UNIVERSITY OF CAMBRIDGE

Briefing Paper series from the Cambridge Centre for Climate Change Mitigation Research

4CMR

Modelling Electricity Technology Substitution

Policy summary

Future energy planning which aims to avoid the risk of climate change will require drastic reductions in greenhouse gas emissions, possibly an almost complete decarbonisation of the current global energy sector. Such a transformation is expected to involve drastic costs, and large uncertainties surround the concept of decarbonisation and as to whether it is feasible economically. The transformation of the energy sector is likely, therefore, to have major consequences on the global economy, and it is difficult to model the energy sector without including its interactions with global economic activity.

Modelling

The transformation of the energy sector is likely to have a number of important consequences for the global economy

E3MG is a disaggregated global macro econometric model which features an electricity technology submodel, involving a powerful combination of top-down and bottom-up approaches to power systems modelling. However, this submodel currently lacks a treatment of natural resources, and does not reproduce adequately some of the important dynamics underlying changes in technology and energy infrastructure. Researchers at 4CMR are proposing a novel approach to electricity technology substitution modelling as a development of the electricity submodel of E3MG. As opposed to traditional energy models based on cost optimisation procedures, it focuses instead on the dynamics of technology substitution in connection with induced technological change. Technology costs are influenced by learning-by-doing effects, which lead to strong path dependence. The model is designed to work with several world regions and thus with local energy landscapes. These regions are defined by the availability and costs of natural resources. Preliminary calculations using a single world region are given in order to explore the properties of the model given very simple sets of assumptions. The results highlight how technological change dynamics emerge from the set of equations at the root of this model.

Researchers have introduced the concept of the logistic shares equation, which is based on probabilistic arguments regarding the likeliness of growth of various components of an energy market. This involves the current size of these components of the market and their rates of expansion based on plant construction times and lifetimes, and a comparison of their respective levelised cost of electricity. Given the number of switchings between the various options of the market, the system evolves in time as the levelised costs change.

The Briefing Papers series by 4CMR provides policy makers, organisations, communities and citizens with advanced research on the roles of economic, energy and environmental strategies for reducing the risk of climate change.

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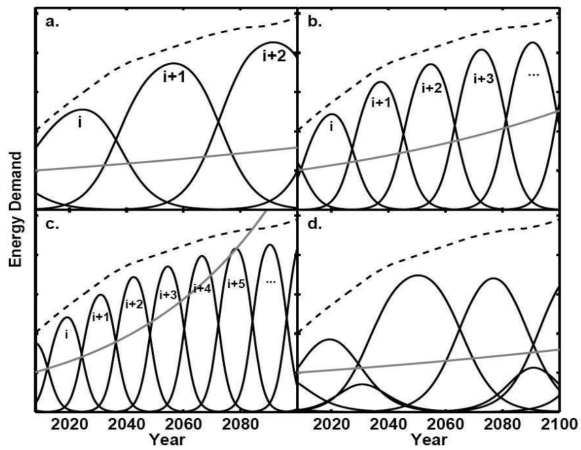
The levelised costs evolve through three possible effects. The first is technological learning-by-doing, where costs decrease with cumulative deployment of a technology. The more a technology is deployed, the cheaper it becomes. The second effect is resource depletion, where costs increase with deployment according to cost-supply curves. The third effect is through the pricing of emissions of CO2, which we assume occurs only through combustion of various fuels. Without constraints, the shares equation represents equally each energy technology.

However, real energy systems are highly complex and various energy sources are connected together in various ways. Energy markets are generally formally represented by the so called merit order, where plants are used in order of cost of use, up to where the total demand is met, at every moment of the day. The plant with the highest cost normally determines the price of electricity. Such a representation is too complex for our purposes, and we have devised a simpler way of representing the matching of supply to a varying daily demand, represented by our technical constraints.

The Results

The research also provides a number of results given different sets of assumptions, regarding mainly the discount rate and the evolution in time of the price of carbon. These results differ markedly, however they follow roughly what is expected. We observe an interesting phenomenon, which we named the energy technology ladder, where, with an exponentially increasing cost of carbon, technologies are gradually replaced by others with lower CO2 emissions, which are subsequently replaced themselves later by newer technologies with even lower emissions, and so on. The system progresses gradually in order through the use of the most cost-effective solution at each step, however particular solutions change as the cost of carbon gradually increases. A whole range of systems is therefore expected to be seen temporarily before a final solution is found. This is an effect which has not been imposed in our system by assumption. Rather, it *emerges* from the complexity of the equations.

Sketch of the energy technology ladder concept.



Energy technologies are gradually replaced as the price of carbon increases. The electricity generation by technology is shown as solid lines, the total energy demand is the dashed line, while the price of carbon is shown as a grey curve. Technology i is replaced by i+1 which in turn is replaced by i+2 etc.

Conclusion

We consider that many other sectors of the economy involving competing markets could in principle be modelled in a similar way, for instance in transport. This model covers only the electricity production sector, and therefore a complete model of the energy sector could include transport and heat production using a similar mathematical description.

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The Cambridge Centre for Climate Change Mitigation Research (4CMR) studies the interconnected economic, energy and environmental policies at the heart of climate change policy.

This Briefing Paper was developed from research by Jean-François Mercure of 4CMR.

For more details, see:
Mercure, J-F. (2011) Global Electricity Technology Substitution Model with Induced Technological Change Tyndall Centre for Climate Change Research Working Paper 148

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