Ideal modelling with RES
Presentation context

1. Supply curves approach
2. Least cost planning approach
3. Portfolio approach
4. RES integration in operational models
5. Ideal planning model
6. Desirable Features of Planning Tools
Presentation context

1. Supply curves approach
2. Least cost planning approach
3. Portfolio approach
4. RES integration in operational models
5. Ideal planning model
6. Desirable Features of Planning Tools
The optimal level is achieved when marginal cost of RES equals marginal cost of conventional generation, with the condition that:

\[ \text{RES + Conventional} = \text{Demand} \]
Optimal RES Level

Where both supply curves meet each other, is the optimal amount of RE penetration and the marginal cost of RE (the cost of the last RE plant that is cheaper than the last conventional plant replaced).
Optimal RES Level

- **Value of RES energy**: Supply curves are only based on unit costs, and cannot identify the value of the energy produced. Different types of RES may have the same unit costs, but the energy produced may have a different value for the demand,

- **Contribution to peak demand meeting is not considered** in typical supply curves, so RES with similar unit costs may have a different contribution to reliability, and consequently a different value for demand,

- **Externalities** consideration is very simplified,

- **Zonal spread of renewable resources is poorly considered** in the supply curves approach. Particularly when RES projects require to reinforce the transmission system,

- **Supply curves are static**, but the process of meeting the electricity load is dynamic. Static approach hardly considers relevant issues like technological development, learning curves, large scale projects, etc
**Value of the RES energy**

- **Hydro without reservoir:**
  - Cost of energy: 53 $/MWh and value of substituted energy: 40 $/MWh
- **Hydro with reservoir:**
  - Cost of energy: 57 $/MWh and value of substituted energy: 63 $/MWh

The supply curve may lead to bad decisions because it does not consider the actual value of energy substituted by RES, but only the cost to produce the energy.
Contribution to system security of supply

• The firm capacity is not taken into consideration in the curves elaboration
• Solution: build two supply curves
  • one for RES with zero firm capacity, which is compared with the STMC
  • another with firm capacity equal to a % of installed capacity, compared with the LTMC.
  • RES with zero firm capacity only substitutes thermal generation, whose capacity is necessary to protect system adequacy, while RES with firm capacity do not need firm capacity back/up.
• However cases where firm capacity is in an intermediate value, or when it is possible to increase the firm capacity are not considered
Consideration of externalities

• Externalities (linked to emissions like CO2, SO2, etc) are considered by increasing the LRMC with the cost of the emissions

• Implicit assumption: RES generation will replace exactly the emissions of the expansion technology used to calculate the LRMC

• But in reality an additional MW of RES is replacing emissions from the marginal technology

• Besides, supply curves methodology is not able to include the dynamics of technology evolution and its impact on externalities reduction
Zonal spread of RES

• In most of the cases there is not a direct and linear relationship between RES penetration and transmission reinforcement costs.

• Therefore it is impossible to include in the supply curve a good estimation of grid reinforcement costs linked to each type of RES in each zone

• An example...

If the hydro project is developed it will use the entire capacity of the line, and it becomes also necessary to reinforce the line A-load to transport the energy of the wind project.
Need of a dynamic approach

• Supply curves are static but optimal electricity supply is dynamic

• Dynamism need to model:
  • Technology development
    ➔ competitiveness of some RES may change in time
  • Technological learning

• Optimal generation mix depends not only of candidate’s technologies but also on the initial mix
  ➔ conventional supply curves change in time
Presentation context

1. Supply curves approach
2. Least cost planning approach
3. Portfolio approach
4. RES integration in operational models
5. Ideal planning model
6. Desirable Features of Planning Tools
Least Cost Planning Approach

- The objective of expansion power planning studies is to determine a sequence of capacity reinforcement in generation and transmission so as to meet the future electricity demand complying with the conditions of lowest cost (as a proxy of highest social welfare).
- It is sought to minimize the investment, fuel, operation and maintenance costs, as well as the expected (social, shadow) cost of the expected unserved energy.
- These requirements are to be achieved while meeting reliability, social, financial, political, geographical and environmental constraints.
- The power planning effort implies therefore the minimization of total costs while ensuring the optimization, or at least an adequate representation, of the power system operation (i.e., a sound simulation of the energy dispatch), while meeting an acceptable (or pre-specified) level of supply reliability.
Least Cost Planning Approach

• Objective function

\[
\min \sum_{i=1}^{N} \left( \frac{\text{Variable Costs}_i}{(1 + dr)^t} + \frac{\text{Investment cost} + \text{Fixed O & M}_i}{(1 + dr)^t} \right)
\]

• Subject to the following constraints:
  • Meeting forecasted demand (at region or node level)
  • Appropriate security of supply (e.g. measured as minimum firm reserve)
  • Transmission constrains
  • Emissions constrain
  • Operational constrains
  • Physical laws (e.g. Kirchoff’s)
  • Availability of water, wind, sun,…
  • Use of better primary resources zones first,
  • etc.
The whole planning process: the issue of granularity

• Although the LCP model is typically the core of the planning process, it needs to be complemented with additional models and processes.

• The approach to deal with LCP models that cannot manage all needed variables is through the concept of successive stages (or zooming), each stage having a different scope and detail level (granularity). The key issues regarding granularity are:
  • It is not possible to analyse the whole with the same details that a part of the whole. Besides its obvious computationally and technical difficult, it is not an economic alternative.
  • Therefore, planning is composed of many problems of approximately same (manageable) size but different scope, it is like zooming in the problem in successive steps.
  • The analyst should perfectly know what is the goal of the study s/he is undertaking.
Planning is Granular

Need of granular approach arises from the practical impossibility to address all the variables at the same time.
The entire planning process

LCP model: optimisation of generation and transmission expansion, Planning horizon: 30 years, Assessment of the retirement of existing units, CO2 emissions constrains, Hydro-wind combined scenarios, Only main transmission links considered (existing and candidates) 200,000 real variables, 1,500 integer variables (transmission links, hydro, nuclear), Resolution time 1-2 hours, System in N conditions.
The entire planning process

Simulation model, with ability to manage: 10 years horizon simulation of the optimal expansion, Unplanned outages of major transmission and generation facilities (N-1 criteria testing) Wind, hydro, solar, others, stochastic series Detailed network representation (e.g. all lines, substation voltage > 100 kV) Minimum cost dispatch on weekly basis
The entire planning process

Power system simulation: Load states defined with the simulation model for normal and extreme conditions,
Using standard power system analysis models, Detailed load flows,
short circuit studies with typical load states (peak-valley, high-medium-low renewable) from simulation model
Voltage profiles, compensation needs, N-1 verification, Cost adjustment

Input
- Expansion candidates
- Security Standards
- Policies
- Socio-economic & environment

Process
- Scenarios
  - Optimal Expansion Model
    - Expansion Plan G&T
  - Simulation Model
    - Expansion Plan Performance
      - System operation
  - Power System Simulation
    - Transmission Performance

Outputs
- Yes: Done
- No: Adjust parameters
  - Go to scenarios
  - Performance OK
RES in LCP: addressing the drawbacks of supply curves

• **Value of RES energy**: the LCP approach includes RES in the economical dispatch to calculate variable costs. As dispatches are simulated at periods level (month, quarter), the LCP model will calculate exactly the variable costs savings of existing or new thermal plants, considering the eventual seasonality of RES production.

• **Security of Supply**: the LCP planning models addresses the security of supply issue through the adequacy constrains and the possibility to manage stochastic variables.

• **Externalities**: LCP models allow considering directly the cost linked to different types of pollutants emission, through the forecasted dispatch of each technology.

• **Zonal spread**: the LCP approach is zonal, so candidates or existing RES resources can be considered with appropriate granularity.

• **Dynamic Approach**: the LCP approach is dynamic. Long time horizons can be considered, that allows taking into account expected technological developments, technological learning, decommissioning of existing units, and to reduce the impact of initial or final boundary conditions.
Enhancing LCP to consider RES

- Modify the LCP approach in order to capture the intrinsic characteristics of some RES technologies that are not captured in the conventional planning

- Modelling intermittent RES:
  - Intermittency of some RES cannot be modelled with the classical stochastic approach, as rapid generation changes along the day can distort the variable costs estimation.
  - A possible approach for modelling intermittency of RES such as solar, wind, tidal, etc. is based on the load duration curve concept.
- Modelling contribution of intermittent RES to security of supply
- Modelling dynamic parameters
Enhancing LCP: modelling intermittent RES

- The figure on the left shows a monotone duration curve of demand minus wind.
- While the figure on the right side shows how this can be implemented in a block wise structure.
Enhancing LCP: modelling contribution to security of supply

- The wind power load duration curve can be used also to define the power that can be available with some probability level.

For instance it can be verified that 5.3% or more of the installed capacity is available 95% of time. Firmness coefficients could be defined based on defining a probability of availability. In this case the coefficient would be 5.3%.
Enhancing LCP: Modelling dynamic parameters

- Model learning curves by approximating the non-linear exponential learning curve through a piece-wise approximation
Presentation context

1. Supply curves approach
2. Least cost planning approach
3. Portfolio approach
4. RES integration in operational models
5. Ideal planning model
6. Desirable Features of Planning Tools
Classical portfolio theory

• Classic portfolio theory aims to the creation of minimum-variance portfolios for any given level of expected (mean) return, which is equivalent to the creation of portfolios that maximize return at any level of expected risk (variance).

• In the power system world: calculation of the optimal technological expansion given a set of scenarios of a random variable (i.e., fuel prices). This would lead to, what is called in modern portfolio theory, the efficient curve of generation costs versus portfolio risk (measured as the variance of variable costs).
Portfolio theory and RES

• Although the portfolio optimization could be aimed at different objectives (security of supply, fuel price volatility, etc.), we understand that from the point of view of a planner, it is the **security of supply** the main variable to consider and the most important risk to take into account when RES modeling becomes a fact.

• Portfolio theory could also be used to analyze energy prices, particularly price (or costs) spikes, however it would require considering the strong asymmetry of electricity prices (costs), that is not reflected by distribution functions with “slim tails”.

• Portfolio theory can be used using the mean-variance techniques for small problems (non-linear) or can be adapted (linearized) with the use of the CVaR concept in order to be used in larger scale problems.
Presentation context

1. Supply curves approach
2. Least cost planning approach
3. Portfolio approach
4. RES integration in operational models
5. Ideal planning model
6. Desirable Features of Planning Tools
Integrating RES in operational models

• To cope with variability and lack of predictability of RES output:
  • Build ad-hoc forecasting models or use commercial statistical packages to enhance output prediction accuracy
  • Set Control Centres of aggregated renewable plants to implement remote control on these plants and also interact with the System Operator
  • Install advanced control devices at RES facilities to provide ancillary services such as ramps, voltage control and reactive power
Integrating RES in operational models

• To cope with interaction between RES and conventional generation:
  • Implement economic Compensations for those conventional generation technologies that provide generating reserves due to they are required operating at less efficient level.
  • Promoting energy storage devices such as pumped-storage hydro and chemical devices (batteries) to reduce renewable energy spillage and excess of cycling of conventional generating units
  • Design adequate demand-response programs, including direct load control, interruptible and curtailable rates, real-time or critical-peak pricing and dynamic energy pricing
  • Large control areas allow much greater flexibility and lower costs in operating and controlling a portfolio of resources than multiple smaller control areas. Reinforce interconnections between Power Systems will be pointing in this achievement direction.
Presentation context

1. Supply curves approach
2. Least cost planning approach
3. Portfolio approach
4. RES integration in operational models
5. Ideal planning model
6. Desirable Features of Planning Tools
Key features of the ideal “Planning” model (I)

General description

- The objective function to be optimised is the minimization of the total costs of the system (generation plus transmission).
- The model is able to run up to 40 year-long simulations.
- The model is stochastic and scenario oriented.
- The model uses advanced mix-integer programming (MIP) techniques.
- Joint planning of transmission and generation.
- Candidate projects can be continuous or discrete.

Load and system modelling

- Load is considered on a monotone curve basis divided into blocks chosen by the user.
- Interruptible load can be modelled.
- The model should consider from nodal to regional possibilities.
- Reliability coefficients should be entered as a parameter in the simulation.
- The supply/balance equilibrium should be assured by non-supply energy generators.
- Investments should be forced or constrained.

Generation subsystem

- Different types of plants should be modeled separately.
- Hydro/Pump Storage Generators: water values should be calculated by the model with the use of an optimization algorithm prepared for this.
- Candidate projects should be considered either continuously or discretely.
- Outages should be set by the user or randomly generated with Monte Carlo simulation.
### Key features of the ideal “Planning” model (II)

**Transmiss. subsystem**
- The user can choose between no grid, interconnected model or a full transmission model based on a DC OPF approach. DC links can be modelled under all assumptions.
- Constrains regarding power flow limitation: Max/Min limits, emergency limits, corridors constraints, etc.
- Losses are taken into account at the user’s command
- Candidate projects should be considered either continuously or discretely
- Outages should be set by the user or randomly generated with Monte Carlo simulation

**RES modelling**
- RES should have a dedicated module
- RES volatility and firmness should be considered in the model
- Candidate projects should be considered either continuously or discretely
- Outages should be set by the user or randomly generated with Monte Carlo simulation

**Others: software interface, reporting.**
- User friendly interface
- Possibility of saving inputs and outputs
- Marginal values should be available for the user
- Full reporting capabilities
- Maintenance and support for one year. Training is available
- Licenses
- Quality of the provided documentation
Presentation context

1. Supply curves approach
2. Least cost planning approach
3. Portfolio approach
4. RES integration in operational models
5. Ideal planning model
6. Desirable Features of Planning Tools
Desirable Features of Planning Tools

**Model features**

- Ability to produce scenarios easily and quickly, not cumbersome to use.
- Its friendliness and ease of use leaves more time for analysis of results than for learning how the model works.
- Ideally the model should be able to model the transmission system, even if in a simplified manner.
- The model should be able to model specifically different solar technologies PV, CSP with and without storage, etc.
Desirable Features of Planning Tools

Model features

• Ability to incorporate different hard-to-model risk.

• Ability to model renewable technology cost trends.

• It would be a plus if the model can identify short-term impacts of variability and how they should be considered in long-term planning.

• The model should be well documented and technical support and working groups should be available to share experiences with its use.
Desirable Features of Planning Tools

Key questions

- Given existing government policy targets on renewable energy in the power sector (specially wind and solar power), what should planners do to complement the ‘non’-renewable part of the plan?

- What long-run investments should be made to ensure that the given targets are met reliably from the long-run reserve reliability perspective?

- What are the extra cost on long-run reserve requirements, or others, in other to plan generation to meet supply and meet at the same time renewable energy plans?
Desirable Features of Planning Tools

Key questions

• Could the model determine a "maximum possible" level of renewable energy additions that can be managed from the reliability perspective?

• What would be the impact on emission of different strategies to fulfill the targets up-to 2030 and beyond?

• Would the model help produce quickly and efficiently a solution that is robust enough to uncertainties, like: changing conditions in demand, project details, and other (hard-to-model) uncertainties, like renewable energy generation cost evolution?
Thanks for your attention