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# Addressing the Geo-Spatial Aspects of VRE in Long-Term Planning: Country Experience from IRENA Regional Workshops

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# Agenda

1. **Models/tools used by governments**

2. **Methodologies for geo-spatial representation of VRE in government models/tools**

3. **Improvement priorities**

# 1. Models/tools used by governments

# Models and tools used by governments – Ex. LATAM

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| | | Planning steps - Tool coverage | | | |
|---|---|---|---|---|---|
| **Country** | **Tool** | Technical network studies | Dispatch simulation | Geo-spatial planning | Generation Expansion |
| **Argentina** | PSS/E | X | | X | |
| | OSCAR-MARGO | | X | | |
| | MESSAGE; TIMES | | | X | X |
| **Bolivia** | PowerFactory | X | | | |
| | SDDP | | X | | |
| | OptGen | | | | X |
| **Brazil** | ANAREDE, ANATEM, ANAFAS, PacDyn | X | | | |
| | NEWAVE | | X | | |
| | In-house EPE model | | | X | X |
| | MATRIZ | | | X | X |
| **Chile** | PCP; PLP | | X | | |
| | PET | | | X | X |
| **Colombia** | PowerFactory | x | | | |
| | SDDP | | X | | |
| | OptGen | | | | X |
| **Ecuador** | PowerFactory | X | | | |
| | SDDP | | X | | |
| | OptGen | | | | X |
| **Mexico** | PSS/E; DSAtools | X | X | | |
| | PLEXOS | | | X | X |
| **Paraguay** | NERC excel model | | | | X |
| | MESSAGE; OSeMOSYS | | | | X |
| **Peru** | NetPlan | X | | | |
| | SDDP | | X | | |
| | OptGen; TIMES | | | | X |
| **Uruguay** | PSS/E | X | | | |
| | SimSEE | | X | | X |
| | WASP; MINGO | | | | X |

# Example – Saudi Arabia

| Model | Purpose | Method | Spatial scale | Temporal scale employed | Generation Technologies |
|---|---|---|---|---|---|
| Plexos | • Investment support<br>• Operation support<br>• Scenario analysis<br>• Power systems analysis | • Mixed integer programming<br>• Linear programming<br>• Non-linear programming<br>• Mixed integer quadratic programming | Project to National | Hourly | • Conventional<br>• Renewable<br>• Desalination<br>• Cogeneration<br>• Storage (Fuel, Thermal and Electric) … |
| Strategist | • Investment support<br>• Scenario analysis (with stratRob*) | • Dynamic programming | Project to National | Hourly for a typical week | • Conventional<br>• Renewable |
| Kingdom energy model (KEM)* | • Energy sector analysis<br>• Policy support<br>• Investment support | • Partial equilibrium | National | Chronological load curves | • Conventional<br>• Renewable<br>• Desalination<br>• Cogeneration<br>• Electric and Thermal storage |
| Super* | • Investment support<br>• Policy support | • Linear programming | Project to National | Hourly | • Conventional<br>• Renewable<br>• Desalination<br>• Cogeneration<br>• Electric and Thermal storage |
| Mothra* | • Investment support<br>• Decision support (multi-criteria analysis) | • Simulation<br>• Heuristic optimization | Project to National | Hourly | • Conventional<br>• Renewable<br>• Desalination<br>• Cogeneration<br>• Electric and Gas storage |

# 3. Methodology used by governments

# Latin American context

Summary from *““Exchanging best practices to incorporate variable renewable energy into long-term energy/power sector planning in South America” - 10 countries*

- Most countries have **developed solar and wind resource maps** to define renewable energy zones, with some adding multiple nodes and/or map layers of further technical and non-technical information to aid model representation of transmission expansion
- Important to note that **investment and construction costs, and not only resource quality**, can also be based on location
- The general **co-optimisation of generation and transmission expansion planning** processes remains a challenge in many cases
- The regional representation in long-term models is sometimes based on characteristics of other resources, such as hydro (in Brazil) or gas (in Argentina), and it is important to analyse whether **different regional representations** could have a material impact on model results

# VRE Siting & Transmission Methodology - LATAM

| | Represented in long-term capacity expansion? | | Description |
|---|---|---|---|
| | Yes | No | |
| **Argentina** | X | | Long-term capacity expansion modeling is complemented by electrical system modeling (PSS/E) to capture system stability issues and transmission expansion requirements, in an iterative process. |
| **Bolivia** | X | | Long-term capacity expansion modeling is complemented by static grid power flow studies. |
| **Brazil** | X | | Representation of large regions is included in capacity expansion modelling, with an associated transmission cost between each region. |
| **Chile** | X | | Site specific projects and generic resource potential is represented geographically in the model. While the model can also represent transmission investment needs, this Is not addressed in the Ministry's long-term planning exercise. |
| **Colombia** | X | | No detail provided |
| **Ecuador** | | X | NA |
| **Mexico** | X | | Site-specific projects and generic resource potential is represented geographically in the model, and transmission capacity expansion takes into account feasible projects identified in capacity expansion planning. |
| **Paraguay** | | X | NA |
| **Peru** | | X | NA |
| **Uruguay** | | X | NA |

# Example: Chile

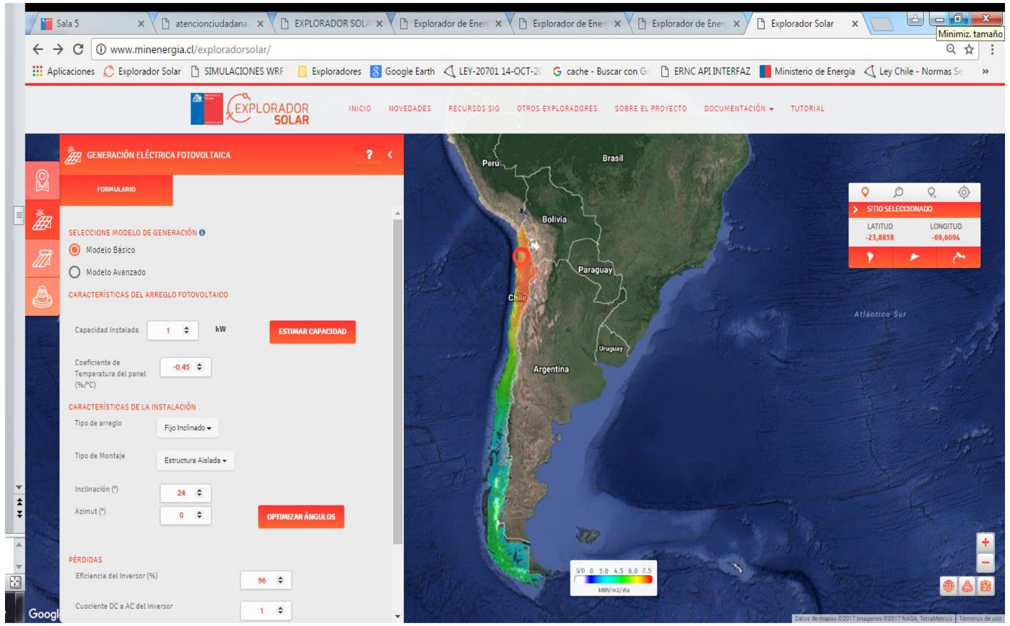


1

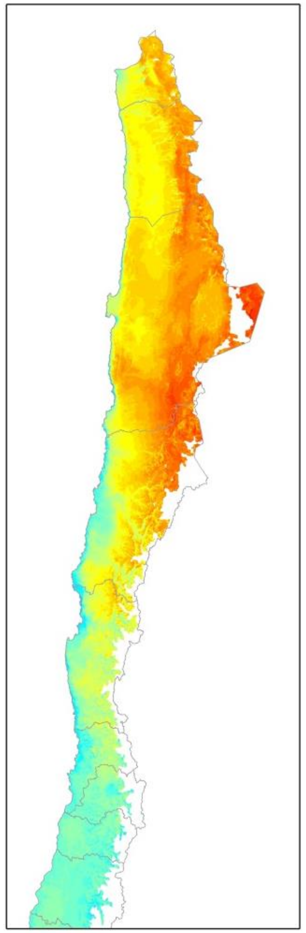
**Resource identification:**

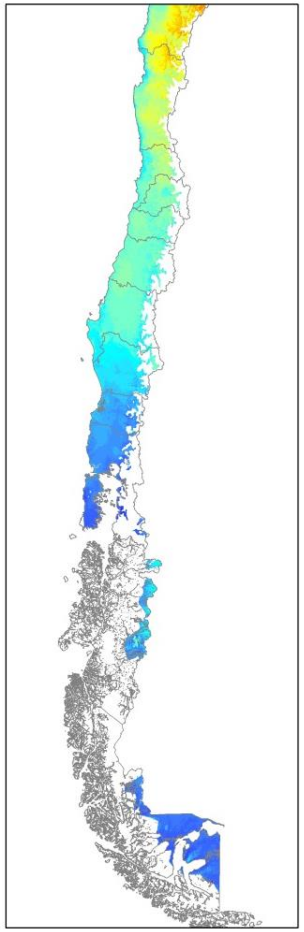
**Solar resource**

- **Solar resource information:** "Explorador de Energía Solar"




http://www.minenergia.cl/exploradorsolar/





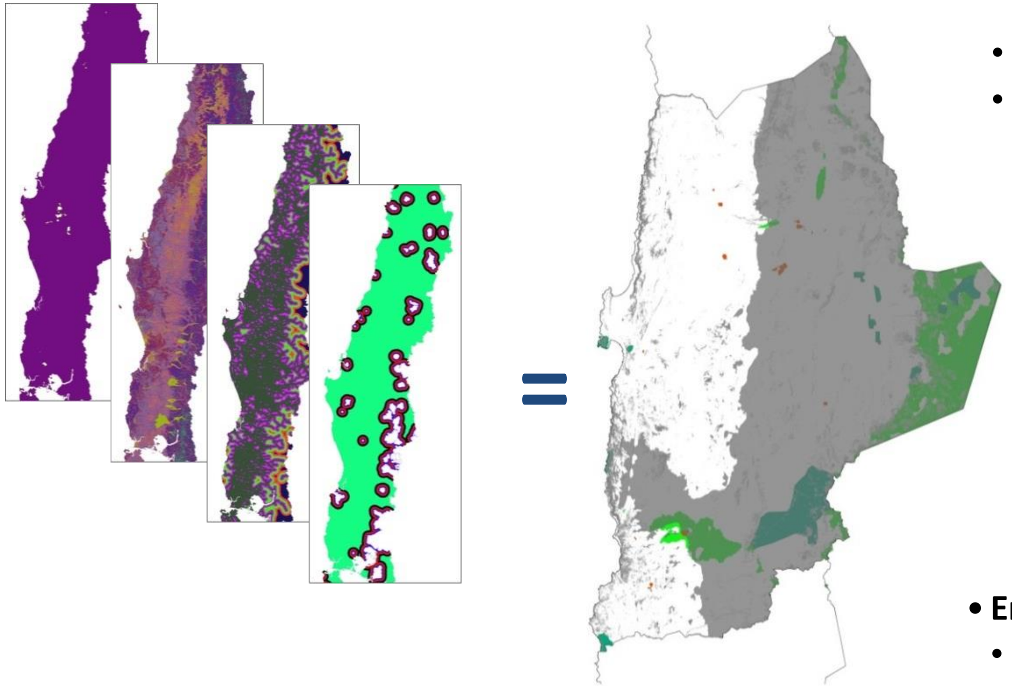
Geotiff files, available at "Explorador de Energía Solar":

PV: Capacity Factor of 1 axis tracking
CSP: DNI kWh/m2/day: Capacity Factor, 12 hr. storage

# Example: Chile

2

## Feasible area identification

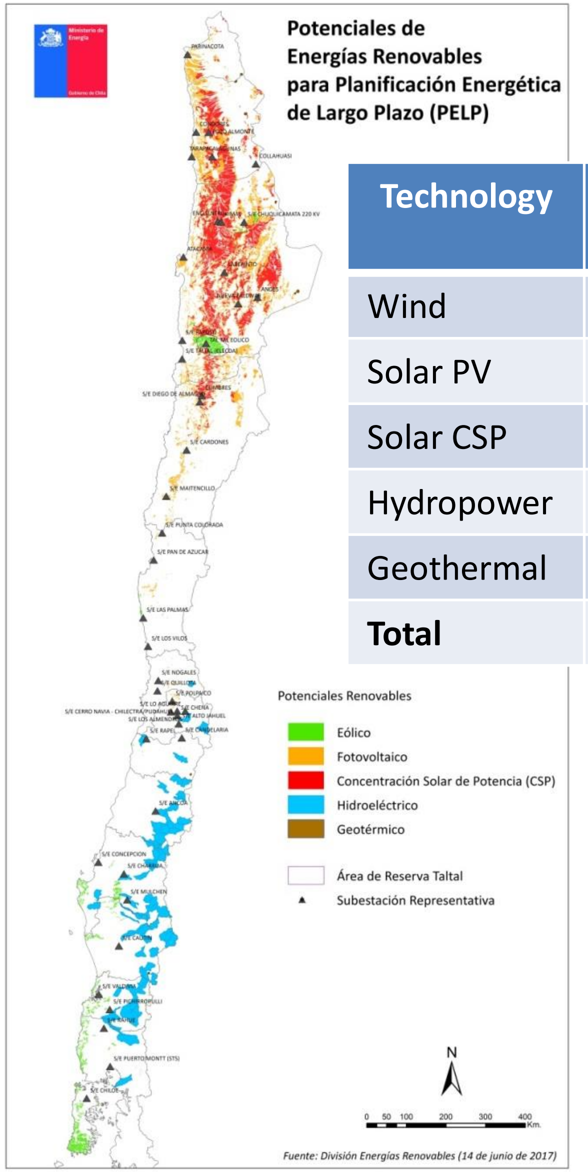


**Technical-spatial analysis**

- Capacity Factor
- Current operational and under construction projects are excluded.
- Projects related with distribution tender results are excluded
- Slope
- Altitude

- **Territorial-spatial analysis**
  - Cities limits
  - Road network (Source: MOP)
  - Anthropized Water bodies (MMA)
  - Hydrographic network(BCN)
  - Coast border (INE)

- **Environmental-spatial analysis**
  - SNASPE (Source: MMA)
  - RAMSAR (Source: MBN)
  - Water bodies (Source: MMA)




| Technology | Potential (MW) |
|---|---|
| Wind | 36,543 |
| Solar PV | 829,409 |
| Solar CSP | 510,074 |
| Hydropower | 5,701 |
| Geothermal | 599 |
| **Total** | **1,382,326** |

Gobierno de Chile | Ministerio de Energía

# MENA context

Summary from "*"Exchanging best practices to incorporate variable renewable energy into long-term energy/power sector planning in MENA" - 15 countries*

- There are **established power sector planning practices** in only some of the countries.
- Application of **simplified models of the grid at generation planning level is widely used**, especially for countries that have clearly separated operating areas, such as Saudi Arabia.
- Using the development of a large-scale VRE plant in a remote area to interconnect two previously separated systems is being studied, notably by Saudi Arabia and Algeria.
- For most of the countries, **the development of a VRE project is preceded by a detailed grid integration study**, which can lead to a revision of the siting of the plant based on the hosting capacity of the different possible substations.

# VRE Siting & Transmission Methodology– Arab region

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| | Represented in long-term capacity expansion? | | Description |
|---|---|---|---|
| | Yes | No | |
| **Algeria** | | X | NA |
| **Bahrain** | | X | NA |
| **Egypt** | X | | Renewable siting is reflected through providing hourly generation data to reflect the diurnal and seasonal characteristics of the available renewable resources at the site as well as the correlation with the system demand. The connection of the variable renewable energy site to the transmission grid and the related technical factors are also reflected in the optimisation process. |
| **Iraq** | | X | NA |
| **Jordan** | X | | Represented through PLEXOS. |
| **Lebanon** | | X | NA |
| **Libya** | | | NA |
| **Morocco** | X | | NA |
| **Oman** | X | | NA |
| **State of Palestine** | | X | NA |
| **Qatar** | X | | NA |
| **Saudi Arabia** | X | | Through a combination of GIS analysis and power system simulation of the full network. |
| **Somalia** | | X | NA |
| **Sudan** | | X | NA |
| **Yemen** | | X | NA |

# Example – Saudi Arabia

## Renewable representation in models - Production

Renewable production from a mixture of measurement and modelling

- **Meteorological stations - KACARE and Aramco**
  - DNI, DHI, GHI, Wind speed and direction (up to 100m), Temperature, Humidity etc.
- **Renewable production models**
  - PV (SAM and PVsyst)
  - Wind (Mesoscale model and measurements)
  - CSP with Storage (SAM)


*K.A.CARE measurement sites*

# 4. Improvement priorities

# Areas identified for future improvement

## LATAM

| Geo-spatial resolution/VRE zoning and siting: | # of countries interested (out of 10) |
|---|---|
| 1. Developing resource maps to define regions and include multiple nodes in models | **6** |
| 2. Representing policy limitations on regional VRE generation/capacity (e.g. building constraints for priority zones, proximity to transmission) | **3** |
| 3. Incorporating zone/region-specific investment costs | **2** |
| 4. Incorporating transmission losses into model | **2** |
| **High-level issues:** | |
| **1. Investigating the right temporal/spatial resolution for modelling** | **3** |
| 2. Collecting better data (on costs, resource characteristics, system operation, etc.) | **7** |
| **3. Co-optimising generation and transmission planning** | **6** |
| 4. Improving forecasting (short-term and long-term, for both VRE and demand) | **4** |
| 5. Working to model the relationship between hydro and VRE generation realistically | **2** |
| 6. Developing methodology for model-coupling and feedback | **4** |
| 7. Incorporating small-scale distributed generation | **1** |

# Areas identified for future improvement

## Arab region

| Geo-spatial resolution/VRE zoning and siting: | Current practice? | Improvement priority? |
|---|---|---|
| 1. Including multiple nodes in your models to capture VRE resource quality and generation profiles in different regions | **5** | **8** |
| 2. Adding site-specific transmission investment costs for VRE projects or zones before they are chosen for investment | **9** | **9** |
| 3. Co-optimising generation and transmission planning (i.e. fully integrating both planning processes) | **10** | **11** |

## Flexibility also key topic in both regions

- **"For more advanced flexibility analysis at higher VRE penetration levels, hourly and sequential representation"**
- **5 of 10 in LATAM**
- **11 of 15 in Arab region**

# Guiding questions

1. What are the roles of energy system modelling in long-term policymaking?
2. What methods are used to estimate and account for geospatial factors in long-term energy planning models? If applicable, how are capacity credit of VRE, transmission constraints and flexibility requirements addressed?
3. What kind of geospatial data resolutions, processing tools and widgets are used and how and where do you get your data from?
4. What are the challenges in representing long-term VRE impacts and limitations of current geo-spatial tools and long-term energy models to capture this?

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# 1. Regional IRENA AVRIL Workshops

# Regional AVRIL workshops

## 2017 – Buenos Aires, Argentina – LATAM

- Co-organised by IRENA and Argentina's Ministry of Energy and Mining; with representatives from NREL, OLADE, and the World Bank
- Representatives from **ten Latin American countries - Argentina, Brazil, Bolivia, Chile, Colombia, Ecuador, Mexico, Paraguay, Peru, and Uruguay**

## 2019 – Astana, Kazakhstan – Central Asia

- Co-organised by IRENA and Ministry of Energy of Kazakhstan; with representatives from ADB, USAID, EBRD, UNECE, UNDP
- Representatives from **five Central Asia countries - Azerbaijan, Kazakhstan, Kyrgyzstan, Tajikistan, and Uzbekistan**


## 2019 – Amman, Jordan – Arab region

- Co-organised by IRENA, League of Arab States, IsDB and RECREEE
- Representatives from **ten Arab countries - Algeria, Bahrain, Egypt, Iraq, Jordan, Libya, Palestine, Qatar, Saudi Arabia, and Somalia**

# 2017 LATAM Regional workshop on long-term planning with VRE

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- Co-organised by IRENA and Argentina's Ministry of Energy and Mining in Buenos Aires
- International and regional representatives from NREL, OLADE, and the World Bank
- National planning representatives from ten Latin American countries – Argentina, Brazil, Bolivia, Chile, Colombia, Ecuador, Mexico, Paraguay, Peru, and Uruguay
- **Extensive national planning surveys completed beforehand**

**<u>Workshop objectives:</u>**

- **Exchange experience in best practice for long-term power system planning and modelling with high shares of VRE**
- **Identify opportunities for improvement**

Workshop link: http://www.irena.org/events/2017/Aug/Incorporating-variable-renewables-into-long-term-energy-sector-planning-in-South-America

# 2017 LATAM Regional workshop on long-term planning with VRE

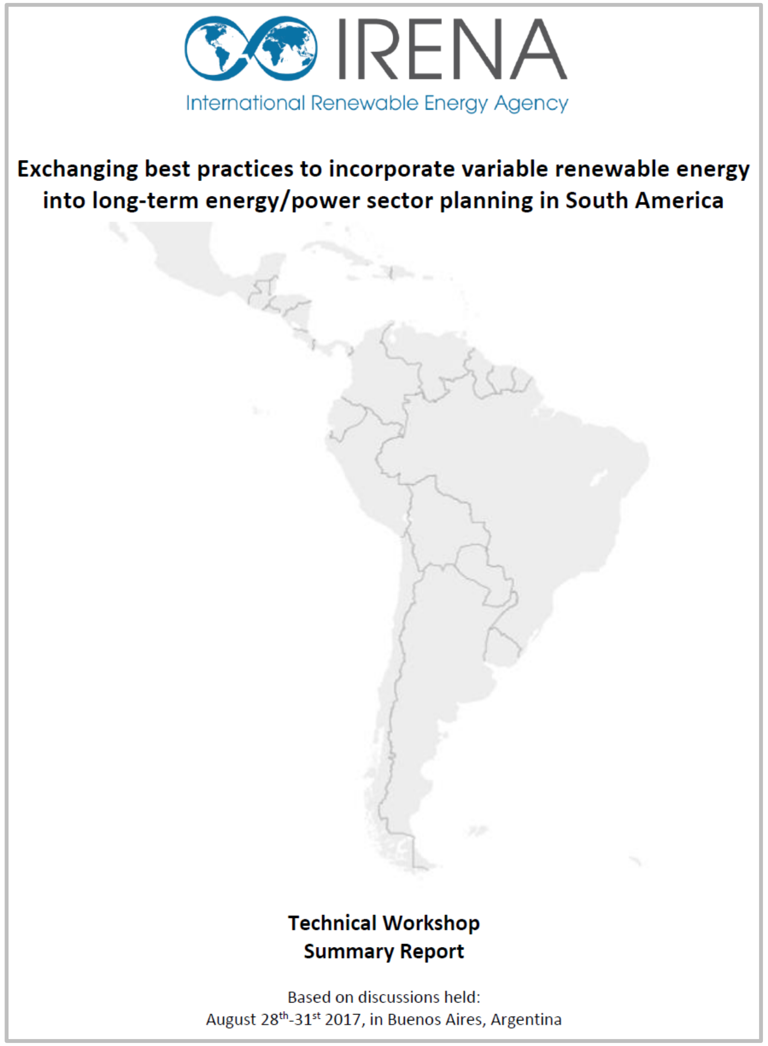
**Opportunity for a follow-up technical workshop:**

» Participants confirmed **there is a need for such dialogue focused on planning & modelling for VRE**

» **Workshop summary report contains surveys and extensive list of working-level topics that countries in the region are eager and able to follow up on** - the opportunity for collaboration is significant

» The most cited **areas for a potential follow-up workshop** are:

- System Flexibility
- Capacity credit of VRE
- RE data improvement: e.g. costs and resources
- Topics beyond the modelling: e.g. grid codes and the remuneration of energy system services (e.g. flexibility and transmission investment)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**Exchanging best practices to incorporate variable renewable energy into long-term energy/power sector planning in South America**

**Technical Workshop**
**Summary Report**

Based on discussions held:
August 28th-31st 2017, in Buenos Aires, Argentina

Workshop link: http://www.irena.org/events/2017/Aug/Incorporating-variable-renewables-into-long-term-energy-sector-planning-in-South-America

# What is the purpose of long-term planning? Examples from LATAM

**Colombia:**
**Basis for policy making**, establishing **signals for investment** and capacity expansion needs

**Brazil:**
To be used as a **basis for formulating public policies**

**Uruguay:**
**To design policies** to support technologies to promote and **investment needs**

**Argentina:**
To establish a framework of discussion for the **design of new policies** and for the **discussion with actors of the sector**.

# Models and tools used by governments – Arab region

| | | Planning steps - Tool coverage | | | |
|---|---|---|---|---|---|
| Country | Tool | Technical network studies | Dispatch simulation | Power demand forecast | Generation expansion |
| Algeria | MAED | | | X | |
| | DAP | | | X | |
| | NOMITOR | | | X | |
| | WASP | | | | X |
| | MESSAGE | | X | | X |
| | SPIRA package | X | | | |
| | SIMONE | X | | | |
| Bahrain | PSS/E (Power System Simulator for Engineering) | X | X | | |
| Egypt | Eviews | | | X | |
| | EGEAS (Electric Generation Expansion Analysis System) | | X | | X |
| | PSR models | X | X | | X |
| | PSS/E | X | | | |
| Iraq | NA | | | | |
| Jordan | PLEXOS | | | X | X |
| | Excel model | | | X | |
| | WASP | | X | | |
| | PSS/E | X | | | |
| | DIgSILENT PowerFactory | X | | | |
| Lebanon* | Estimation | | X | X | |
| | CYME | X | | | |
| | Remap | | | | X |
| Libya | NA | | | | |

# Models and tools used by governments – Arab region

| Country | Tool | Technical network studies | Dispatch simulation | Power demand forecast | Generation expansion |
|---|---|---|---|---|---|
| Morocco* | OPTGEN | | | | X |
| | SDDP | | X | | X |
| | NCP | | | | |
| | PSS/E | X | | | |
| Oman* | NA | | | | |
| State of Palestine | Excel model | | | X | X |
| | ETAP | X | | | |
| Qatar | Excel Model + @RISK | | | X | |
| | In-house model | | X | X | |
| | PLEXOS | | | | X |
| | PSS/E; PSS SINCAL | X | | | |
| Saudi Arabia | Mothra | | | | X |
| | SUPER | | | | X |
| | Strategist (+ stratRob) | X | X | | |
| | PLEXOS | | | | X |
| | KEM | | X | | X |
| | ProMod | | X | | |
| | PSS/E | X | | | |
| | In-house tool | | | X | |
| Somalia | Excel model | | | X | |
| Sudan* | | | | | |
| Yemen* | NA | | | | |

# Methodology – LATAM - Highlights

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| | |
|---|---|
| Brazil | **Addressing geo-spatial elements in overall process:** A wind data collection system has been implemented, which obtains data from almost all operating wind power plants in Brazil - this data has enabled detailed studies of wind patterns, which allows better representation of the variability of generation (e.g., capacity factor and capacity credit p95 probability). A model to forecast the diffusion of small distributed generation (PV and biogas) has been developed.<br>**Multiple Spatial Nodes in Expansion Models:** Nine interconnected regions are modelled as part of long-term capacity expansion analysis, with an associated transmission cost between each region.<br>**Capacity Credit:** Inherently covered with multiple node expansion model and site specific VRE data.<br>**Transmission Costs:** Accounted in generation expansion model.<br>**Co-optimization of Generation and Transmission:** Transmission costs are optimized in generation expansion model. |
| Argentina | **Addressing geo-spatial elements in overall process:** For geospatial aspects, PSSe and MESSAGE/TIMES are used iteratively to gauge transmission expansion requirements and stability issues.<br>**Multiple Spatial Nodes in Expansion Models:** Currently model 8 regions, with a monthly time resolution, and daily time slices divided into super peak, peak, valley, and remainder<br>**Capacity Credit:** The correspondence between demand and VRE generation is analyzed outside expansion model. For firm capacity representation, % of installed capacity is assigned per technology. Wind technology is disaggregated by region, and the correlation of generation between sites in those regions is analyzed to determine current and future wind contribution to the system by region. Solar PV generation (adjusted by region) vs. demand peaks is analyzed to assess contribution to operational margin. Distributed solar PV generation is included separately, with lower load factors due to assumption of fixed panels<br>**Transmission Costs:** Not accounted in generation expansion modeling.<br>**Co-optimization of Generation and Transmission:** Not done |
| Chile | **Addressing geo-spatial elements in overall process:** RE inputs are considered very important to the modelling process – have broken up their representation in three steps: 1. Identify the resource; 2. Identify RE zones based on resource, but also perform feasibility assessments based on other decision layers (environmental, proximity to transmission, etc.); 3. Create hourly generation profiles<br>**Multiple Spatial Nodes in Expansion Models:** The spatial granularity of the system is modelled, with 44 substations.<br>**Capacity Credit:** VRE capacity credit is not explicitly represented though generation profiles are among model inputs.<br>**Transmission Costs:** Site specific projects and generic resource potential is represented geographically in the model. While the model can also represent transmission investment needs, this Is not addressed in the Ministry's long-term planning exercise.<br>**Co-optimization of Generation and Transmission:** Not done |
| Mexico | **Multiple Spatial Nodes in Expansion Models:** Have hourly demand for 50+ model nodes and 100+ load zones<br>**Capacity Credit:** Fixed values are defined exogenously, and site specific renewable generation profiles are also among model inputs<br>**Transmission Costs:** No data<br>**Co-optimization of Generation and Transmission:** Site-specific projects and generic resource potential is represented geographically in the model, and transmission capacity expansion takes into account feasible projects identified in capacity expansion planning. So not done. |

# Methodology – Arab region - Highlights

| | |
|---|---|
| Egypt | **Capacity Credit:** Site specific hourly VRE data is given in EGEAS which then estimates capacity credit inherently.<br>**Transmission Costs:** Eqypt accounts the site-specific transmission costs of VRE. Its highly likely that they are not considered in expansion model runs but nothing mentioned in the report in this regard.<br>**Co-optimization of Generation and Transmission:** Egypt uses transmission proximity and other technical factors in optimizing VRE site selection but both types of planning are not fully integrated. |
| Saudi Arabia | **Addressing geo-spatial elements in overall process:** Generation profiles from over 50 wind and solar resource monitoring stations are analyzed using NREL SAM tool to find complementarity to system demand. The results are handed over to utilities which run detailed network analysis to test different locations and run long term generation models opting renewable energies only on least cost basis.<br>**Multiple Spatial Nodes in Expansion Models: Yes**<br>**Capacity Credit:** Inherently covered in expansion tools if given site specific data<br>**Transmission Costs:** VRE site specific transmission costs are determined through GIS mapping and other grid investments are estimated from power system simulations of full network. Such VRE specific costs are accounted in generation expansion tools which already include simplified representation of transmission networks. Simplified transmission modelling is easy to implement in case of Saudi Arabia given the individual grid regions are almost isolated.<br>**Co-optimization of Generation and Transmission: Yes** |
| Jordan | **Multiple Spatial Nodes in Expansion Models: Yes**<br>**Capacity Credit:** Report states that VRE capacity credit is a main criterion to select VRE site.<br>**Transmission Costs:** VRE siting and transmission needs are determined through PSSE and DigSilent. It is highly likely that they are not considered in expansion model runs but nothing mentioned in the report in this regard.<br>**Co-optimization of Generation and Transmission:** Capacity expansion is now done side-by-side with the transmission grid expansion. The ministry cannot proceed with the project without coordinating with the off-taker, who evaluates transmission congestion constraints. Investments are now being made to absorb further projects. |
| Qatar | **Multiple Spatial Nodes in Expansion Models: Partially done**<br>**Capacity Credit:** The capacity credit is assumed depending on penetration levels. The difference between the maximum of both load duration curve and residual load duration curve is used as a capacity credit. So no geospatial approach is used.<br>**Transmission Costs:** VRE siting is not fully integrated in the long-term planning process, but whenever a capacity expansion is planned the TSO utility is consulted to rank the potential sites based on a number of relevant criteria<br>**Co-optimization of Generation and Transmission:** Partially done as per above stated approach. |

# Some high-level conclusions

» **The paradigm in the region is changing** – in 30 years the region's power system/s are expected to be very different

» Although all country contexts are different, concerns are similar **"*we all worry about the same things...it's good to know that planners in the region are not alone*"**

- **Modelling renewable costs:** **translating international cost projections into local contexts is a challenge**
- **Modelling generation adequacy (i.e. capacity credit):** there's **difficulty with hourly historical VRE generation** and load data, **uncertainty around future load profiles**, and realistic **depiction of VRE-hydro dynamics**
- **Modelling flexibility:** **representing newer flexibility options such as storage and demand-side response is challenging**
- **Modelling transmission:** **VRE projects can be spread to smooth variable production** (e.g. wind generation in Argentina), but **co-optimisation of generation and transmission planning remains a challenge**

» There is extensive global experience with power systems and VRE, and **good practices from outside the region can be shared and adapted**

» **International institutions such as IRENA should serve as a platform** to identify specific needs, and countries that have already resolved them to facilitate exchange

# The region is preparing for major changes in the power sector

<u>**Some examples:**</u>

» **Argentina** has a target to meet 20% of demand with renewable sources by 2025, up from 8% in 2017-18

» **Brazil** explores scenarios with increases of 120% in the installed capacity of non-conventional renewable sources like biomass, solar and wind in 10 years (from 29 to 63 GW)

» **Chile** considers scenarios with shares of up to 90% renewable energy, even some with 75% VRE, in 30 years

» In **Colombia** there are scenarios that include more than 2 GW of wind power in the next 15 years

» **Bolivia** expects a transition from thermal generation to a system based on renewable energies

» In **Uruguay**, the share of wind energy in total generation jumped from 1% to 27% between 2012 and 2016 (1.4 GW installed). In 2017 the share of renewable energy was 98%.

# High-level conclusions: RE and VRE characteristics in the region

- RE shares are currently high across the region, but that is mainly driven by hydropower, and there remain several countries with significant thermal capacity (e.g. Argentina, Bolivia, Chile, and Mexico)
- Hydro is set to grow in some countries (e.g. Bolivia with large export plans, Ecuador, possibly Peru), but remain stable or decline elsewhere (e.g. Brazil due to environmental concerns)
- VRE shares are currently low, with the exception of Uruguay, which has significant shares of wind generation, and certain regions within Brazil and Chile
- Nevertheless, in many cases national plans to expand VRE capacity represent rapid increases relative to current shares, over a short period of time
- The benefits of new VRE capacity heavily depend on complementarity between VRE generation, existing resources, and demand – e.g. in Brazil, wind generation complements hydro seasonality, and solar can complement biomass availability and an increase in summer air conditioning demand
- Uncertainty around future resource/demand complementarity is a key challenge, e.g. in the same Brazilian context, GWs of diesel capacity – rather than solar – are being used to meet demand growth amidst declining hydro production, since peak demand shift from evening to summer daytime is not certain

# Detailed insight: Regional representation of VRE investment costs

| | Represented in long-term capacity expansion? | | Description of approach |
|---|---|---|---|
| | Yes | No | |
| **Argentina** | X | | Possible trajectories of capital costs, as well as operation and maintenance costs, for both renewable and conventional technologies are based on information from renewable energy auction rounds, as well as cost evolution estimates made by different international organizations. Discount rate projections are used to confirgure final cost inputs. |
| **Bolivia** | | X | NA |
| **Brazil** | X | | Solar cost evolution is forecast based on international references, such as *IRENA The Power to Change: Solar and Wind Cost Reduction Potential to 2025* (2016) and *IEA Technology Roadmap – Solar Photovoltaic Energy – 2014 Edition* (2014), and benchmarked against actual project-specific data from auctions. Other renewable costs are maintained constant. |
| **Chile** | X | | Cost forecasts are based on the following methodology: 1. Compilation of base year cost data (real); 2. Compilation of internationally reported projections (eg IEA, BNEF, etc.); 3. Normalization of projections to the base year data; 4. Construction of an envelope of all possible cost evolutions; 5. Construction of an intermediate trend. |
| **Colombia** | X | | Levelised costs of generation are calculated and used as model inputs. |
| **Ecuador** | X | | Installation costs of non-conventional renewables are in accordance with those reflected in current regulation. Variable costs of operation are not considered in simulations as renewable sources are treated as preferentially dispatched. |
| **Mexico** | X | | Investment, operation and maintenance costs of renewable generation technology is taken into account, adjusted to a learning curve. |
| **Paraguay** | | X | NA |
| **Peru** | X | | Future cost trajectory of renewable technologies are based on information from renewable energy auction rounds |
| **Uruguay** | X | | An average of the latest available regional or national cost information is used, based on public tenders. No future projections are made given the level of uncertainty surrounding costs, and current costs are considered a 'worst case' as they will likely evolve downward. |

# Detailed insight: Regional representation of generation adequacy

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| | Represented in long-term capacity expansion? | | Description |
|---|---|---|---|
| | Yes | No | |
| **Argentina** | X | | The correspondence between demand and renewable generation data is analyzed outside of the model, and this determines the distribution of renewable generation by model timeslice. The year is divided into 12 months with superpeak, peak, rest and valley hours. In TIMES it is also possible to define the contribution of each technology to peak demand, as a separate variable. A reserve margin is defined for the whole system, and a percentage of firm power is assigned by technology to perform this calculation. |
| **Bolivia** | | X | NA |
| **Brazil** | X | | For wind, a seasonal value is estimated probabilistically based on historical data, independent of the wind energy share. For solar PV, capacity credit is considered to be zero, due to a lack of detailed studies. As solar CSP is modeled with storage, the capacity credit is equal to a conventional thermal power plant. |
| **Chile** | | X | Not explicitly represented, though renewable generation profiles are among model inputs |
| **Colombia** | | X | NA |
| **Ecuador** | | X | NA |
| **Mexico** | X | | Fixed values are defined exogenously, and renewable generation profiles are also among model inputs |
| **Paraguay** | | X | NA |
| **Peru** | | X | NA |
| **Uruguay** | | X | NA |

# Detailed insight: Regional representation of system flexibility

| | Represented in long-term capacity expansion? | | Description |
|---|---|---|---|
| | **Yes** | **No** | |
| **Argentina** | X | | Flexibility is considered in relation to hydro reservoirs, but not in relation to thermal generation |
| **Bolivia** | X | | N-1 criteria is considered to ensure system reliability, as is the cost of energy not supplied |
| **Brazil** | X | | Power plants are modeled with minimum load levels, and dispatchable plants are also included. |
| **Chile** | X | | Flexibility is partially represented through the renewable energy generation profiles and base generation capacity of the system. Since the PET model used does not represent hourly generation, not all aspects related to flexibility are reflected. Hourly representation in the short-term PCP model considers, among other aspects, ramp rate restrictions, startup and shutdown costs, curtailment, primary and secondary frequency control, minimum operation time, and outage rates. |
| **Colombia** | | X | NA |
| **Ecuador** | X | | None |
| **Mexico** | X | | Operation constraints of generation units are represented. |
| **Paraguay** | | X | NA |
| **Peru** | | X | NA |
| **Uruguay** | X | | Hourly representation in the SimSEE model can represent storage technologies such as pumped storage and hydro reservoirs, as well as energy generation profiles for VRE, based on historical sub-hourly pluri-annual data series and statistical modelling of underlying stochastic phenomena. Operation constraints of thermal units can be represented, such as minimum load levels, ramp rate restrictions, startup and shutdown costs, minimum operation time and outage rates. |

# Detailed insight: Regional representation of stability-related operational constraint

| | Represented in long-term capacity expansion? | | Description |
|---|---|---|---|
| | Yes | No | |
| **Argentina** | X | | Long-term capacity expansion models are complemented by electrical system models (PSS/E) to capture system stability issues and transmission expansion requirements, in an iterative process. |
| **Bolivia** | | X | NA |
| **Brazil** | | X | NA |
| **Chile** | X | | Taken into account to the extent possible in the hourly representation of the short-term PCP model used to complement long-term capacity expansion modelling. |
| **Colombia** | X | | None |
| **Ecuador** | | X | NA |
| **Mexico** | | X | NA |
| **Paraguay** | | X | NA |
| **Peru** | | X | NA |
| **Uruguay** | | X | NA |

# LATAM: Areas identified for future improvement

IRENA International Renewable Energy Agency

| | # of countries interested (out of 10) |
|---|---|
| **Costs:** | |
| 1. Having a clearer view of which cost components (e.g. finance, labor, etc.) will drive future wind and solar cost reductions | **3** |
| 2. Translating international cost forecasts into local estimates | **5** |
| 3. Using scenarios to explore the influence of VRE cost uncertainty | **0** |
| **Generation Adequacy/Capacity Credit:** | |
| 1. Considering the contribution of VRE to firm power | **5** |
| 2. Performing probabilistic analysis (e.g. Monte Carlo simulation) of available system generation with/without VRE | **2** |
| 3. Reducing uncertainty around the future load profile | **1** |
| 4. Using hourly VRE data to find VRE generation during peak | **1** |
| **Flexibility:** | |
| 1. Validating that long-term generation mix meets short-term flexibility requirements (e.g. frequency and length of ramping), and reflects flexibility costs (e.g. cycling, efficiency loss, etc.) | **6** |
| 2. For more advanced flexibility analysis at higher VRE penetration levels, hourly and sequential representation | **5** |
| 3. Representing storage, and investigating methods to include energy withdrawal, injection, and revenue streams | **7** |
| 4. Incorporating demand response | **4** |

# LATAM: Areas identified for future improvement

| | # of countries interested (out of 10) |
|---|---|
| **Geo-spatial resolution/VRE zoning and siting:** | |
| 1. Developing resource maps to define regions and include multiple nodes in models | **6** |
| 2. Representing policy limitations on regional VRE generation/capacity (e.g. building constraints for priority zones, proximity to transmission) | **3** |
| 3. Incorporating zone/region-specific investment costs | **2** |
| 4. Incorporating transmission losses into model | **2** |
| **Stability:** | |
| 1. Performing grid integration studies on multiple long-term VRE capacity scenarios, to assess and feed back the costs of stability | **2** |
| **High-level issues:** | |
| 1. Investigating the right temporal/spatial resolution for modelling | **3** |
| 2. Collecting better data (on costs, resource characteristics, system operation, etc.) | **7** |
| 3. Co-optimising generation and transmission planning | **6** |
| 4. Improving forecasting (short-term and long-term, for both VRE and demand) | **4** |
| 5. Working to model the relationship between hydro and VRE generation realistically | **2** |
| 6. Developing methodology for model-coupling and feedback | **4** |
| 7. Incorporating small-scale distributed generation | **1** |
| **Beyond the modelling (policy, market design, and regulation):** | |
| 1. RE policy targets and incentives | **4** |
| 2. RE deployment through auctions/tenders | **3** |
| 3. Remuneration of energy system services and improvements | **8** |
| 4. Grid access and extension | **2** |
| 5. VRE in grid codes | **8** |

# Arab region: Areas identified for future improvement

| | Number of countries (of 15) | Score |
|---|---|---|
| Costs: | Current? | Priority? |
| 1. Having a clear view of which cost components (e.g. finance, labor, etc.) will drive future wind and solar cost reductions | **10** | **9** |
| 2. Translating international cost forecasts into local estimates | **10** | **6** |
| 3. Using scenarios to explore the influence of VRE cost uncertainty | **4** | **10.5** |
| Generation Adequacy/Capacity Credit: | | |
| 1. Considering the contribution of VRE to firm capacity | **7** | **11** |
| 2. Using hourly VRE data to represent VRE generation profile | **9** | **9** |
| 3. Performing probabilistic analysis (e.g. Monte Carlo simulation) of available system generation with and without VRE | **5** | **7** |
| Flexibility: | | |
| 1. Validating that your long-term capacity mix meets short-term flexibility requirements (e.g. ramping), and assessing flexibility costs (e.g. cycling costs, efficiency losses, etc.) | **7** | **12** |
| 2. For more advanced flexibility analysis at higher VRE penetration levels, hourly representation | **6** | **11** |
| 3. Assessing the contribution of storage and demand response to flexibility | **5** | **9** |

# Arab region: Areas identified for future improvement

| | | |
|---|---|---|
| Geo-spatial resolution/VRE zoning and siting: | | |
| 1. Including multiple nodes in your models to capture VRE resource quality and generation profiles in different regions | **5** | **8** |
| 2. Adding site-specific transmission investment costs for VRE projects or zones before they are chosen for investment | **9** | **9** |
| 3. Co-optimising generation and transmission planning (i.e. fully integrating both planning processes) | **10** | **11** |
| Stability: | | |
| 1. Performing grid integration studies on long-term VRE capacity scenarios, to assess and feed back the costs of stability solutions | **9** | **12.5** |
| 2. Ensuring stability needs for VRE are reflected in grid codes | **11** | **12** |