IRENA
International Renewable Energy Agency

Proceedings Report

IRENA Workshop on Addressing the Geo-Spatial Aspects of Variable Renewable Energy in Long-Term Planning

12-13 December 2019 Bonn, Germany

Content

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Workshop Background and Objectives

Since 2015, IRENA has been supporting its Member States to enhance the quality of energy planning and modelling with high shares of Variable Renewable Energies (VRE) through the AVRIL project, short for 'Addressing Variable Renewables in Long-term Energy Planning'. IRENA launched its first report under the AVRIL project in 2017, focusing on strategies for practitioners to represent VRE in Long-Term (LT) modelling of crucial system requirements. The unique geospatial aspects of VRE were introduced in the report as they held crucial importance in comprehensively capturing the system wide needs for generation adequacy, flexibility and transmission capacity in LT models.

In recent years, accessibility to geo-spatial data and tools has been significantly improved, and hence increasingly included in the government planning processes. Another emerging aspect is for planners to better reflect potentials for distributed renewable energy pathways, including embedded generations and decentralized rural electrification in the long-term energy planning process both in well-developed and under-developed grid systems. Experts worldwide have rolled out novel and sensible approaches to such issues, but a clear overview of options for energy planning practitioners is still needed to broaden their application. In this context, IRENA has planned a thematic update of the first AVRIL report to elaborate the geo-spatial aspects of VRE in LT energy planning, along with practical examples of solutions to reflect those aspects in long-term energy scenarios. IRENA workshop, held on 11-12 December 2019 in Bonn, was a first step to collect the insights on the subject from the government practitioners, experts and research institutions involved in long-term energy modelling worldwide. The workshop aimed to achieve three main objectives:

1. To discuss the current use of geospatial information in long-term energy planning processes of governments;
2. To collect inputs from experts on the latest developments regarding data and methodologies that could bring practical advancements;
3. To discuss the planning methodologies and interlinking geospatial aspects, that help to optimise the VRE linked long-term investments falling under multiple concern areas such as system flexibility, grid infrastructure and electrification pathways.

Proceedings for Workshop Day-1:

Date and Time: 12th December-2019, 08:45 – 17:30

Participants: 45

Session 1: Introduction

The session included welcome remarks and scene setting presentation from IRENA staff along with a short round of participant self-introductions.

Welcome remarks – Dolf Gielen (Director, Innovation and Technology Center (IITC) IRENA) welcomed all workshop participants on behalf of IRENA. He emphasized that the world renewable electricity share needs to increase significantly to have a sustainable energy future. He particularly, quoted IRENA REMAP scenario which recommends that the current global VRE share in electricity of roughly 10% needs to reach 60% by 2050. He further stated that the aim of the IRENA AVRIL project is to assist Member States to robustly plan a cost-efficient energy transition towards renewables. Building further on AVRIL 2017 report that featured a broader planning framework, IRENA, now plans to develop spin off reports, focusing the important elements one at a time. The upcoming spin off report focus is to address the geospatial modelling aspects of LT energy planning.

Scene Setting Presentation – Asami Miketa (IRENA) began by mentioning that many governments conduct LT energy planning exercises within their ministerial departments to serve several important purposes such as defining the basis for policy making, setting policy targets for renewables and assessing needs of future investments. They typically employ quantitative techno-economic analysis of differing time horizons and technical scopes. She indicated that over the years, two key energy planning aspects, mostly linked with power systems, are growing in government circles. Firstly, the policy makers are increasingly realizing the benefits of RE power and are motivated to promote it through sound policies and secondly the concerns are growing about integration challenges posed by variable nature of Solar and Wind generation sources. She mentioned that the 2017 AVRIL report, addressed these key concerns by providing high level overview of data, tools and methodologies on how should the LT power system planning change and what are the institutional and model specific needs in this regard. The report mainly focused on the high relevance KPIs of LT generation expansion planning, namely, the Firm Capacity, Transmission Capacity and Flexibility. In the end, she mentioned that realizing the rapid improvements in GIS based data access, in last couple of years, IRENA has planned to bring forward a spin-off report on the subject.

Bilal Hussain (IRENA), continuing the scene setting presentation, briefed the audience on the geospatial aspects covered under 2017 AVRIL report and gave highlights on three solutions recommended by the report, namely, **[1]** increasing geospatial resolution of LT expansion models, **[2]** linking grid investment costs with VREs and **[3]** site specific representation of generation and transmission investments. He then briefed the audience about the topics to be included in AVRIL spin off report and with this context, explained the workshop objectives and scope for each session. He also indicated that the new topics, namely, the capturing of climate change aspects and reflecting distributed VREs (grid and off-grid) in LT energy planning, are included in the workshop focus given their rapidly increasing relevance among IRENA Members.

Session 2: Country Experience

The session comprised of two parts and included short presentations from experts developing long-term energy scenarios for national policy-making using modelling tools either within a respective national government or within specialised agencies affiliated with a government. Each speaker presentation was followed by short Q&A from audience. This section presents a summary of the insights generated during the presentations and Q&A sessions.

Session-2 (Part 1):

Moderator – Daniel Russo (IRENA) started with a short overview of the session objectives and shared the general findings collected through regional IRENA AVRIL workshops held in Africa, Central Asia, Latin America and the Arab region. In summary, he stated that most countries, in general, consider the inclusion of geospatial aspects in their LT planning processes as one of the priority areas of improvement. They also consider the co-optimization of generation and transmission, challenging to implement from modelling and institutional context. In many cases the reflection of geospatial aspects is project based and does not come under LT planning scope. However, the countries with relatively advanced long-term planning practices, mostly, have developed GIS based VRE resource maps. Some countries also account the region based costs such as grid investments, transport and construction costs linked to VREs with in the LT models. They also often soft link the generation expansion models with more geospatially resolved models for network studies. Several countries also include multiple regional nodes within LT generation expansion models, which is mostly based on the spatial characteristics of the dominant supply side resource.

Expert Presentations:

Abu Dhabi (Department of Energy) – Ahmed Ali Al Bloushi (Oil & Gas Senior Specialist, Integrated Energy Model Team Leader) introduced to audience the Abu Dhabi Cube based scenario modelling approach accounting three key dimensions as cube corners, namely, Energy carriers, Demand Sectors and Scenarios. He highlighted that, currently, the geospatial analysis is being done on project basis and is not fully integrated into LT planning. He shared his expectation to get useful insights from this workshop to evolve their cube modelling approach by incorporating geospatial elements especially in context of LT system flexibility and reserve needs.

Saudi Arabia – Ali Al Heji (Policy & Strategic Planning Deputyship, Ministry of Energy, Industry and Mineral Resources) introduced to the audience, the general planning process of the country indicating each stakeholder. He highlighted that the country's LT energy planning process, utilizes tools to perform technoeconomic system analysis and future resource mix is finalized based on cost optimization. The planning process takes into account several geospatial elements of modelling, namely, the spatial resource maps of Solar and Wind, location based land availability constraints, grid connection costs and VRE capacity factors. Effects of important geospatially linked parameters are also considered such as the temperature effect on solar performance. The final step, of country's planning framework, also performs the geospatial analyses for the site optimality of supply options duly considering the Life Cycle Cost of Energy (LCOE) and proximity to grid and demand centres. He informed that a siting study has also been recently performed for grid based storage duly accounting the supply-demand complementarity and other aspects at high geospatial resolution. Mr. Al Heji also informed that the improvements are under way to evolve the country's LT models to account for more geospatially linked factors such as the terrain related construction costs.

Insights from Q&A:

- ✓ Solar capacity factor for Saudi Arabia ranges between 20-27% depending on location and technology type
- ✓ Weather related Typical Meteorological Year (TMY) files are synthetically prepared inhouse by combining satellite based data and ground measurements.

Egypt – Abdel Zaher Elshafey (Egyptian Electricity Holding Company, Ministry of Electricity and Renewable Energy) introduced to audience the country institutional structure relating to power system planning. He stated that Egypt is now targeting 42% RE electricity shares by 2035 which would constitute around 36% of VREs. Given the strong site-specific nature of VREs, the country's traditional decoupled generation and transmission planning processes are now integrating and modern tools in commercial domain have been acquired. Modern tools are enabling Egypt to optimize system flexibility and transmission related costs in addition to reflecting firm capacity in LT models. On data access side, Egypt has produced Solar and Wind atlas to identify high quality resource areas and employs online satellite based databases. In the end, Mr. Elshafey indicated two important priorities of LT planning for Egypt, namely, improving on the front of geospatial data availability and training of planning practitioners.

Session-2 (Part 2):

Moderator – Pablo Carvajal (IRENA) briefed the proceedings of the 2nd part of session-2, which featured four presentations from representatives of the institutions directly working with governments in building LT energy plans and scenarios.

Germany - Dennis Volk (Federal Network Agency (BNetzA)) informed the participants that German government plans to reach at least 65% RE share in electricity by 2030 and Wind power (onshore and offshore) is a major driver of future transmission needs in the country. BNetzA plays the major role in transmission planning which follows the country's long-term generation planning step. BNetzA transmission models are based on around 450 nodes and the planning process starts with the step of **Regionalization** during which the future generation capacity and load is allocated to each model node. Weather data is obtained from German Meteorological Institute which features around 200 meter grid resolution. Several pre-processing steps are followed including the allocation of wind speed data to different hub heights. Data on existing and future land use and land availability are collected from statistics offices of 16 German States. State specific rules such as the required minimum distance of power plants from the settlements and RE targets are also factored into the model. Mr. Volk mentioned that Generation and Transmission co-optimization is not currently followed in the country planning process and looked forward to workshop proceeding to collect more insights on this domain. He also indicated that in future, emergence of flexible storage options, in particular, the power to gas applications may bring additional geospatial analysis aspects because such options are location specific and their interlinkage with locational demand and grid conditions are important to asses in LT planning.

Insights from Q&A:

- ✓ Comparative impact of low capacity factors of VREs on transmission investments is not assessed by the BNetzA model. The model generates future transmission proposals, duly factoring in the general year-long over-supply conditions in the regions.

Croatia - Lucija Krstanović (Energy Institute Hrvoje Požar (EIHP)) introduced the research focus of EIHP and shared brief highlights of recent long-term energy planning studies conducted by the institute for Croatia, Botswana and Malawi. For former two studies, the institute used *MESSAGE* based 2-region model, whereby the demand projections were developed for each region. On supply side, GIS based analysis was conducted with VRE resource maps while accounting environment protection zones, populated areas and other land uses. The candidate VRE capacities, thus determined, were aggregated for each of the model region. For the Botswana study, IRENA's zoning information for Africa was also utilized. The later study for Malawi was conducted using *Plexose*, employing single node due to lack of data, however, it featured deeper temporal analysis.

Lithuania - Arvydas Galinis (Lithuanian Energy Institute (LIT)) informed the participants that the energy policy in Lithuania is built on the basis of country's long-term energy strategy document which is initially developed using LT model analysis. The strategy document is debated in the parliament to include political adjustments. LIT has been actively involved in LT model based analyses that contribute to the strategy document. LIT has several models which feature different spatio-temporal resolutions depending on the research problem. Normally, most of the input data is obtained from utilities, meteorological stations and national statistics departments. Long term studies are done with high emphasis on modelling the system security (reserves). Mr. Galinis mentioned that although, the transmission development is not the focus of the strategy document, an inhouse study indicates preference to place wind power plants near transmission lines. Mr. Galinis, mentioned two key challenges of LT planning with VREs, namely, the lack of information about the VRE sites to be developed in future and increasing level of data confidentiality.

Insights from Q&A:

- ✓ Reserve modelling is done in detail by LIT. Three types of reserves are accounted, namely, frequency restoration, containment and replacement reserves. For each model time slice, the network element, whose exclusion (contingency) brings in the highest drop of capacity, is defined. The resulting maximum capacity is the amount of reserve to be secured for that time slice.

European Union - Andreas Schmitz (Joint Research Centre (JRC), European Commission) informed the participants that JRC's LT energy planning model, named 'Prospective Outlook on Long Term Energy Systems' or *POLES*, is integrated into various toolboxes that support EU policy making. The model coverage is global with most nodes representing individual countries. JRC holds the actual hourly load data of around 60 countries for at least one year. *POLES* implement a unique strategy to represent the VRE plant's locational effects on the model's capacity predictions. Five different kinds of spatial distribution of future VRE plants are built, each considering a single factor, for example, resource quality or population density. From each distribution, hourly VRE profiles are generated using typical technology based supply curves and spatial hourly meteorological data. Finally, an algorithm selects a certain no of representative days by clustering 365 days in a year based on similarity of hourly load, wind and solar profile. Accuracy of the model is validated by comparing the duration curves of actual net load with the one synthesized by representative days at each model node. Mr. Schmitz concluded his talk by sharing a recent study result, which indicated a maximum of 10% variation in the model predicted solar and wind capacities owing to the effects of different spatial distributions.

Session 3: Increasing Spatial Resolution of Long-term Generation Expansion Models

The session started with a short introduction to session objectives by the moderator, followed by two expert input presentations. Each expert presentation was followed by short Q&A from audience. Input presentations were followed by a moderated open discussion. This section presents a summary of the insights generated during the presentations, Q&A sessions and moderated open discussion.

Moderator – Valentin Bertsch (University of Bochum) started by mentioning that modelling for high VRE shares requires using high spatial resolutions to ensure sufficient accuracy. However, increasing the spatial resolution, requires more R&D efforts, which increases the modelling and computational complexity. He stated that the objective of the session is to generate insights on how to strike a good balance between model accuracy and complexity.

Input Presentation - Galen Maclaurin (National Renewable Energy Laboratory) informed the audience that NREL ReEDs model is used for LT capacity expansion studies with typical planning horizon till 2050 but recently, studies are also done for as far as 2100. The model implements supply-side optimization by identifying the least cost energy mix and operation of resources, including storage, that simultaneously meets grid service requirements (load balancing, planning reserves, operating reserves), power flow constraints and regulatory constraints. The model also takes several scenarios as input. A variety of factors define input scenarios, for example, a scenario may represent a specific production tax credit regime or a certain wind cost curve. ReEDs feature around 356 resource based geographical regions. The resources within each region are further grouped into 2-8 classes depending on resource variability and are placed into 5 LCOT[1] bins. Using this approach and with pre-processing aid from NREL's Renewable Energy Potential (reV) model, ReEDS can cover over 9,000 resource regions representing discrete non-contiguous spatial extents. Demand inputs are taken from 134 balancing areas while future load projections are synthetically scaled for each county using census data on population. To reduce computation time, ReEDS employ reduced form dispatch by optimizing model results for 17 time slices and in a two year sets. Outside the optimization, the capacity credit of Solar, Wind and other RE generation sources is also determined on spatial basis, from hourly resource and load data. The transmission assets and energy flows between 134 balancing areas is also represented and transmission upgrades are modelled as one of the options to reduce congestion during model optimization. In the end, Mr. Galen highlighted that ReEDs does not yet implement unit commitment, DC load flows and full 8760 hour chronological despatch. These aspects are captured in other NREL models such as the one based on *PLEXOS-ST*.

[1] Levelized Cost of Transmission (LCOT) bins group up the resource locations based on the comparable costs incurred on connecting such resources to nearest grid point.

Insights from Q&A:

- ✓ NREL has an own built VRE data set which features around 8 years of 5-minute to hourly Wind data on a 2km grid resolution and 20 years of half hourly solar data on a 4km grid resolution.
- ✓ There is more confidence in ReEDs model results for longer time horizon, at least above 10 years, where it models long term impacts of important drivers such as future cost curves of different technologies.

Input Presentation - Yvonne Scholz (German Aerospace Center (DLR)) started by mentioning that DLR follows almost identical three steps, as described by earlier presenters, when it comes to modelling geospatial aspects for RE sources. These are, firstly, to access and pre-process spatiotemporal data for RE resource, secondly, to select appropriate model regions and thirdly, to develop existing and future spatial power plant distributions. Ms. Scholz, then shared brief insights of DLR's long term modelling framework, REMix, which is a cost minimization model to optimize long term operation and expansion costs of generation and transmission. She stated that REMix gets resource and demand related inputs on a very fine spatiotemporal resolution and currently DLR is expanding its 20 years of historical resource data base to 30 years while also exploring the possibility of achieving even finer spatial data resolutions with statistical downscaling approach, required in some cases. To increase computational efficiency, DLR has also managed to develop a parallel solver to run the model in high performance computing environments. Ms. Scholz also shared results of one of the recent DLR study to assess the sensitivity of computational effort and accuracy indicators of model driven results, to various spatiotemporal model resolutions. The results indicated that the model's computational indicators such as the solver ticks, memory requirements and others, increase almost linearly with spatial and temporal resolutions. The accuracy indicators, however, showed varying sensitivity trends based on the indicator type. In particular, the indicator for transmission expansion (GWs) showed high sensitivity to both, spatial and temporal, model resolutions while the indicator for storage expansion (GWhs) was highly sensitive to model temporal resolution. The study gave a fine estimate of how much of the model resolution could strike a good balance in the trade-off between model accuracy and computational complexity.

Insights from Q&A:

- ✓ The intelligent time slice selection with methodologies like clustering can achieve higher accuracy results with comparatively much lower computational efforts. Similar results can be expected by intelligent selection of model regions.
- ✓ Efforts are underway by DLR to enable open source access to model solvers.
- ✓ REMix has the capability to represent detailed transmission network using DC load flow model. Model can also utilize an aggregate of line capacities between model regions, in cases where simpler transport modelling approach is suitable.

Vocal Intervention - Marianne Zeyringer (University of Oslo) highlighted two important points in context of LT power system models. Firstly, she emphasized the need for practitioners to duly analyse the difference of model results for different weather years. She indicated that the typically followed approach of average of multiple weather years might still yield very different results to when different weather years are separately analysed. Secondly, she emphasized that the spatial modelling can enable capturing the locational differences in the social acceptance to developing new power plants and transmission lines. It, however, requires more work together with the disciplines of social sciences and psychology. Nevertheless, such models can possibly also investigate the options to ameliorate social acceptance issues, which is not a focus under traditional cost optimal planning.

Insights from Moderated Open Discussion:

Representing Non-Technical Aspects:

- ✓ Traditional LT models, sometimes, give results with unrealistically high capacity for a favourable RE resource in a favourable region. It happens often because of limitations in considering all kinds of land use preferences, social acceptance issues and other important factors. In this context, NREL is now working with new concept of exploring deployment potential of RE resources in regional context, considering more and more influencing factors in addition to traditional technical parameters.
- ✓ Capturing state based policy targets as upper limit to deployment of RE resources can, inherently represent, up to some degree, the social acceptance in LT models. Other option could be to incorporate decisions based on the analysis of evolving social perceptions outside the model.

Addressing Data Limitations:

- ✓ The lack of access to demand and transmission data, owing to confidentiality requirement, is understandable, however, it is also limiting the capacity of academic modelling community to produce innovative analyses.
- ✓ Resource data is increasingly available in finer spatiotemporal resolutions but such resolution is much coarser for demand data. Coarser data resolution of demand side, significantly limits the value added by high resource side spatial resolution in LT models.
- ✓ NREL's approach to increase demand data resolution is to downscale the demand data available from balancing areas to county level, scaling as per the county population statistics available from census results. On similar lines, REMix's approach is to downscale the load data available at national level to sub-national levels using spatial proxy data such as settlement size or population statistics. Such downscaling approaches, however, bring some uncertainty to model results.

- ✓ There are approaches available in research literature, to use bottom up demand modelling techniques that involves stacking up the standard load profiles of end users such as industries or residential units and validating the resulting demand profiles with actual load profiles available for coarser regions from transmission operators. Such demand profiles can be then downscaled to finer regions using statistics data.
- ✓ IEA executed the bottom up demand modelling with its TIMES model and also captures the correlation of demand profiles with important weather parameters, especially Temperature.

Session 4: GIS tools, Data-processing Widgets and Climate Impacts

The session started with a short introduction to session objective by the moderator, followed by four expert input presentations. Each expert presentation was followed by short Q&A from the audience. This section presents a summary of the insights generated during the presentations, Q&A sessions and enlist key session takeaways.

Moderator – Paul Deane (University College Cork) emphasized that the simplicity of input/ output data format and clarity are two main preferences of LT planning practitioners. He stated that the session objective is to understand the practical data related issues of LT models and explore the features of existing data sources, associated tools & platforms.

Input Presentation - Galen Maclaurin (**National Renewable Energy Laboratory**) introduced the NREL's reV model, which works at regional and continental spatial scale. He briefly described the individual reV modules and modelling steps. First module, in the pipeline, provides wind and solar (PV and CSP) resource data, available at very fine spatiotemporal resolution. In the next module, coupled with System Advisor Model (SAM), reV can flexibly produce spatial generation profiles at different temporal resolution employing any no of technology power curves. In subsequent step, resource LCOE curve is determined using Fixed Charge Rate (FCR) method and spatially plotted. Next module executes the spatial exclusions on technical grounds such as accounting urbanized areas and protection zones. The resulting spatial distribution is analysed for Euclidian distances to existing transmission infrastructure in the next modular step, which also helps in determining the annual technical potentials. Finally, the coupling modules interface the reV results to NREL's LT and production cost models. Mr. Galen also briefed the ongoing developments of reV model such as the development of least cost path concept for grid connection in addition to Euclidian approach, further refining of the spatial exclusion methodology with deployment potential concept, and spatially explicit LCOE estimations accounting the regional labour and land cost differences. In the end, he informed that reV model is expected to be available as open source by February next year and wind data for North America is already accessible through amazon web services.

Input Presentation - Iratxe González-Aparicio (Accenture Research) started by emphasizing the importance of increasing spatial resolution of wind resource data because it enables capturing more wind speed classes that can lead to more accurate generation profiles and better decisions regarding long term planning considerations such as the reserve sizing. She briefed her recent research work of 2017 at EU JRC on *'European Meteorological-derived HIgh resolution Renewable Energy Sources generation time series*' (EMHIRES) dataset. The project employed a statistical downscaling of comparatively coarser reanalysis wind speed data from MERRA dataset to increase its spatial resolution. The new dataset was then compared with another, fine resolution, European centric database based on the operational forecasts. After converting the improved resource data to power generation profiles, it was further validated with historical generation data from Transmission Operators to determine causes and magnitude of systematic errors.

Insights from Q&A:

- ✓ The spatial distribution of wind resource data to finer resolutions by statistical downscaling is computationally much less intense then running numerical weather prediction models, which, in addition, have much higher modelling complexity.
- ✓ Validation of model calculated wind generation profiles with TSO data showed systematic errors stemming from errors in resource dataset and precision gaps in assuming wind power curves.

Input Presentation - Imen Gherboudj (IRENA) introduced to audience, the IRENA global atlas, an online tool to bring RE resource data access to all IRENA member states. She elaborated that the online platform has a collection of almost 2000 maps and datasets of annual averages of meteorological quantities, developed by different institutions worldwide. Although, the online platform does not provide time series data, it can be provided to Member states, upon request, for sites of their interest. The platform serves two important objective uses of GIS data, namely, to support in generation and transmission expansion planning and to support project development. In context to each objective, IRENA maintains inhouse tools to extend support to its Member states, upon request, providing services such as large-scale resource suitability assessment, RE generation profiles and RE project site assessments.

Input Presentation - Sebastian Sterl (Vrije Universiteit Brussel) briefed the audience, the typical methodological steps to capture long term impacts of global climate change to local renewable power generation and demand. Modelling processes generally start with selecting a Representative Concentration Pathway (RCP) that feeds into Global Climate Models (GCM). Results from GCMs are often translated to local spatial extents by either statistical or dynamic downscaling, which is implemented in Regional Climate Models (RCM). RCM driven results for climatic parameters, such as rainfall, are subsequently fed into Impact Models (IMs) to translate effects on local power systems, for example, determining the long-term temporal characteristics of hydro resource available for hydropower plants. In the end, Mr. Sebastian emphasized on two important points. Firstly, referring to a West African case study showing widely diverging long-term rainfall predictions from climate models, he stated that the right approach is to plan for worst future scenarios while hoping for the best, instead of either simply considering the relatively moderate mean or median trends of various predictions or completely avoiding any planning at all due to high uncertainties involved. Secondly, referring to a European case study, he indicated that already power systems are adapting to long term climate change impacts, for example, the expansion of hydropower capacities in Nordic EU states in response to glacial melting trends or revising the distribution line power ratings in England and Finland in response to rising temperature profiles of future.

Insights from Q&A:

- ✓ In general, the climate models are predicting an increase in frequency and magnitude of climatic extremes in future. Power system demand and availability of hydropower resources, are strongly affected by climatic extreme events of seasonal timescale nature such as drought or heat spells.
- ✓ Climate change impacts on VRE performance may, in many cases, have less significance then the inter-annual variations of VRE yield, which can be appropriately captured from historical data.
- ✓ Individual climatic extreme events may have significant implications for power systems, but compounding effects of simultaneously occurring extremes in different quantities - such as low power generation occurring at the same time as high demand - calls for system level thinking while modelling the impacts.

Demonstration - Wim Clymans (Flemish Institute for Technological Research) introduced to the audience, a Dynamic Energy Atlas for Belgium, a desktop based pre-processing tool, that can prepare inputs, such as generation profiles and spatial distribution of power plants, for LT and production cost models. He briefed that the tool was developed to aid in the BREGILAB[2] project for Government of Belgium to maximize use of renewables with minimal grid development costs. With the atlas tool, the users can add any no of GIS exclusion layers, agents, technology related parameters and create own scenarios. Equipped with an algorithm to deploy power plants with minimum grid upgrades, the atlas tool can prepare the results at a 100m grid resolution but can flexibly aggregate to customizable higher resolutions.

Vocal Intervention - Craig Hart (International Energy Agency (IEA)) indicated that the acquisition of high quality data is a significant factor in achieving LT model results with high certainty, citing examples from IEA's recent assessments on long term system flexibility in various regions. He emphasized that the modelling studies should also address the trade-off between data limitations and quality of model results and how it impacts the study driven technical and policy recommendations.

Session Key Takeaways:

1. GIS based future VRE generation distribution analyses need better integration of not only the RE resource potential and technical exclusion layers, but also the practical constraints to refine maximum boundaries for deployment of RE.
2. High temporal and spatial resolution provide better accuracy at the costs of complexity and computational power, for example, the need for High-Performance Computing (HPC).
3. Aggregation (clustering) and disaggregation schemes are needed for data coming from different sources at different resolutions. Model validation requires calibration of simulated data and comparison with measured data in systematic manner.

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[2] Balancing the Belgian electricity system for maximal use of Renewable Energy generation by a Grid Injection Limit Algorithm and optimal Battery deployment

4. Several VRE resource databases and pre-processing tools and models are becoming accessible as open source which do not require very high skill set to use.

Session 5: Distributed Variable Renewable Energy (VRE)

This part of the workshop took place in two parallel sessions. Each session started with a short introduction to session objectives by the moderator, followed by expert input presentations. Each expert presentation was followed by short Q&A from audience. Input presentations were followed by a moderated open discussion. This section presents a summary of the insights generated during the presentations, Q&A sessions and moderated open discussion.

Parallel Session 5A: Grid-connected Distributed VRE

Moderator - Bilal Hussain (IRENA) started by mentioning some of the significant long term investment implications posed by the recent unprecedented growth of grid-connected distributed renewable generation, such as rooftop PV. Continuing the context, he stated that the objective of this session is to explore the relevance of accounting Distribution Generation (DG) in LT generation expansion planning, and what should be some practical methodologies to capture it.

Input Presentation - Kais Siala (Technical University of Munich) started by emphasizing the flexibility of LT models to capture spatial resolutions as per requirements of research question instead of simply following administrative boundaries. Referring to his recent study results, he indicated a strong sensitivity of energy mix output of LT models to the criteria of region selection. He further informed that mostly, data on DGs is of statistical nature, available at national level scales and missing geo-reference information. In such cases, a generally followed approach is to downscale data to higher resolutions, distributing DGs as per resource potential along with modelling other randomness factors of deployment. Naturally, it brings modelling uncertainty but aggregating the capacity back to relatively bigger model regions can result in some uncertainty reduction. Also to account DG data comprehensively, it is essential to consult multiple data sources as each data source may have different minimum capacity thresholds and thus, often, missing a significant capacity portion. Double counting effect can also arise when data sources of demand and supply, both cover the DGs. Normally, it is necessary to unpack the demand data for which, one simple approach, for example, in case of rooftop PV, would be to start with historical demand data before its rapid uptake in past. Of course, it would require modelling the evolution of underlying sectoral demand patterns over that time to effectively unpack the actual demand from rooftop PV generation.

Insights from Moderated Open Discussion:

<u>Relevance of Capturing Distributed Generation in LT Expansion Planning:</u>

- ✓ There are multiple reasons, depending on a country, that emphasize the need to capture grid connected DGs based on VREs in LT planning. In some countries, distributed PV is one of the major driver for distribution network expansion. In some countries, these resources may substitute investments in central generation and transmission.

- ✓ Generally, power systems have a certain hosting capacity for grid connected DGs, however, when their deployment grows above a certain threshold, it becomes important to capture them explicitly in demand forecasts of LT studies, to ensure that sufficient long-term measures for system security and reliability can be planned during resource scarce periods or resource non-availability periods.

Data on Grid-Connected Distributed Generation:

- ✓ Unlike central generation, grid connected DGs are deployed as small capacity units and in high quantities, distributed over wider geographical area. They connect at low or medium voltage networks whose detailed data is often not collected traditionally for LT planning and is often treated on aggregate basis. All these factors make the data collection task, on VRE based DGs, a very big challenge.
- ✓ Full fledge simulation of DGs is a computationally intense task and modelling wise, a complex task. A usual practice is to model DGs using statistical data and aggregation approaches in contrast to approaches used for central generators.
- ✓ Currently growing trend of smart metering, is generating a lot of prosumer data. That data can be made available in an appropriate format so that the consumer confidentiality is not compromised but the sufficient information can be extracted for a cost-efficient LT planning.
- ✓ Remote sensing techniques can capture spectral signatures of rooftop PV to measure their distribution pattern in a given area. However, such methodology requires high definition satellite imagery or LIDAR data which is very costly to arrange.

Modelling Approach to Capture Grid-Connected DGs based on VREs:

- ✓ Current LT models, both in government sector and research world, normally optimize costs or social welfare. Under both criteria, VRE based DGs cannot outcompete large central VRE power plants. However, the growth incentives for such DGs exist, for example, due to cheaper solar self-consumption or tax credits or the consumer preference for self-reliance. In addition, there can be macrolevel advantages such as the GDP growth, through job creation and development of small and medium enterprise. Sometimes, these incentives increase by coupling multiple technologies together, for example, the rooftop PV with storage. Therefore, there is a need for LT models to capture value of VRE based DGs in a broader manner.
- ✓ There is a consensus that LT models should be sufficiently flexible to capture the significant effects of VRE based DGs, endogenously or exogenously or both ways depending on the nature of the aspect.

- ✓ Some experts suggested that LT models should take, as inputs, the exogenously developed capacity growth scenarios for VRE based DGs, because their growth is not as controllable as the central generation sources. Scenario based approach is also essential, given the high degree of uncertainties attached to their future growth and temporal profiles. In addition, the scenario development should be done through dedicated modules externally as executing it inside LT models is computationally expensive and weakens model tractability.
- ✓ NREL's approach towards modelling solar rooftop in ReEDs, is by feeding input scenarios from a quasi-agent based model that takes into account the rooftop resource potential maps and technical assessments such as tree shading effects, roof structural aspects, azimuth or tilt parameters, analysed from LIDAR data.

Parallel Session 5B: Distributed VREs - Energy access, rural electrification, mini-grids, stand-alone technology

Moderator - Pablo Carvajal (IRENA) briefed the audience about the session scope which focused on how the development of distributed VREs under the broader context of electrification can be reflected in long-term central energy planning and how the use of geospatial information can facilitate the planning process.

Input Presentation - Anteneh Dagnachew (PBL Netherlands Environmental Assessment Agency) briefed the audience about the scope of PBL's electricity access related work in Sub-Saharan Africa. He explained the methodology applied in PBL's inhouse electrification cost optimization model for the region, built using PBL's 'The IMage Energy Regional model', also referred to as TIMER. Within each iteration, the model uses a decision tree approach when deciding about the mode of electrification for every cell within the geographical grid of 0.5° resolution. Grid extension is selected for areas within economic distance from the existing grid and having the favourable LCOE of grid based electricity. Otherwise, mini-grid electrification mode is chosen for areas within 50km distance from existing grid and where the mini-grid option is favourable over standalone systems, which is decided based on two conditions, namely, the mini grid LCOE is lower than standalone and the per capita electricity demand intensity is above a certain economic threshold. Mr. Dagnachew also shared insights on the latest study results of the model which indicated a strong role of stand-alone systems in the scenario of providing universal access (UA) of electricity in Africa by 2030 as per Sustainable Development Goal (SDG-7). Further extending the UA scenario scope to include climate mitigation policies, the model suggested a strong growth of VRE mini-grid based electrification technologies in Southern Africa.

Insights from Q&A:

- ✓ Electrification decision of grid extension, mini-grid or stand alone is taken yearly, but only once for each cell of the geographical grid.
- ✓ Bottom-up approach is followed to model electricity demand by taking into account the income and urbanization factors along with estimations from night time illumination maps.

- ✓ TIMER Sub Saharan Africa model takes around eight minutes to solve a scenario. In addition to supply costs, the least cost investment results from the model also include costs for grid connection, transformers, transmission and distribution.

Input Presentation - Dimitrios Mentis (World Resources Institute) started by emphasizing that the spatial modelling aspects such as location dependent VRE supply variability, region based energy access infrastructure and consumer level characteristics are crucial factors to consider when planning cost optimal long-term electrification pathways. He also highlighted that the lack of geospatial data at sufficiently high resolution is a key challenge in energy access planning. He then briefed the audience about the methodology applied in the Open Source Spatial Electrification Tool (OnSSET), which determines least cost technological options for electrification of un-served areas. The model is developed based on python and QGIS plugins. The model works with geospatial resolution of one km^2 and iterates on a five-year basis. GIS features enable efficient scenario planning. Electrification planning can be performed at all five access levels. Mr. Dimitrios also shared the results of one of the recent OnSSET studies on Sub Saharan Africa which recommended around an 80% share of standalones in the cost optimal LT electrification mix for universal access in the region at tier-1 electricity demand level. It also indicated that the LT mix moves towards mini-grids and grid based electricity as the consumption level increases from tier-1 to tier-5. In the end, Mr. Dimitrios mentioned an interactive online platform called 'Energy Access Explorer', which enables the users to do multi-criteria analysis of GIS based electrification access data for some regions in Africa. One interesting application of the tool is to determine the regional locations which offer the most favourable opportunities of electrification as low hanging fruit.

Insights from Q&A:

- ✓ OnSSET uses a 5-year time step as it provides favourable computational performance. OnSSET also accounts for the daily solar cycles and models the appropriate storage to match consumption when selecting the electrification technology for a particular vicinity.
- ✓ Several kinds of electrification tools and models are being developed worldwide and there is a strong need to work on the side of developing data standards to improve interoperability of different geospatial electrification planning tools.

Session Key Takeaways:

- ✓ Geospatial analysis is imperative for electrification planning – *Business as usual* scenarios will not lead to universal access as per global SDG vision and serious planning is needed.
- ✓ Supply and demand data need to be treated equally, with the same level of geo spatial detail and modelling.
- ✓ Social and productive end-use consumption of energy should be added to the spatial analysis, because it can influence the optimal mix.
- ✓ Open source tools and joint collaboration from institutions looking into electrification is important.

Proceedings for Workshop Day-2:

Date and Time: 13th December-2019, 09:00 – 13:30

Session 6: Representing grid investments in capacity expansion models

The session was held in two parts. First part included four expert presentations highlighting simplified and detailed methodological approaches to represent grid investments in capacity expansion models. Each speaker presentation was followed by short Q&A from audience. Second part consisted of a moderated open discussion around the session guiding questions. This section presents a summary of the insights generated during the presentations, Q&A and open discussion.

Session-6 (Part-1: Input Presentations):

Moderator: Asami Miketa (IRENA) started by mentioning two key reasons to consider transmission costs associated with VREs at the stage of LT generation planning. Firstly, it enables the capturing of VRE site specific trade-off between resource quality and transmission costs. Secondly, it helps early planning for appropriate transmission infrastructure to support VRE future growth, by giving a first-hand approximation of transmission costs. She mentioned that the objective of part-1 of session-6 is to hear updates from experts on the research works cited in AVRIL 2017 report featuring simplified and detailed representations of transmission costs in LT planning, either in regional models with coarser spatial resolution or multi node country based models, through different kinds of exogenous and endogenous methodologies.

Input Presentation - Tim Mennel (DNV-GL) briefed the audience about one of the joint work of DNV-GL with IRENA where a simplified excel based methodology was applied to determine grid expansions costs for a certain future mix of VRE capacities. The approach included multi-node analysis of load and VRE generation profiles to reach at a certain transmission capacity value that equalizes the further grid development costs and opportunity cost of curtailing excess energy. Mr. Mennel emphasized that such simplified approach can provide a quick first-hand estimation of grid expansion costs linked to a certain governmental plan for future VRE portfolio before boarding onto a full fledge optimization based network expansion study.

Input Presentation - Yvonne Scholz (German Aerospace Centre (DLR)) briefed the audience that DLR's long term ReMix model can determine cost optimal grid expansions under different scenarios. She informed that ReMix is capable to linearly model transmission grid either on transhipment (transport or pipeline) model basis or DC power flow model basis with or without Power Transfer and Distribution Factor (PTDF) matrices. PTDF matrix approach allows updating internodal flow limits based on different grid conditions during model optimization process. She further stated that the transmission costs are modelled on annuity basis. ReMix is equipped with technical and commercial data on different types of transmission line technologies. Terrain related cost multipliers are also assumed. In some cases, she indicated that the underground cable can also be considered as an option to represent social acceptance constraints in long term modelling. Ms. Scholz, indicated that for regions outside EU, where grid data is not readily available, the approach of aggregating capacities of internodal transmission links is used. She also emphasized that the RE driven distribution grid expansion represents significant long-term costs that should be captured in LT models, however, currently it is not being done in ReMix. In the end, Ms. Scholz cited a DLR's recent LT study that coupled EU level power grid model with gas and transport models which showed a definite economic benefit of sector coupling to maintain seasonal balances of EU grids.

Insights from Q&A:

- ✓ Modelling grid expansions in LT scenarios can yield cost optimal pathways which can enable policy makers to create incentives for future generation deployments in favourable geographic regions.
- ✓ During optimization in ReMix, the internodal transmission line technology selection is done on basis of line size. Each line option has its specific costs and performance parameters such as energy losses.

Input Presentation - Kostas Tigas (University of Patras) briefed the audience about the approach of modelling transmission grid expansion in a TIMES based Greece model. He elaborated the methodology of taking into account both the shallow and deep transmission connection requirements for integrating new generation while complying network security criteria(N-1). The GREECE TIMES model used an equivalent grid model, a reduced form of actual grid system developed based on efforts from several Greece power system experts. Network security constraint was added into the model using loading coefficients for each internodal transmission corridor. Loading coefficients are driven from *NEPLAN* based steady state analyses. *NEPLAN* model of the Greek grid system is also soft linked with the LT model in a feedback loop to enable both the AC and DC based load flow modelling in one pipeline respectively. While sharing some study results from the model, Mr. Tigas emphasized that the use of discrete transmission investment option and Mixed Integer Programming (MIP) solver of TIMES, showed better accuracy in the model results. Additionally, Mr. Tigas informed that a separate feedback loop also exists in Greek LT modelling framework that considers the dynamic grid constraints on maximum VRE feed in. He elaborated the methodology of driving dynamic grid constraints and stated that the feedback loop enables capturing the curtailment and grid constrained capacity factors of VRE generation in LT scenarios.

Insights from Q&A:

- ✓ Greece TIMES model has a regional resolution of 14 and a nodal resolution of 10. The model takes on average around 8 hours to solve.

Input Presentation - Yunshu Li (IRENA) started by briefing the audience about IRENA's inhouse *MESSAGE* based LT expansion model for Africa region with country based model nodes. The model is built using IRENA's **S**ystem **Pla**nning **T**est (SPLAT) tool, an excel based interface to MESSAGE. She further stated that around 2000 favourable VRE zones were identified for Africa region by IRENA in collaboration with Lawrence Berkeley National Laboratory (LBNL) in 2015. This joint exercise yielded zone based data on several important parameters such as the technology based LCOE, proximity to transmission grid and distance to roads. Building on this work, the IRENA Africa model pre-screens the VRE zones based on multicriteria scoring of zone specific LCOE, distance to grid and capacity value of wind generation. The reduced no of zones (around 330) then serve as regional options to deploy VREs within the model's optimization process. The zone based grid connection costs are added as part of generation CAPEX. The model implements 3 seasons and 10 day based time slices. The model also allows transmission to build up between countries, during model run, to achieve co-optimization of generation and transmission costs. In the end, Ms. Yinshu, shared the results of several IRENA LT studies on Africa region.

Session-6 (Part-2: Moderated Discussion):

Moderator: Emanuele Taibi (IRENA) briefed the audience about the session scope and stated that the aim of the mutual discussion is to analyse the aspects of LT energy planning from the view point of what can be and should be done to keep LT models simple yet still capturing the important factors either endogenously or exogenously.

Vocal Intervention - Arvydas Galinis (Lithuanian Energy Institute) stated a methodology whereby grid topography can be modelled in LT models, representing transmission and distribution networks in two layers, interconnected at any no of points representing the transformers. Power plants can be connected to both layers depending on their size. Under this methodology, expansion can be modelled endogenously, not only in transmission and distribution networks, but also in form of new transformer stations interconnecting high and low voltage networks. Such models can also implicitly determine curtailment and losses. Mr. Arvydas also highlighted an optimization challenge regarding choosing the right line capacities. He mentioned that high capacity lines have lower specific costs. The model generally choses lower cost high capacity lines to serve expansion requirements during optimization process but they remain significantly unloaded. Approach to address this phenomenon may require having more integer variables in the model or by excluding the significantly un-loaded lines in between model iterations.

Insights from Moderated Open Discussion:

<u>**Data limitations and model simplification:**</u>

- ✓ Handling the task of downscaling or aggregating high resolution data to different resolutions of interest through pre-processing tools outside the LT model and then soft linking, helps avoiding the computational intensity and model complexity.
- ✓ Different research questions necessitate different modelling requirements. Expanding a single model to cover more and more questions, increases model sophistication. In contrast, both the utility planners and decision makers are, in general, reluctant to

adopt sophisticated tools. A good practical approach is to always keep the models modular and shortlist the most impactful factors to address.

- ✓ Solar and Wind related data at high spatiotemporal resolutions, is increasingly becoming accessible worldwide through global data platforms. Access to grid related data, however, remains a challenge. It is also a country specific issue, where some countries allow free access to most of the grid data and some consider it confidential from security point of view.
- ✓ Research should be done for country cases such as Germany or USA, on lines of investigating the impacts of omitting some parts of high resolution input grid data, on reliability of the model results. This can reveal important insights for methodology simplification when LT planning is done for countries where high resolution data is not easily accessible.

Stakeholder communication and capacity building:

- ✓ LT planning results, especially with high VRE shares, generally involve technically complex investment implications. This complexity makes the communication to policy makers, a highly challenging task. There is always a need for planners to simplify outcomes of their analyses and soft link their model driven results with simpler tools to bridge the communication gap with policy makers.
- ✓ There is a need for governments to realize that planning for high penetration of RE requires addressing the complex issues relating to system adequacy, flexibility and stability. Utilities are often highly concerned to such aspects. There is a certain degree of training required at government level as well as the utility level to clearly understand the important issues to better plan and decide.

Workshop Closing and Next Steps:

Asami Miketa (IRENA) thanked the participants for their valuable contributions throughout the workshop and informed that the next step will be to synthesize the knowledge collected through the workshop and supplement it with more desk research and deeper insights through one to one discussions with the participants in future to reach at a draft spin off report to AVRIL 2017 publication. She also looked forward to getting feedbacks of the participants on the draft report, especially the viewpoints of the government practitioners to keep high relevance of the contents. The workshop was then concluded with the valedictory remarks of workshop participants.