal granularity.

2. The complexity of a model increases with the replication of increasing market features. Therefore, optimisation of the code was required to maintain computational tractability, to allow for multiple scenario runs.

3. Once the model has been developed, its long-term behaviour must be verified to ensure accuracy. In this work, cross-validation was used to validate ElecSim.

4. To ensure that the salient parameters are found, a sensitivity analysis was run. In addition, various example scenarios were generated to show the behaviour of the model.