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# Improving the understanding and modelling of innovation in the low carbon energy transition – workshop report

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# 1 Context

The 6th session on innovation during the 74th ETSAP Workshop was organised with the aim of bringing together innovation practitioners and experts within the energy systems modelling community. It was organised by the Energy Technology Systems Analysis Program (ETSAP) modelling community partners in collaboration with innovation experts from the International Renewable Energy Agency (IRENA). ETSAP - a Technology Collaboration Programme within the IEA – has as one of its main goals the investigation of solutions to advance knowledge in energy systems modelling platforms. IRENA is an intergovernmental organisation that supports countries in their transition to a sustainable energy future by providing cutting-edge information on innovative solutions to enable energy sector transformation.

Despite rapid growth in the installed capacity of wind power and solar-PV globally, overall decarbonisation of the energy system is still progressing slowly. There is a need to accelerate the low carbon energy transition to align with the rapid decarbonisation aims agreed in the Paris Agreement. Energy system optimization models (ESOM) are widely used to develop long-term decarbonisation pathways to inform climate and energy policy. At the same time, technology innovation has proven to be a driver of recent energy system decarbonisation progress and is likely to be instrumental in future energy system decarbonisation [1]. Therefore, two open questions are: how well do ESOMs capture the role of innovation and how should the impact of disruptive technologies and innovation solutions [2] - which are expected to play a key-role in a decarbonised future [3] - be represented?

# 2 Workshop objectives and format

The objectives of the workshop were to bring together sets of experts in long-term energy system modelling and innovation, to discuss the latest findings, barriers and open questions related to the representation of technology innovation in long-term energy system modelling. Topics covered included technology innovation concepts, current barriers and modelling limits, and some of the best available methods to overcome these issues. How innovation is measured, tracked and represented was also discussed. In addition, the workshop was used to present a range of recent undertaken projects, which dealt with the improvement of the representation of innovation in energy system modelling as part of the IRENA-CEM[1] campaign, MI actions[2], and IEA RD&D[3] program.

The format was a joint opening address from ETSAP and IRENA, a series of presentations on the frontiers of current knowledge, current modelling practices, and audience discussion. This workshop report adopts this structure and also adds summary and reflections on the presentations and discussion.

[1] Clean Energy Ministerial (CEM) is a forum of energy ministers of the world's key economies working together to accelerate the global clean energy transition. More information at: https://www.cleanenergyministerial.org/

[2] Mission Innovation (MI) is a global initiative announced after COP21 (2015) aiming to accelerate global clean energy innovation. More information at: http://mission-innovation.net/

[3] International Energy Agency (IEA)

# 3 Opening address

In their opening address, the two chairs of this session, Brian Ó Gallachóir (IEA-ETSAP) and Paul Durrant (IRENA), highlighted the current vision of technology innovation as encompassing modellers and innovation practitioners. It has previously been shown that the two worlds are missing a point of contact between the reality of technology innovation and what is being represented in energy systems modelling.

Technology innovation has been identified as one of the main push factors behind the implementation of renewable energy technologies in an energy system. Disruptive technologies and innovation solutions including the adoption of new financial and market models, artificial intelligence, and digitalization, are contributing to enabling an energy system transition towards a low carbon future [3]. Therefore, a question from innovation practitioners to energy system modellers is to what extent are these innovations currently reflected in long-term scenarios?

The perspective from the energy systems modelling community is to understand how to track technology innovation, how to measure it, and thus to understand which innovations in technology or business models should be reflected in long-term scenarios to investigate its implications.

At present, the state-of-art models do not consider disruptive innovation, however, some innovation elements are explored in the latest models. For example, modelling energy performance (i.e. capacity factors), and technology costs (e.g. investment costs) is in large part about the integration of technology innovation in long-term optimization energy system modelling. The current methods are capable of describing the technology innovation impact on energy scenario results. Thus were the limits of modelling and the opportunities to implement innovation discussed in the opening address.

# 4 Presentations

## 4.1 Review of current knowledge

Current methodologies used to describe innovation in terms of technology cost reductions were shown, as well as the complexity of their implementation. Fionn Rogan (UCC)[4] presented a review of multi-factor learning curves, as discussed in the literature, showing the uncertainty of representing cost reduction with this multi-factor approach. In the literature, the one-factor learning curve method has been the most applied, but moving from one-factor learning curves to multi-factor learning curves, there is an increase of uncertainty regarding the choice of parameters to represent innovation elements and associated data gathering. The presentation showed that learning curves may vary at 1) different stages of development, 2) between global or local learning, and 3) for different technological components of a macro technology. Moving to multi-factor learning curves requires a better understanding of the myriad dynamics behind technology innovation. For example, with certain elements such as RD&D public support, the knowledge is split between the country, technologies or stakeholders; in addition to this, there is the impact of markets on cost reduction.

## 4.2 Current modelling practice

Three examples of practices developed to find solutions to measure technology innovation were presented: Hans Christian Gils (DLR)[5], Uwe Remme (IEA)[6], Alessia Elia (UCC-IRENA)[7].

Hans Christian Gils described selected results of the RegMex project where different energy system models were compared and evaluated regarding their ability to take disruptive elements into account. The results of the projects allow defining a list of innovation elements, mostly considered disruptive innovation elements, and the main parameters of a long-term energy system model that might be influenced by these innovation elements. For example, "shortage

[4] Elia, A.; Rogan, F.; Ó Gallachóir, B. - *From single-factor to multi-factor learning curves for modelling innovation – a review*. Link: https://www.slideshare.net/IEA-ETSAP/from-singlefactor-to-multifactor-learning-curves-for-modelling-innovation-a-review)

[5] Gils, H. C. - *Consideration of disruptive elements in energy system models.* Link: https://www.slideshare.net/IEA-ETSAP/consideration-of-disruptive-elements-in-energy-system-models

[6] Remme, U. – *Challenges in the modelling of experience curves.* Link: https://www.slideshare.net/IEA-ETSAP/limitations-in-representing-innovation-in-energy-systems-models

[7] Elia, A.; Taylor, M.; Rogan, F.; Ó Gallachóir, B. - *Deepening cost analysis for Onshore Wind Technology*. Link: https://www.slideshare.net/IEA-ETSAP/deepening-cost-analysis-for-onshore-wind-technology

or cost explosion of structural materials" innovation elements may influence technology costs. Still, these disruptive elements were not implemented in the energy system models and linked with the parameters.

Uwe Remme presented the current approach used at IEA to include in the IEA-ETP model technology innovation through a soft-linked one-factor learning curve. Moreover, he discussed some of the challenges in the use of learning curves and approaches to address them, such as component-wise learning, global versus local learning and the limited availability of empirical data for new technologies with little deployment so far. Uwe also talked about the endogenous representation of one-factor learning curves in energy system models, pointing out some new formulation approaches with some potential computational benefits compared to the traditional formulations.

Alessia Elia discussed an alternative method to investigate onshore wind cost reduction, stepping away from the most common use of a learning curve. The method is based on a cost disaggregation bottom-up cost model, and the aim is to identify and understand how costs are influenced along the stages of development of a technology and which are the main elements influencing them. For example, structural materials, labour salary, industrial progresses, the cost related to the installation and transports and the effects of demand markets were explored.

## 4.3 Innovation projects

During the workshop, three innovation based projects being undertaken by three different organizations were presented. The projects were related to long-term energy system modelling to improve the tool and reduce the uncertainty in order to promote their adoption.

The first project is the new IRENA-CEM campaign "long-term energy scenarios (LTES) for clean energy transition" presented by Paul Durrant[8]. The project aimed to encourage the use of models and to identify gaps and improvements required through the share of the use between different modeller groups.

The second project described the work done on energy innovation from the International Energy Agency (IEA) presented by Uwe Remme. This included the tracking and collection of RD&D expenditures and the progression of clean energy technology in the IEA's annual

[8] Durrant, P. - *IRENA-ETSAP – Innovation in long term energy scenarios.* Link: https://www.slideshare.net/IEA-ETSAP/irena-cem-campaign-and-innovation

Tracking Clean Energy Progress report as well as the identification of innovation gaps, to provide a comprehensive picture of the current stages of development for different technologies.

Daniele Poponi (Directorate General for Research & Innovation, European Commission)[9] presented the 'Tracking Progress' activities of the Mission Innovation initiative (MI). Four related work strands are currently being implemented: (a) Tracking the Impact of MI (e.g. MI members are requested to submit information and data related to investments and national plans through "MI country surveys"; (b) Enhancing existing data collection on government spending for energy RD&D (E.g. through capacity building activities); (c) Tracking private-sector investments (e.g. e.g., by exchanging information to improve understanding of clean energy innovation needs of the corporate sector) and (d) Tracking Overall Progress to Accelerate Clean Energy Innovation (e.g. through the development of an indicator framework based on innovation outputs).

[9] Poponi D. - *New approaches to understanding innovation*. Link: https://www.slideshare.net/IEA-ETSAP/new-approaches-to-understanding-innovation

# 5 Summary of presentations

The presentations highlighted the limits of long-term optimization energy system modelling, which included many aspects of energy technology innovation, but also the limited understanding of the elements driving technology innovation. Furthermore, the presentations showed the current difficulties in implementing endogenous cost reduction with learning curves and modelling disruptive elements of innovation. Through a show-of-hands informal poll, it was revealed that most of the participants in the audience did not endogenously implement the one-factor learning curve in energy system modelling, or any other tool. Moreover, it remains unclear how innovation can be adequately modelled. Learning curves are a limited methodology and are only related to costs, but not to other parameters that could be affected by the innovation, such as technology parameters and energy demand, as discussed in Hans Christian Gils's presentation.

The three projects underway with IRENA-CEM, IEA and the European Commission are a starting point to allow for a better implementation of innovation in energy system modelling by including and tracking the innovation underway before market deployment. The goal of these projects is to better represent the path of emerging energy technologies and any disruptive innovation influencing them. Still, most of the disruptive technologies, such as digitalization, are not represented in modelling. The outputs from the RegMex project shows an initial attempt to discuss disruptive elements that may influence the innovation of emerging energy technologies. Furthermore, it can investigate the parameters that could be used to implement innovation impact on energy system modelling.

# 6 Reflection on presentations

The presentations revealed two points that are missing from the current state-of-art energy systems modelling:

1. It is not clear within the energy system modeller community how to track technology innovation.
    a. The most credited method to capture the innovation is the learning curves, but the one-factor learning curves are too simplistic, while multi-factor learning curves are uncertain in the research community. Moreover, it is complex to gather the required data. When we compare this method with the innovation practitioner community, as the IRENA experts, we can conclude that innovation involves a myriad of disruptive elements. These disruptive innovation elements are related to technology changes or to system changings such as digitalization or the impact of the industry 4.0.
    b. Technology innovation does not only take technology cost reduction into account but also other technical parameters, and energy system elements. The picture is complex to gather and to model.
2. A method to implement the impact of innovation in long-term energy system modelling is missing.
    a. The most widely used approach is to discuss technology innovation in terms of impact on cost reduction with one-factor learning curves. Method of implementing more than the one-factor learning curve is imprecise, and both of these learning-curve tools are limited in representing technology innovation in energy system modelling.
    b. Many of the disruptive innovation elements identified by innovation practitioners do not find representation in the current state of energy modelling, and neither can all of them influence cost reduction. They may be responsible for technology performance improvements and deployment but there is no representation of these effects in the models.

# 7 Audience Discussion

## 7.1 Chaired Q&A

After the presentation, three opening questions were proposed to the audience regarding the gaps and what is missing in long-term energy scenarios:

1) Which innovations in technology or business models should be reflected in long-term scenarios of clean energy transitions to 2030-2050?

2) To what extent are those innovations currently reflected in scenarios?

3) In general how can long-term scenarios be made more relevant to business planning and policy making under large innovation-related uncertainties?

### *7.1.1 Which innovations in technology or business models should be reflected in long-term scenarios of clean energy transitions to 2030-2050?*

The answers from the first question are aggregated into 5 categories (Table 1): new emergent innovative technologies, inclusion of additional characteristics of energy technologies to map their innovation path, innovative business model paths, innovative policy, and the representation of consumer behaviour. The participant agreed that the current energy system models do not include all the proposed innovation types, and they risk providing an unrealistic representation of the medium term of the upcoming future (2030-2050). Models do not depict the impact of emergent and innovative technologies, attributes, policy, consumer behaviour and business model all together. This creates space for future ideas regarding what should be included in modelling, ensuring an integrated innovation.

*Table 1. Answer from the audience question 1*

**Innovation to implement in long-term scenarios**

| Energy Technology integration | Business model | Innovation Policy | Consumer behaviour | Technology attributes |
|---|---|---|---|---|
| Smart grid decentralised production<br>Autonomous drones<br>CCS<br>Multi-purpose batteries storages<br>Shared mobility<br>Autonomous vehicles<br>Bio-materials<br>Ocean energy<br>Nuclear fusion<br>Micro-grid<br>Off-grid<br>Cellular solutions | Peer to peer trading<br>Circular economies business models | Mechanisms to incentivise lifestyle changes | Change in lifestyle<br>Public ownership / acceptance<br>Alternative business income (Facebook advertising) | $CO_2$ and resource recycling<br>Reduction in costs<br>Digitalisation impact on technologies (more service managed by one device)<br>EV chargers pattern management<br>Grid and infrastructures flexibility |

### *7.1.2 To what extent are those innovations currently reflected in different scenarios?*

The energy modelling community agrees that innovation is mainly included indirectly with the adoption of exogenous variables, such as adjusting the parameters describing the existing technologies. However, the emergent innovation aspects highlighted in the previous question are still missing, as well as the consideration of innovation impacts in multiple parameters of the model. Moreover, current modelling norms do not allow innovative elements effects to link with the future technology deployment.

The main issues highlighted from the audience in the discussion are:

i. Innovation is represented via specific parameters, such as costs and technology technical parameters, but a reflection on the impact of other innovation element is missing. Technology learning consistently underestimated for renewables.

ii. Innovation is introduced in an exogenous and simplistic way and is applied on few technologies, while missing the comprehensive picture, which leads to biased results. The only way to investigate the variation of the level of innovation is through a sensitivity analysis of the parameters used, such as costs and capacity factors. This gives rise to the question as to whether innovation is an input or whether it should be endogenously generated in the model. So far, it has been assumed that technologies will achieve the specific innovation, and the parameters are exogenously set up in the model.

iii. Disruptive innovation is not a gradual change of parameters, but a drastic step-change. It is not currently reflected in the models. New emergent innovative technologies are not represented either, with the exception of CCS technologies. Therefore, the signs of a totally different trajectory cannot be represented because emergent technologies and disruptive innovation do not exist in the model.

iv. The current models do not take into account the changes in service demand with the introduction of disruptive innovation. The fact that most models employ perfect foresight creates modelling problems.

### *7.1.3 In general, how can long-term scenarios be made more relevant to business planning and policy making under large innovation-related uncertainties?*

In conclusion, the last question underlined the main points that would help energy system models to become more relevant for business planning and policy making. The following actions were suggested:

1) Include

- Different time horizons with alignment to different business cycles or political electoral cycles.
- Near-term measures and transition strategies.
- Co-production between resources, e.g.: future bio-fuel plants, co-electrolysis and bioenergy.
- Speculative technologies, even if controversial.

2) Adopt

- Stochastic methods (Montecarlo analysis setup).
- Black swan scenario/Unknown-unknown scenario.
- Wide spread of scenarios with contrasting scenarios.

3) Combine with

- Historical lessons, i.e. what went well, and what didn't.
- Use of historical innovation examples to illustrate the dynamics.
- Different modelling approaches to provide complementary insights on similar scenarios.
- Better visualization of results: illustrating the required technologies, resource constraints and sector linkage.

4) Clarify

- Scenarios that are not predictable but indicative and based on system constraints and assumptions.
- The uncertainties with the scenarios analysed and the appropriate way to work on it. More transparency on the constraints.

# 8 Reflection on audience discussion

At the end of this second audience question, the discussion nurtured new ideas which could be beneficial to solve the issues on integration of innovation in modelling. The following 4 points were highlighted by people in the audience as some of the main points to focus on in the near future:

1. Aware of the issues behind learning curve tools, the inclusion of more elements of disruptive innovation could require even more complex application and create more uncertainty without adding additional accuracy or insights. It is suggested to investigate to what extent it is important to introduce complicated innovation in the model, and where is the trade-off between complexity and results generated. Due to a lack of data, modellers should perhaps start with one-factor learning curves before analysing more complex methods. Very few people in the audience are using endogenous learning curves in the modelling at the moment, and the representation is flawed in the case of one-factor. There should be modelling exercises to incorporate one and multi-factor learning curves, or other methods between modellers, so that they can gain more experience using endogenous innovation and then be able share their experiences and findings within the ETSAP community.

2. Scenario sensitivity analysis could be a less complex and more certain form to capture some extreme and large variations related to the innovation impact that normally with the current models are not captured. Exploratory scenarios could be developed, such as, for example, how much cost reduction is required, so that disruptive technologies can compete with the current one, and how much deployment or investment is necessary to achieve that cost reduction.

3. To understand how to model disruptive technologies, most of the 2040 disruptive technologies could still not exist. For example, how to design a technology that will substitute most incumbents and induce energy service demand changes in short-time in the model, e.g. the smartphone. If technologies that are free riders, without any learning imposed, they appear late in the model horizon. Modellers should consider additional constraints as growth rate constraints, investment spending and anticipated costs, given

by how that technology might appear without considering RD&D costs. Also in this case scenario analysis could assess demand disruption.

4. An ex-post analysis is also important to understand why cost reduction happened and accelerated in the case of well-known renewable energy technologies such as solar-PV and onshore wind. In order to understand if those assumptions taken to calculate cost reductions in the past can be used in the future. The audience agreed on the importance on using right assumption because these are used to inform government policies and markets. Therefore, a wrong assumption could lead to misinformation. Better understanding of the dynamics pushing technology success in a system is required to catch the learning and the lack of improvement in the past. A combination of factors may be specific to wind, thus it is necessary to understand whether that pattern is likely to repeat again and how it might impact in the same way for another technology. Analysis of historical technology innovation paths could also explain what went wrong, e.g. offshore wind slow down - Risk ratio parameters of investment that can change the amount of investments done in a technology.

# 9 Conclusions

The workshop revealed important questions that are a starting point for further work in this field. They can be summarised in three main points (Fig. 1); firstly, it is necessary to develop an explorative collaboration in the analysis of learning curve in models. In order to learn from each other's experiences, to understand the limits of the modelling in including learning curves, which is the border to the models capability, and which elements driving technology innovation can be included both exogenously or endogenously. The final goal would be reaching a level that determines some understanding as to whether the results are imperfect and why, rather than some unknown that we are trying to represent describing a one-factor learning curve.

Secondly, to focus the analysis on the effect of one technology and translate them to emerging technologies. For example, are cost reductions on wind transferable to other technologies? Understanding how to use information from the past or from incumbent technologies to more efficiently inform what might happen in the future is vital, and should not just translate to a learning rate factor. Working with exogenous parameters is an appropriate method, but there is need of sensitivity analysis of scenarios and to obtain a better understanding of the dynamics of what has happened, to learn how to transfer information from one technology to another.

Finally, continuing the investigation of disruptive technologies and elements and explorative exercises to include them in the modelling in the future. Quantifying something that it is not well understood such as technology innovation dynamics and the impact of disruptive elements.

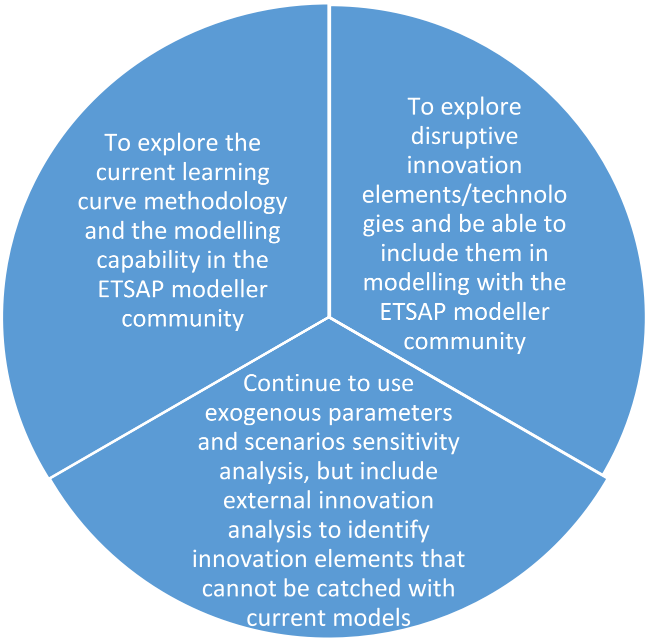


*Figure 1. Concluding recommendations*

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