

Proceedings of IRENA IEW 2017 Side Event

Planning for the Renewable Future

Improving the representation of variable renewable energy in long-term modelling and tools

DATE: 12 July 2017
HOUR: from 12:30 pm to 1:30 pm
PLACE: Potomac Ballroom, College Park Marriott Hotel & Conference Center, Maryland, United States

Event background

The concept of a renewable future – one in which large shares of solar, wind, and other renewable power sources come to define our energy mix – is becoming a rapidly approaching reality. The economic momentum behind variable renewable energy (VRE) sources such as solar PV and wind is particularly strong, and many in the energy sector are now anticipating a landscape in which those sources meet a large portion, if not the majority of national or regional demand.

The prospect of such a transition, however, is often met with concerns around reliably operating power systems with large shares of VRE. IRENA member states have been proactive in this regard, and have expressed a keen interest in improving their energy planning practices, data, and methodologies to better account for the variability of wind and solar power. The modelling methodologies used by national and international planning organisations for long-term capacity expansion planning are often cited in this context as insufficient to adequately represent the variability of wind and solar power, and to assess its operational and economic consequences.

To address this challenge, IRENA initiated the Addressing Variable Renewable Energy in Long-Term Energy Planning (AVRIL) project in 2013. Building on the expertise gained through various discussions and sessions held under the AVRIL project – including IEW side events held in Beijing in 2014, and in Abu Dhabi in 2015 – IRENA released its [*Planning for the Renewable Future – long-term modelling and tools to expand variable renewable power in emerging economies*](#) report in January 2017. The report reviews a range of planning methodologies practiced around the world to specifically address the improved representation of VRE in long-term planning tools.

The *Planning for the Renewable Future* report benefitted immensely from thoughtful engagement during past IEW side events, and from thorough commentary by a number of conference attendees during the review process.

This side event at the 2017 IEW meeting in College Park, MD allowed IRENA to acknowledge the critical role that modelling communities around the IEW conference have had in the publication of the *Planning for the Renewable Future* report, to disseminate its findings, further discuss its main themes, and to maintain deep engagement with energy modelling researchers from around the world.

Objective and format

This session at IEW 2017 was organized with the following objectives:

- » To discuss best practices as they currently stand regarding the representation of VRE in long-term modelling
- » To gain a clearer view of how IRENA can support the continued maintenance and exchange of knowledge in the modelling community around this topic

The session was structured in two parts, moving from five short invited interventions to an open discussion where additional examples of best practice and methodological gaps were welcomed from attending experts in the audience.

The session focused on three questions:

- » What are the important characteristics of VRE that we need to consider in long-term energy modelling?
- » What are the known best practices in representing characteristics of VRE in long-term energy modelling?
- » What are the areas that need further research in better representing VRE in long-term energy modelling?

The session was attended by over 70 international energy modelling experts, and benefitted from the contributions of many attendees (see summary of the discussion below).

Session agenda

12:30pm - 12:35pm – Introductory remarks

- » **Chair: Prof. Brian Ó Gallachóir** –
MaREI Centre, University College Cork

12:35pm - 1:00pm – Invited interventions

- » **Dr. Asami Miketa** – International Renewable Energy Agency
- » **Dr. Roberto Schaeffer** – Universidade Federal do Rio de Janeiro
- » **Dr. Joseph DeCarolís** – North Carolina State University
- » **Dr. Todd Levin** – Argonne National Laboratory
- » **Dr. Bethany Frew** – National Renewable Energy Laboratory

1:00pm - 1:25pm – Open interventions from the audience

1:25pm - 1:30pm – Closing remarks

- » **Chair: Prof. Brian Ó Gallachóir** –
MaREI Centre, University College Cork



Panel of five invited modelling experts (top) and side event audience (bottom)

Summary of the discussion

Opening:

The session was opened by the Chair, Prof. Brian Ó Gallachóir of the MaREI Centre, University College Cork and the IEA ETSAP Technology Collaboration Programme, who welcomed the participants to the side event.

He noted that many parallel sessions at the IEW touch upon the importance of this session's topic – how to incorporate the characteristics of variable renewable energy (VRE) into models. He also noted that the topic has recently become quite politicised, with major press coverage of an academic debate in the US over differing views of the difficulty and cost of large-scale VRE penetration into electricity systems. In this context such a gathering of the scientific modelling community is welcome, to focus on the methodological aspects of the issue, and the three questions framing this session's discussion:



- » What are the important characteristics of VRE that we need to consider in long-term energy modelling?
- » What are the known best practices in representing characteristics of VRE in long-term energy modelling?
- » What are the areas that need further research in better representing VRE in long-term energy modelling?

He also noted that the purpose of the session is twofold. First, one of IRENA's roles is to act as an interface between the policymaking community and academic research community - particularly around the topic of this session, given the recent *Planning for the Renewable Future* publication - so if anyone is interested in engaging with IRENA to discuss and disseminate their work, this is an opportunity to do so. Second, IRENA is aiming to maintain and update the compendium of methodological approaches contained in the *Planning for the Renewable Future* report, so attendees are encouraged to share their thoughts on the state of the art in representing VRE in long-term models.

Invited Intervention 1:

Dr. Asami Miketa (IRENA, Germany) explained that over the past years, many government planning officials approached IRENA for advice on how to incorporate wind and solar power into the models they use to support planning documents. They began to see high penetration of these VRE sources in modelled optimal generation mixes due to their declining technological costs, and want to assess the realism of those results.

To answer that question, IRENA established the AVRIL - Addressing Variable Renewable Energy in Long-term Planning – project, around three years ago. Through this project, IRENA collected inputs from the



network of researchers around the IEW community, and published the *Planning for the Renewable Future* report earlier this year.

Based on that report, there are several points to be made around the three questions framing this discussion.

On the first question – what are the key characteristics of VRE that we need to consider in the long-term planning – Dr. Miketa pointed out four aspects:

1. The fact that when solar and wind generation is strong, it is not necessarily the period when demand is strong. Therefore, effective utilization of solar and wind capacity may be limited – the concept of capacity credit needs to be represented to capture this effect, and to ensure an adequate level of generation exists at all times.
2. Because outputs from solar and wind introduce more sudden changes to a system, the rest of the system needs to flexibly change its output in order to keep demand and supply in balance. Models therefore need to be able to capture the flexibility of power plants, and additional options that provide flexibility to the system.
3. Because good quality sites for solar and wind resources may be far from demand centers, the trade-off between resource quality and transmission investment needs to be captured in models.
4. The operation of a power system with high shares of so-called non-synchronous generators poses an engineering challenge with regards to maintaining system stability, and because solar and wind generators are non-synchronous generators, there could be a limit to their share in a system. There could be certain circumstances where such limitations should be reflected in models.

On the second question - what are the best practices in addressing key characteristics of VRE in long-term models – IRENA has seen three main approaches. One is to have a “super model” that incorporates both long- and short-term elements, with very a high temporal and geographical resolution. Another is a model-coupling approach, which uses multiple models that cover different time horizons to find solutions iteratively. The third is to use simplified constraints, which force the model to mimic the impacts of unique VRE characteristics. For government practitioners, Dr. Miketa believes the third option will be particularly relevant, while the second approach may need to be used in parallel.

On the last question - what we still don't know - one issue that remains open to IRENA is the balance between the need for more data-intensive detailed analysis of power system operation, and the relevance of detailed assumptions in future years (particularly in the context of fast growing economies with a large margin of uncertainty). An example given is the relevance of hourly demand profile assumptions for a country like Egypt in 2040. The knowledge base around the flexibility of different generator types could also be improved. Ideally, IRENA would like to see more research done in these areas.

Invited Intervention 2:

Dr. Roberto Schaeffer (Universidade Federal do Rio de Janeiro, Brazil) explained that he was first exposed to this issue of VRE in electricity systems in 2010, as one of the authors of the modelling chapter of the IPCC Special Report on Renewable Energy (SRREN). At that time there were some views emerging about possible problems that VRE could introduce to power grids, but studies on the issue were scarce, so simplified penetration limits were often set in modelling exercises.



Now, as Dr. Schaeffer continues work with highly complex integrated assessment models (in terms of scope, i.e. beyond only power sector operations), his team runs a dispatch model in parallel to their long-term energy expansion model, as a reality check to the power capacity expansion model results. Rather than setting simplified penetration limits, strict climate scenarios with high levels of VRE penetration are post-processed in dispatch models to assess their operational feasibility. This soft-linking approach has allowed Dr. Schaeffer's team to discover greater sensitivity in power systems to climate change, as dispatch models can capture the impact of climate-driven variability in water precipitation for hydropower generation, wind, and cloud cover.

As a next step, Dr. Schaeffer explained he is looking to work with an even more granular model to explore the electrical implications of VRE penetration on aspects such as frequency, voltage, and harmonics. Generally, he sees this as rounding off a three-step approach of first analysing power capacity expansion, then dispatch, and system electrical properties. He sees an advantage to this disaggregated approach over the more complex "super model" approach, especially in terms of developing countries where the level of detail necessary to populate a fully aggregated model may not be available.

Invited Intervention 3:

Dr. Joseph DeCarolis (North Carolina State University, United States) began by addressing the first framing question - what are the important characteristics of VRE that we need to consider in long-term energy modelling? First, he considers the uncertain cost evolution of VRE to be important, and to be addressed through robust sensitivity analysis.



Second, the spatio-temporal resolution of a model is a critical factor consider when discussing VRE. Spatially, the resource quality of solar and wind will vary geographically, and distance of those resources to transmission may also be an important cost driver. Temporally, he cites two concerns – the need for sufficient flexibility to meet demand at all times (and thus potential need for dispatchable capacity), and the need to meet peak demand (and thus the need for adequate reserve capacity). In a long-term capacity expansion model, one can address these concerns by expanding the number of time slices (i.e. time segments used to represent combinations

of seasons and times of day) to better capture the variability in VRE generation. Ramp rate and reserve capacity constraints can also be imposed in a model to ensure sufficient dispatchable capacity exists in modelled future generation mixes.

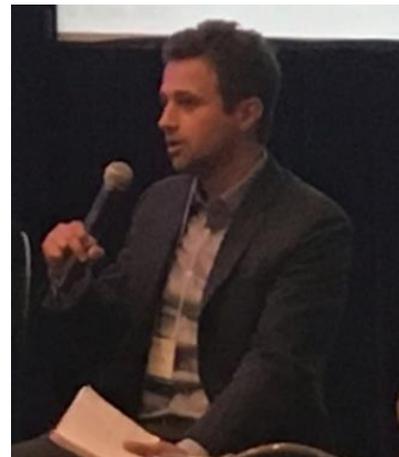
In terms of areas that need further research in better representing VRE in long-term energy modelling, Dr. DeCarolis echoed Dr. Miketa's question about the appropriate level of detail in the application of long-term capacity expansion models, particularly given that the impacts of VRE range from millisecond to decadal scales. He invited the community to question whether greater detail always implies better modelling, especially in the context of renewables.

Regarding best practice to represent VRE in long-term energy modelling, Dr. DeCarolis cited rules that could also be applied to modelling in general – parsimony, i.e. understand the question that needs to be answered, then build the simplest model to answer that question; open source, i.e. make models publicly accessible so that the research community can understand and build on each other's work; and robust uncertainty analysis, i.e., explore the decision space to avoid misleading insights based on only a few scenarios.

Invited Intervention 4:

Dr. Todd Levin (Argonne National Laboratory, United States) began by expressing agreement with the points raised in the first interventions, particularly with regards to the challenge of capturing sub-hourly VRE impacts in long-term models.

Dr. Levin noted his intervention will focus more on the modelling of VRE in the context of competitive markets, where high levels of penetration have investment implications that are difficult to capture in long-term capacity expansion models. Two of the primary impacts resulting from high VRE penetration are the reduction of wholesale electricity prices due to zero marginal cost VRE generation, and the need for greater reserve capacity and ancillary service requirements.



Dr. Levin noted that under these circumstances, conventional generators will potentially see their wholesale market revenue decline, and come to rely more heavily on revenue from more valuable capacity or ancillary service contracts. This fragmentation of markets as a result of VRE penetration is important to capture if we would like to represent investment decisions in long-term capacity expansion models more realistically.

He noted that this is not so simple, however – we already see outcomes in reality that depart from modelled optimal behaviour in wholesale markets (e.g. units bidding above/below marginal cost due to various market rules), and it is unclear at what scale this could occur in capacity and ancillary service markets where marginal cost signals are much less apparent. As a result, he recommended that in addition to least-cost optimisation models, better representing energy systems with high shares of VRE will require models that more accurately portray consumer/investor behaviour in a competitive market context, such as agent-based models. Given the immaturity of capacity and ancillary service markets, even in highly developed electricity systems, obtaining better data to support their modelling is also becoming an important issue.

Invited Intervention 5:

Dr. Bethany Frew (National Renewable Energy Laboratory, United States) first discussed an effort she is involved with at NREL to conduct multi-model comparison of different capacity expansion models with EPRI, EIA, and the EPA. The main goal of this effort is to compare the institutions' respective models, to understand the differences between them and how those drive differences in results. Dr. Frew noted she will be drawing on this project in her intervention.



Dr. Frew approached the session's framing questions through three categories – temporal and spatial resolution, capacity adequacy, and overall economics. In terms of temporal and spatial resolution of models, she noted that one of the more interesting findings from the multi-model comparison was that the selection method of modelled time and space elements is just as important as the resolution of those elements. For example, she cited results in which cost trends could vary substantially across models despite the same specified resolution. It follows that understanding how time periods or spatial areas are chosen in the model is just as important as the absolute level of resolution when modelling high levels of VRE penetration.

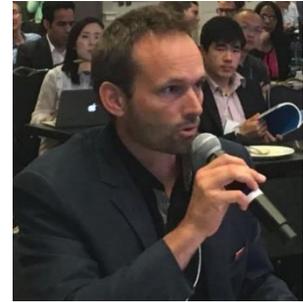
In terms of capacity adequacy, Dr. Frew specified that she refers here to the concept of capacity value when discussing long-term modelling of VRE. To represent the capacity value of VRE, there are many simplifications, approximations, and rules of thumb that currently exist, and many of these are static values. However we know that many of these simplifications are not accurate, e.g. as VRE penetration increase, capacity values typically decrease, with solar capacity values declining more rapidly with marginal additions. She noted that there is still work to be done around how to estimate these trends in long-term capacity expansion models.

Regarding the modelling of economics in relation to VRE, Dr. Frew focused her comments on the issue of curtailment. Limiting curtailment is critical to capture the value of VRE, and work at NREL has found that accurately representing the minimum generation levels of conventional generators matters more than ramp rates when it comes to this issue.

Dr. Frew also pointed out that long-term models have chronological issues related to the above points. For example, if you are not representing the full hourly resolution of a year, issues around accurate intertemporal storage representation arise, which can have important implications for both capacity value and curtailment of VRE.

Open interventions from the audience:

Dr. Kenneth Karlsson (Technical University of Denmark, Denmark) mentioned that though VRE penetration is often framed as a problem, Denmark is aiming to have 50% VRE penetration in the electricity system by 2020, with current plans pointing to around 80% penetration before 2035-40. In this context, the modelling focus is instead on how to accurately represent the phase out of technologies hindering system flexibility, such as old coal-fired generators, nuclear plants, or in the future, CCS required to run around the clock.



Dr. Hans-Martin Henning (Fraunhofer Institute, Germany) commented that he thinks the community has made good progress on understanding the temporal and spatial issues related to modelling VRE. From the German experience, one aspect he did not see covered was the issue of social acceptance – if we are to begin taking a more holistic approach to modelling, as was recommended in one of the morning’s keynote presentations, there is now space to go beyond technical and economic elements and begin thinking about how to integrate other limitation categories (e.g. citizens’ willingness to build extensive distributed wind generation) with high levels of VRE deployment.



Dr. Francesco Gardumi (KTH Stockholm, Sweden) raised a point for discussion regarding how to model VRE in different modelling frameworks. From what he has seen in studies around the OSeMOSYS model, it is not always the case that with increased penetration of VRE you need greater reserve capacity – it is related more to the variability of the generation mix rather than the overall share. In that sense, there are now attempts to make the representation of reserve capacity proportional to the variability of the generation mix, though this measurement naturally varies from country to country, and the experience of other modelling groups is welcomed. As a second point for discussion, Dr. Gardumi raised the need to accurately model options to provide system flexibility, such as flexible conventional power plants with high ramping rates and storage. Regarding storage, there is still an open question about reliable long-term techno-economic estimations for a technology and market that is still at such an immature stage.



Mr. Fabian Gotzens (Forschungszentrum Jülich, Germany) shared the level of temporal resolution in his current long-term modelling (8 representative days with 24 hours, or 192 time slices), and would find it helpful to hear from the modelling community about their experience regarding the optimal amount of time slices, and what would be recommended for particular uses.



Dr. Alam Mondal (International Food Policy Research Institute (IFPRI), Washington DC, US) acknowledged the importance of the three questions framing this session. From his perspective, three things stand out as important – keeping the SDGs, i.e. energy access, in mind, and conducting exercises like IRENA’s Renewable Energy Readiness Assessment to determine policy and data constraints for modelling; taking a holistic approach; and using integrated modelling frameworks to capture the impact of energy-economy feedbacks.



Dr. Michael Kintner-Meyer (PNNL, US) made a number of observations related to the discussion. First, he asked whether the questions discussed in the session only apply to VRE, or can be applied more broadly. For example, the introduction of potentially more volatile demand-side uses like fast-charging batteries could introduce equally difficult modelling challenges. The broader question then becomes how to deal with uncertainties in modelling more generally, and the answer depends on what specific question you are trying to answer. When it comes to the largest-scale investments, Dr. Kintner-Meyer contended that decision makers in the investment and utility communities look at mid-range, rather than long-term time horizons. Too many uncertainties exist out to 2050, making such a time frame less relevant. Therefore, if we are looking to use long-term studies to influence the decisions of investors, one way to get around the challenges related to VRE discussed in this session is to conduct optionality analyses across a range of scenarios, and communicate value within that framework.



Dr. Samuel Carrara (FEEM, Italy and UC Berkeley, US) shared his experience within the ADVANCE project, working with the integrated assessment model WITCH. From this perspective, most solutions related to better representing VRE-grid integration were based on the direct or indirect implementation of residual load duration curves (RLDCs), complemented by other explicit grid, flexibility, and capacity constraints. In lower resolution integrated assessment models, the issue of time resolution is a challenge, but when comparing their results to more granular model results (from REMix) they found that the models perform well. However, although many researchers have come to a good point in pure modelling of VRE, much more needs to be done in a broader sense to better model expected complementary energy system dynamics around storage, grid and demand response.



Closing remarks:

The Chair, Prof. Brian Ó Gallachóir, closed the session by providing a summary of expert interventions from the invited panel and attending audience.

In practice, the methodological toolbox to represent VRE in long-term energy modelling has become larger and more robust since IRENA's 2014 IEW event on the issue, as summarised in IRENA's [Planning for the Renewable Future](#) report, and reflected in the rich range of approaches and thought processes put forth in this session.

He noted that perhaps the key open question to emerge from the discussion and interventions was now around the essential level of detail in long-term modelling of VRE – which methodologies and tools are appropriate in which context, and to what extent?

In terms of model structure/framework, Dr. Schaeffer shared his disaggregated and flexible three-step approach of capacity expansion-dispatch-grid analysis, and Dr. DeCarolis' stressed a recommendation to tailor models to the particular question at hand.

In terms of model scope, Dr. Levin introduced the evolution of competitive market dynamics with high shares of VRE, and how that aspect will become important to integrate in long-term models if we would like to more accurately represent capacity investment. Open interventions from the floor also raised the prospect of expanding model scope in relation to social constraints, new possibilities (and uncertainties) around flexible technology and demand, and the link to broader economic dynamics and goals (e.g. SDGs).

Dr. Frew complimented the conversation around appropriate model scale and scope with a discussion of appropriate spatial and temporal selection methodology within the chosen scale/scope.

To conclude, Prof. Ó Gallachóir encouraged attendees to continue engagement with IRENA on this topic, as the agency will be taking this conversation and open questions forward through their own work, and continued discussion with the IEW community.

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As noted, IRENA will be taking this conversation forward through future work, and welcomes continued engagement with the academic research community around events such as the IEW.

We encourage any readers of this summary who may have existing or upcoming work on the issue of modelling variable renewable energy to be in touch, for potential inclusion in IRENA's compendium of methodological approaches.