Imperial College London

Grantham Institute
Briefing note No 7

June 2017

The changing costs of technology and the optimal investment timing in the power sector

CLARA F. HEUBERGER, DR IAIN STAFFELL, PROFESSOR NILAY SHAH, AND DR NIALL MAC DOWELL

Headlines

- The value of a power technology depends on the system it is operating within and on the services it can provide such as capacity, flexibility, carbon mitigation, etc.
- The right policies can bring down the cost of individual technologies and contribute significantly to a reduction in the overall system cost.
- Existing metrics for assessing the value of power generation technology, such as the levelised cost of electricity (LCOE), are insufficient for the 21st century power system.
- New metrics must take account of whole system integration and the dynamics of this system.
- Starting investment in promising technologies earlier will make long-term decarbonisation easier and more cost-effective.

Introduction

Decarbonisation efforts in the UK, as well as in many countries around the world, are reshaping the structure, operation, and economics of electricity systems. Energy policies are aiming to shift power generation from dispatchable (where output is flexibly adjustable) carbon intense fossil fuel power plants, to variable low-carbon renewable energy technologies. Nuclear and bio-energy could regain importance as dispatchable near-zero carbon power supply options. The national and international electricity interconnectors play an increasingly important role in power supply and transportation[1]. This so-called energy transition also includes a discernible trend towards modular, small scale, and distributed power generation.

Changes on the power demand side involve a growing electrification of transport, buildings and industry[2]. Balancing services and increasing flexible or 'smart' power end use, are increasingly important. While most 20th century electricity systems in Europe were designed to follow electricity demand patterns, today the increasing share of intermittent power generation requires a portfolio of control mechanisms to balance supply and demand. Without such mechanisms in place, system operators might be forced to discard some of the wind or solar power – so-called curtailment. Tightening surplus capacity could increase the risk of power supply disruption and overall system reliability may go down[3].

The differences between the supply and demand sides are blurring. Large power consumers are beginning to meet their requirements by onsite power production, while at the same time dispatchable power generators are forced – and often paid – to flexibly adjust their production to prevent supply-demand imbalances.

The cost structure of power generation is also changing, with a shift from operational to capital cost. Power plants with high operational expenses (OPEX), including fuel and other operation and maintenance costs are being displaced by units with low OPEX but high upfront costs, such as wind and solar power plants[4].

Carefully designed policy instruments and market incentives are needed to pave the way to a low-carbon energy system. Power system services, such as balancing, backup reserve, or the provision of carbon negative power[i], will affect the role and value of power technologies. This paradigm shift has to be recognised to promote a cost optimal energy transition which balances carbon, cost, and security of supply.

Technology valuation

Power system operators and policy makers use a range of tools to assess and compare the value of power generation, storage, and transmission technologies when making investment decisions. The transformation of the traditional power system also requires a rethink of these assessment tools. Traditional technology valuation metrics, such as the levelised cost of electricity (LCOE), were appropriate for comparing technologies that provide similar levels of dispatchable power but are inadequate today. The LCOE assesses technologies in isolation and neglects the system they are operating within. The system conditions can have a significant impact on the profitability of an energy infrastructure project (see box 1). Where intermittent renewables generate a high proportion of electricity, investment in an additional wind power plant, for instance, is less valuable than in the context of a system composed of conventional thermal power generators. Conversely, the value of dispatchable power plants, due to their flexibility and firmness, is high in a situation where wind penetration levels are high.

Two key ideas are shaping the debate on systemic technology valuation. The first aims at improving existing metrics such as the LCOE to properly account for additional cost components[5]. The second approach is based on whole energy system models. These range from global integrated assessment models (IAMs) to detailed sector specific tools, each appropriate depending on the scope of the analysis and area of application. The value of a certain technology is then based on the difference in total system cost with and without the observed technology[6,7,8,9]. This approach has been used to demonstrate how the technology value changes with increasing penetration into the system[10].

In the following sections, we refer to the whole system analysis approach as the system value metric[11]. See box 1 for a comparison of these approaches.

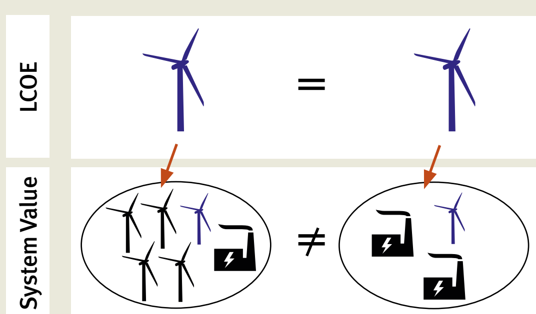
Technological change in power systems planning

In addition to supporting the valuation of individual technologies, power system models can guide decisions on the optimal mix of technologies and the timing of investments. Crucial model inputs are the costs associated with building and operating a power generation or storage unit, which vary from project to project and change as deployment increases.

The consideration of technological change, so-called technology learning, is crucial to determine how cost reductions are affected by policy decisions and vice versa[12,13]. The stimulation of innovation through public and private sector research, as well as economy wide policies (e.g. emission targets) have the potential to drive technological change[14,15]. Box 2 illustrates the phenomenon of technology cost reduction

Box 1: LCOE vs. system value

Scope of valuation metrics of power infrastructure project under different energy system environments



- ➔ Balancing issues
- ➔ Need for grid reinforcement
- ➔ Curtailment
- ➔ (Carbon-intense) back-up capacity
- ➔ Electricity price lower
- ➔ System wide carbon intensity lower
- ➔ Portfolio diversity increases

Creative Commons 'Turbine' image courtesy of Callum Taylor

The core strengths (+) and weaknesses (–) of the traditional LCOE and the system value metric.

LCOE

+ Widely used
+ Easily calculated
– Does not account for integration effects
– Does not consider temporal component of power supply/demand (electricity is treated as homogeneous product)

System value

+ Explicitly accounts for integration cost*
+ Explicitly accounts for when/where supply/demand occurs
+ Quantifies individual cost components
– Requires holistic energy system model
– Complex interdependencies can be difficult to interpret

*e.g. back-up capacity, grid reinforcement, associated CO_2 emissions

i. Power generation from bio-energy in combination with carbon capture and storage could provide electricity with negative emissions, i.e. CO_2 is removed from the atmosphere.

for onshore wind and solar capacity, and compares the current approaches taken to modelling these learning effects. Learning rates for a wide range of power generation and storage technologies are available[16,17,18].

Energy and power systems models have shown that:

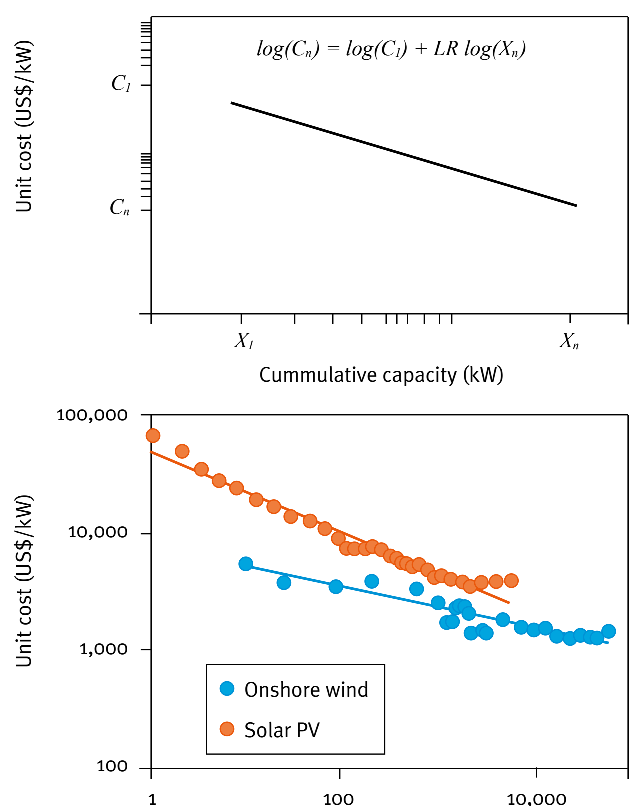
- When considering technology learning effects, the optimal timing for investment in technologies with cost reduction potential moves to earlier planning years[19].
- Building an experience base early drives technology learning and reduces investment costs[12].
- Total system cost for low-carbon and secure power supply can be reduced by early investment in promising technologies, e.g. offshore wind capacity or carbon capture and storage (CCS) technology[20].
- To achieve full decarbonisation of the power sector, the deployment of low-carbon renewables, bioenergy, CCS equipped power generation, and energy storage technologies must be accelerated. The associated cost can be reduced by driving technological learning through early investment[20,21].
- In scenarios tested, decarbonisation via a carbon price alone did not lead to a decarbonisation of the power sector by 2050[22,23].

Figure 2 highlights the impact of technology learning in a power system model[24] when applied to the UK. To achieve a full decarbonisation of the power sector, the model estimates a significantly different optimal power generation mix for 2050 and lower total investment cost, if technology learning effects are considered. The results of our analysis in the UK power system context indicate that:

- The consideration of technology cost reduction upon deployment increases the competitiveness of offshore wind capacity, CCS equipped power capacity, and energy storage (battery, pumped hydro) capacity most significantly.
- The deployment of cost competitive offshore wind capacity could increase by up to 75% when learning effects are taken into account. The optimal deployment level ranges from 5GW-30GW, for partial or full decarbonisation, respectively.
- The optimal timing for offshore wind capacity additions moves five years earlier – to 2025 – if technology learning is taken into account.
- Combined cycle gas turbines with CCS remain the most valuable option among fossil fuel power plants as they can provide very low-carbon power as well as balancing and capacity reserve services. Coal with CCS benefits from the learning based cost reduction. The total optimal deployment level of CCS equipped power generation by 2050 is 16GW-25GW.

Box 2: Technology learning and cost reduction

Historical observations have shown that with each doubling of cumulative installed capacity the capital cost of a technology reduces at a constant rate – the so-called learning rate (LR).



Representing technology learning in power system models**

Exogenous	**Endogenous**
Cost reduction as dependent input parameter	*Cost reduction as in-function of technology deployment*
+ Easy modelling	– Complex model integration, non-linear
– Requires external cost reduction projections	– Increases model size/ computational complexity
– Tend to predict investment timings late when technology cost are assumed to have reduced	+ More accurate representation of cost reduction effects

**technology learning typically refers to a reduction in capital cost. The theory can also be applied to operation and maintenance cost, or a change in other performace parameters.

Figure 1: Theoretical cost reduction curve (top) and historic empirical unit cost versus global cumulative installed capacity for onshore wind and solar power capacity[26] (bottom). Note the logarithmic scale.

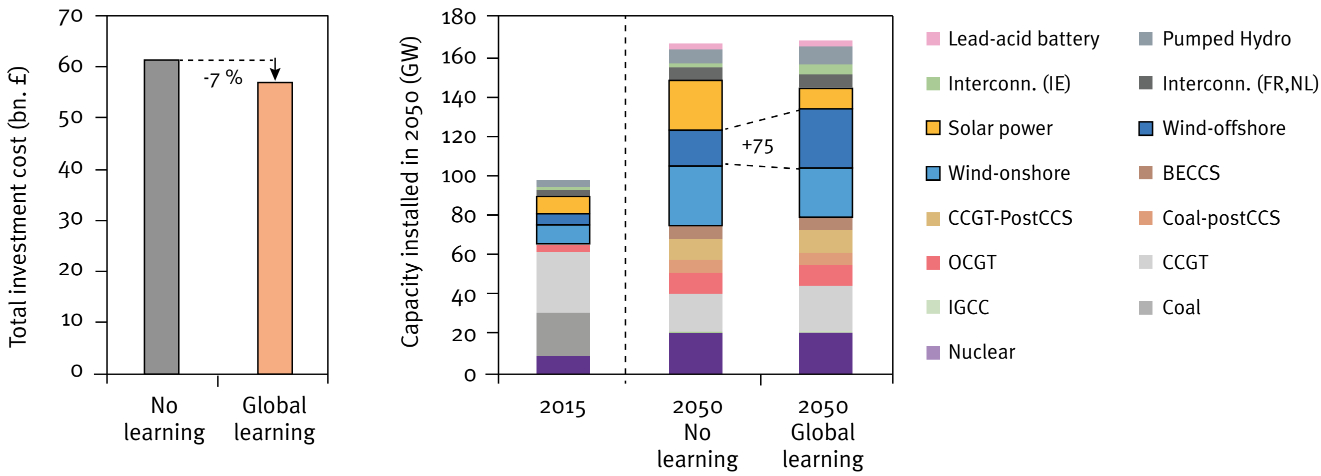


Figure 2: Total cumulative investment cost for a cost optimal capacity expansion of the UK power system from 2015 to 2050 in the case of considering no learning or global learning effects (left), mix of power generation in 2050 in the case of considering no learning or global learning effects (right). The presented scenario enforces a complete decarbonisation of the power sector by 2050 as extrapolation of the UK carbon budget[25]. Interconn.: high-voltage direct current interconnector, CCGT: comined cycle gas turbine, PostCCS: post-combustion CCS, OCGT: open cycle gas turbine, IGCC: integrated gasification combined cycle.

Conclusions

By analysing power technologies in a whole system framework, we can assess and determine their potential role and value to the future electricity system. Technology deployment contributes to technology learning and brings down unit cost. The consideration of these technology cost reductions influences the optimal investment timing and deployment level of technologies. Total system cost of the British power sector by 2050 can be reduced by optimising the timing of investments in new power generation and storage capacity.

Technology learning can be promoted by investment in research and development, demonstration projects, feed-in tariffs, and other policy instruments.

It is important that technology specific policy support mechanisms are designed to focus on valuable system services (e.g. reserves, balancing, flexibility). The ability to assess technologies in an integrated system can help support policy makers by identifying key technology specific features and evaluating the system wide implications of their promotion.

In the case of offshore wind capacity and CCS equipped power generation, dedicated policy support and continuous development increases their competitiveness and reduces total system cost by mid-century. Proactive investment can accelerate and enable deployment of low-carbon power technologies at the lowest cost.

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Acknowledgements

We thank the International Energy Agency Greenhouse Gas R&D Programme (IEAGHG), the Multi-scale Energy Systems Modelling Encompassing Renewable, Intermittent, Stored Energy and Carbon Capture and Storage (MESMERISECCS) project under grant EP/M001369/1 from the Engineering and Physical Sciences Research Council, and the Grantham Insititue – Climate Change and the Environment for the funding of this project. We are also in debt to Ed Rubin for major contribution to this work, as well as to Niels Berghout and Piera Patrizio for helpful comments.

About the authors

Clara Heuberger is a PhD student at the Centre for Process Systems Engineering and the Centre for Environmental Policy. Her research is supported by the International Energy Agency Greenhouse Gas R&D Programme (IEAGHG). She holds a Bachelor's and Master's in Mechanical Engineering from RWTH Aachen University. Clara studied and conducted research abroad at Carnegie Mellon University Department of Chemical Engineering and Department of Engineering and Public Policy, and MONASH University.

Dr Iain Staffell is a multi-disciplinary scientist holding degrees in Physics, Chemical Engineering and Economics. He lectures in Sustainable Energy at Imperial College London, and previously held posts at the University of Birmingham and Imperial College Business School. He has authored fifty papers and chapters, and two books across the topics of decarbonising electricity, heat and transport. He is the lead author of the Electric Insights reports into the British power sector, and co-creator of the Renewables.ninja platform for simulating renewable energy resources.

Professor Nilay Shah is a Professor of Process Systems Engineering and Head of the Department of Chemical Engineering at Imperial College London. His research interests include the application of multi-scale process modelling and mathematical/systems engineering techniques to analyse and optimise complex, spatially and temporally explicit low-carbon energy systems, including carbon capture and storage systems. He also develops methods for the design and operation of complex systems such as large scale supply chains and chemical processes.

Dr Niall Mac Dowell is a Senior Lecturer in Energy and Environmental Technology and Policy in the Centre for Environmental Policy at Imperial College London, where he currently leads the Clean Fossil and Bioenergy Research Group. He is a Chartered Engineer with the Institution of Chemical Engineers and is on the Executive Board of the IChemE's Energy Centre, a member of the Technical Working Group of the CCSA and the ZEP on industrial decarbonisation and a member of the UKCCSRC.

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