Decision-making under Uncertainty using Different Multistage Stochastic Optimization Approaches

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PES GM 2017

Panel:
Transmission Planning for Non-Synchronous Variable Resources

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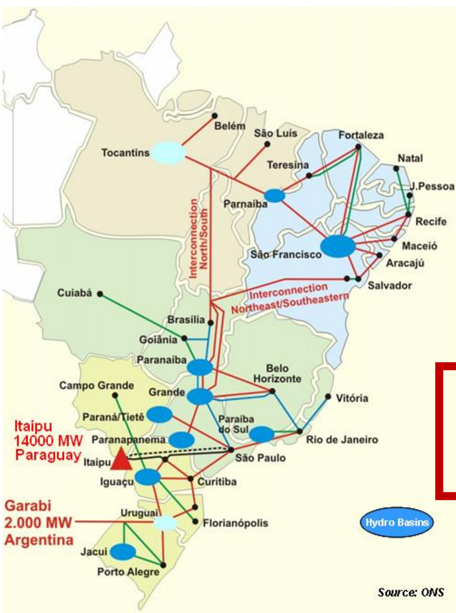
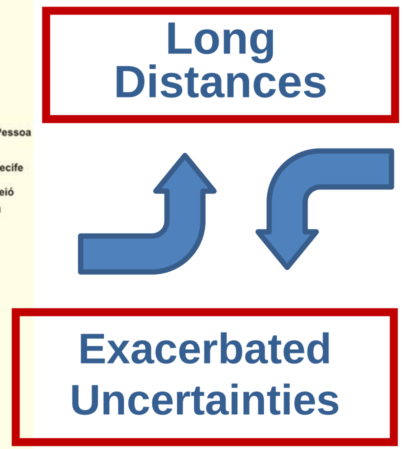
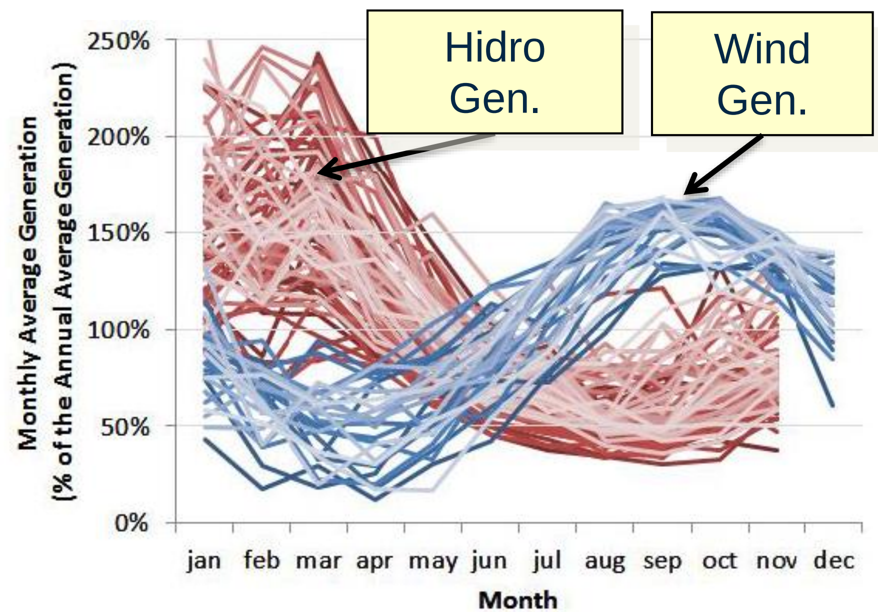
Introduction

- There are several reasons to explain why transmission system loading is less than 100%:
  - Uncertainties associated with the demand growth forecast;
  - Binary decision associated with line construction & modularity of the circuits;
  - Reliability;
  - Different economic dispatch scenarios ➔ associated with RES;

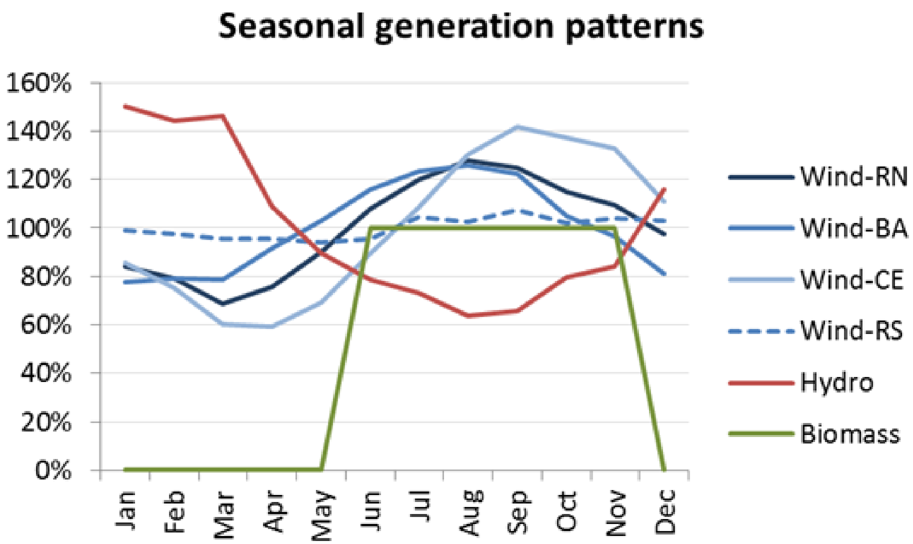


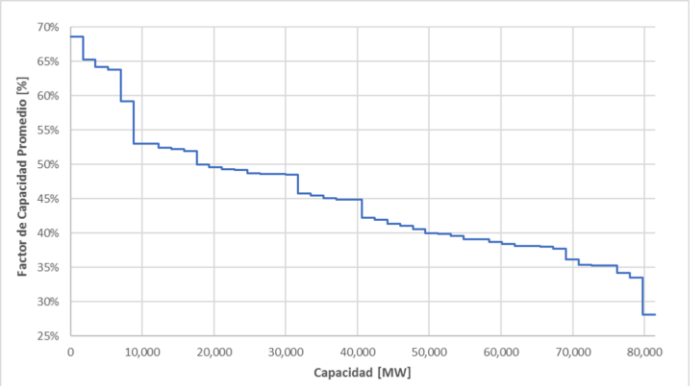


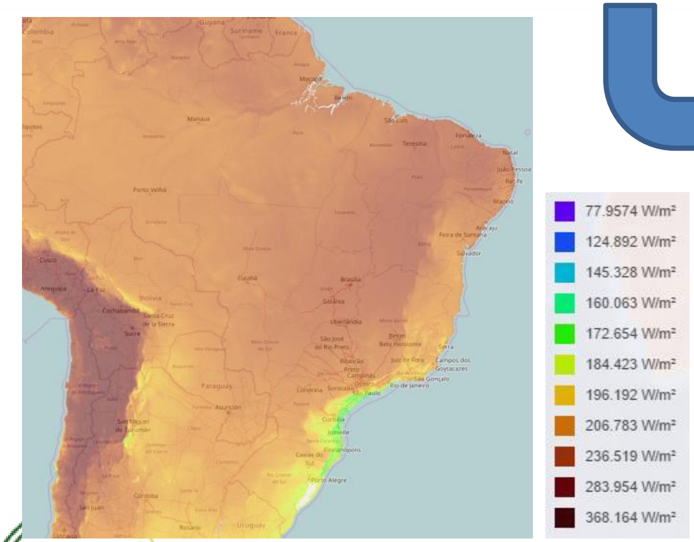


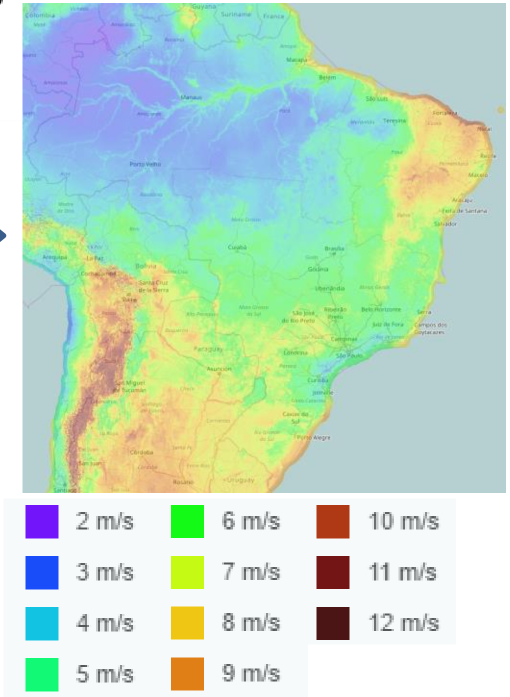
- **Objective ➔ determine a robust least-cost expansion plan!**

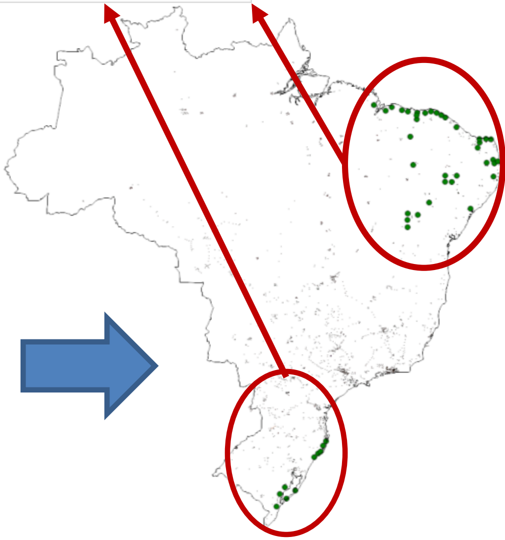
The Brazilian System: Prospecting Wind and Solar Potentials











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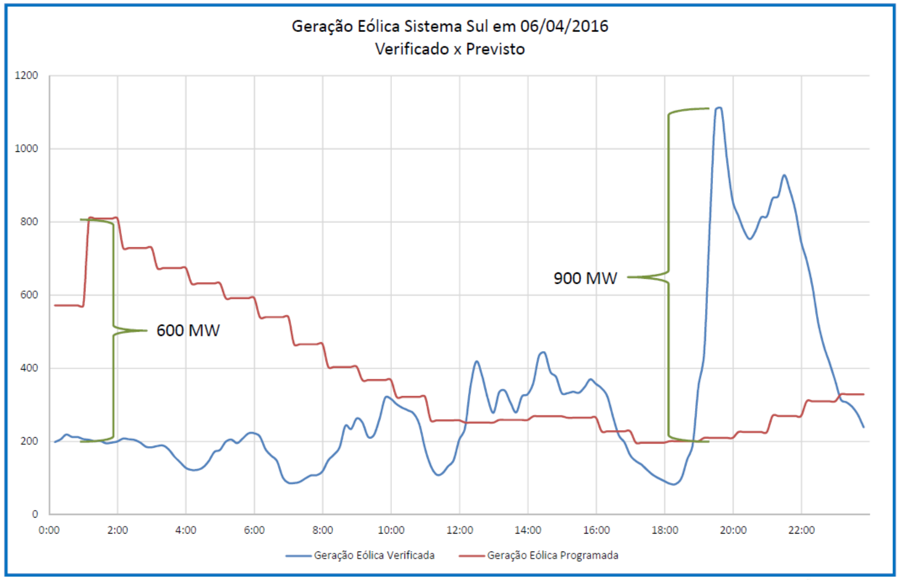
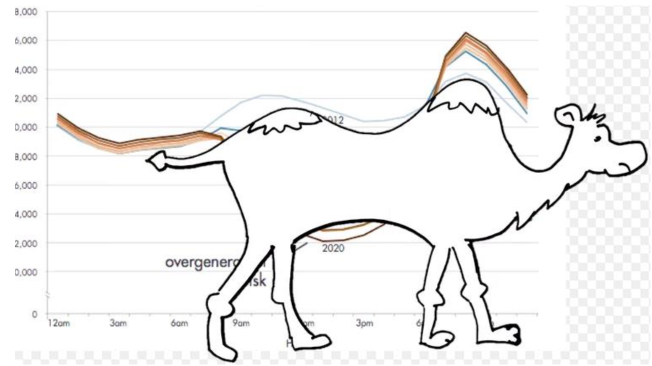
Introduction

- The **challenges** also:

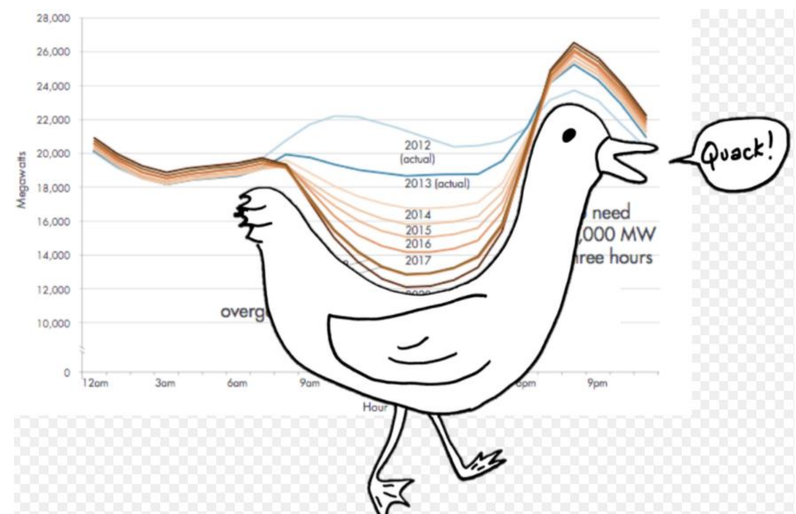


1000 MW ramp in 1 hour

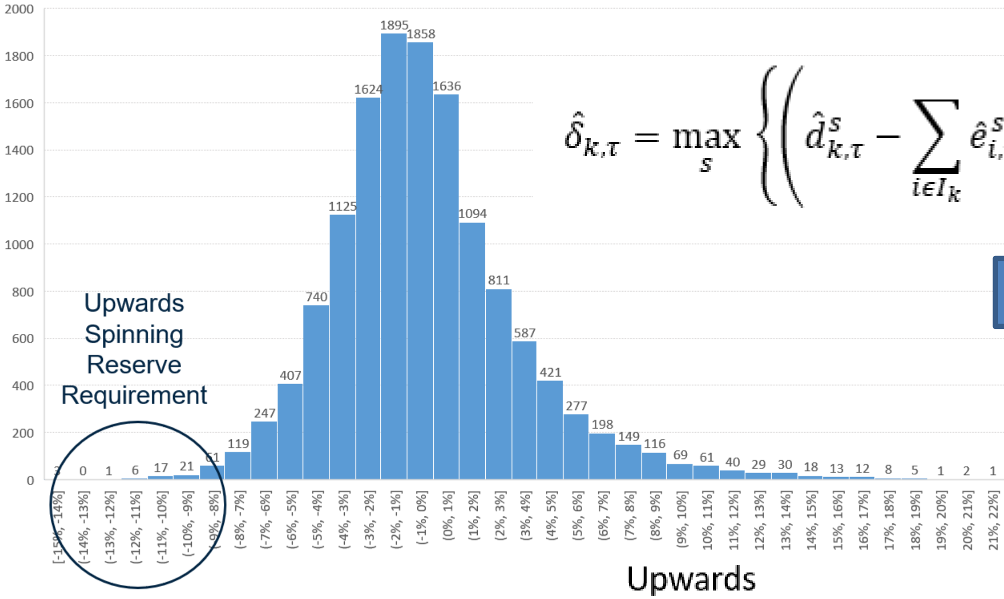
900 MW difference between scheduled and verified



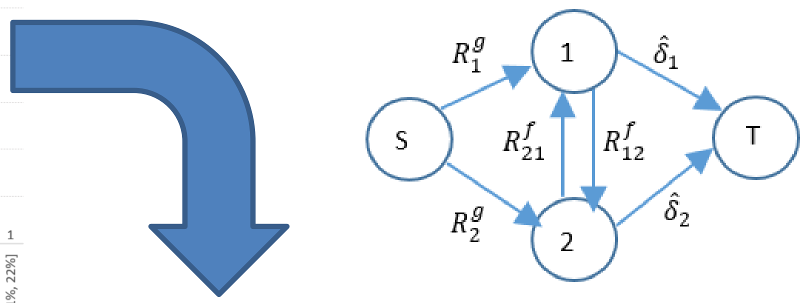
From dromedary to duck



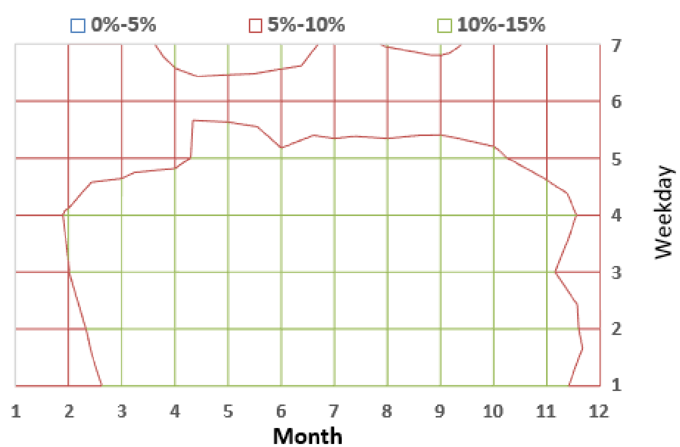
Calculation of Probabilistic Generation Reserves (considering the joint fluctuations of renewables and load)



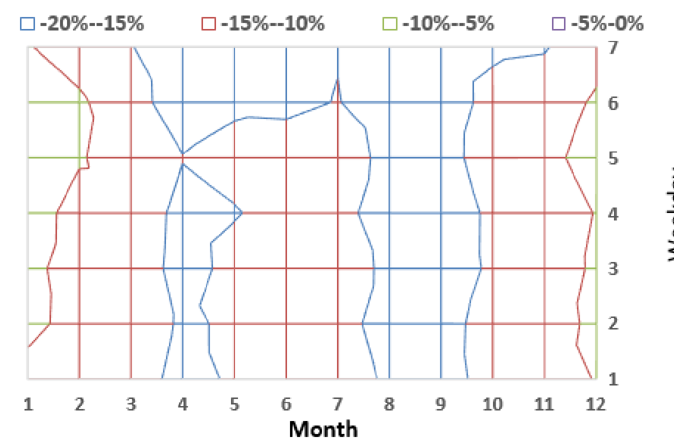
$$\hat{\delta}_{k,\tau} = \max_{s}\left\{\left(\hat{d}^{s}_{k,\tau} - \sum_{i\epsilon I_k} \hat{e}^{s}_{i,\tau}\right) - \left(\hat{d}^{s}_{k,\tau+1} - \sum_{i\epsilon I_k} \hat{e}^{s}_{i,\tau+1}\right)\right\} + \max_{j\epsilon J_k}\left\{\overline{g}_j\right\} \quad \forall k,\tau,l\epsilon\Omega_k$$



Upwards



Downwards

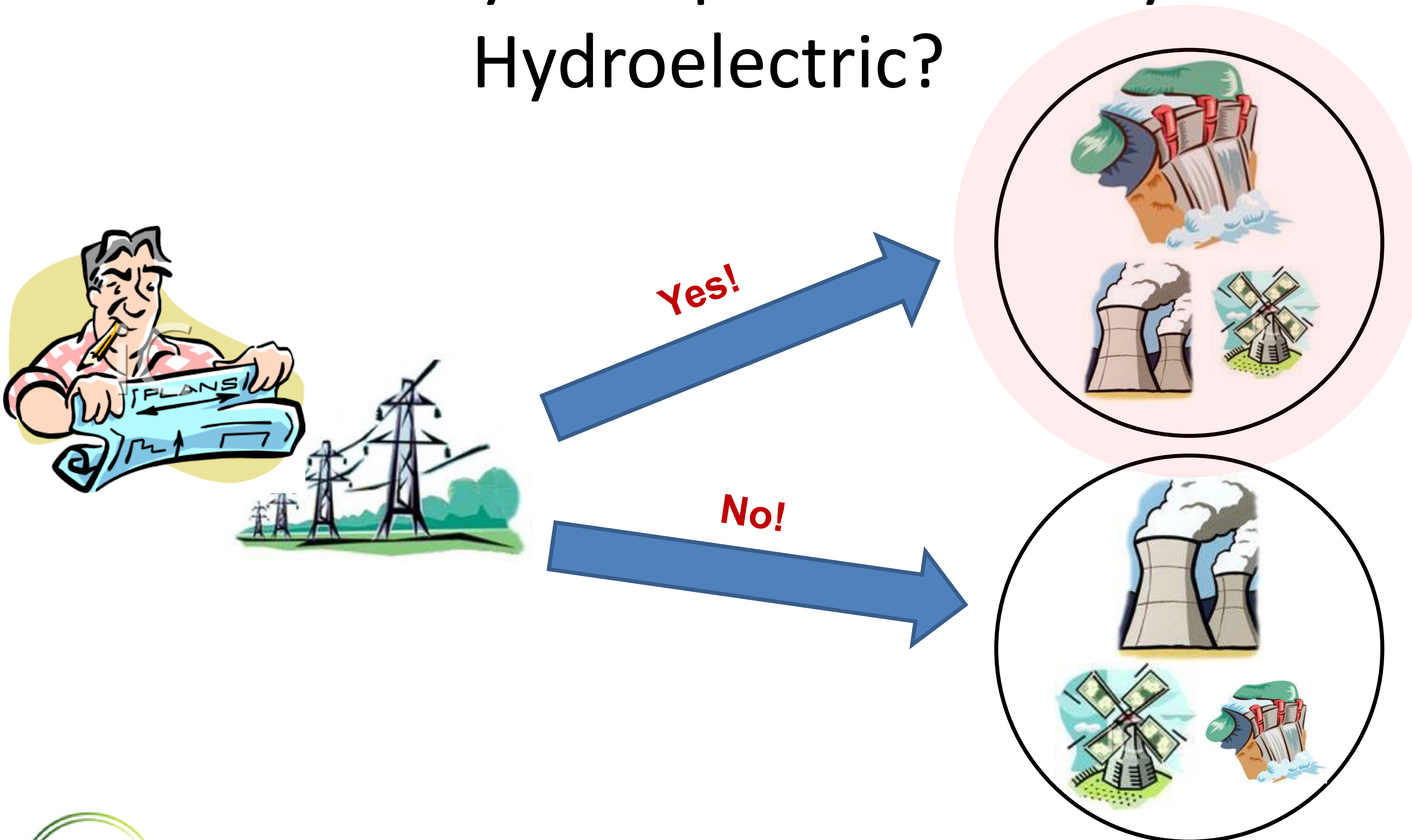


Which approach should be used?

Integrated G&T Planning Approach

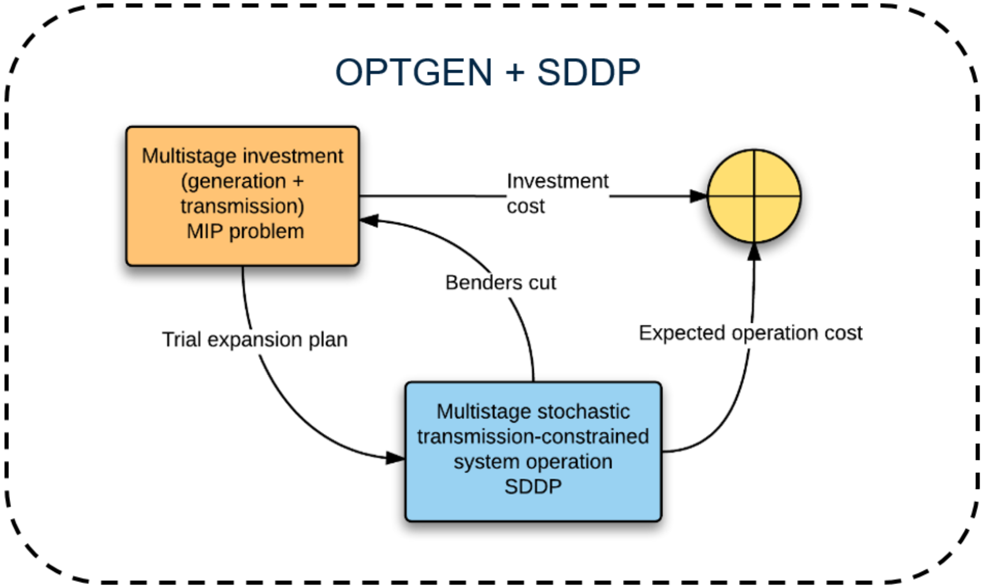
Hierarchical G➔T Planning Approach

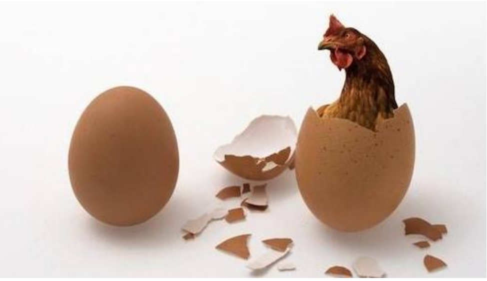
Is the System predominantly Hydroelectric?



Benders-based Joint Generation-transmission-probabilistic Reserve Planning Method

- Two-stage optimization problem solved by a customized Benders decomposition:
  - **First-stage:** investment problem, formulated as a large scale Mixed Integer Linear Programming (MILP) problem;
  - **Second-stage:** operation problem, solved by SDDP.





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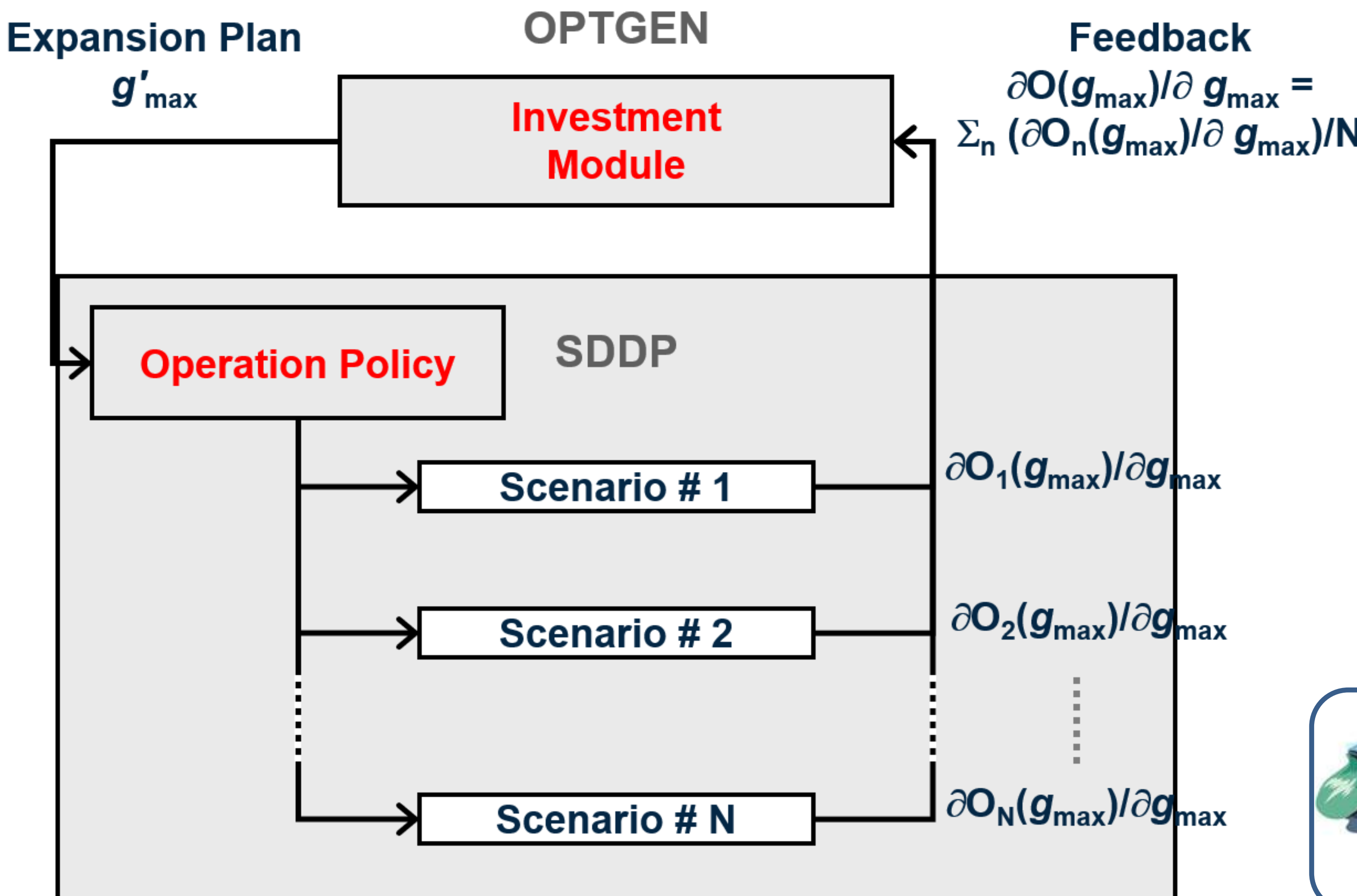

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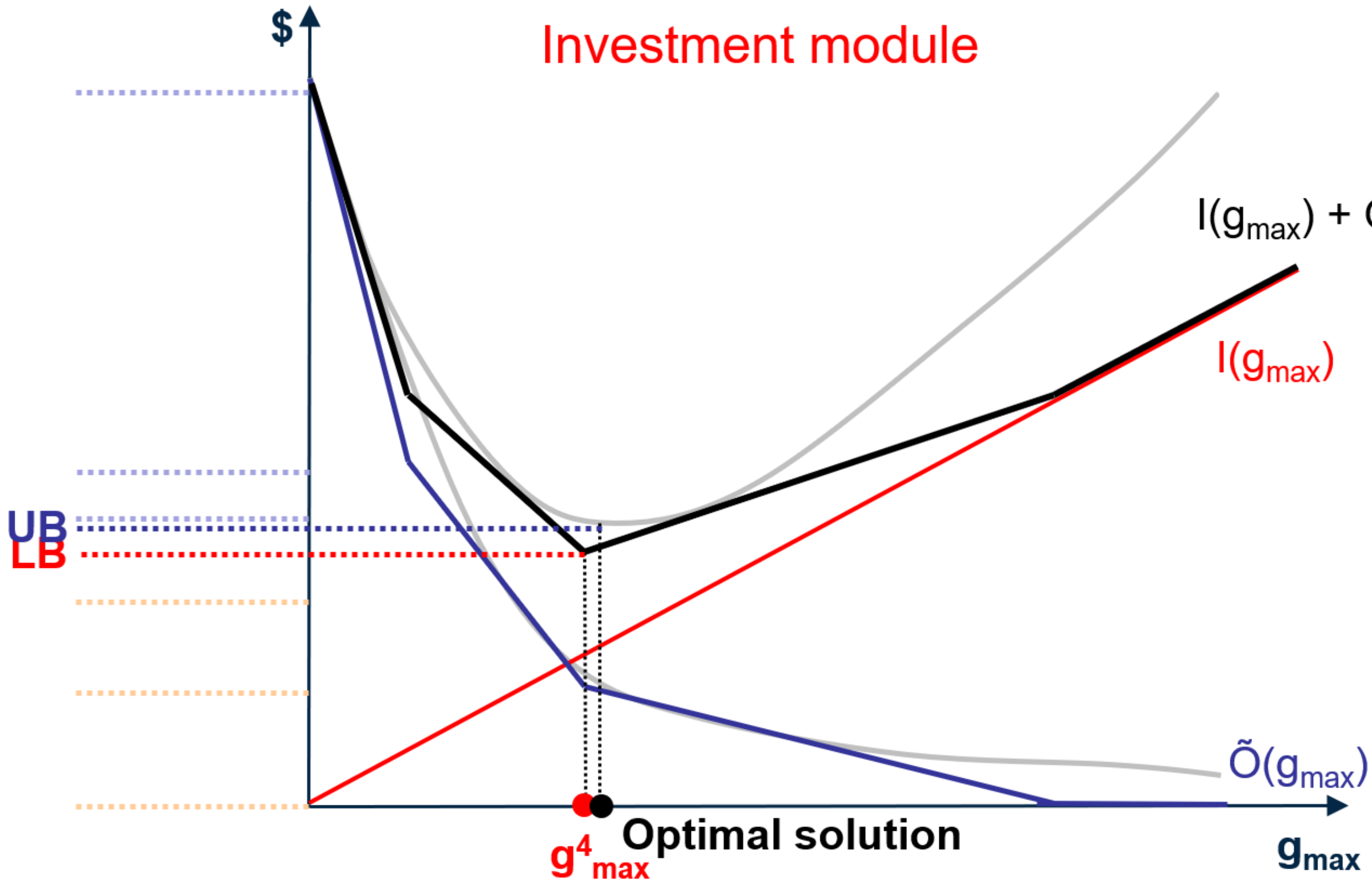
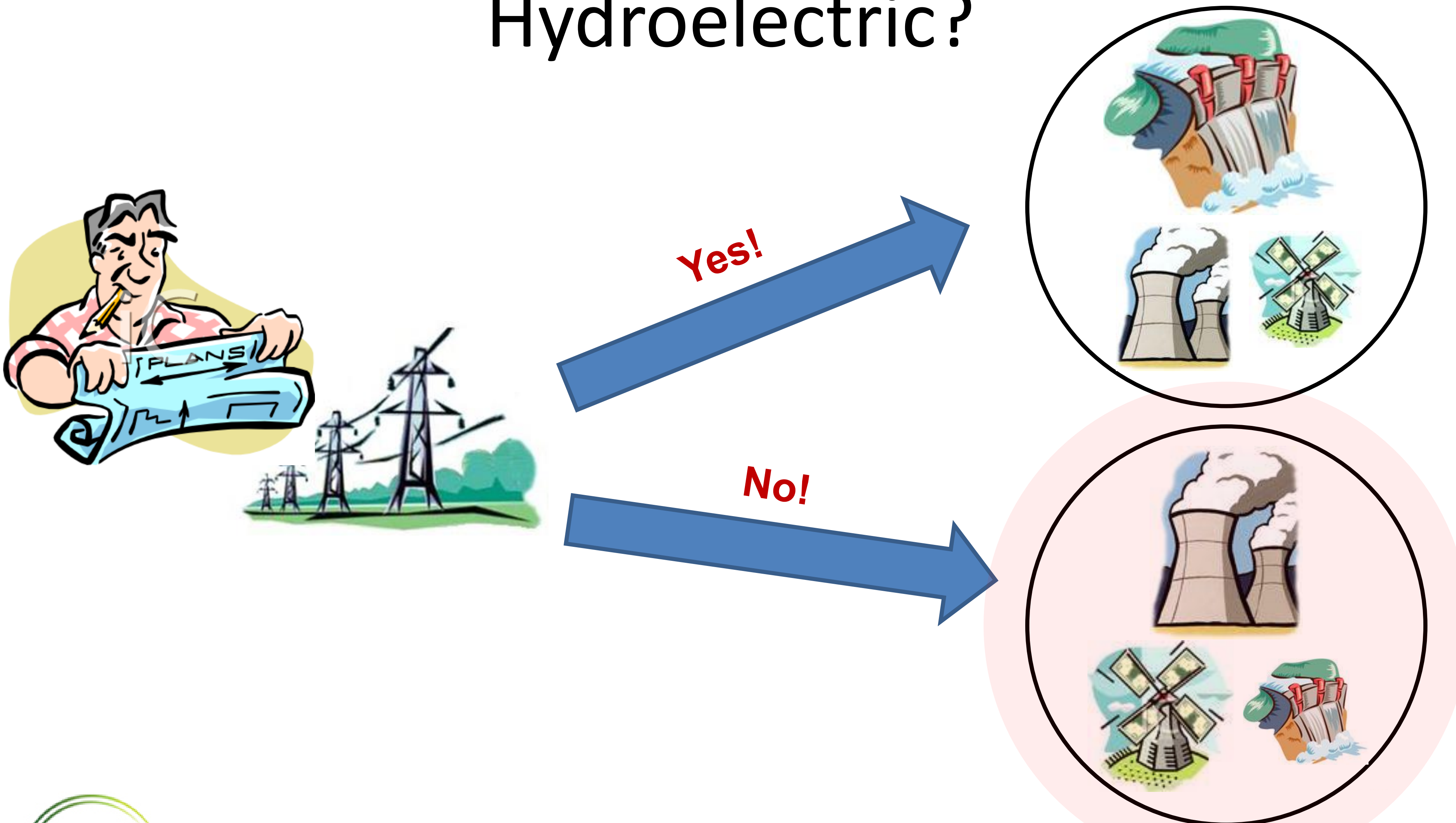
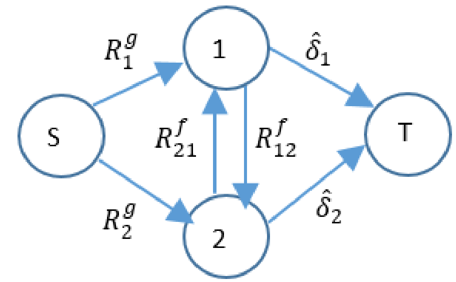


Is the System predominantly Hydroelectric?



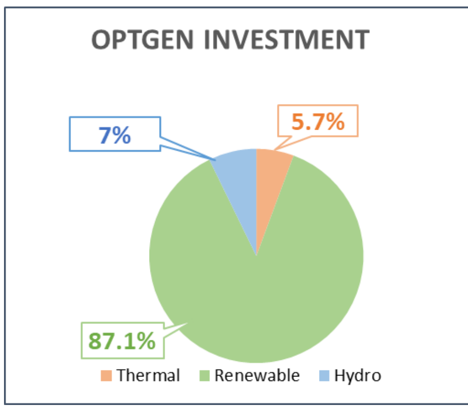
T&R Joint Generation-transmission-probabilistic Reserve Planning Method

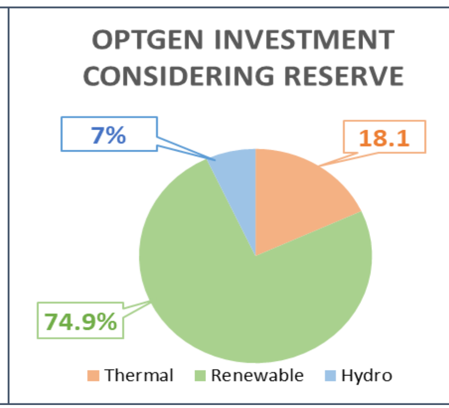
$$Min \sum_{j\in J_x} I_j\, x_j + \sum_{l\in L_x} I_l\, x_l + \sum_{n}\sum_{k} \Delta_k^n \left[\sum_{\tau} \delta_{k\tau}^n \left(\sum_{j\in J} c_j^n\, g_{jk\tau}^n\right)\right]$$

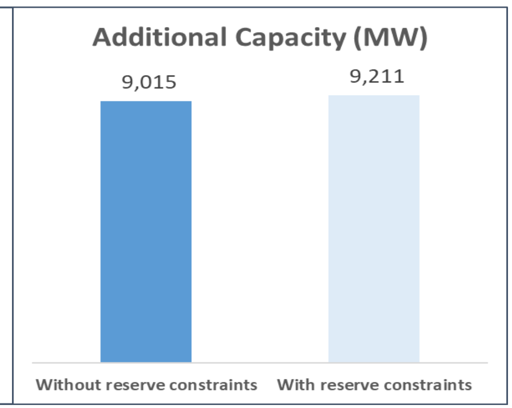


$$\sum_{j\epsilon J_k} g_{j,\tau} - \sum_{l\epsilon\Omega_k} f_{kl,\tau} + \sum_{l\epsilon\Omega_k} f_{lk,\tau} = \hat{d}_{k,\tau} - \sum_{i\epsilon I_k} \hat{e}_{i,\tau} \qquad \forall \tau, k$$

$$\hat{\delta}_{k,\tau} = \max_{s} \left\{\left(\hat{d}_{k,\tau}^s - \sum_{i\epsilon I_k} \hat{e}_{i,\tau}^s\right) - \left(\hat{d}_{k,\tau+1}^s - \sum_{i\epsilon I_k} \hat{e}_{i,\tau+1}^s\right)\right\} + \max_{j\epsilon J_k}\left\{\overline{g}_j\right\} \quad \forall k, \tau, l\epsilon\Omega_k$$







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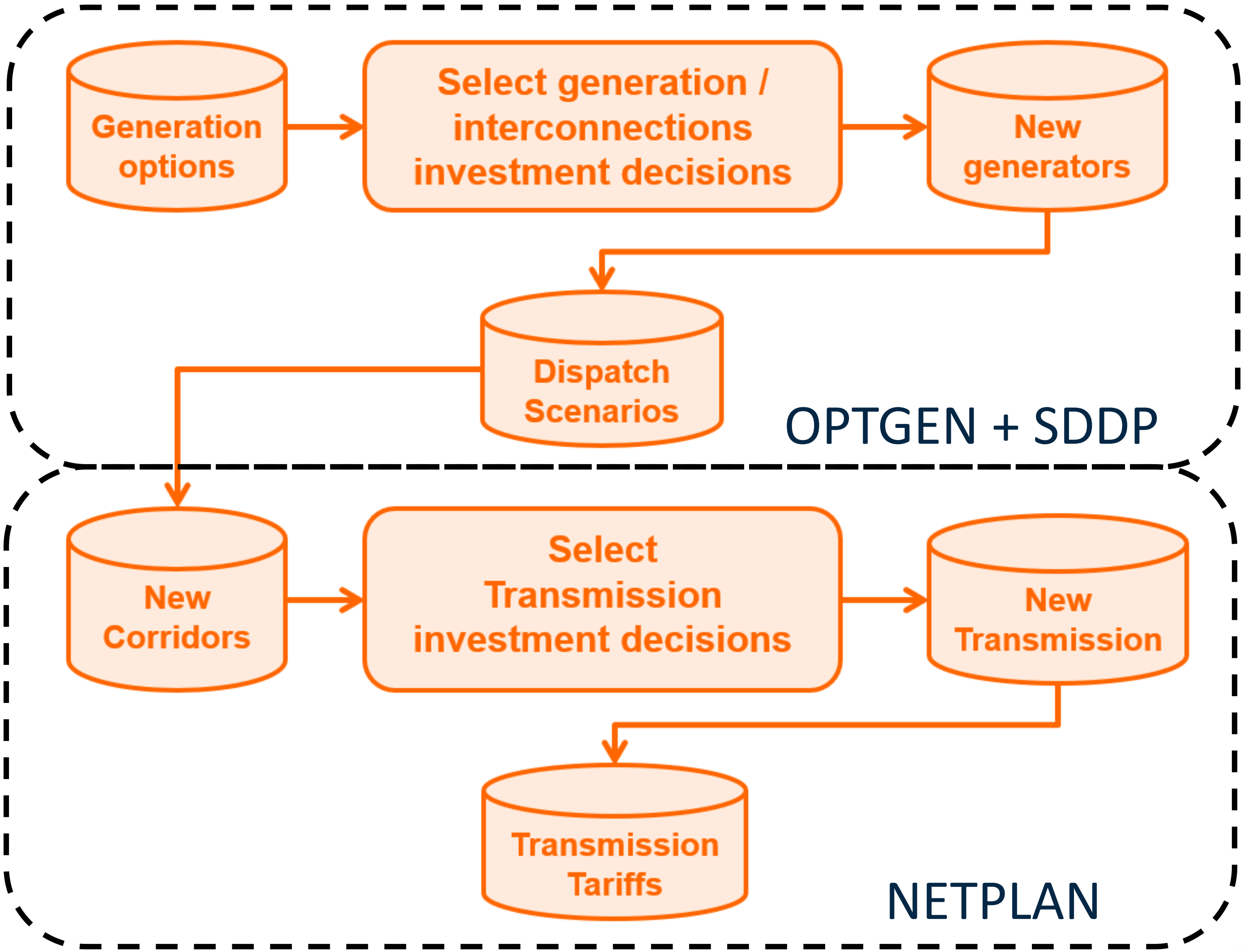
Hierarchical G➔T Planning Approach

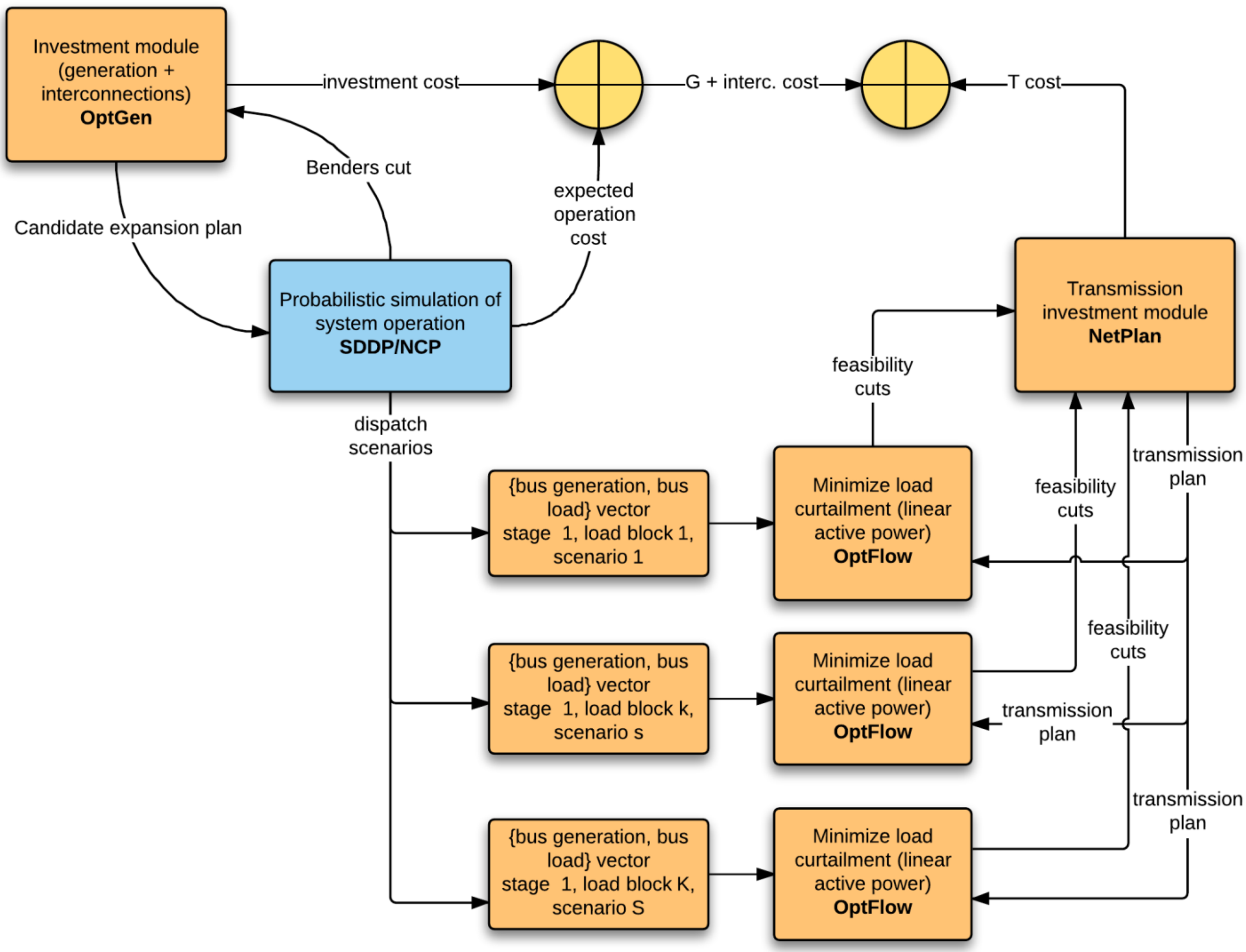
Hierarchical G→T Planning Approach



Hierarchical G→T Planning Approach

- NETPLAN is used in two basic types of planning: (i) hierarchical; and (ii) interactive
- Hierarchical transmission planning scheme:
  1. OPTGEN is initially used to determine the optimal expansion of generation and regional interconnections
  2. A probabilistic simulation of the system operation for the plan produced by OPTGEN is then carried out. This simulation produces a set of *dispatch scenarios* (vectors of bus loads and generation)
     - For example, a simulation with 200 scenarios in monthly steps with five load blocks per month produces 200 x 12 x 5 = **12.000 dispatch scenarios per year!**
  3. The NETPLAN transmission planning module is then applied to determine a robust least-cost expansion plan, i.e., that does not lead to overloads in any dispatch scenario:
     - The optimization technique is based on Benders decomposition with feasibility cuts. An initial step with a heuristic "greedy" algorithm is used to determine an initial feasible solution and a set of strong Benders cuts.

Hierarchical G→T Planning Approach



Application Example: Central America

Transmission System	
Num. of Buses:	**1980**
< 69 kV	1291
69 kV	283
115 kV	74
138 kV	151
230 kV	179
400 kV	2
Num of Circuits:	**2075**
Interconnections	13
Lines	920
Transformers	1142

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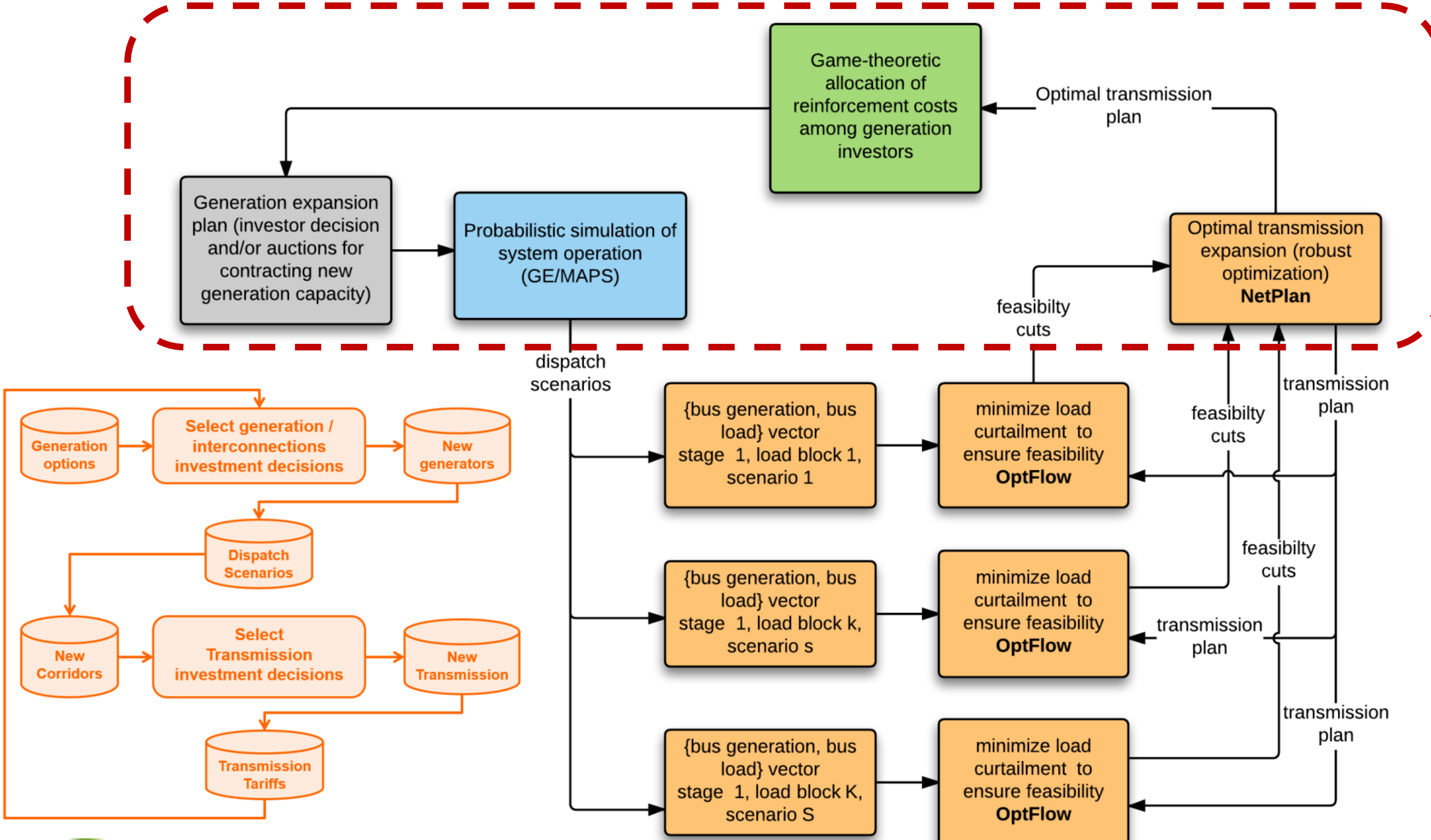
Application Example: 9 countries!

Interactive Transmission Planning

- In the interactive scheme, the generation expansion and dispatch scenarios are provided as an input data, not calculated by OptGen. This corresponds to situations where investors freely decide on new generation capacity, or generation is contracted through auctions;
- As will be shown, the transmission planning model NetPlan is used in a similar way as in the hierarchical planning (robust least-cost transmission plan for the dispatch scenarios). However, it becomes necessary to send a *feedback* to the generation investors, which are the transmission charges that will be applied in case they go ahead with the generation construction;
- The following diagram illustrates the interactive transmission planning scheme that was developed for WECC. PSR developed both the transmission planning module (essentially NetPlan) and the transmission tariff calculation module, based on game theory (Aumann-Shapley).

Interactive Transmission Planning



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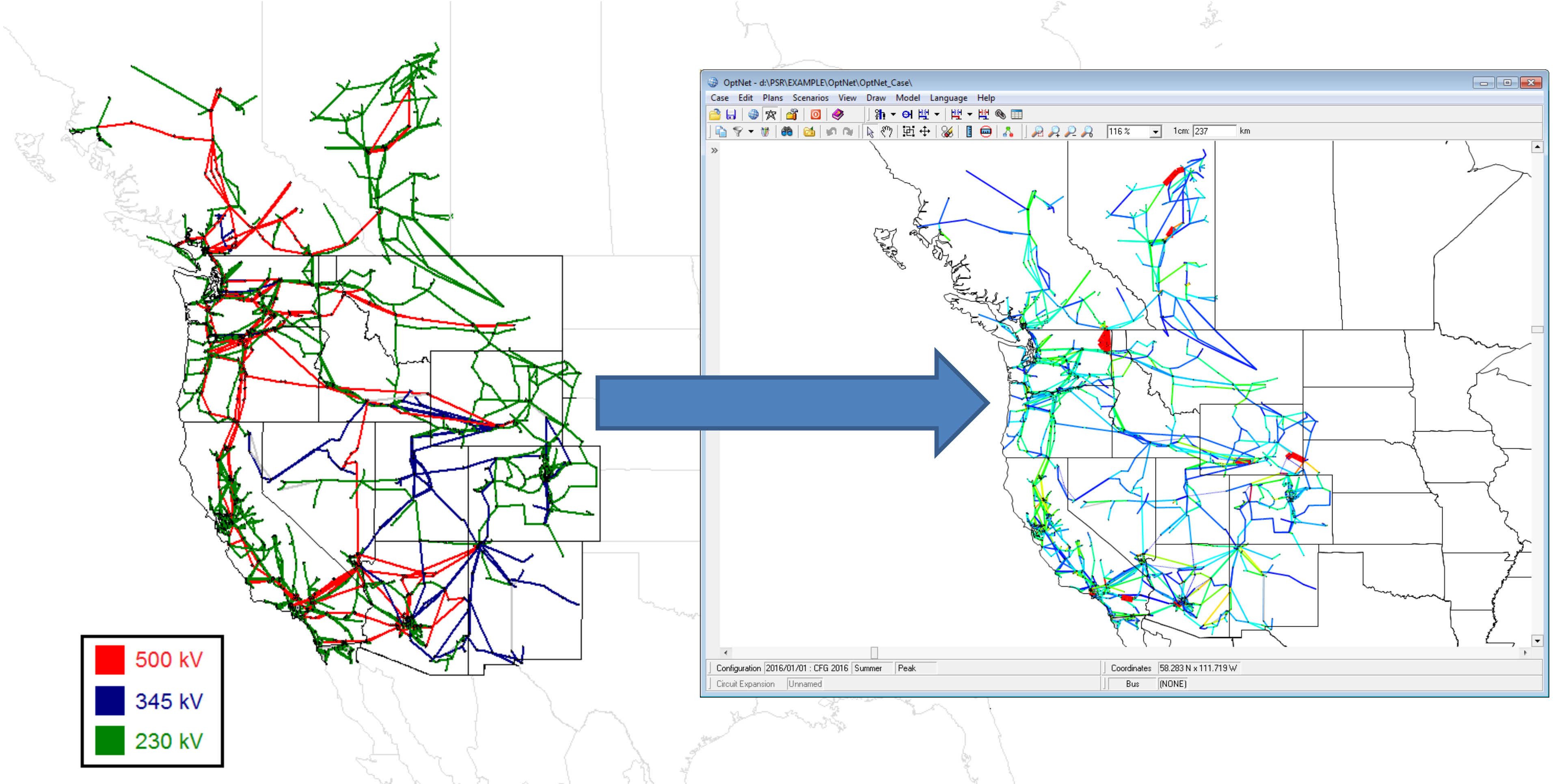
Application Example: WECC

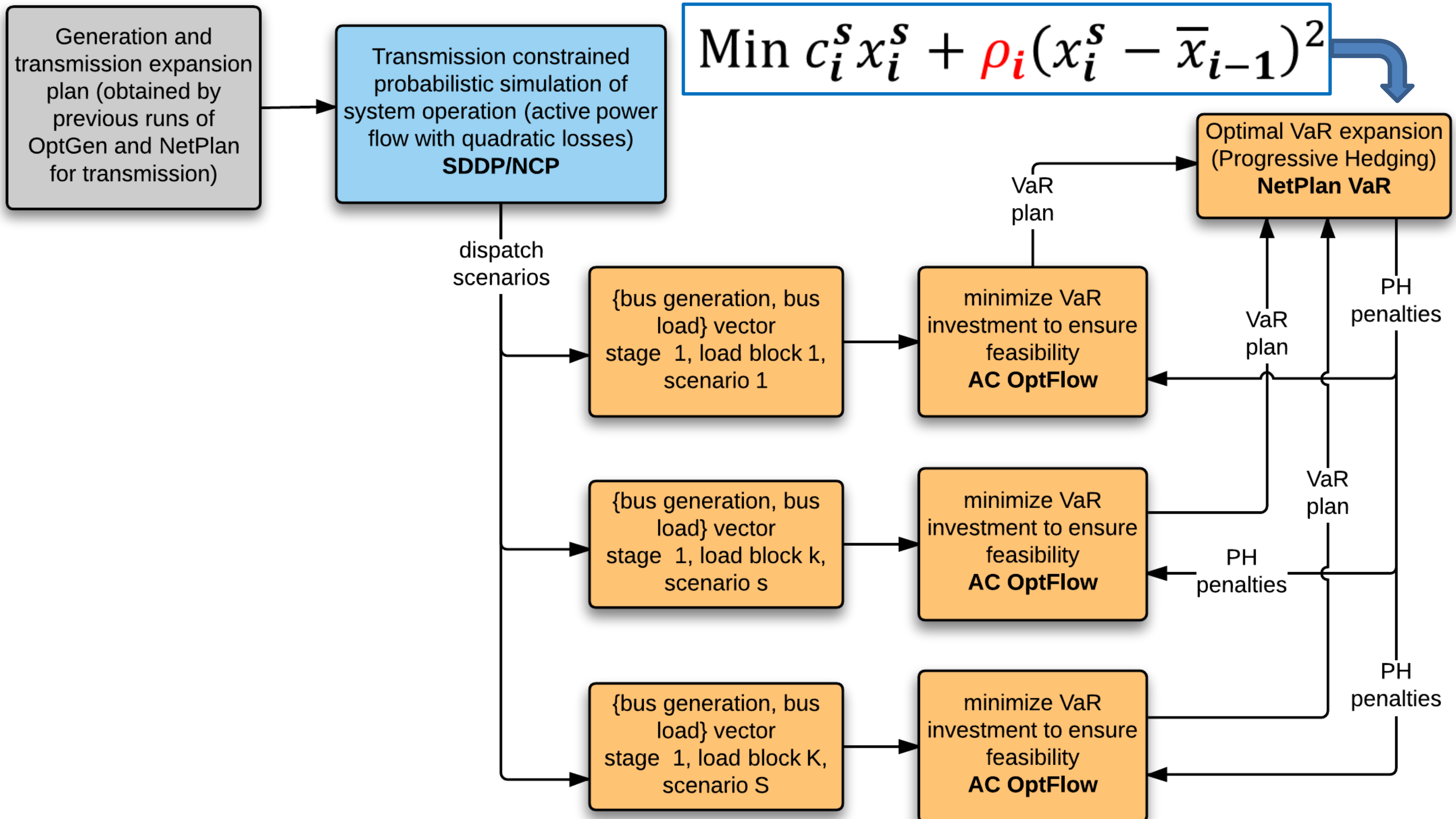


Optimal VAr Planning

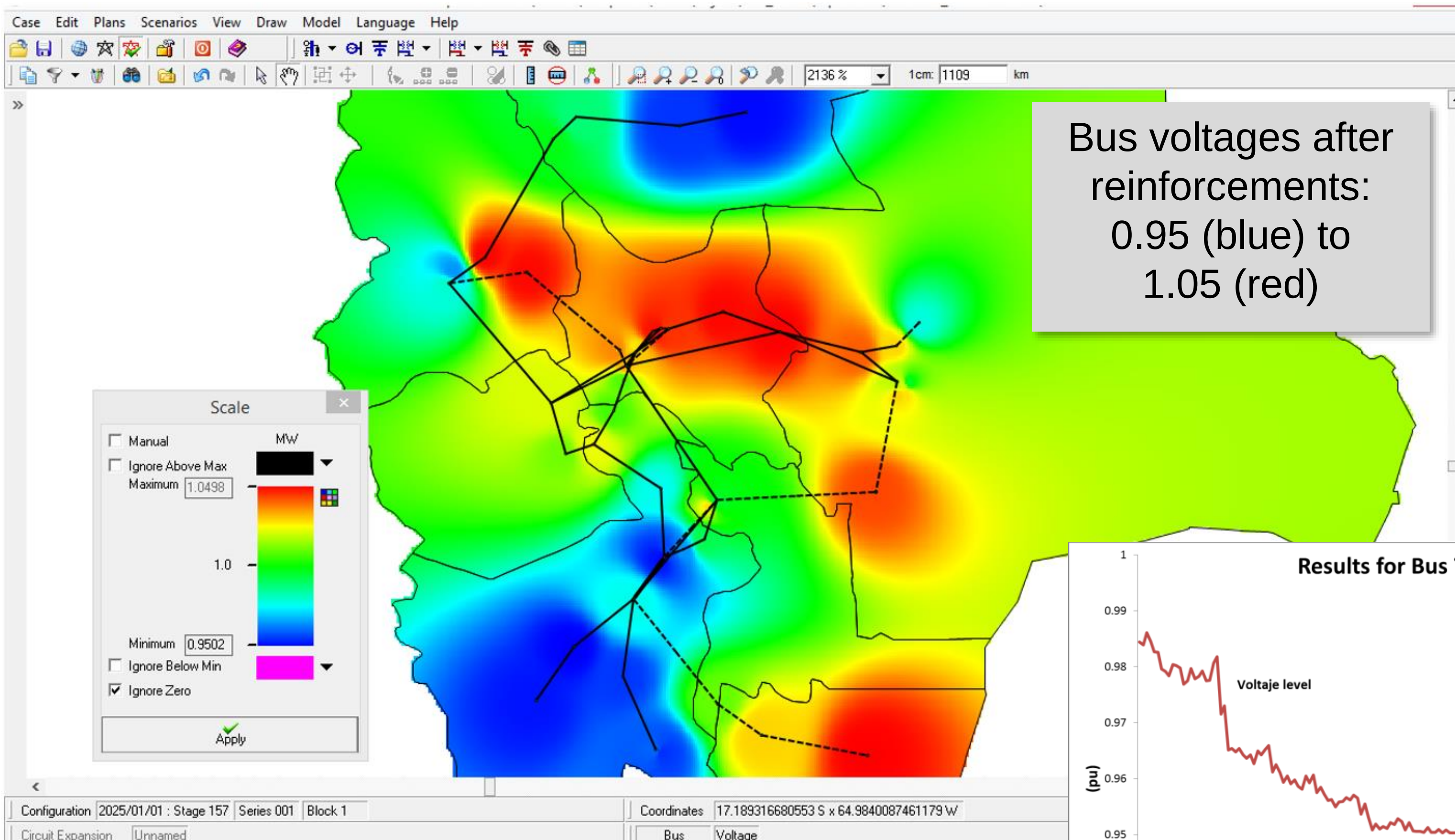
- The VAr planning model is executed after the transmission planning model
- The planning scheme is also based on a set of dispatch scenarios, produced by a probabilistic transmission-constrained simulation of system operation:
  - In this case, the simulation assumes that the transmission reinforcements have been implemented and uses a linearized optimal power flow model with quadratic losses.
- The optimal Var plan is obtained by a progressive hedging (PH) algorithm
  - Each dispatch scenario is evaluated by a full AC optimal power flow model, where the objective is to minimize investment costs in VaR resources (capacitors, reactors) that eliminate operating violations (typically bus voltage limits) + a quadratic term associated to the PH scheme

Optimal VAr Planning

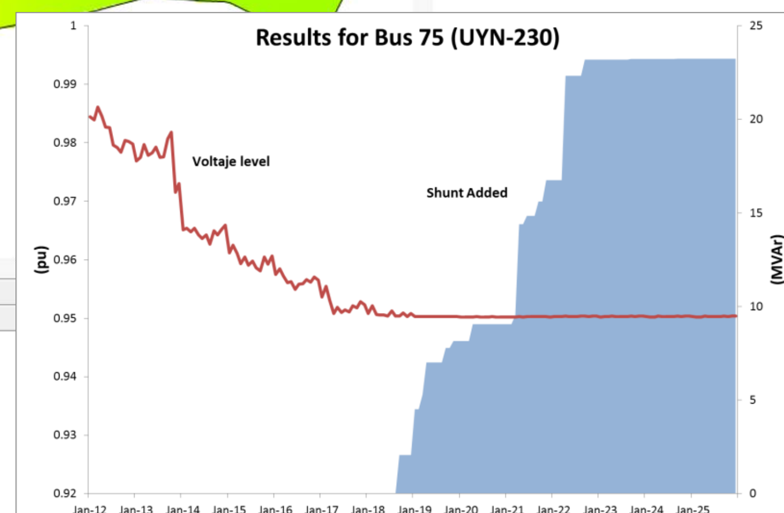
$$\text{Min } c_i^s x_i^s + \rho_i (x_i^s - \bar{x}_{i-1})^2$$



Application Example: Bolivia



Bus voltages after reinforcements: 0.95 (blue) to 1.05 (red)



Conclusions

- When the system is predominantly hydro, the optimum solution using the average values is always optimistic in comparison to the expected value that comes from the real stochastic simulation → optimal operating policy → Benders-based two-stage approach;
- The integrated G&T approach (generation, transmission and reserve co-optimization) obviously reduces the total costs;
- On the other hand, there are situations in which it is better to use a hierarchical approach, instead of an overall optimization scheme → multi-country, country's regulation, combinatorial nature of the G&T problem, and so on.
- Due to the stochastic nature ad the spatial correlation of inflows and wind → system's expansion planning and operation must take advantage of the regional portfolio effect in order to co-optimize dispatch and reserve margins in order to reduce operating costs;
- "Energy" & "Power" offices need to interact further!

Questions? Thanks!

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