International Renewable Energy Agency

Proceedings

Expert Workshop
Addressing Variable Renewables in Long-Term Planning (AVRIL)

2-3 March 2015

IRENA Innovation and Technology Centre (IITC), Bonn, Germany

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Agenda

2 March 2015

9:30 – 9:40	1. Welcome address by Mr. Dolf Gielen (Director, IRENA IITC)
9:40 – 10:20	2. Objective and scope of the meeting by Ms. Asami Miketa (IRENA IITC)
10:20 – 10:50	3. Planning challenges for RE deployment: North African perspective - Presentation by Ms. Rim Boukchina (RCREEE) - Discussion
11:10 – 12:00	4. What are the actual challenges of system planners in North Africa – experiences with variable renewables from a planners perspective - Presentation by Ms. Emna Bali (STEG, Tunisia) - Presentation by Ms. Mellouki Filali (ONEE, Morocco)
12:00 – 13:00	5. Relevant system impacts of variable renewables on power system reliability that need to be considered in long-term planning - Brief input presentation by Mr. Francisco Gafaro (IRENA IITC) - Group discussion
14:00 – 15:00	6. Tools to support planning with renewable energy and their time horizon - Brief input presentation by Ms. Hannele Holttinen (VTT, IEA Wind Task 25) - Brief input presentation by Mr. Falko Ueckerdt (IRENA IITC) - Group discussion
15:00 – 17:50	7. Approaches to improve the representation of variable renewable impacts in long-term energy planning models - Addressing flexibility in energy system models – Synthesis from a JRC workshop by Mr. Wouter Nijs (JRC Institute for Energy and Transport) - Brief input presentation by Mr. Falko Ueckerdt (IRENA IITC) - Input on the ADVANCE project results by Mr. Robert Pietzcker (PIK) - Discussion
17:50 – 18:00	Wrap up

3 March 2015

9:30 – 10:00	8. Feedback from North African delegates on Day 1 discussion
10:00 – 12:15	9. Communication of the AVRIL project findings - Brief input presentation by Ms. Asami Miketa (IRENA IITC) - Group discussion
12:15 – 12:50	10. Next steps

About the AVRIL Project

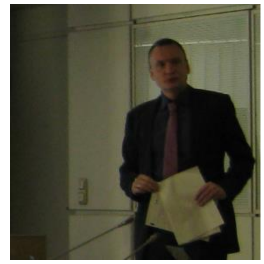
Given the long lifespan of energy infrastructure, investment decisions made today can shape an energy system for decades. Long-term planning is therefore crucial to support cost-effective variable renewable energy (VRE) integration into energy systems. Credible energy plans need to account for both the long-term impact of investment decisions and the short-term variability of wind and solar PV. Bridging these time scales poses a challenge to energy planning tools suited to analyse systems with conventional thermal and hydropower technologies. Long-term energy plans with high shares of wind and solar power are often, - rightfully or not - , challenged by system operators who are concerned that their variability could endanger the reliability of power supply.

IRENA has received requests from its member countries to support them in enhancing the quality of energy planning with higher VRE shares. To respond to these requests, IRENA initiated the AVRIL project, aimed at improving long-term energy planning tools that better represent the important impacts of VRE on the power system. Consequently, we have extended the common research focus to include developing countries, which are characterised with a rapid demand growth and relatively weak network infrastructure. A first step is the identification of those VRE impacts on the power system that are relevant to long-term planning. The second step is to identify key pillars of a robust energy planning methodology that addresses such impacts to increase the validity of future energy plans with higher VRE shares. The final project deliverable is a guideline report targeted at energy planners.

IRENA sought the advice of international experts to guide the development of the guideline report. To this end, IRENA convened 27 international energy experts from European-based institutions (mostly academic) as well as energy planners from selected North African countries.

2 March 2015 – Day 1

1. *Welcome Address by Dolf Gielen (IRENA)*



Mr. Dolf Gielen welcomed the participants, and introduced IRENA's activities on the integration of VRE into power systems. This meeting was held under one of the six thematic components of IRENA, namely, *Planning for the Global Energy Transition*. IRENA's analysis shows that the share of generation from VRE sources (solar and wind) in the total power production is anticipated to grow substantially over the next 15 years and therefore, proactively preparing for this transformation is a key interest of many IRENA member states.

IRENAs service products that address this interest range from those that cover policy and institutional aspects, such as grid integration roadmaps and grid codes, dissemination of technology information that supports VRE integration into power systems, to improving methodologies for capacity expansion planning and grid stability assessment with higher shares of renewable energy.

The AVRIL project aims at improving methodologies for capacity expansion planning and also to investigate the link between the planning tools and methodologies across different planning time horizons. The inputs gathered at this workshop will be reflected in the AVRIL guideline report that will be used as a basis for providing advisory service to the member states.

2. *Objective and scope of the meeting by Asami Miketa (IRENA)*

Link to the presentation

Ms. Asami Miketa introduced the objective and scope of the meeting. She explained that 'planning the global energy transition' is one of the six priority areas at IRENA. With the AVRIL project, IRENA addresses how long-term plan can be improved for policy making on power sector development with high shares of VRE. VRE are singled out as they are expected to have impact on the reliability of a power system at a higher share, and a new set of technical constraints and/or granularity may need to be introduced to planning models. IRENA received a number of requests from its member countries that are struggling with incorporating features of VRE into their planning tools, as their tools tend to be configured to analyse a system with conventional fossil-based and hydropower plants. Against this background, the AVRIL project was initiated last year, focusing on capacity expansion models that many countries use for policy making purposes, as well as on particular needs from energy planners in developing and emerging countries.

This phase of the AVRIL project aims at developing a report summarising various modelling practices to address the integration of VRE into long-term energy planning models. The literature in this field is rapidly growing in academic literature, and particularly in the European context. IRENA aims to bridge these knowledge barriers to energy planners in developing and emerging countries.

During this AVRIL meeting, the participants were asked to keep particular features of developing and emerging countries in mind. North African perspectives were included in this meeting to stay focused on their needs and reality.

The publication will also benefit from other IRENA ongoing activities, such as network planning methodologies, renewable zoning analysis, island transition planning, and transmission investment cost assessments.

Ms. Miketa concluded her introductory remark with thanking the participants for their contributions and encouraged them to actively engage in the discussion.

3. ***Planning Challenges for RE Deployment: A North African Perspective by Rim Boukhchina (RCREEE)***

Link to the presentation

Ms. Rim Boukhchina began her presentation with a description of the status and prospects of power systems in the North African region. The regional power generation mix is dominated by fossil-fuel based generation. Only a small share of wind and solar power contributes to the regional energy mix. Three North African countries, Morocco, Egypt and Tunisia, have so far developed wind power projects. In Morocco and Tunisia, wind power plants already generate 7% and 6% of their total power demand respectively. PV is used mainly for rural electrification, and hardly any grid-connected PV power is in place yet. Pumped hydro systems in Morocco are the only storage options installed in the region. Most countries in the region have ambitious RE targets for the power sector, including Algeria (40% of electricity generation) and Tunisia (30% of electricity generation).

Ms. Boukhchina identified that the existing long-term investment planning models used in the region improperly reflect VRE specificities. Consequently, there are needs for improved long-term planning tools and methodologies to be used for national policy making.

The main challenges for RE deployment are:
- Arbitrary political decisions for RE objectives (not necessarily based on numerical analysis)
- Weak national grid infrastructure in the region
- Underdeveloped interconnections among North African countries (even if they exist, they are underutilized)
- Subsidies on fossil fuels for electricity production
- High upfront investment costs of RE technologies
- Lack of storage options (Hydro Pump-Storage, others)
- Limited interconnection with European countries
- Absence of regional markets
- Inappropriate long-term investment planning models to take account of the high share of VRE in the system
- Miscommunication between policy makers and stakeholders in the power sector

The following elements need to be considered in improved energy planning models:

- Rapidly changing load curves due to increasing AC
- Impact of grid connection: How could interconnection reduce costs and investments? Some interconnections exist between the countries, but only for emergency purposes. There is no existing power market.
- Extra costs linked with RE integration
- Intermittence and variability of wind and PV. Currently they are modelled as normal dispatchable power sources, not as variable.
- National RE potential

Ms. Boukhchina noted that existing planning models need to be adapted and broadened to address regional needs. Regional integrated planning has many advantages such as a reduction of overall capacity requirements. Many North African countries are already interconnected, however, electricity exchanges between countries remain underdeveloped and underused.

She further pointed out that many plans are made in the region, and energy planning capacities and institutions exist and function. However, the region needs to improve the planning with respect to a system with a higher share of VRE.

Discussion

Two main points were discussed, the first point touching on how the targets are derived, whether they were informed by numerical analysis or driven primarily by political contexts. The second point raised the issue of the national planning process and who is involved in it.

Policy makers currently set RE targets and optimization analysis of RE expansion are not necessarily informing the policy decisions.

State owned utilities are in charge of generation and transmission planning. Transmission and generation planning tend to belong to separate administrative units. The participation of independent power producers (IPP) grows slowly in North African countries.

In North Africa, planning committees are commonly set up consisting of policy makers and utilities. Policy makers tends to push for ambitious RE targets, while utilities tends to take a more conservative approach fearing to compromise reliability of the power system. The conflict is possibly driven by misunderstandings and a lack of a common perspective on the challenges between the two sides.

4. ***What are the Actual Challenges of System Planners in North Africa – Experiences with Variable Renewables from a Planner's Perspective***

Presentation 1: ***Integration of Renewable Energy in Long-Term Energy Planning – The Tunisian Case: Current Situation and Challenges by Ms Emna Bali (STEG)***

Link to the presentation

Ms. Emna Bali, a power system planner from the Tunisian state utility company STEG, gave the first presentation of this session on the current situation and challenges of energy planning with increasing shares of VRE in Tunisia.

She commenced with the current situation of the power system in Tunisia, which is characterised by a rapid increase of power demand (5% per year on average). Tunisia relies heavily on natural gas for power generation (97%), has limited power exchange with neighbouring countries and faces the increase of energy price subsidies. Furthermore, it also faces the structural deficit in the energy balance (41% in 2014), i.e. a high import dependency particularly on natural gas. The government aims at diversifying the power production, by increasing the RE share to 30% RE by 2030 (15% wind, 10% PV and 5% CSP). The challenges associated with this target include the high RE investment costs, the need for pumped storage, the need for flexible generation units, and the need for backup capacity.

Ms. Bali briefly explained how the WASP model is used for energy planning at STEG. VRE are modelled as thermal power plants with no consumed fuel and with an availability corresponding to their load factor. She pointed out the specific drawback of a lacking representation of diurnal variability of solar PV plants.

She raised the concern that introducing VRE will require quickly ramping down CCGT plants in a large range, which is not possible due to both technical and economic reasons. It is technical from the point of view that CCGT plants work with high minimum load (designed to operate as base load plants, not flexible). From the economic perspective, it is not efficient to shut down CCGT plants due to the variability of high shares of RE because the start-up costs are too expensive.

Ms. Bali mentioned two possible directions to address this concern: (1) Use a different approach in WASP: optimizing the non-VRE part based on residual electricity demand curves (i.e., changing the LDC approach of WASP to a RLDC approach), or (2) Use other planning models that can represent VREs more properly such as MESSAGE.

Discussion

The main discussion point was related to the lack of technical power plant flexibility in the Tunisian power system, due to the design of these plants. This will likely pose technical challenges as it moves towards 30% VRE generation share. There was a consensus, however, that thermal power plants generally could be operated sufficiently flexibly to complement high VRE shares. It was noted that there was not a single blackout due to increasing renewable shares in any power system in the world, including isolated systems. Flexibility such as ramp rates and minimum load, do not only depend on the fuel and power plant type, but on the specific layout of the plant. For instance, CCGTs can be optimized to operate at very high efficiencies or alternatively to be very flexible. The corresponding technical parameter and start-up costs differ. Future power plants will likely become even more flexible. Additional flexibility can be provided from future VRE generators, e.g. ramping them down if necessary.

***Presentation 2:* Moroccan Power System by Ms. Loumia Mellouki Filali (ONEE)**

Link to the presentation

This presentation was jointly given by Ms. Loumia Mellouki Filali from ONEE, a Moroccan state owned utility company, and Nawfal Saadi from IRENA. Like Tunisia, Morocco's power demand increases at a rapid pace (6.5% average annual increase). The national energy strategy includes the diversification of the energy mix, achieving higher energy efficiency, promoting regional integration via reinforcing interconnectors, and increasing RE capacity to a 42% share of total installed capacity by 2020. Currently, Morocco has 8 GW of installed electricity capacity, where 10% are VRE generators, composed mostly of wind power generation. Morocco is connected to the Spanish electricity market and is thus able to purchase power from Spain. In future, the government has set targets for RE shares in the capacity mix as 14% solar, 14% wind and 14% hydro by 2020. In Morocco WASP and VALORAGUA are used as planning tools. WASP was designed for a hydrothermal planning, which makes it difficult to address characteristics of VRE. The tools are used to identify the least-cost development plan for generation, transmission and distribution in order to meet the demand.

Four issues of VRE integration are distinguished:

i) The low contribution of VRE generation to cover peak demand and the need for "back-up capacity"
ii) The reduction of load factors (full-load hours or utilization) of thermal plants
iii) Sufficient flexibility such as ramping and cycling of power plants to balance VRE in the short term
iv) The mismatch of low demand situations and VRE overproduction leading to curtailment.

5. Relevant System Impacts of Variable Renewables on Power System Reliability that Need to be Considered in the Long-term Planning

Input presentation by Francisco Gafaro (IRENA)

Link to the presentation

In order to have a common framework to structure different aspects of VRE impacts and their relation to reliability of a power system, Mr. Francisco Gafaro presented a matrix with four elements: generation adequacy, generation security, network adequacy; and network security. Note security is defined to include stability. For each of the four elements, the matrix describes how VRE may impact these elements. The matrix is presented below.

	Generation (+ load, DSM and storage)	Networks (T&D)
Adequacy	Variability reduces contribution to firm capacity	Location-constraints may require grid extension and reinforcement
Security	Variability and limited predictability requires system to follow residual load Lack of inertia and governor response may pose the technical limit to VRE penetration	Location-constraints may change voltage control requirements Distribution level connection may affect voltages and protection system coordination RE's behavior during fault may affect system stability

He then further elaborated how these impacts could be mitigated for each of the four elements, as presented below. IRENA uses this matrix as a starting point to discern important investment needs.

	Generation (+ load, DSM and storage)	Networks (T&D)
Adequacy	More generation capacity would be needed	Transmission investment costs
Security	Cost for deploying flexibility measures Cost for device to provide inertia and governor response	Transmission and Distribution network enhancement (new lines and devises)

Discussion

The following suggestions were made:

- Add another row, representing "energy", in order to distinguish energy and capacity.
- Analyse adequacy also in terms of "energy" as not only capacity can be scarce, but also fuel or energy. This refers to the availability of fuels in the long-term and energy security issues.
- Use "resource" instead of "generation".
- Use terminology like "balancing" and "flexibility" instead of "inertia" and "governor response", in order to make the terminology friendlier.
- "Inertia" and "governor response" could also be provided by VRE technologies in the future.
- Important market design issues need to be addressed in the matrix.
- The terminology (matrix) should be more focused on the technical aspects affecting the reliability of the system, therefore market design issues need not be addressed in the matrix.

6. ***Tools to Support Planning with Renewable Energy and their Time Horizon***

Presentation 1: ***Wind Integration – Capturing Impacts to Power Systems by Hannele Holttinen (VTT, IEA task 25)***

Link to the presentation

This session started with a short presentation given by Ms. Hannele Holttinen, who presented the IEA Task 25 work on recommended practices in wind integration studies. The focus of the integration studies are not on analysing the long-term capacity expansion pathways.

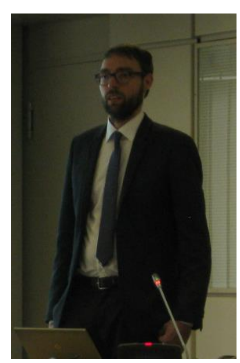
The main recommendations of the IEA report for wind integration studies include:

- Using *synchronous* wind generation and load time series as an input that:
  - Is representative for regions and considers potential smoothing impacts
  - Captures the wind capacity value of 10 years (for balancing issues 1 year is acceptable)
  - Distinguishes forecast data, i.e. uncertainty at different time scales
- Recommendations on the use of dispatch simulations:
  - Account for the impact of uncertainty on commitment decisions.
  - Consider the limitations of flexibility (ramp/start costs, part load efficiency, minimum online load; using interconnections for balancing).
- Dynamic stability should be analysed for higher penetration levels, and should also consider the support of VRE generators to the grid (e.g. provision of ancillary services)
- For larger penetration levels, changes in the remaining non-VRE part of the system may be required and should be considered in wind integration studies accordingly

She noted that most of these recommendations are also applicable to solar PV.

Ms. Holttinen also addressed issues for long-term planning models. Generally, VRE integration impacts are not adequately captured and consequently the impact of high shares of VRE are underestimated. More specifically, it is important to capture the grid restrictions, especially stability issues at high penetration levels. The grid needs to be prepared for penetration levels above about 5-10 % of yearly generation (depending on the existing grid). This process of enhancing and extending the grid can take 10 years so grid studies need to be conducted in parallel to long-term generation expansion studies. Stability becomes a potential issue usually for larger shares, i.e., 20 % and above.

Presentation 2: ***How do different tools support long-term energy planning? by Falko Ueckerdt (IRENA)***



Link to the presentation

This short input presentation aimed at spurring the discussion on how different tools with different scopes, level of detail and purpose interact and how they need to support and inform long-term planning models.

Long-term energy planning models optimise the generation capacity expansion with a time horizon of 20-35 years (intertemporal optimization often until 2050). Typical models used in the focus countries of the AVRIL project (developing and emerging countries) are WASP, MESSAGE, TIMES, OSeMOSYS, or BALMOREL. These linear capacity expansion models distinguish 1-36 regions; have a temporal resolution of 1-5 years (for investment decisions) and 8-288 time slices per year (typically about 12). In addition, they optimize power flows and net transfer capacities between the regions.

It is noted that multiple tools are needed to plan and design a power system. In the context of energy planning, models can be categorised based on their typical scope (e.g. time horizon) and detail (e.g. temporal resolution and technological representation). We distinguish between:

a) **Production cost models** which optimise or simulate the power system operation of a given power system for typically one year with hourly resolution. Thus, they account for short-term variability of VRE and load, as well as for technical constraints of different generation units (e.g. operating reserves, minimum up- and down times, ramp-up and down constraints, start-up costs, and part-load efficiencies).
b) **Transmission planning**: It became apparent that 'transmission planning' is not a clear and common term for the analysis we wanted to describe here. Siting studies are necessary based on a spatial resource assessment, taking into account the existing infrastructure as well as spatial load and VRE resource distribution. A good example is IRENA's zoning activity, which prioritizes the siting of VRE generators in Africa based on a multi-criteria analysis including resource potential, distance to load centres and existing transmission infrastructure.
c) **Load-flow analysis** are a static assessment of a given transmission infrastructure. It calculates voltages and currents, active and reactive power flows in an AC grid and draws conclusions on the technical feasibility, thermal stresses and potentially required grid enhancements.
d) **Stability studies** typically involve dynamic simulations of a power system after a disturbance with a temporal scope of about 1min-1s and a high resolution of 1s-1ms. Different types of stabilities can be analysed such as rotor angular (including transient), frequency and voltage stability.

These models and analysis complement and inform each other in a somewhat hierarchical order, due to their different scope, detail and purposes. The relationship of these components was presented in a schematic figure.

With increasing VRE shares, the analysis and models need to be more concerted because VRE impacts to some extent appear on short-term time scales and small-scale system components. More detailed analysis may need to inform the long-term model analysis. The overall question is therefore: what are crucial feedback loops that need to be considered because they affect the optimal generation capacity expansion?

Several aspects suggest an improved coordination of generation and transmission planning. VRE sites with capacity factors might be distant from load centres. Interconnecting power systems, countries and regions can reduce adverse VRE impacts, e.g. smoothening variability, and pooling flexible resources.

Production cost models might need to inform long-term planning models about the flexibility requirements in particular in scenarios with high-shares of VRE. These highly detailed models can support long-term models in three ways: (1) parameterizing the long-term model, (2) validating its results, or (3) by soft-linking both models to derive a common optimum of generation capacities with sufficient flexibility.

One question posed to the experts was whether highly resolved analysis in particular grid studies (load flow analysis and stability studies) are sensible for future years (>2025) given the uncertainty about the details of the future power system and technological progress?

In other words, it may be adequate to neglect or only approximate some aspects like stability issues when deriving long-term scenarios; and resolving potential challenges on a shorter time horizon. Simple approaches to ensure system stability could be to approximate a limit of the instantaneous VRE penetration in the long-term model analysis.

Discussion

The discussion focused on which tools are needed for the planning of an energy system, and the roles of long-term energy planning models. A range of viewpoints arose among the participants. Some of the differences appeared to originate from different understandings of the term "long-term energy planning". The main conclusion drawn was that the AVRIL report should be very clear in defining the purpose of so-called long-term energy planning models and the additional need for more detailed models.

7. Approaches to Improve the Representation of Variable Renewable Impacts in Long-term Energy Planning Models

***Presentation 1:* Addressing Flexibility in Energy System Models – Synthesis from a JRC Workshop by Wouter Nijs (JRC)**

Link to the presentation

Mr. Wouter Nijs presented the results from the workshop on "*Addressing Flexibility in Energy System Models*" held in December 2014 at the JRC in Petten, Netherlands. These findings will also be published in a JRC report and comprise the following:

- The modelling community is challenged to analyse the transition to future systems with much higher shares of RES
- There is a need for a systematic mapping of key flexibility requirements and state-of-the-art model-based solutions or best practices for modelling
- Data needs to be improved for renewable energy potentials, development of the future demand profiles and demand response.
- It would be convenient to have a more permanent forum to exchange modelling approaches, for instance within the follow up of the implementation of the SET-Plan Integrated Roadmap[1]
- Increasing the number of time slices in long-term energy planning models alone only addresses the variability itself but does not address the operational constraints (coupling large-size energy system models to sector-specific models / below one hour is not necessary)

[1] https://setis.ec.europa.eu/implementation/technology-roadmap/the-set-plan-roadmap-on-low-carbon-energy-technologies)

- The most important guiding principle is *"know what can be simplified without compromising the accuracy and reliability of model results".*
- It is necessary to improve the representation of market and regulatory aspects.
- Retrofitting of power plants is an important option to increase flexibility in the energy system, but modelling retrofitting is a challenge in many models and should be the object of active research.
- Participants stressed the importance of using and sharing open source approaches and publicly available data whenever possible.

Mr. Nijs among other issues also discussed the shortcomings of simple time-slice approaches. A low number of time slices would lead to an underestimation of variability, i.e. a crucial part of the variance of the VRE supply distribution is averaged out. He pointed out the importance of representing possible VRE excess electricity and its absorption by flexible demand, conversion (e.g. hydrogen), storage or otherwise curtailment.

<u>Presentation 2:</u> Approaches to Improve Long-term Models by Falko Ueckerdt (IRENA, IITC)

Link to the presentation

Mr. Falko Ueckerdt presented four different approaches towards an improved representation of VRE in long-term models. Each approach has its merits and is suitable for specific VRE impacts. Many models use a combination of these approaches to cover for different relevant VRE impacts as follows:

1. Directly increasing the temporal resolution of the model
2. Restructuring time to capture variability/flexibility with a low temporal resolution (time slices or RLDC approach)
3. Using a highly resolved model e.g. a production cost model
4. Additional constraints that account for variability or flexibility

One important area for improvement is the design of time slices. Mr. Ueckerdt discussed the pros and cons of two different ways of selecting time slices. Firstly, he explained the conventional way of load-based time slices, which are chosen according to load values (season, weekday/weekend, day/night). Secondly, he elaborated on an advanced way of designing cluster-based time slices which differs from the traditional approach in three respects:

i) They use an optimization algorithm to minimize the deviation of time slices and data
ii) They are cluster-based, i.e. they allow more degrees of freedom when combining points in time to time slices, and
iii) The advanced approaches cluster points in time not mainly according to load values but to a high extent also to VRE supply values.

Furthermore, Mr. Ueckerdt underlined the importance of a model representation of the capacity credit of VRE, which are typically lower than conventional thermal power plans, in particular with increasing VRE shares. This is particularly important for power systems with growing demand, where additional firm capacity is required. In such systems, the deployment of VRE generators needs to be combined with an expansion of conventional plants or other options of providing electricity during peak load hours such as storage technologies. This needs to be reflected in the long-term planning models. Capacity credits cannot be endogenously calculated within a long-term energy-planning model, because it is a system parameter which depends on several factors that partly require a more detailed analysis, such as VRE level and mix, storage, grid congestion, Demand Side Management (DSM) and the spread of VRE sites. Hence, capacity credits need to be estimated beforehand and parameterized into the long-term model. Estimates of the capacity credit as a function of the VRE share can inform the long-term model as i) a peak capacity constraint, or ii) a super peak time slice or iii) part of a representation of RLDCs.

He then further discussed how to represent flexibility issues in long-term models. Flexibility in this context refers to the ability of the non-VRE part of the power system to technically adjust its generation on short notice. Sufficient flexibility is important because the costs of inflexibility can be high as this can cause load shedding, VRE curtailment, or even brown or black outs, and expensive adjustments towards more flexibility. If a power system is carefully planned, adverse impacts of inflexibility can be avoided at low costs.

Finally, the technical detail and temporal resolution (i.e. the width of time slices) of long-term energy models is not sufficient to directly represent flexibility. There are two methodologies of improving the representation of flexibility: (1) by adding constraints to the long-term energy models to account for operational limits and flexibility, or (2) the long-term model is linked to a highly resolved production cost models, which is more suitable to account for detailed operational aspects.

The first approach has the advantage of providing a direct and consistent feedback of variability and flexibility needs on the long-term investment decisions within one model. However, computational resources limit the level of operational details (number of time slices, type and number of operational constraints, no single generation units modelled) such that the constraints need to be very simple and provide only a strong approximation of real system effects.

The second approach, using a soft-link to a dedicated production cost model, allows for a more detailed representation of operational aspects in the model analysis. However, the feedback loop to the long-term energy model requires a careful design of the model interfaces. An elaborated iterative approach needs to carry both models to a common global optimum.

<u>Presentation 3:</u> Modelling System Integration of VRE in IAMs (Insights from the ADVANCE Project) by Mr. Robert Pietzcker (PIK)

Link to the presentation

Mr. Robert Pietzcker presented results from the ADVANCE project, in which a number of state-of-the-art Integrated Assessment Models (IAMs) used for policy advice have worked together on improving their representation of the challenges of integrating solar and wind in power systems. He focused on two approaches of representing VRE impacts: a RLDC approach and integration cost markups.

<u>RLDC Approach</u>

Residual load duration curves (RLDCs) contain the main information about the variability of wind and solar supply, as well as correlations with demand, thereby capturing three major challenges of integrating VRE into power systems, as shown in Fig.2 (right), namely

- Low capacity credit
- Reduced full-load hours of dispatchable plants
- Overproduction of VRE in some hours

A rather novel modelling approach of accounting for variability in long-term energy models is based on a model representation of RLDCs, which change depending on the share and mix of VRE. This reflects the temporal distribution of residual demand, which to a large extent determines the cost-efficient mix of non-VRE power plants. Changes of the RLDCs with increasing VRE shares induce potential shifts in the non-VRE capacity mix, typically from baseload plants to more intermediate and peak load plants. In addition, a representation of RLDCs captures the so-called “profile costs”, which for many power systems is the largest component of VRE integration costs. Profile costs comprise the costs associated to three VRE impacts (1) the low VRE capacity credit, (2) reduced full-load hours of dispatchable plants, (3) overproduction of VRE in some hours.

Integration Cost Markups

For numerically complex, large-scale models that cannot explicitly model the high temporal and spatial resolution required for explicit calculation of optimal measures to integrate VRE, researchers at PIK implemented a simplified integration approach that represents storage and grid costs as well as curtailment. The approach combines estimates of the different integration measures (such as storage and curtailment of summer peaks) into a) a cost penalty due to investments into storage and grid technologies, and b) an energy penalty resulting from storage losses and curtailment. This energy penalty results in the need to install higher production capacities of this VRE to supply a certain share of total power demand, thus increasing net costs. The requirement for these integration measures rises with the share of VRE in the total power mix.

Besides storage and curtailment, future power systems with high shares of renewable supply will require an increase in long-distance electricity transmission from sites with favourable renewable resources to demand centres. As a full representation of this aspect would be too numerically complex, PIK researchers used geometric principles to develop a conservative estimation of additional long-distance grid costs arising from a given share of a VRE source in the electricity mix.

Discussion

The discussion focused mainly on the importance of considering flexibility in long-term models. A range of viewpoints was given, with no conclusive result. A cautious summary would be:

- Flexibility is an important aspect to consider in long-term models, because a lack of flexibility can be very costly.
- There is some evidence that the costs for providing sufficient flexibility with increasing VRE shares are low, i.e. less than 6 EUR per MWh of VRE (<10% of VRE generation costs) even at high wind shares. (Acknowledging that extracting such costs is challenging.)
- While sufficient flexibility and reliability cannot be guaranteed based only on long-term model results, there is some indication that capacity expansion pathways of enhanced long-term models provide sufficient flexibility, i.e. the feedback of a higher-resolved model on the capacity mix is fairly small.

- Additional tools should help to decide on the specific flexibility requirements of a plant, which largely depend on the specific layout (e.g., how many units at which size, minimum load and ramp rates).
- If a model reflects the reduced load factors of conventional plants due to increasing VRE shares, a shift towards more flexible plants is induced without a dedicated model representation of flexibility.

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8. Feedback from North African Delegates on Day 1 Discussion

Ms. Rim Boukhchina (RCREEE) found the discussion very fruitful, even though it might have been too technical in some cases. She stressed the need for an appropriate balance between model complexity, necessary data and the benefit of this complexity. A potential lack of data has to be taken into consideration. She pointed out that different teams are responsible for transmission and generation planning, thus both aspects should not be integrated into one tool. Currently, flexibility is not considered in the existing models, but should be taken into account in the future. Finally, she requested that the AVRIL project would also address the assessment of existing models, capacity building needs and provision of training courses.

Ms. Emna Bali (STEG, Tunisia) underlined once more that generation and grid planning are institutionalised as a separate process and should remain so. Further, she shared her concern of the need to improve WASP, or migrate to other planning tools. In her opinion, WASP is only sufficient for planning of thermal power plants. There was an attempt to use MESSAGE that fell into inconsistent results potentially due to the lack of experience in using the tool. Finally, she mentioned that a model review had been done by MERCADOS, but STEG could not identify a model that is suitable for both generation and transmission.

Ms. Loumia Mellouki Filali (ONEE, Morocco) stressed the irrelevance of transmission planning in the long-term due to the uncertainty in future plant location. Moreover, it is not worth it to combine methods of transmission and long-term planning as it may lead to oversimplification of the results. She stated that flexibility is an especially important topic in the case of Morocco, mainly due to the current lack of flexible power plants, which is why she emphasized the need for tools that include ramping constraints and minimum operating capacity. Concerning time slices, they did not know how close they could get to hourly resolution. In addition, there is an interest in how the time slice approach can help in representing the curtailment of VRE. Furthermore, the main policy question needing answers is how much VRE can be integrated without having any problems.

Discussion

Ms. Hannele Holttinen (VTT, IEA task 25) directly replied to the above question of how much VRE could be integrated without causing any problems. This has been asked for a long time, and it is only possible to give indicative numbers. She mentioned that it is necessary to integrate a few percent before recognizing an impact on the system level at all. It is not necessary to make integration studies before. Mr. Nawfal Saidi (IRENA) added that Morocco already has reached 7% of VRE without trouble. He clarified the concern being the insecurity caused by not knowing when to start worrying about problems caused by deploying VRE.

There was wide consensus on the need for capacity building, followed by a discussion on whether (costly) industry tools and experts are needed, or open source models are sufficient. In any case, in-house planning capacity is crucial for timely and reliable national policy making.

There was a discussion on the purpose and quality of the long-term models. Some questions that were discussed are short-term issues, which cannot be covered by long-term models. The AVRIL report should be very clear in defining the purpose of long-term energy models and their role for energy planning.

9. Communication of the AVRIL Project Findings

Ms. Asami Miketa (IRENA) presented the proposed structure of the AVRIL report. The comments are noted below:

- The focus and scope of the report should be clearly defined as long-term energy planning and long-term models.
- It was suggested to just mention but not to particularly discuss transmission planning and rather focus on generation expansion.
- In addition, “transmission planning” should not be used as a term for the analysis done with long-term models, because it is usually associated with detailed grid studies.
- A discussion with different suggestions regarding the title “long-term energy planning” developed with no clear result, however.
- One part of the report should be a discussion on the renewable resource assessment. Where are suitable VRE sites? This part could contain IRENA’s zoning activity.
- Some participants pointed out that the reliability matrix is missing one important point of improving long-term models with respect to representing VRE impacts. This is the reduction of full-load hours (or reduced utilization) of conventional plants.

10. Next Steps

It is planned that the report will be completed in May. For the development of the report, the participants of the workshop will be contacted to finish the discussion on remaining issues.