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Electric-Gas Co-optimization in the Optimal Generation Expansion Plan Determination of a Multi-country System

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ELAEE
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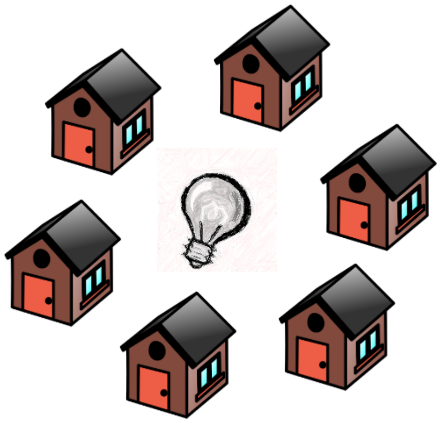
Our team has 54 experts (17 PhDs, 31 MSc) in engineering, optimization, energy systems, statistics, finance, regulation, IT and environmental analysis

Outline

- Electrical System Expansion Overview
- The Proposed Solution
- Study Case: Central America
- Conclusions

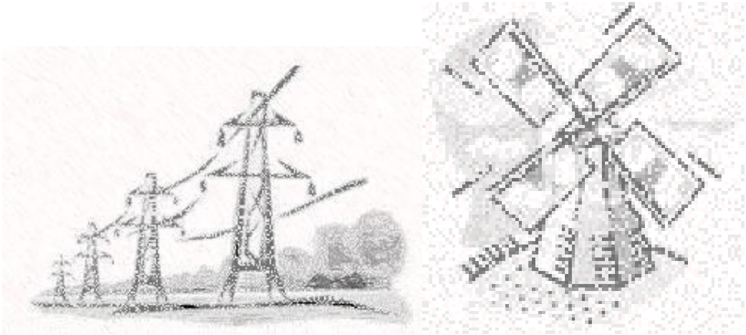
Electrical system expansion

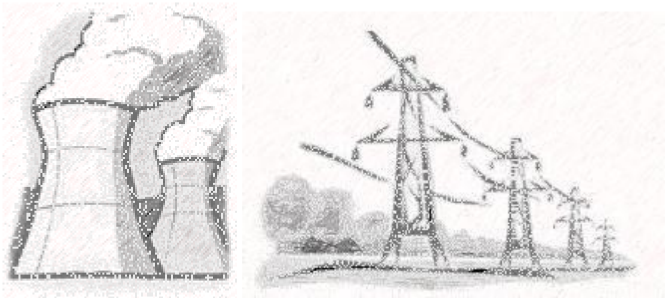
- The origin of the expansion problem of electrical systems resides on the need for new investments in generation and transmission systems required to face the demand growth and meet planning criteria



Electrical system expansion

- Selecting the “best” of a group of alternatives is what characterizes the **combinatorial** nature of this problem





Electrical system expansion

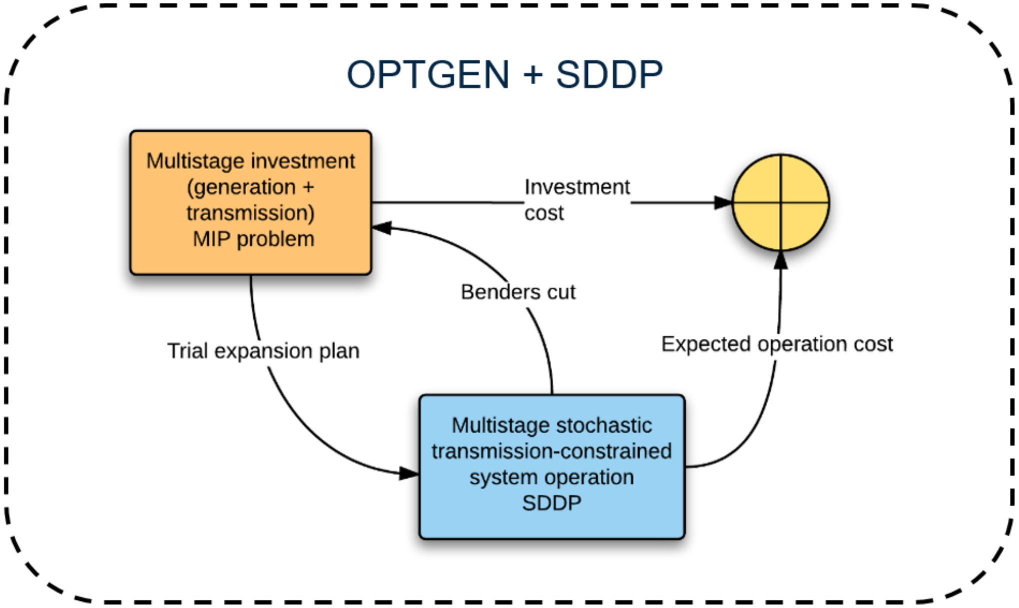
- The optimality of the expansion plan means minimizing a cost function considering: (i) investment (capital) and operation (fuel, O&M, etc.) costs of generation plants and (ii) penalties for energy not supplied, also called deficit costs
- In addition, the Generation Expansion Planning (GEP) task must meet both economic and environmental criteria, within a framework of national energy policies
- A key issue of the GEP methodology is how to deal with the uncertainties inherent to the planning process (load growth, renewable generation, fuel prices, etc)

Electrical system expansion

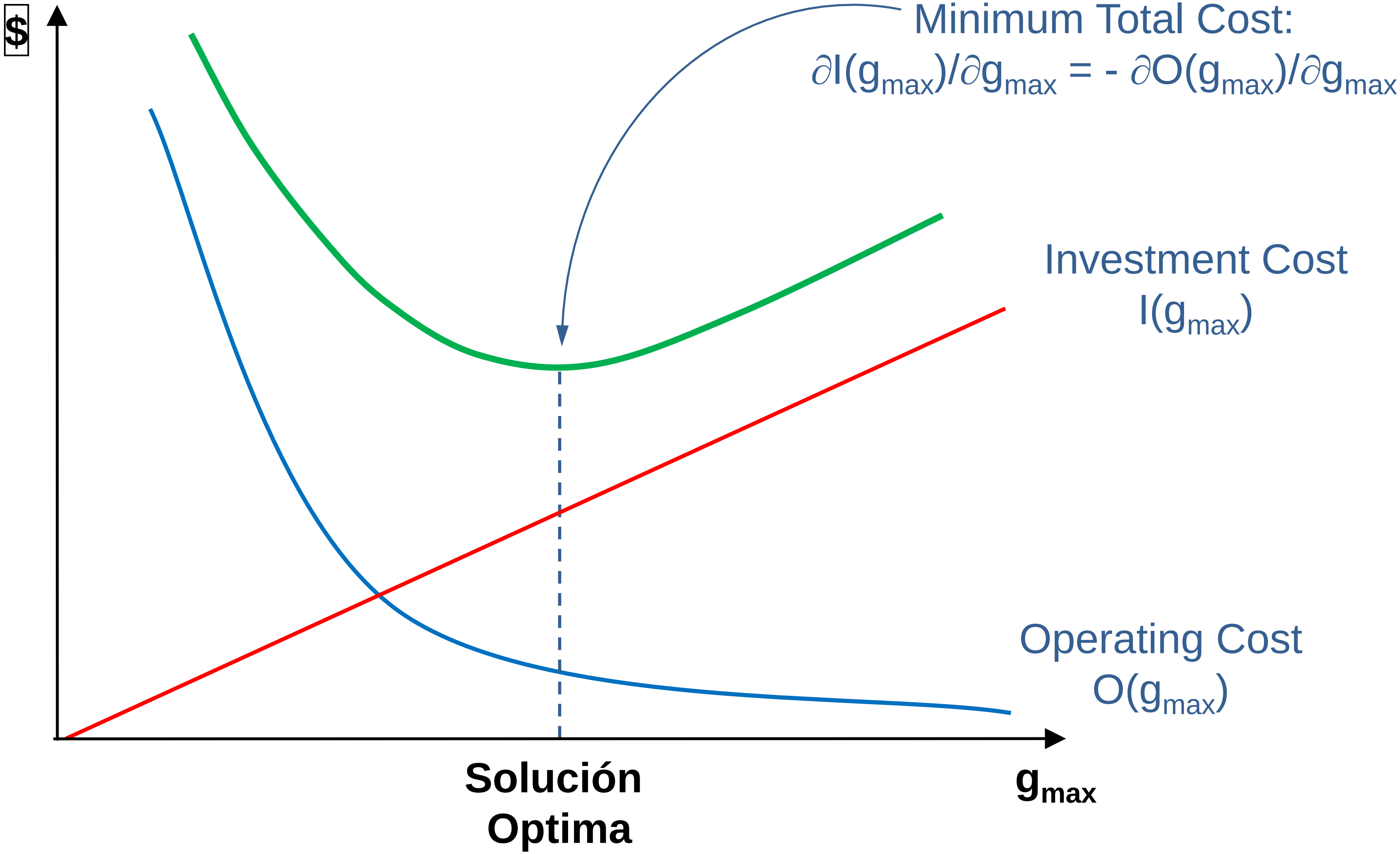
- The GEP task becomes even more complex when decisions regarding integration with other sectors interfere in the decision-making process – such as:
  - Considering the joint optimization of multiple countries;
  - Electric-Gas Co-optimization
- In the second case, because the decision to build a new gas-fired thermal power plant will depend on the gas availability and delivery, an integrated gas-electricity model is needed. The integrated co-optimization allows the model to calculate trade-offs between gas investment and operating costs against other alternatives.

The GEP Task – Solution 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



The GEP Task – Solution method



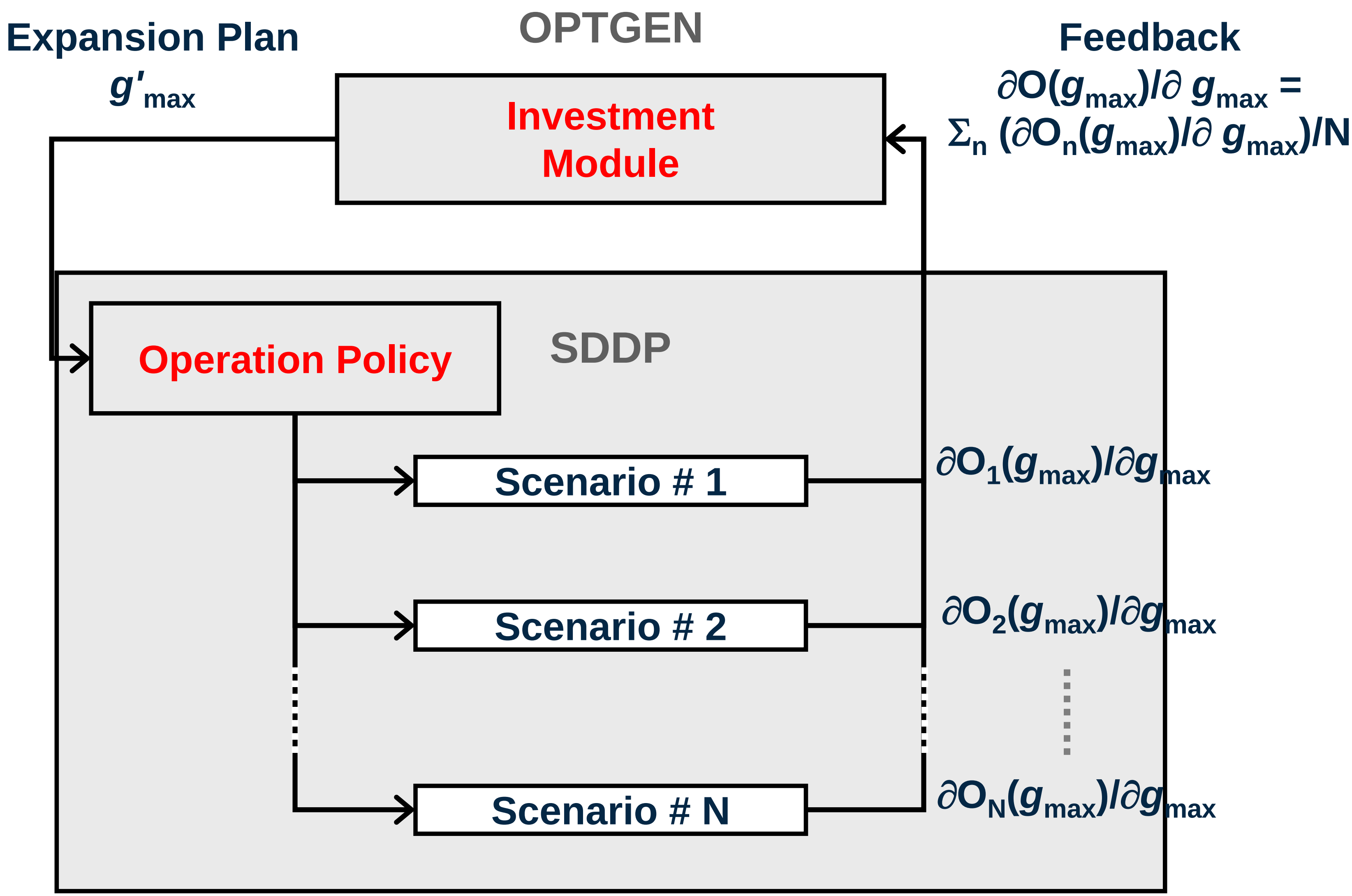
The GEP Task – Plants and system modeling

- Candidate projects
  - Production components: Hydro, Thermal and Renewable plants
  - Interconnection links and transmission circuits (lines, transformers, etc.)
  - Gas pipelines, production nodes, regasification stations
- Additional input data (for investment decision)
  - Investment costs
  - Investment timeframe windows
  - Relational constraints (association, precedence, exclusivity)
  - Budgetary constraints
  - Firm energy and capacity constraints

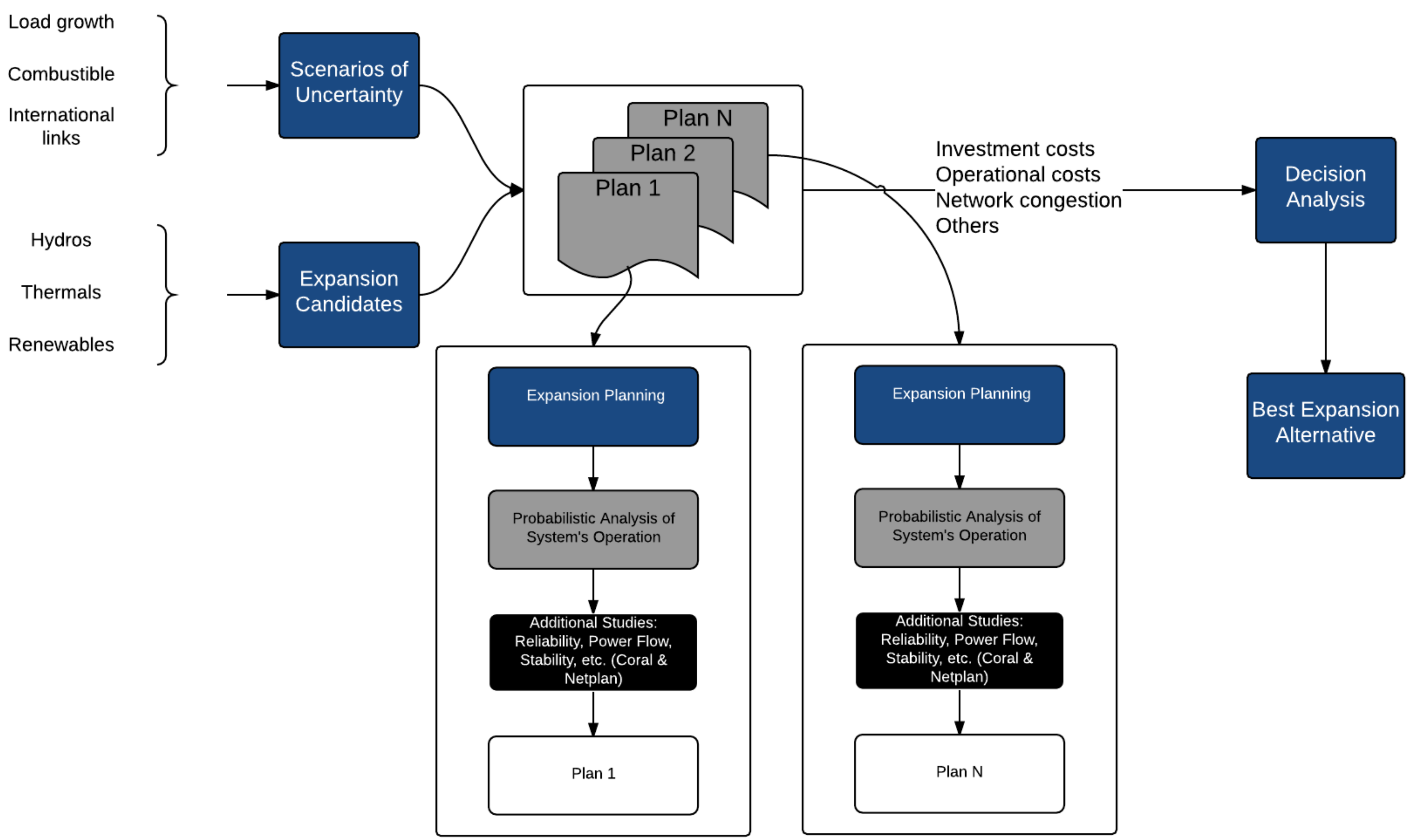
The GEP Task – Plants and system modeling

- The least-cost GEP is achieved by optimizing the trade-off between investment costs to build new projects and the expected value of operative costs obtained from the stochastic hydrothermal dispatch model, which allows a detailed representation of the electric-gas system's operation under uncertainty
- SDDP is used as the operation planning module

Optgen + SDDP as operation module



Expansion Planning under Uncertainty, Process Flow



OPTDEC – An Overview of the Process Flow

- The process flow is divided in four main tasks and is described as follows:
  - **Task 1:** Determining expansion alternatives through OptGen/SDDP, i.e., optimal expansion plans according to different user-defined assumptions
  - **Task 2:** Testing the expansion alternatives in different future scenarios in order to model the uncertainties in assessing the long-term plan.
  - **Task 3:** Defining attributes to compare the expansion alternatives
  - **Task 4:** Comparing the expansion alternatives through their attributes and determining the final expansion plan.

G&T System Planning

More than 300 active licenses worldwide

ePSR

Comporate environment (GUI + DB)

OptGen
- Long-term generation expansion planning

NetPlan
- Power flow analysis
- Transmission expansion planning

SDDP / NCP / CORAL
- stochastic production scheduling
- Short-term dispatch

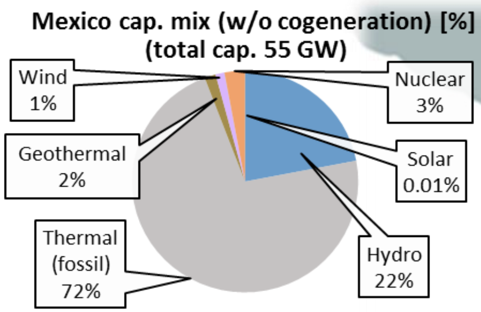
OptDec
- Analysis of expansion alternatives under uncertainty

CLIENT
Systems and Tools

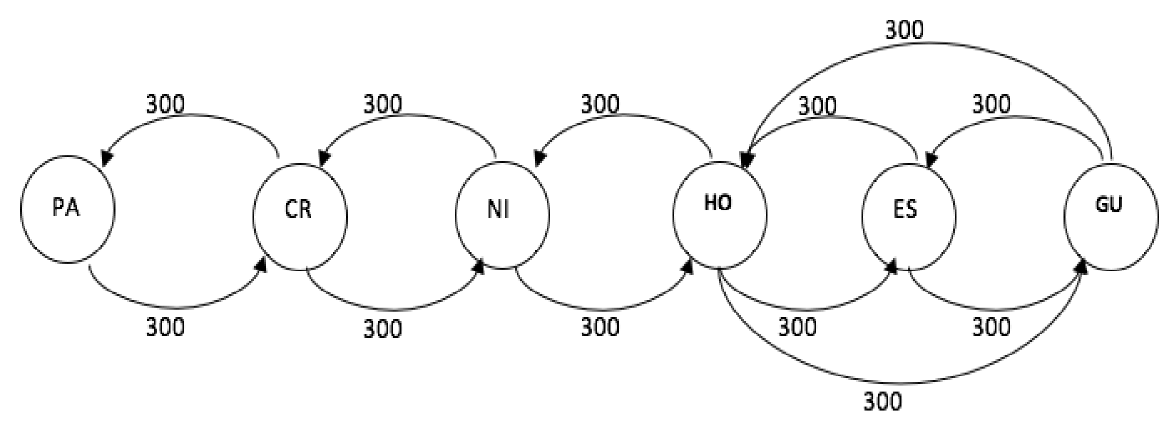
Web Services (XML) & CSV Files

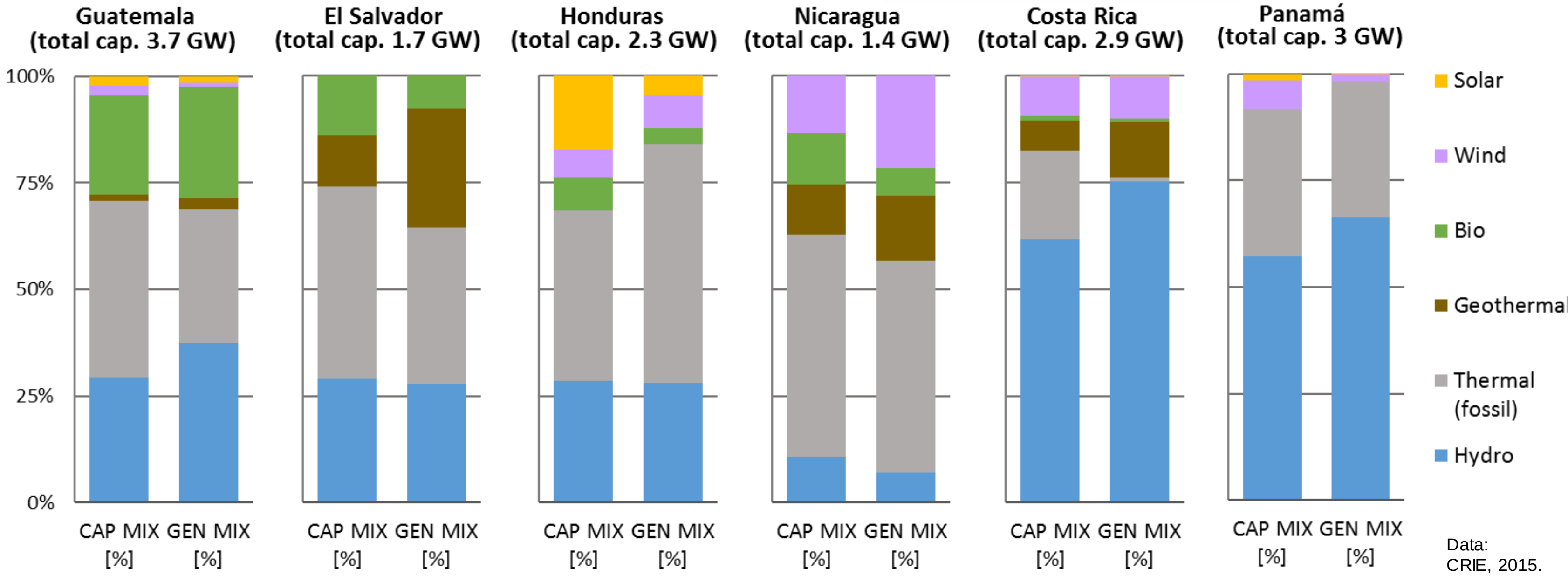
All models optimize complex systems taking into account thermal and renewable production, transmission networks, price-responsive loads, gas pipelines and fuel storage

Study Case: Central America



Data: SENER, 2016.





Data: CRIE, 2015.

Study Case: 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

Study Case: Central America

Study parameters

- Horizon: 2016-2025
- 180 candidate projects

Plant Type	Costa Rica		El Salvador		Guatemala		Honduras		Nicaragua		Panama	
	Num.	Total Cap. (MW)	Num.	Total Cap. (MW)	Num.	Total Cap. (MW)	Num.	Total Cap. (MW)	Num.	Total Cap. (MW)	Num.	Total Cap. (MW)
Hydro	3	709	3	397	1	60	7	911	10	767	11	354
Diesel	6	700	6	700	6	700	6	700	6	700	6	700
Coal	6	1800	6	1800	6	1800	6	1800	6	1800	6	1800
Bunker	2	200	2	200	2	200	2	200	2	200	2	200
Natural Gas	2	1000	3	1000	3	1000	3	1000	3	1000	5	1310
Geothermal	2	110	1	30	3	77	0	0	8	230	0	0
Wind	3	300	3	300	0	0	5	395	4	320	7	416
Solar	0	0	0	0	0	0	0	0	0	0	0	0
Biomass	0	0	0	0	0	0	0	0	1	30	0	0
Total	24	4819	24	4427	21	3837	29	5006	40	5047	37	4780

Evaluated Expansion Plans

- Seven expansion alternatives were evaluated with the OptGen model, considering the following assumptions:
  - A) Base Case
  - B) A + High Efficiency LNG CC TPPs (with regas projects)
  - C) Investment Costs based on the WACC of each Country
  - D) C + High Efficiency LNG CC TPPs (with regas projects)
  - E) Without Regional Interconnection Projects
  - F) Without Regional Plants and Regional Interconnection Projects

Comparison of the Expansion Plans – Uncertanties

- After determining seven different expansion plans, the operation of each one is performed considering different scenarios in order to model the uncertainty in assessing the long-term plan.
- Each different scenario is defined as a possible “future”.

Comparison of the Expansion Plans – Uncertanties

Possible Futures that were taken into account:

- **Future 1:** EIA's Fuel Price Forecast / Reference Load Growth / Central American WACC
- **Future 2:** EIA's Fuel Price Forecast / Higher Growth Rate of the Demand (+ 10%) / Central American WACC
- **Future 3:** EIA's Fuel Price Forecast / Transmission Line with Colombia / Central American WACC
- **Future 4:** WB's Fuel Price Forecast / Central American WACC
- **Future 5:** EIA's Fuel Price Forecast / Reference Load Growth / "Country's WACC"
- **Future 6:** EIA's Fuel Price Forecast / Reference Load Growth / Central American WACC / Investment Costs in Hydroelectric Projects 30% Higher
- **Future 7:** EIA's Fuel Price Forecast / Reference Load Growth / Central American WACC / 25% Price Reduction on oil derived products and natural gas and 10% reduction in coal prices.

Comparison of the Expansion Plans – Uncertanties

Evaluation Criteria:

- Investment Costs + Thermal Operating Costs + Deficit Costs [M US$]
- The evaluation is performed using the expected value and the minimization of the maximum regret (Savage criterion).

The Expected Value Approach

	Investment Costs + Thermal Operating Costs + Deficit Costs [M US$]									
		Central American WACC				Country's WACC	Central American WACC		Expected Value	
			EIA		WB		EIA			
Exp. Plans	Inv. Costs [M US$]	Ref. Dem. 1	Dem. 1.1 2	With CO 3	Ref. Dem. 4	Ref. Dem. 5	Ref. Dem. 6	Ref. Dem. 7	Total Cost	[%]
A	1986	11301	12547	10913	11421	11437	11532	9778	11275	101.5%
B	1790	11148	12374	10749	11253	11307	11380	9548	11108	100.0%
C	2222	11287	12497	11020	11395	11257	11526	9852	11262	101.4%
D	1939	11222	12383	10875	11296	11227	11460	9636	11157	100.4%
E	1777	11342	12689	10986	11452	11480	11542	9775	11324	101.9%
F	2222	11617	12902	11204	11732	11733	11782	10098	11581	104.3%

Observations:

(1) The values highlighted in orange represent the best solution for each scenario (lowest total cost).

(2) The values highlighted in green represent the best solution under the approach that seeks to minimize the average value of the total costs (Investment + Operation + Deficit).

Min-Max Regret Approach

		Regrets for the Considered Future Scenarios [M US$]							
			Central American WACC			Country's WACC	Central American WACC		
			EIA		WB		EIA		
	Inv. Costs	Ref. Dem.	Dem. 1.1	With CO	Ref. Dem.	Ref. Dem.	Ref. Dem.	Ref. Dem.	
Exp. Plans	[M US$]	1	2	3	4	5	6	7	Max. Regret
A	1986	153	172	164	168	210	153	230	230
B	1790	0	0	0	0	80	0	0	80
C	2222	139	123	271	142	31	146	304	304
D	1939	73	8	126	43	0	80	89	126
E	1777	194	315	237	199	253	162	227	315
F	2222	469	528	455	479	507	402	550	550

Observation:

The values highlighted in green represent the best solution under the approach that minimizes the maximum regret, where regret is defined as the difference of the total cost on a scenario and the lowest total cost for the scenario.

Final Expansion Plan

Date	Diesel	Carbon	Natural Gas	Hydro	Wind	Solar	Geo	Bio	Interconnection
	(MW)	(MW)	(MW)	(MW)	(MW)	(MW)	(MW)	(MW)	(MW)
01/2019	-	-	-	419.70	136.00	-	107.00	-	1,800.00
01/2020	-	-	-	241.20	-	-	-	30.00	-
01/2021	-	-	-	-	95.00	-	20.00	-	-
01/2022	- 255.86	-	1,310.02	471.70	-	-	-	-	-
01/2023	-	-	-	-	100.00	-	210.00	-	-
01/2024	-	-	-	-	200.00	-	-	-	-
01/2025	-	-	-	98.19	200.00	-	-	-	-

	Load Marginal Costs [$/MWh]					
Date	Panama	Costa Rica	Nicaragua	Honduras	El Salvador	Guatemala
2016	85	83	118	115	117	113
2017	86	83	110	107	109	106
2018	101	98	109	106	106	103
2019	104	103	104	102	101	100
2020	116	115	116	113	112	111
2021	123	122	122	120	118	117
2022	105	107	106	104	105	102
2023	107	107	106	104	105	103
2024	116	117	114	112	113	110
2025	126	127	124	121	122	119

Conclusions

- When there are hydro candidate projects, as the policy changes according to the constructed plan, OPTGEN's two-stage approach calculates the optimal operating policy related to each candidate expansion plan representing the future uncertainties in the decision making process
- The GEP task needs to evaluate the trade-off between CAPEX + OPEX, taking different generation technologies and interconnections into account
- As illustrated, the Electric-Gas Co-optimization in the Optimal Generation Expansion Plan Determination may also be contemplated

THANKS!

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