PSR

A Julia/JuMP based Integrated Energy Resource Planning Model

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Quick Introduction

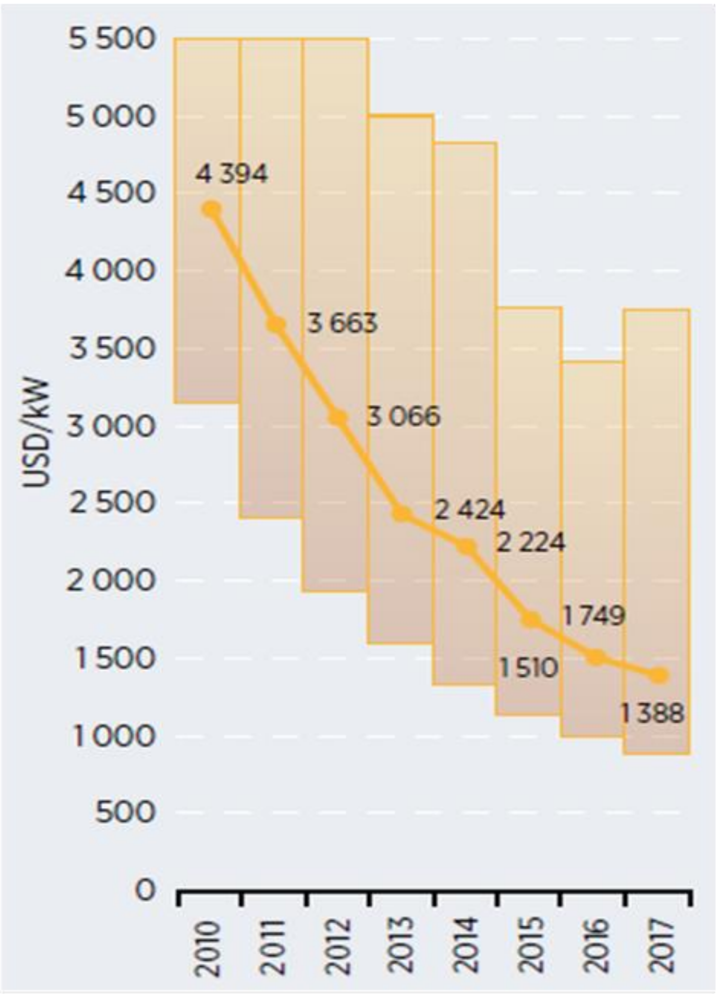
- Graduated in Electrical and Control Engineering at PUC-Rio
- Currently doing Masters in Optimization at PUC-Rio
- Optimization Engineer and Developer at PSR since 2017

Motivation

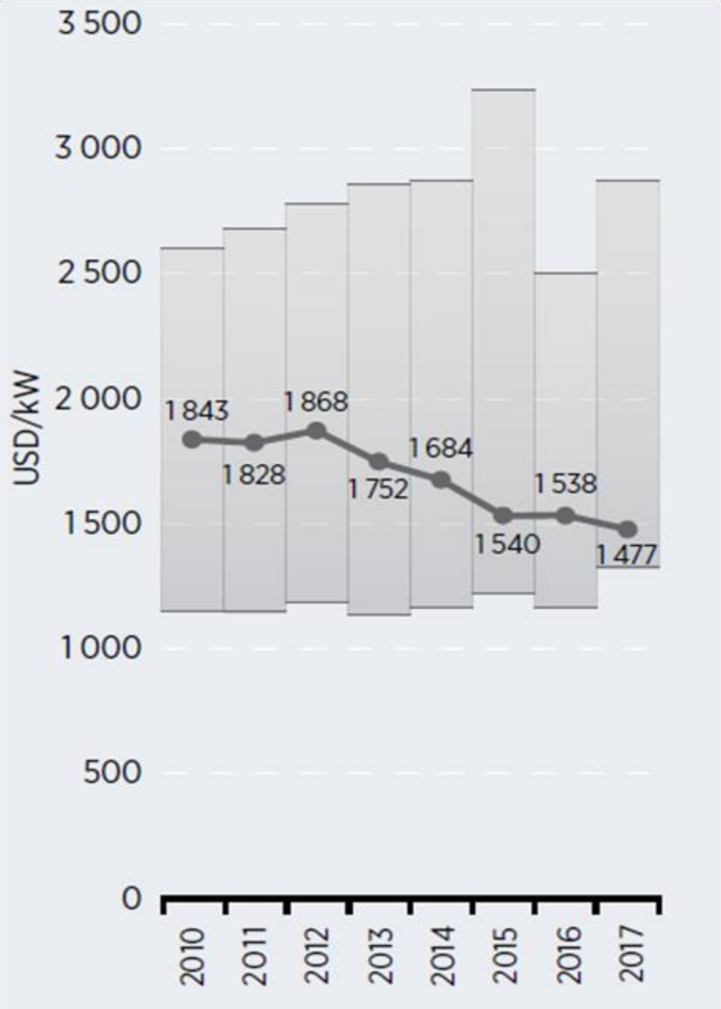
- Hourly resolution
- Unit commitment constraints
- Ramping constraints
- Exogenous calculation of system requirement reserve due to VRE intermittency and unpredictability

Renewable generation - Investment Cost

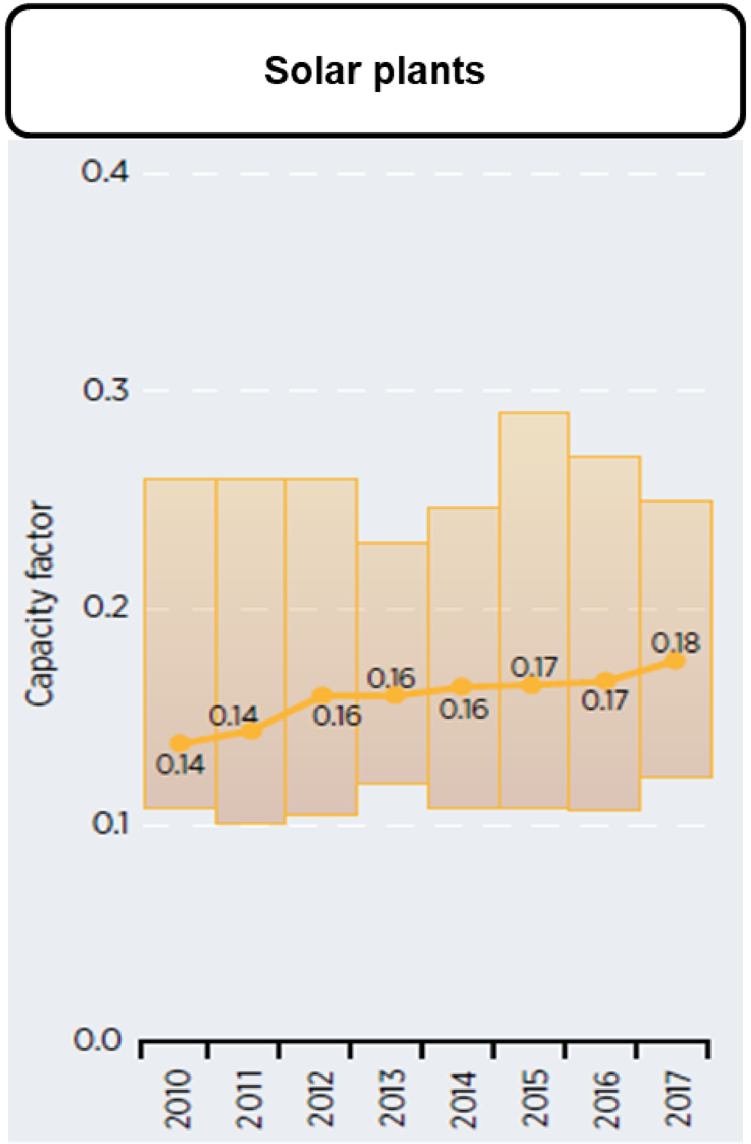
Solar plants

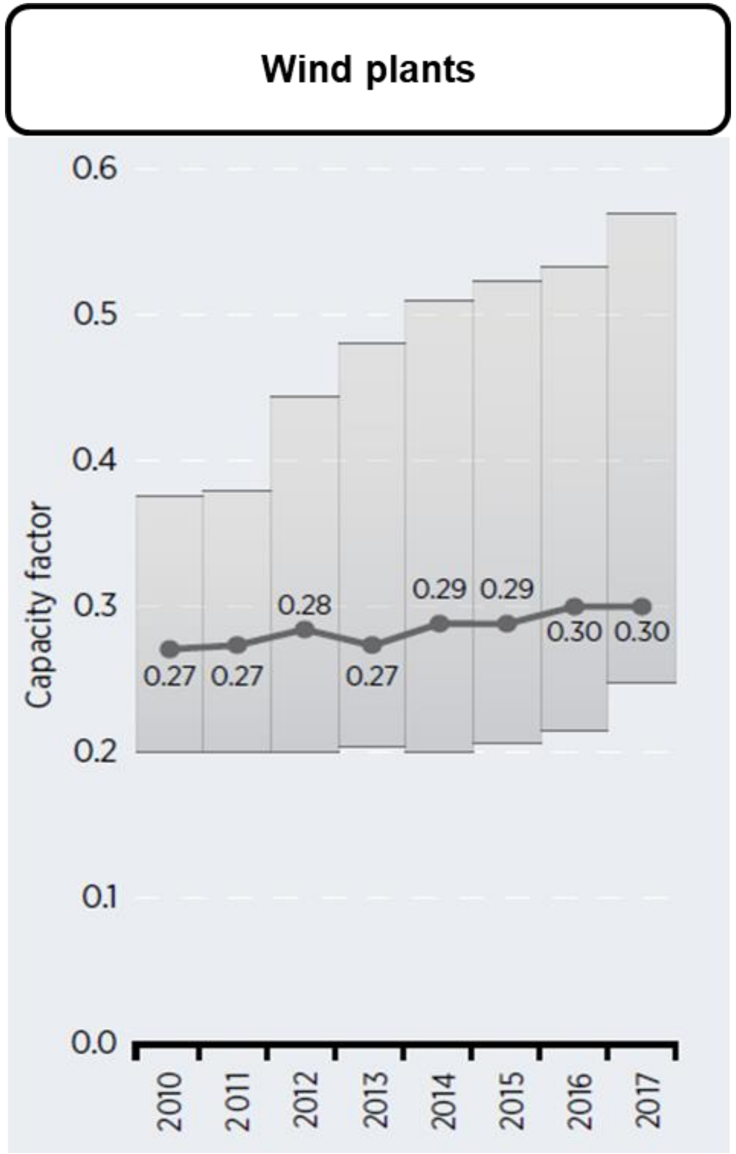


Wind plants

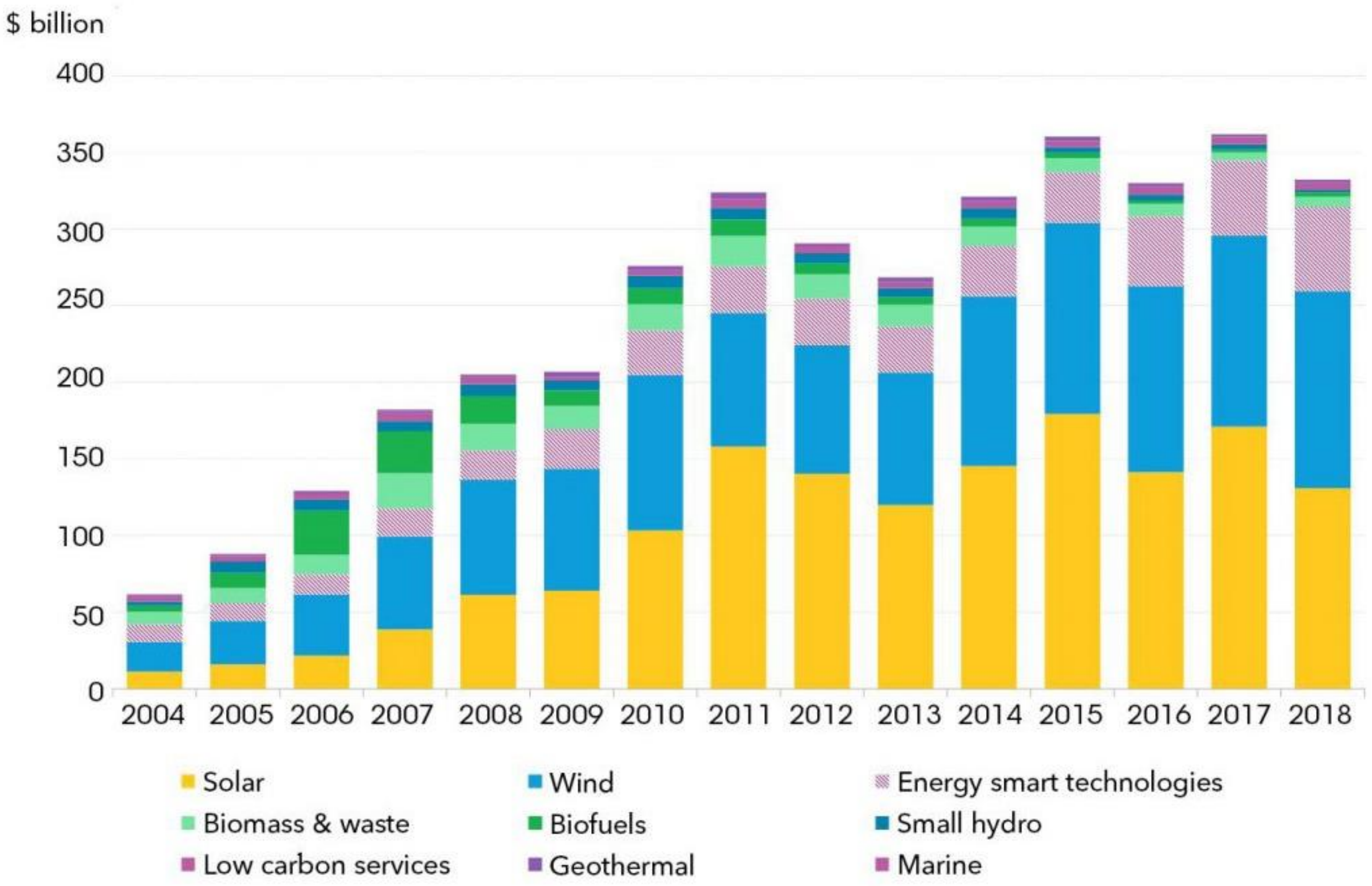


Renewable generation - Capacity Factor (efficiency)

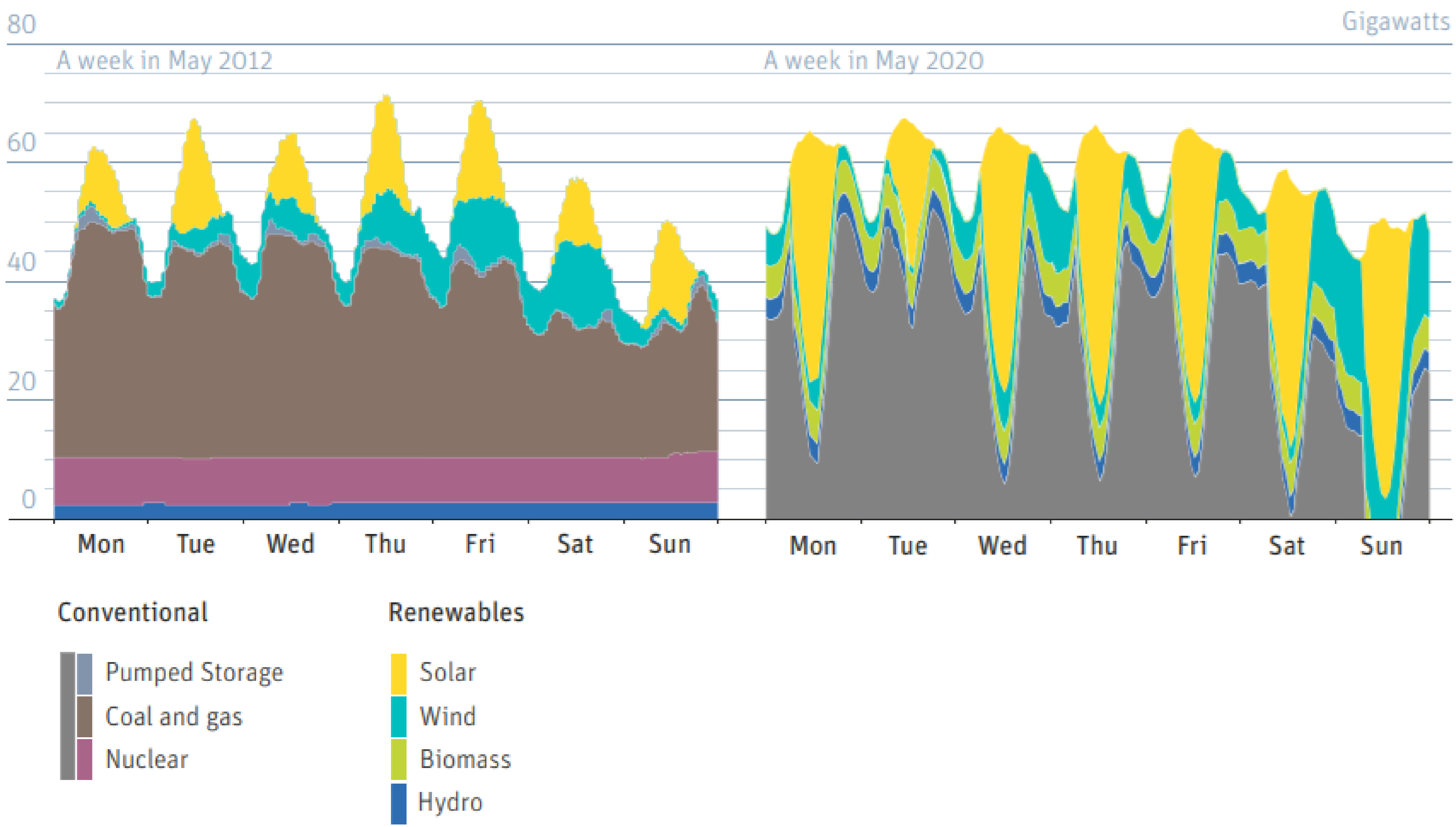




Global investments in renewable energy - Bloomberg



German system - Challenges



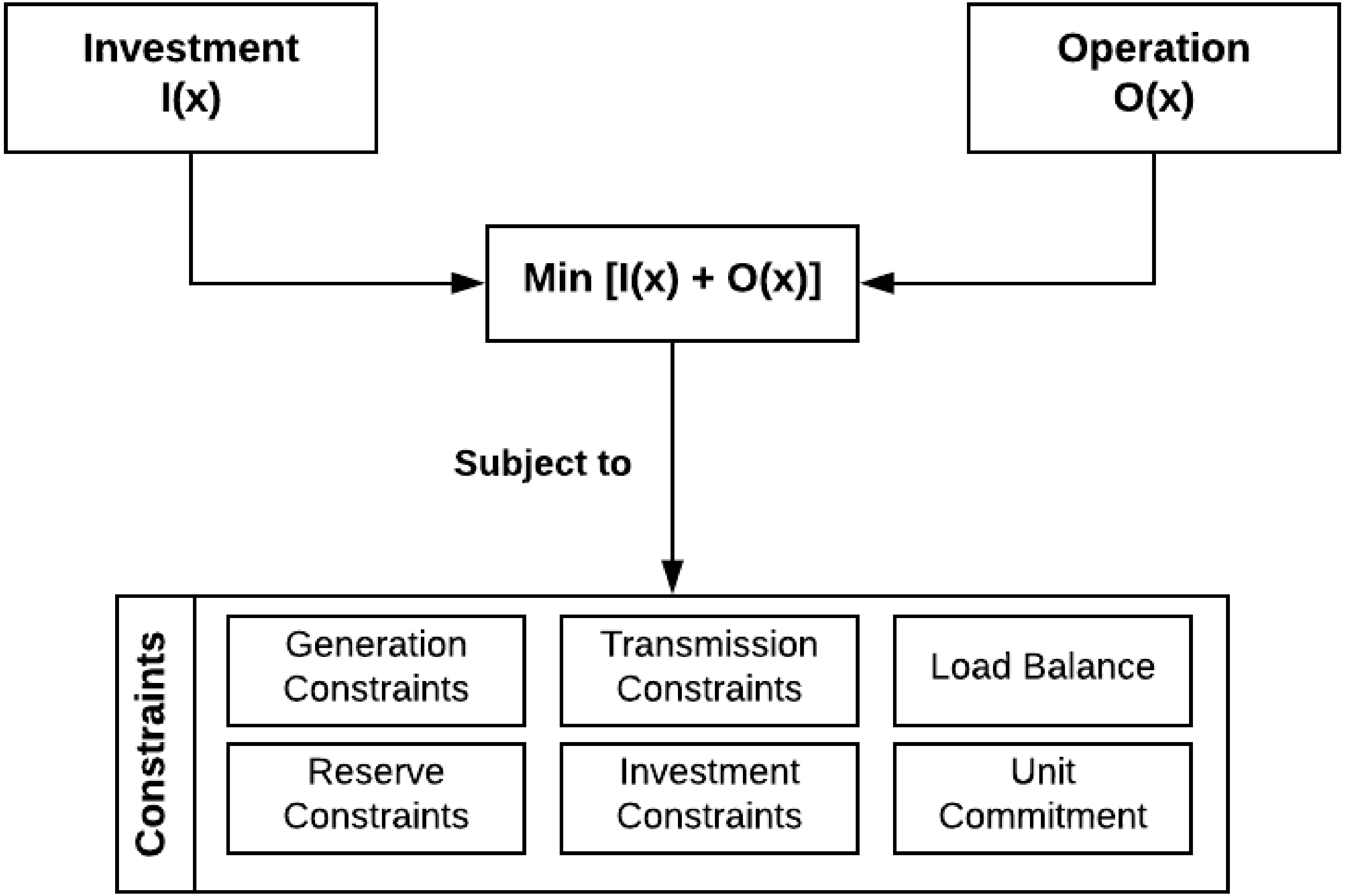
Consequences?

- High variability and uncertainty in the offer
- Large generation ramps
- Excess/Lack of generation
- Need for more system reserve
- Need for more thermal flexibility
- Thermal unit commitment influences expansion planning decision!!

Challenges

- An **expansion planning model** with an **hourly** time step
- **Unit commitment** in expansion planning
- Co-optimization of expansion planning and **system reserve requirement** (due to renewable penetration) modeled as an exogenous variable
- Solving a **MIP** with all of that in a reasonable amount of **time**!

The Model - OptGen

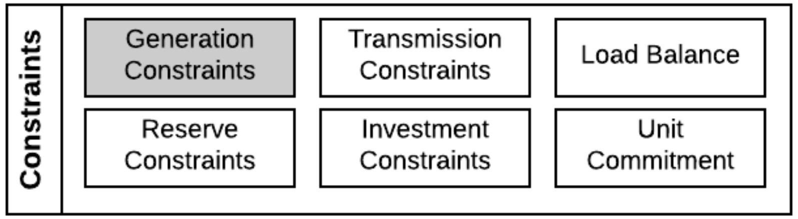


Formulation – Objective Function

Min [I(x) + O(x)]

$$\min_{x,g,q,v} \sum_{t \in \mathbb{T}} \sum_{i \in I} I_i x_{i,t} + \sum_{h \in H} \sum_{j \in G} c_j g_{j,h}$$

Formulation – Constraints



$$v_{i,t}^{s} \leq \bar{v}_i \sum_{\tau=1}^{t} x_{i,\tau}$$

Hydro maximum storage

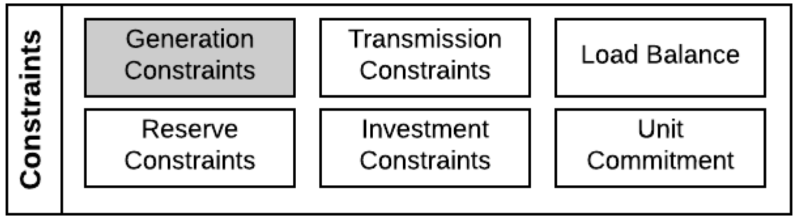
$$q_{i,h}^{s} \leq \bar{q}_i \sum_{\tau=1}^{t} x_{i,\tau}$$

Hydro maximum turbining

$$v_{i,t+1}^{s} = v_{i,t}^{s} + a_{i,t}^{s} - q_{i,t}^{s} - w_{i,t}^{s} + \sum_{j \,\epsilon\, M(i)} \left(q_{j,t}^{s} + w_{j,t}^{s}\right)$$

Water balance constraint

Formulation – Constraints



$$\underline{g}_j y^s_{j,h} \le g^s_{j,h} \le \bar{g}_j y^s_{j,h}$$

Thermal min/max generation

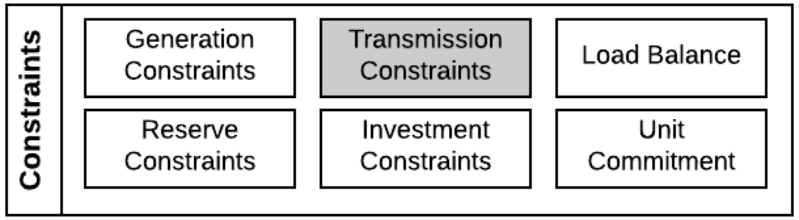
$$y^s_{j,h} \le \sum_{j=1}^{t} x_{j,\tau}$$

Commitment constrained by investment decision

$$g^s_{l,h} \le G^s_l \sum_{\tau=1}^{t} x_{l,\tau}$$

Wind and Solar max generation

Formulation – Constraints



$$f_{k,h}^{+s} \leq \bar{F}_k$$

$$f_{k,h}^{-s} \leq \bar{F}_k$$

Max capacity

$$f_{k,h}^{+s} - f_{k,h}^{-s} = \frac{1}{A_k} \Delta\Theta_{k,h}$$

Second Kirchhoff Law

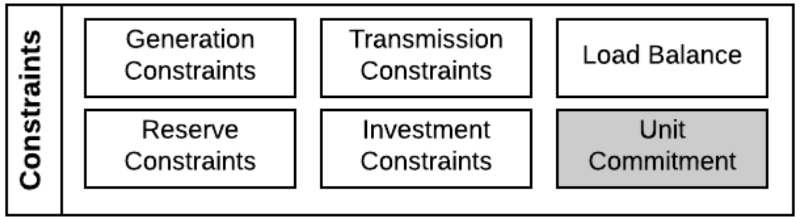
Formulation – Constraints

Constraints			
	Generation Constraints	Transmission Constraints	Load Balance
	Reserve Constraints	Investment Constraints	Unit Commitment

$$\sum_{j \in J} g_{j,h} + \sum_{i \in H} \rho_i q_{i,h} + \sum_{i \in R} g_{l,h} + \sum_{b \in B} (D_{b,h} - C_{b,h}) \sum_{k \in B_{to}} (f_{k,h}^{+s} - f_{k,h}^{-s}) - \sum_{k \in B_{from}} (f_{k,h}^{+s} - f_{k,h}^{-s}) + \epsilon_h = d_h$$

Thermal Generation | Hydro Generation | Renewable Generation | Battery Net Generation | First Kirchhoff Law | Deficit and Load

Formulation – Constraints



$$g^{s}_{j,h} - g^{s}_{j,h-1} \leq R^{UP}$$

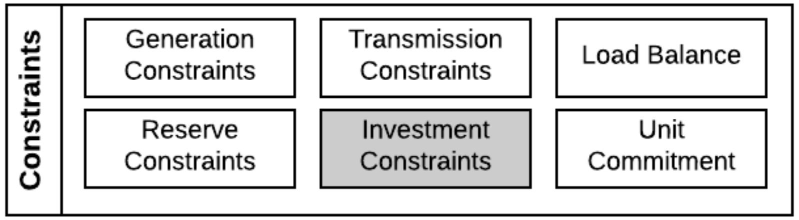
$$g^{s}_{j,h-1} - g^{s}_{j,h} \leq R^{DN}$$

Ramp

$$st^{s}_{j,h} \geq y^{s}_{j,h} - y^{s}_{j,h-1}$$

Start-up

Formulation – Constraints



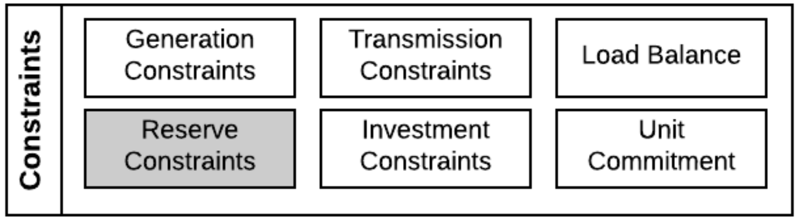
$$\sum_{t \,\epsilon\, \mathbb{T}} x_{i,t} \leq 1$$

$$\sum_{t \,\epsilon\, \mathbb{T}} x_{j,t} \leq 1$$

$$\sum_{t \,\epsilon\, \mathbb{T}} x_{l,t} \leq 1$$

Investment Decision Constraint

Formulation – Constraints



$$\sum_{j \in a} r_{j,h}^{s} + \sum_{i \in a} r_{i,h}^{s} + \sum_{b \in a} r_{b,h}^{s} \geq R_{a,h}^{UP}$$

Reserve Balance

$$g_{j,h}^{s} + r_{j,h}^{s} \leq \overline{G}_{j} y_{j,h}^{s}$$

Thermal reserve

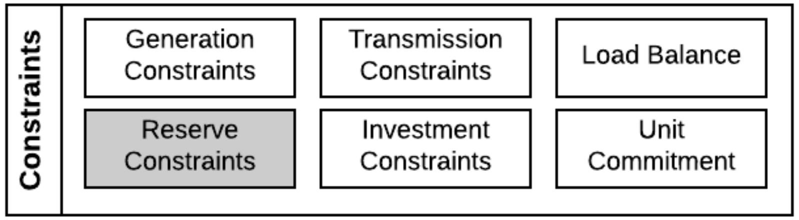
$$g_{i,h}^{s} + r_{i,h}^{s} \leq \overline{H}_{i} x_{i,t}$$

Hydro reserve

$$g_{b,h}^{s} + r_{b,h}^{s} \leq \overline{B}_{b} x_{b,t}$$

Battery reserve

Formulation – Constraints



$$\hat{v}_{l,h} = E[g^{s}_{l,m,h}]$$

Forecast Generation

$$\delta^{s}_{a,h} = \sum_{l \in A^{a}_{l}} (g^{s}_{l,h} - \hat{v}_{l,h}) x_{l,t}$$

Forecast error

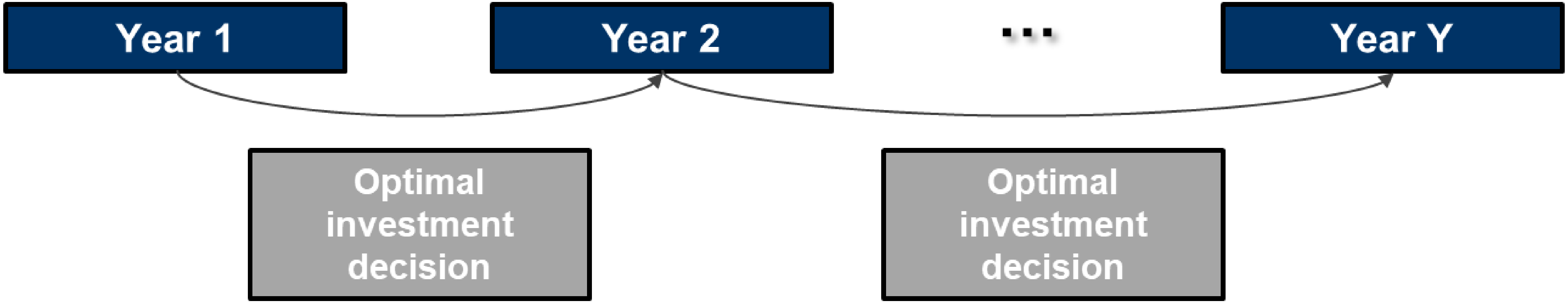
$$\Delta^{s}_{a,h} \geq \delta^{s}_{a,h} - \delta^{s}_{a,h-1}$$

Hourly Variation in Forecast error

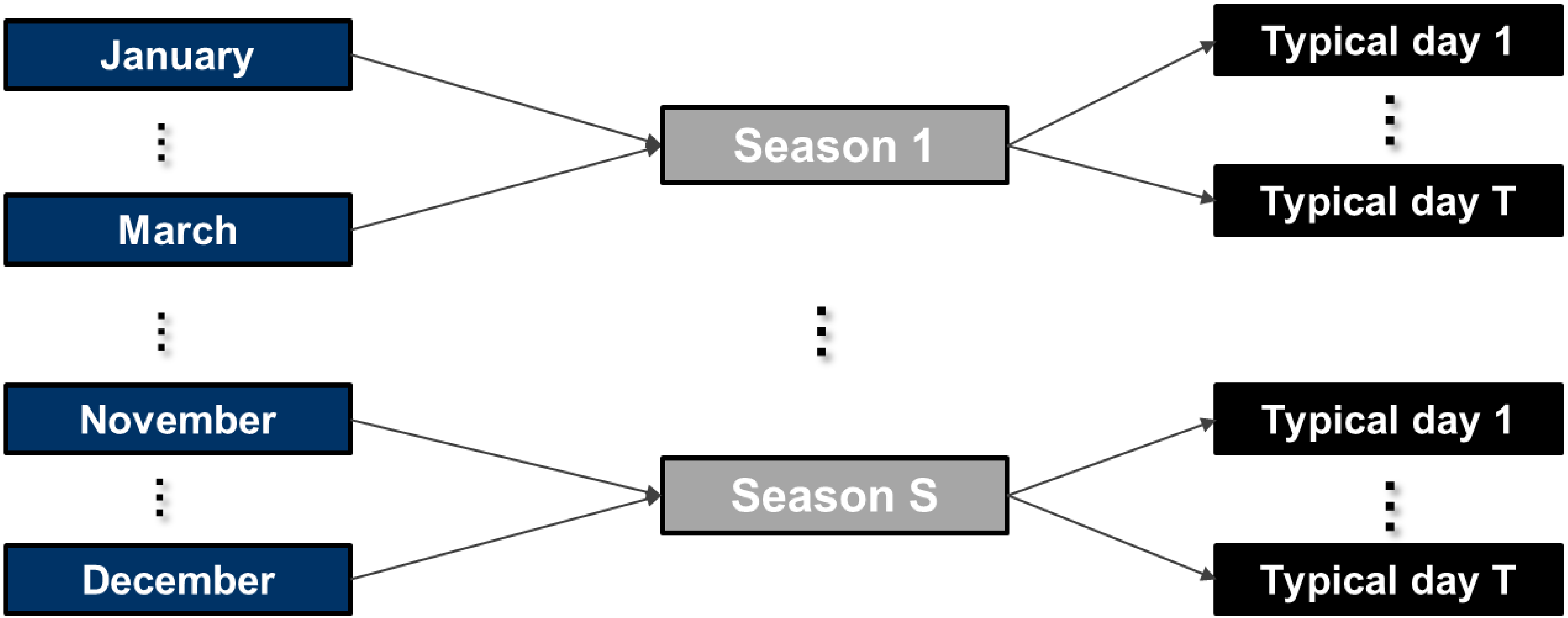
$$R^{UP}_{a,h} \geq (1-\lambda) E[\Delta^{s}_{a,h}] + \lambda CVaR_{\alpha}[\Delta^{s}_{a,h}]$$

Dynamic Probabilistic Reserve Criteria

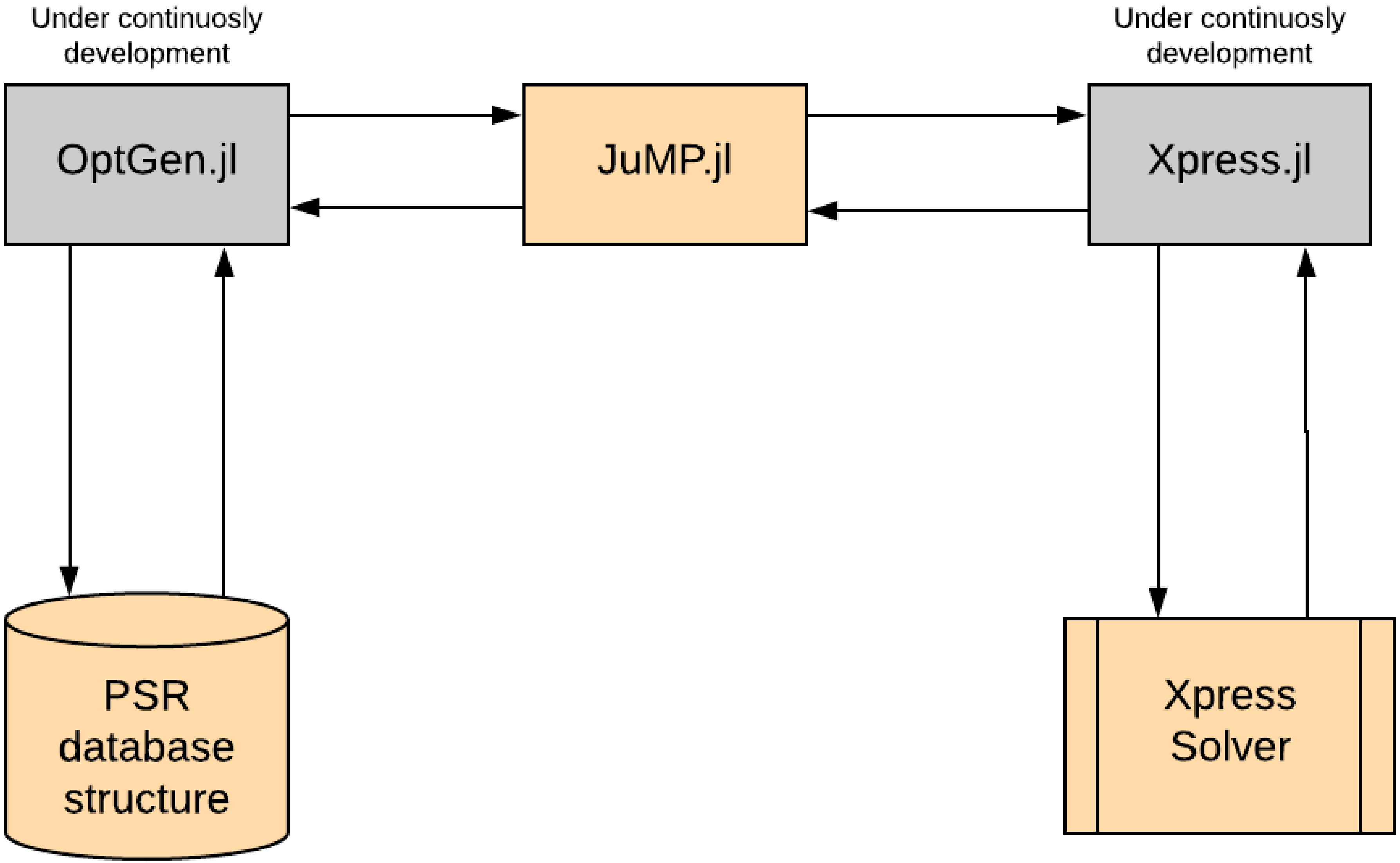
Assumptions and Approximations – Rolling Horizon



Assumptions and Approximations – Daily Aggregation



Basic Structure



International Studies – Chilean Energy System

Generadoras de Chile

Generación eléctrica en Chile | Quiénes somos | Empresas asociadas | Prensa | Documentos

Inicio / Prensa / Mayor aporte solar y eólico reducirá al...

NOTICIAS
29/01/2018

Mayor aporte solar y eólico reducirá al 25% la generación térmica al 2030 en Chile

El 75% restante provendría de energías renovables, según estudio de PSR-Moray.

Eso sí, el análisis encargado por la Asociación de Generadoras señala que el gas, carbón y los embalses aportarán flexibilidad al sistema que se enfrentará a tecnologías variables.

La energía solar representaría 30% de la generación a 2030, lo que aumentaría los costos de flexibilidad que, actualmente, no son remunerados.

Generadoras de Chile

Generación eléctrica en Chile | Quiénes somos | Empresas asociadas | Prensa | Documentos | Tra

Inicio / Prensa / Generadoras participó en Seminario Inter...

30/05/2018

Generadoras participó en Seminario Internacional de Energía Renovable Variable (ERV)

El Director del Centro de Energía UC, Enzo Sauma y el Presidente Ejecutivo de Generadoras de Chile, Claudio Seebach, estuvieron a cargo de la apertura de este encuentro organizado por el Centro de Energía UC y cuyo tema principal fue la integración de ERV al sistema eléctrico chileno.

http://generadoras.cl/prensa/mayor-aporte-solar-y-eolico-reducira-al-25-la-generacion-termica-al-2030-en-chile

http://generadoras.cl/prensa/generadoras-participo-en-seminario-internacional-de-energia-renovable-variable-erv

International Studies – Brazilian Energy System

JUMP julia

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Energy systems of the future in Brazil

Project description

Title: Energy Systems of the Future
Commissioned by: German Federal Ministry for Economic Cooperation and Development (BMZ)
Country: Brazil
Lead executing agency: Ministry of Mines and Energy (MME)
Overall term: 2016 to 2021

Context

Brazil's demand for energy will continue to increase, although the rapid economic growth of the last few years has weakened significantly. Yet based on the economic and population growth forecast for the next 10 years alone, the energy planning authority (EPE) estimates an increase of over 3 per cent in annual electricity demand by 2026.

https://www.giz.de/en/worldwide/12565.html

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News
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"CEM Days - Integration of Renewables in the Electric Sector: Paths and Challenges to Energy Planning

On 21-23 November 2018, Rio de Janeiro hosted the workshop "CEM Days - Integration of Renewables in the Electric Sector: Paths and Challenges to Energy Planning". The event, organized by EPE, took advantage of the framework enabled by the Clean Energy Ministerial (CEM), and its aim to empower energy decision makers around the world with the up-to-date information and tools, as means to accelerate transition to low carbon energy. The workshop brought together experts and policy makers to discuss strategies to support a secure and cost-effective integration of higher shares of VRE – Variable Renewables Energy, such as wind and PV power. The event was promoted and supported by the International Energy Agency – IEA, of which Brazil is associate since October 2017, and GIZ - Deutsche Gesellschaft für Internationale Zusammenarbeit (German Agency for International Cooperation). The event also had special participation by the Brazilian National System Operator (ONS) and the National Laboratory for Renewable Energy – NREL.

In addition to the above mentioned institutions, we had participants from power generation and distribution utilities, industry associations, consulting companies, universities, banks, among others.

It was possible to identify many challenges to adapt the energy planning methodologies and tools, related to emerging technologies that redefine the profile of power generation and the use of transmission and distribution assets, as well as business models, market and regulatory framework, consumer behavior and electricity demand profile, all that transforming the industry, the energy mix and its associated infrastructure.

By organizing this event, EPE strengthens its engagement in high-level technical discussions regarding challenges for the integration of VREs in the power system and consolidates important partnerships with national and international institutions aiming to exchange valuable experiences for energy planning.

The agenda can be accessed at this link

http://www.epe.gov.br/en/press-room/news/-cem-days-integration-of-renewables-in-the-electric-sector-paths-and-challenges-to-energy-planning

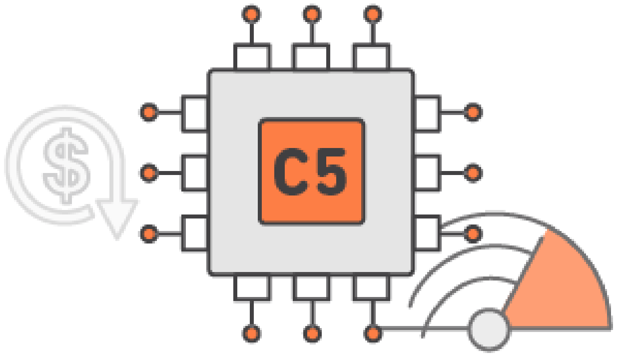
Chilean System Study Example

- 13 years horizon
- 54 scenarios
- 300 thermal plants (100 projects)
- 650 wind and solar plants (500 projects)
- 100 hydro plants
- 12 transmission lines / 6 buses (simplified network)
- ~**5.6 MM constraints** per year
- ~**7.8 MM variables** (**3 MM integer**) per year

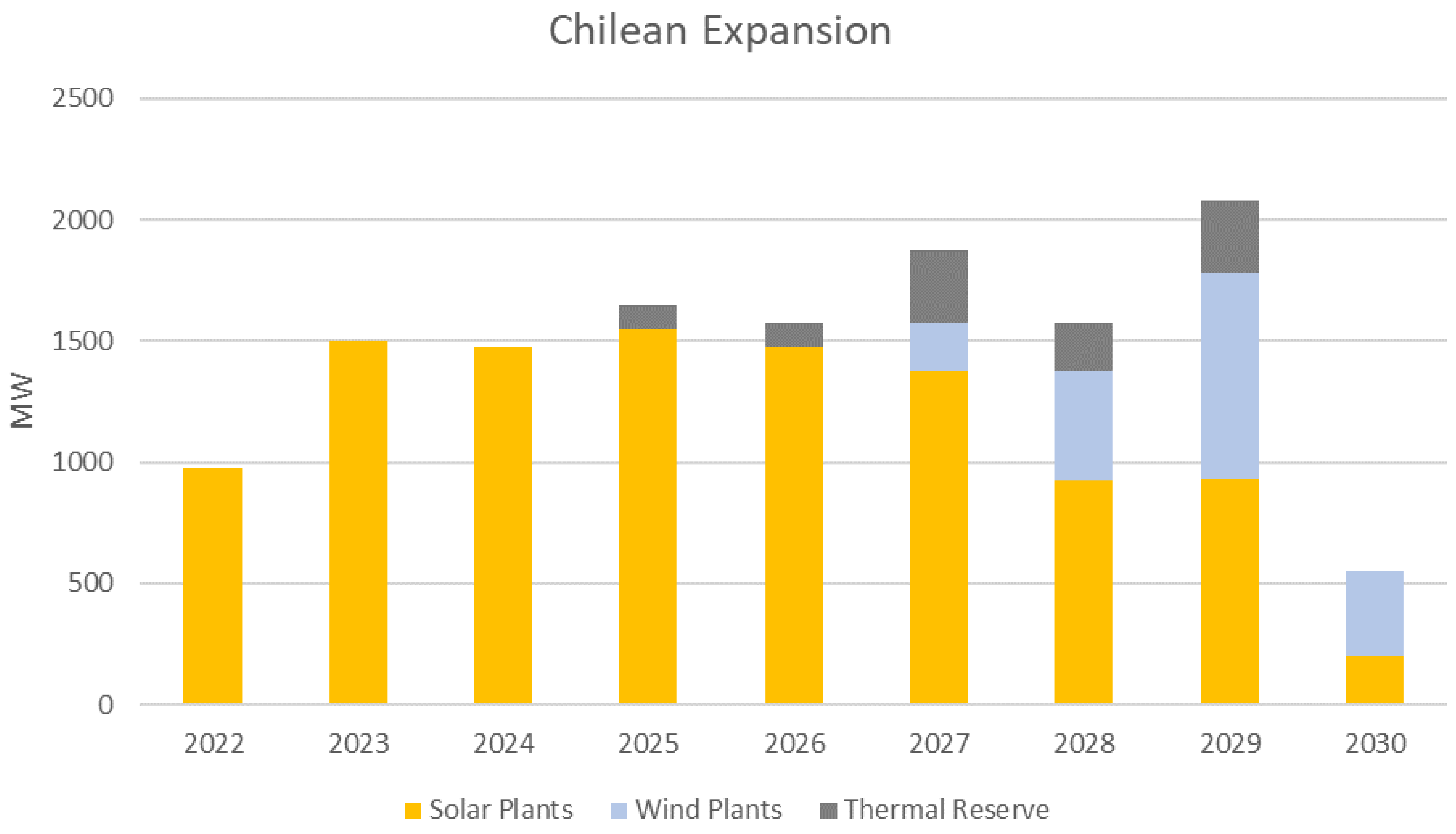
Generadoras de Chile

Solving the Model

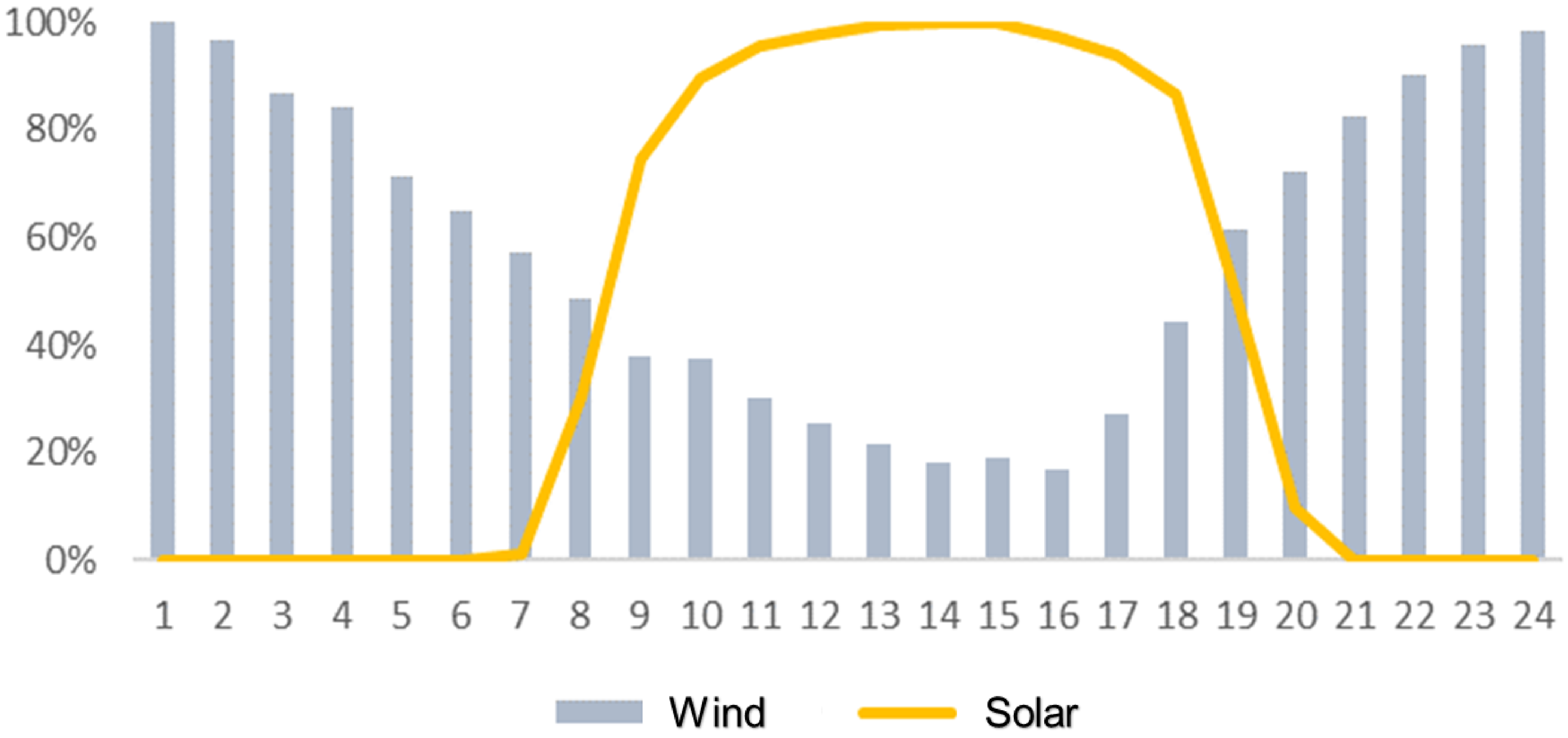
- FICO **Xpress** 8.5 solver
- c5.9xlarge amazon instance - 3.0 GHz Intel Xeon Platinum processors - **36 vCPU** - 72 GB RAM
- Xpress control parameters were **tuned** by Xpress lead developer (Michael Perregaard)
- Solve time: ~**240 minutes** per year



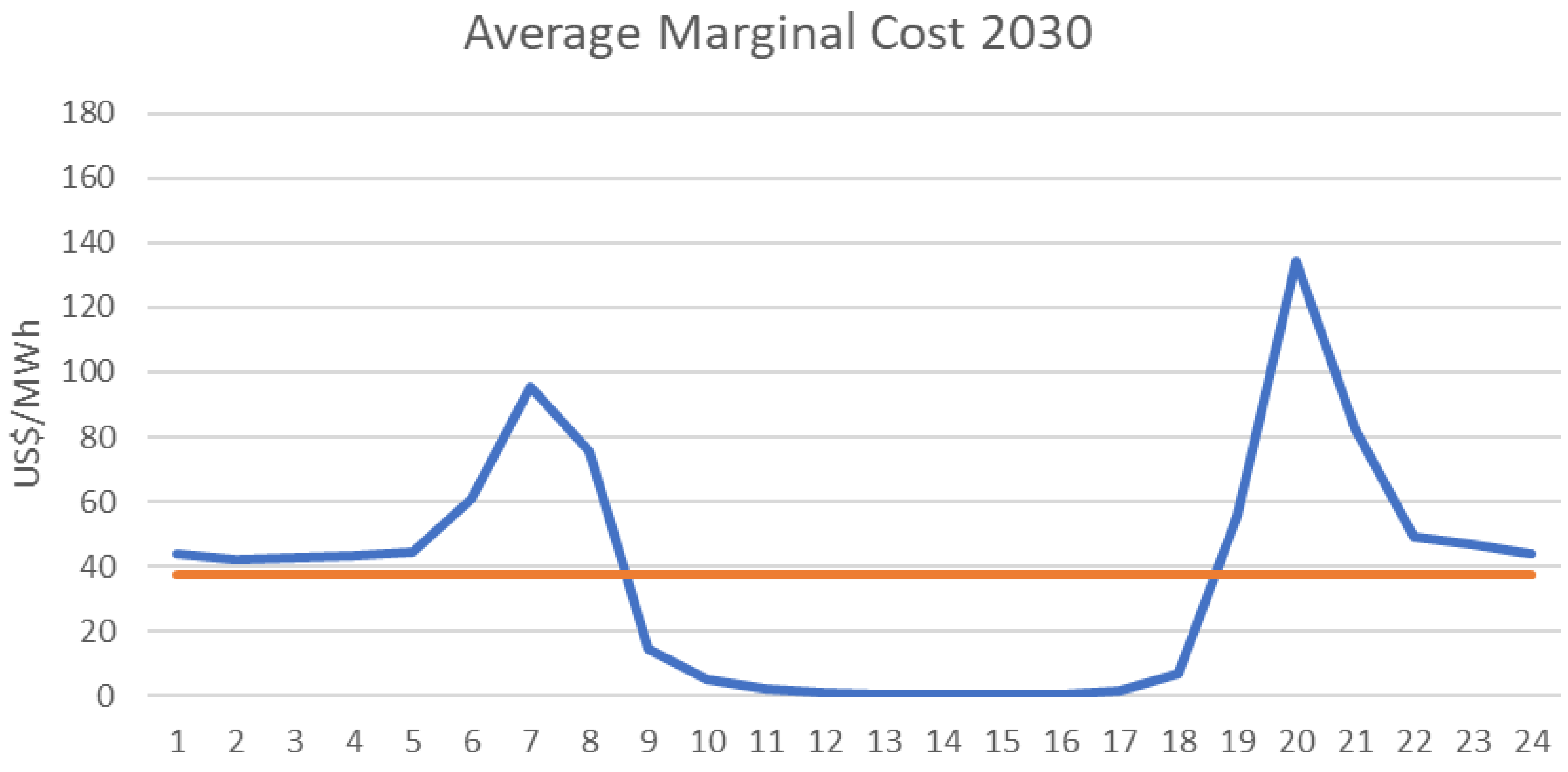
Results - Incremental Expansion



Results - Wind and Solar complementarity



Results - Marginal Costs



Brazilian System Study Example

- 1 year horizon
- 10 scenarios
- 600 thermal plants (400 projects)
- 100 wind and solar plants (30 projects)
- 200 hydro plants
- 10 battery projects
- 50 transmission lines / 30 buses (simplified network)
- ~5 MM constraints per year
- ~4 MM variables (1 MM integer) per year

epe Empresa de Pesquisa Energética

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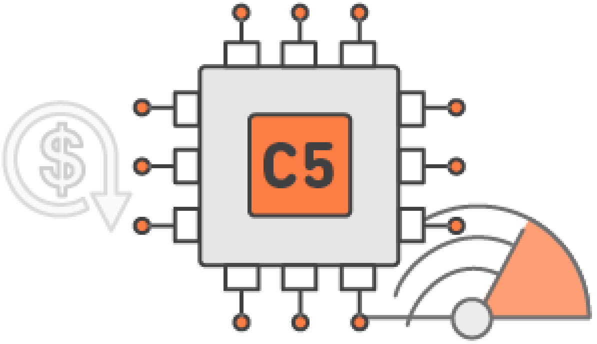
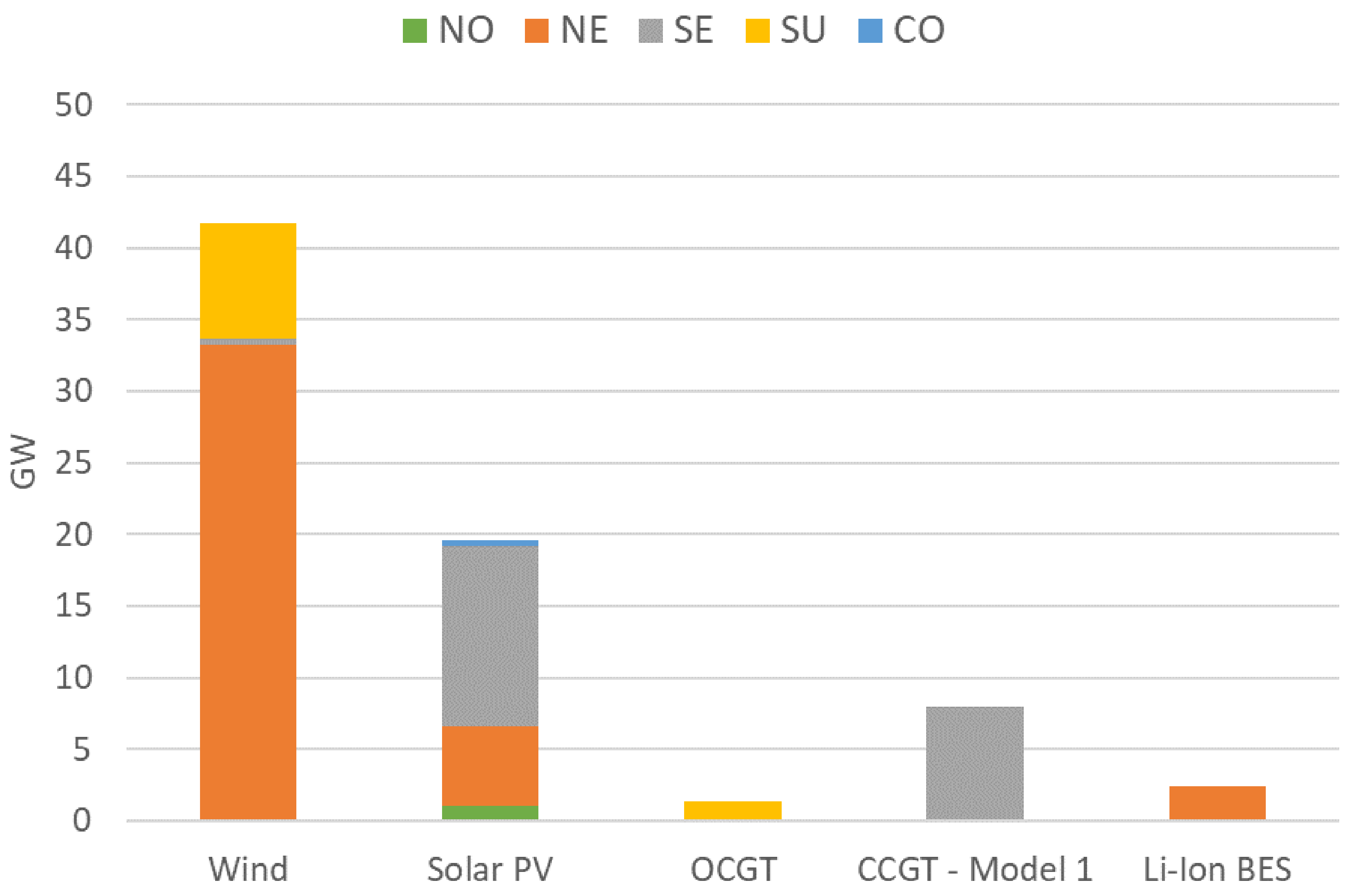
Solving the Model

- FICO **Xpress** 8.5 solver
- c5.9xlarge amazon instance - 3.0 GHz Intel Xeon Platinum processors - **36 vCPU** - 72 GB RAM
- Xpress control parameters were **tuned** by Xpress lead developer (Michael Perregaard)
- Solve time: ~**70 minutes**

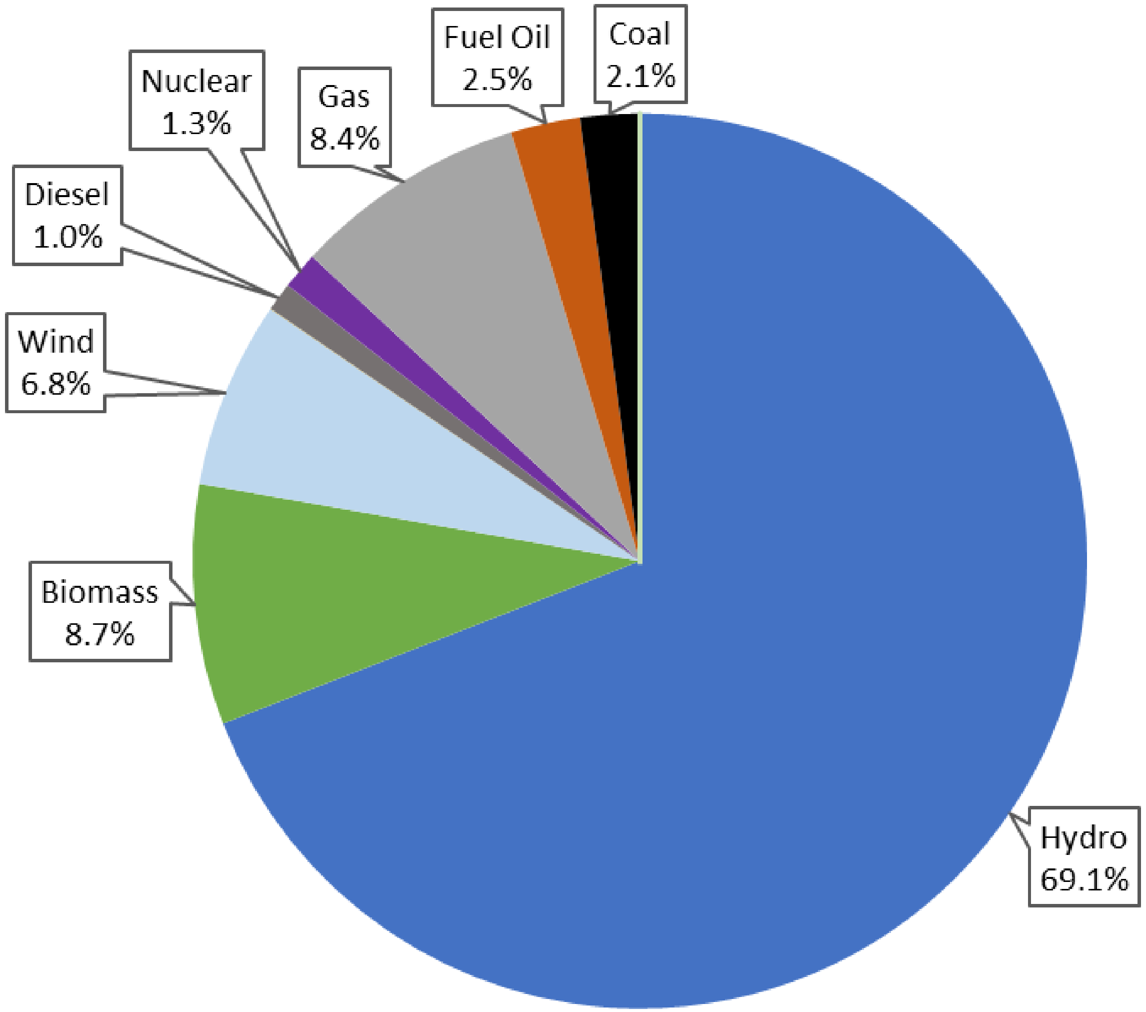


Incremental Expansion

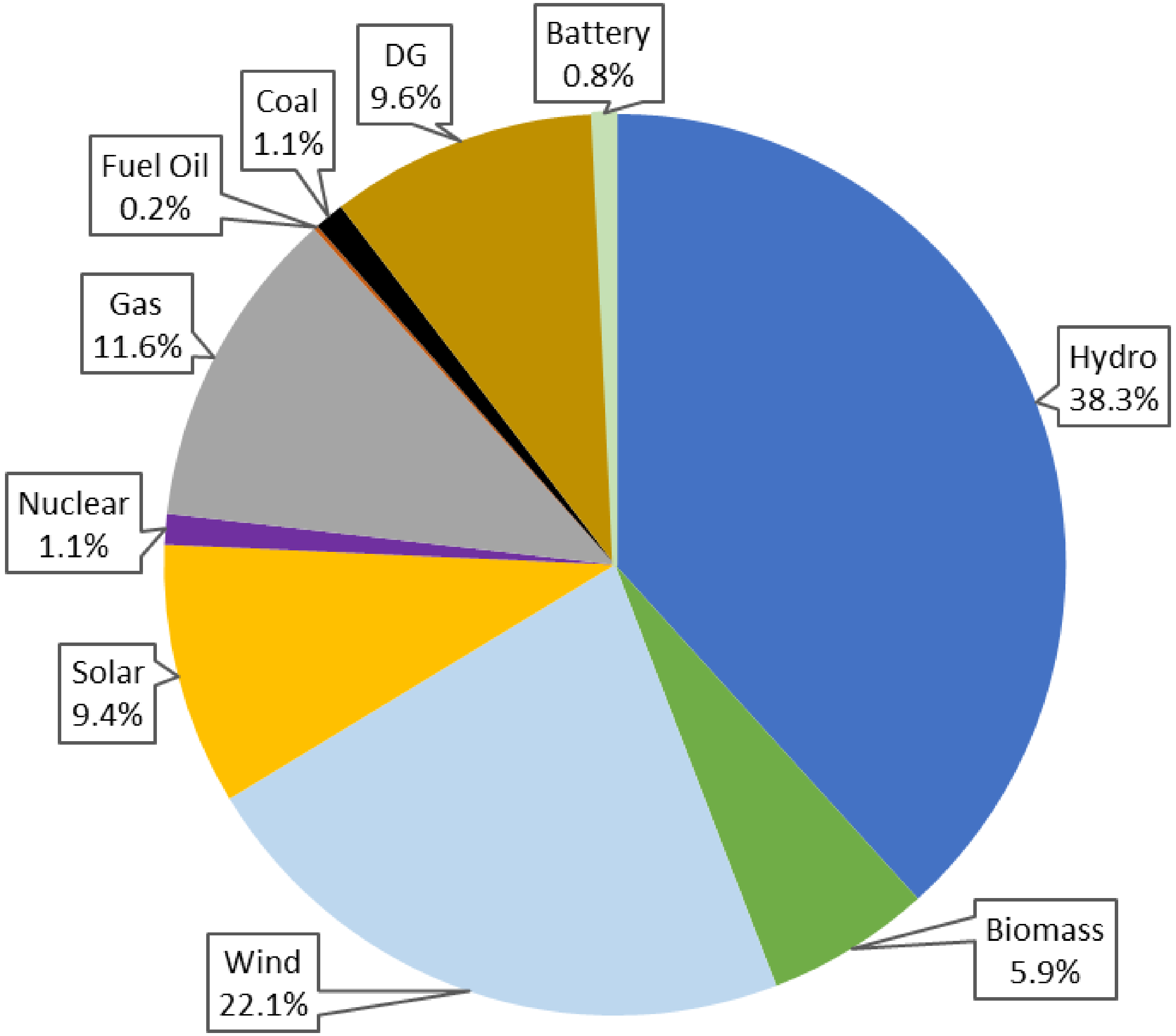


Installed Capacity

2017



~2036



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Thanks!

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