Planning for a new energy era

State of The Art of Energy Storage and Insertion of Intermittent Renewable Sources

São Paulo, March 19, 2018

Gabriel Konzen

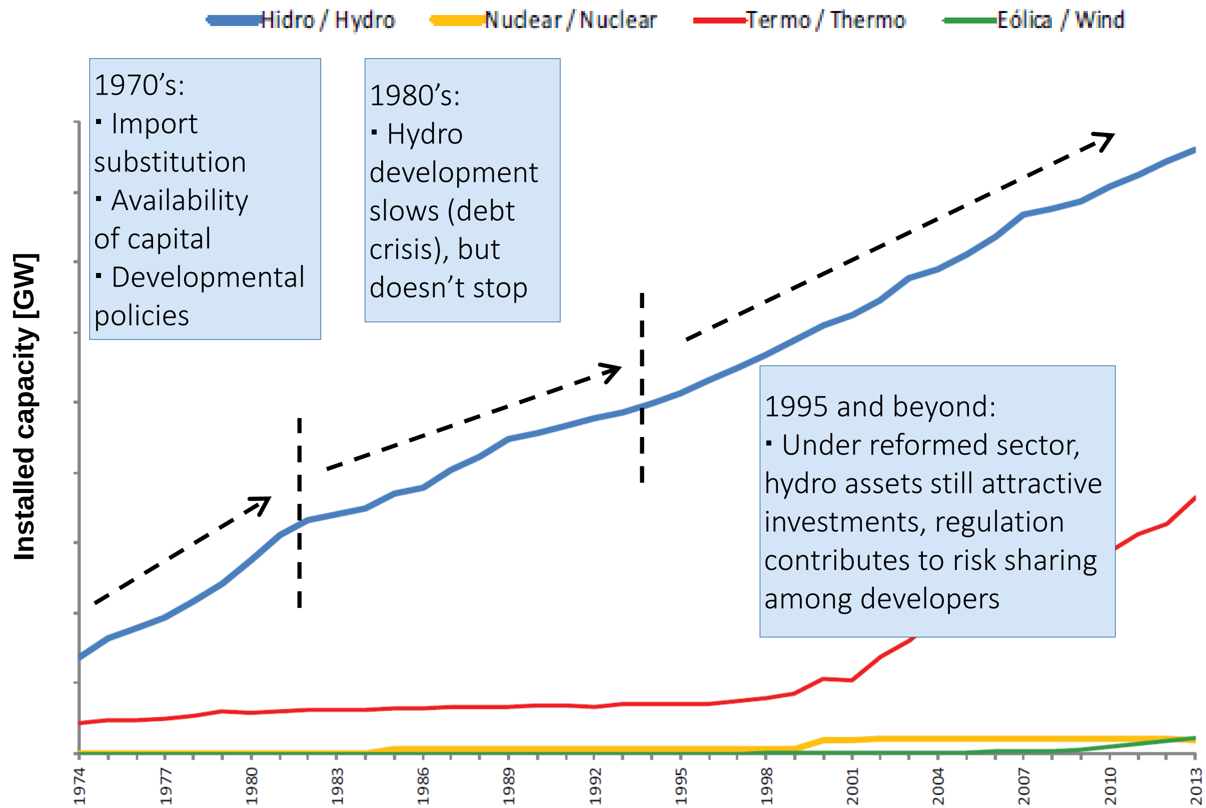
Planning is always linked to our vision of the future

So… What will the future be like?

“Difficult to see. Always in motion is the future..” – Yoda.

What did we do in the past?

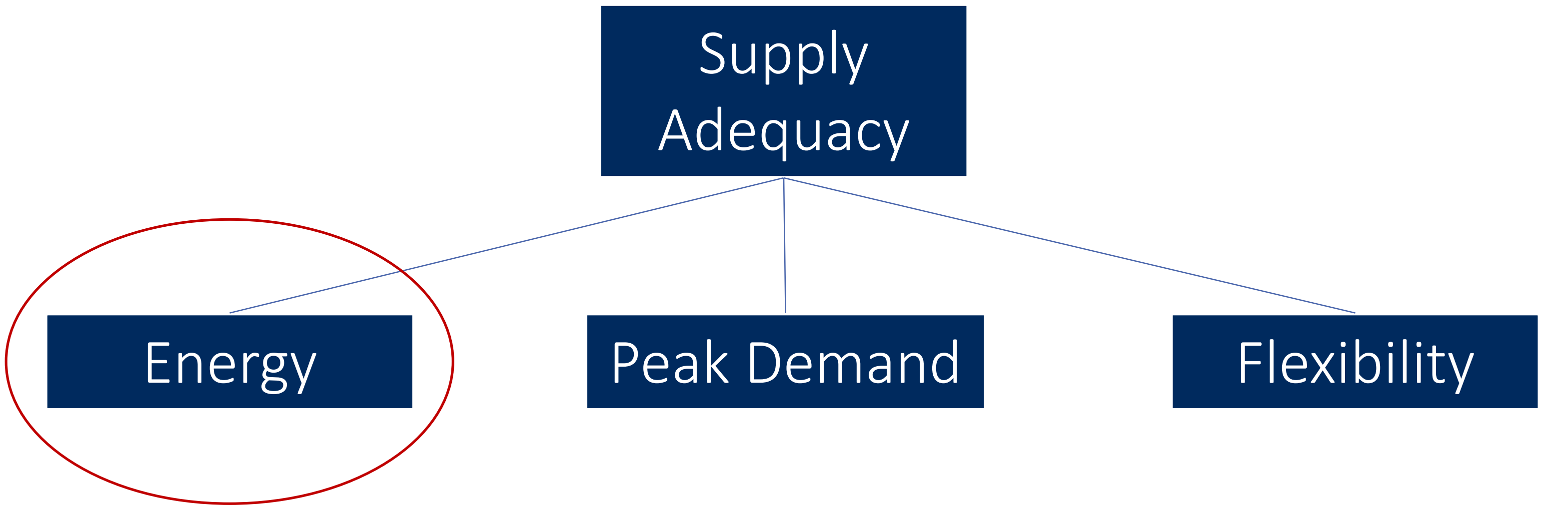
We built hydro, basically



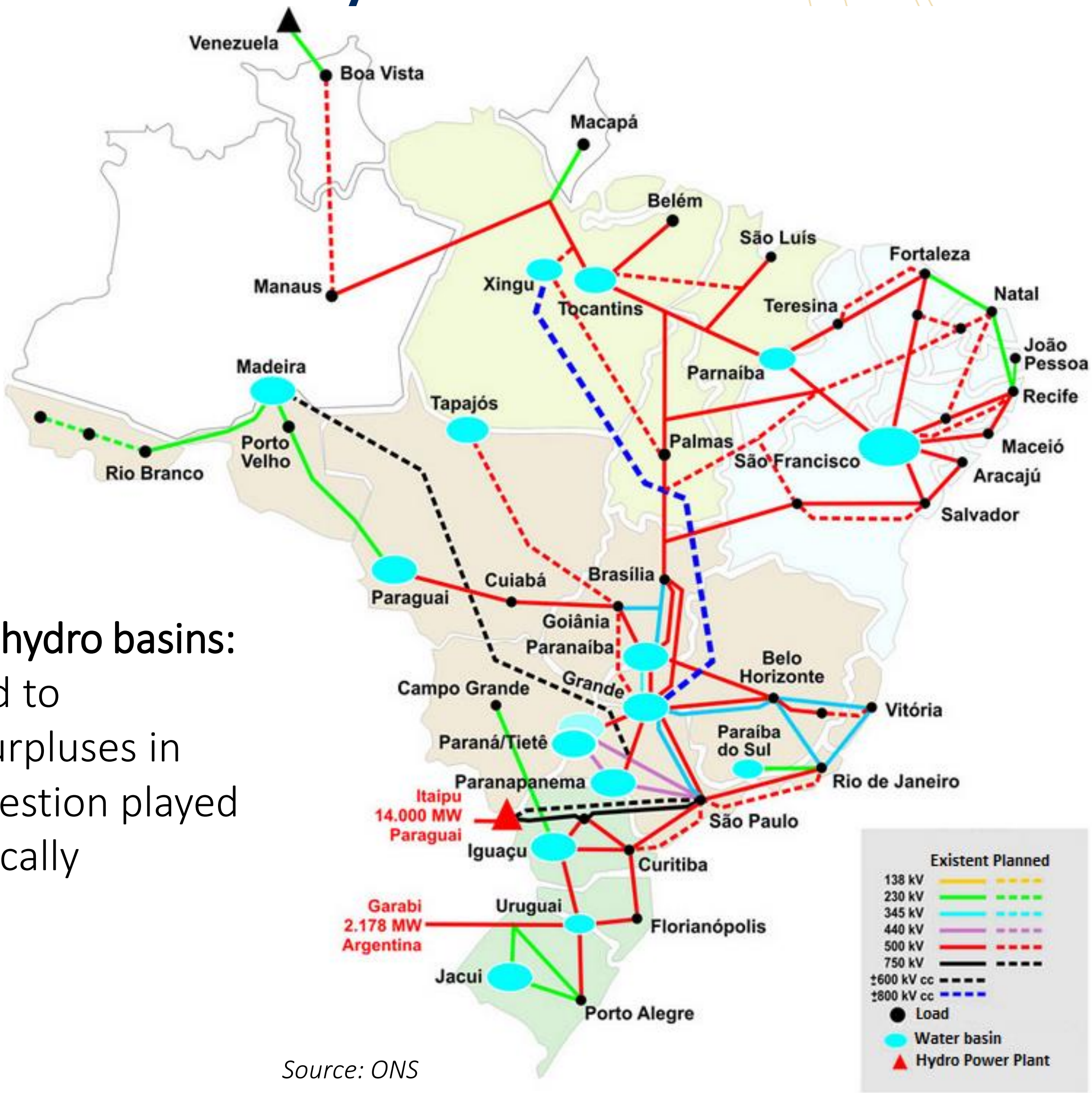
Generation mix (2016):

Hydropower (with large reservoirs) historically met systemic flexibility needs

- Constructive characteristics of hydro plants:
  - Need to take advantage of good hydrological conditions for each basin → installed capacity much higher than average output and firm energy
  - Significant reservoir capacity → flattening of daily/weekly marginal operation costs
  - This and other features allowed providing flexibility at low incremental costs, despite operation constraints (e.g., min and max outflows) that always existed.



Our reservoirs are all electricly interconnected



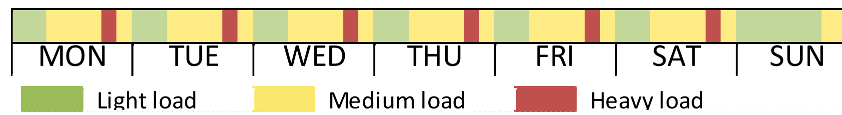
Source: ONS

Coordinated operation of different hydro basins:

Transmission system designed to accommodate hydrological surpluses in each individual basin → congestion played a relatively minor role, historically

Regulatory, commercial & operation frameworks were created in this context

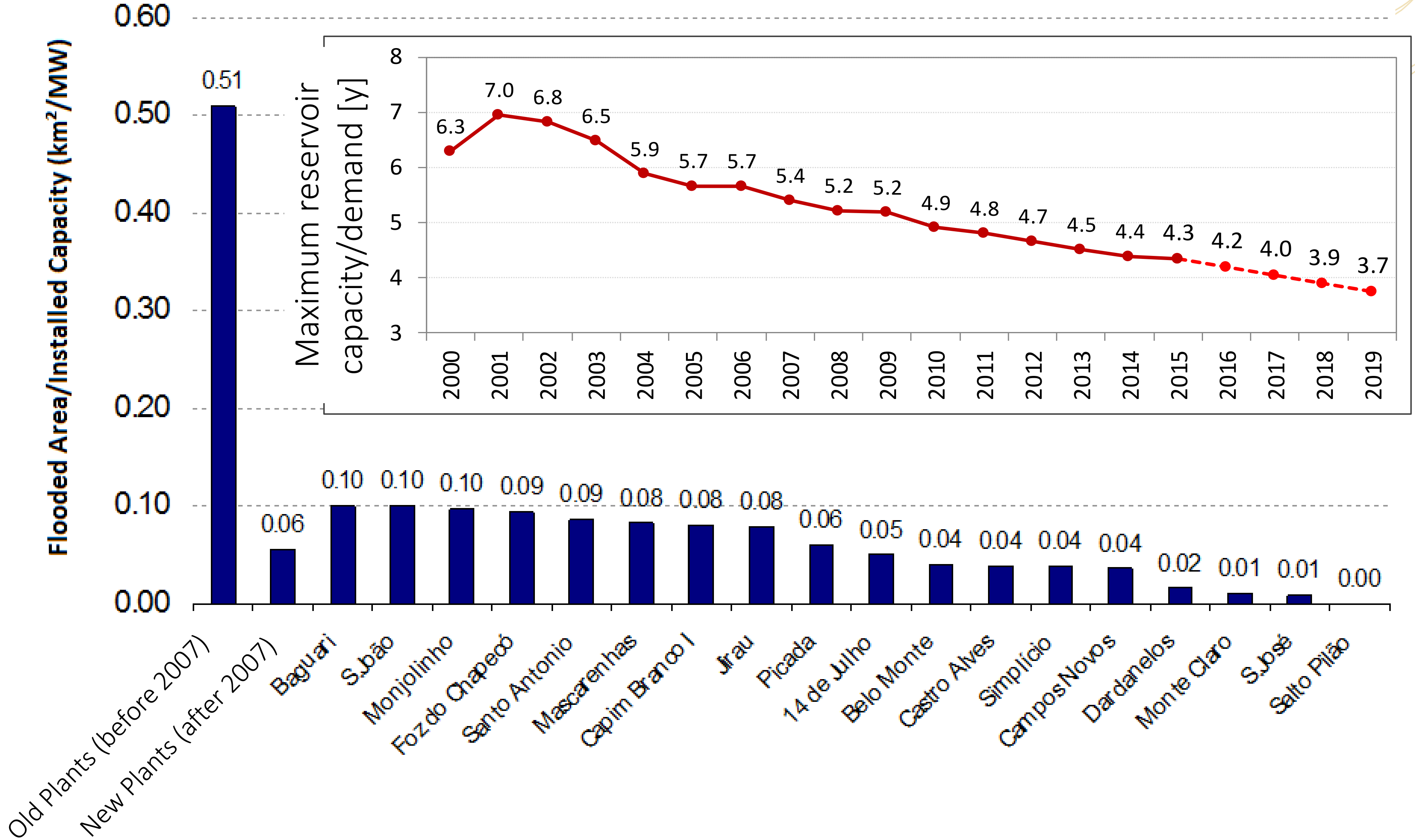
- Focus on ability to respond to changes in supply in the long-term (seasonal and supra-seasonal) due to hydrological uncertainty.
- Some selected examples of current framework…
  - Wholesale energy prices & settlement periods: load blocks within week.



  - Ancillary services not procured competitively:
    - Ex. of secondary reserves: direct selection of providers (all hydros), regulated payment basically to cover investments in control and IT, and expenses with O&M personnel
  - Long-term resource adequacy based solely on firm energy.
  - Retail tariffs: large parcel of customers exposed to dampened economic signals.

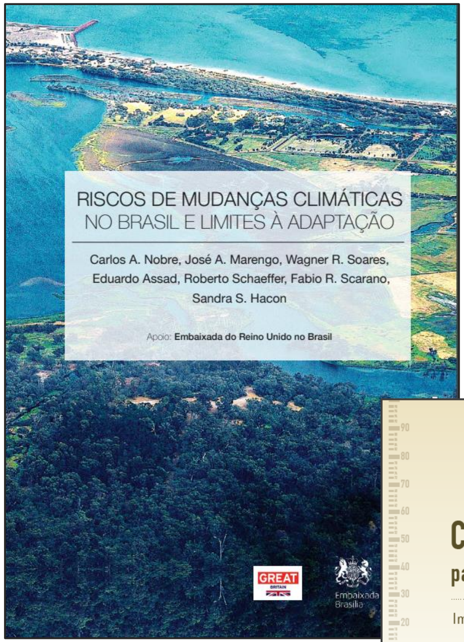
The new energy era

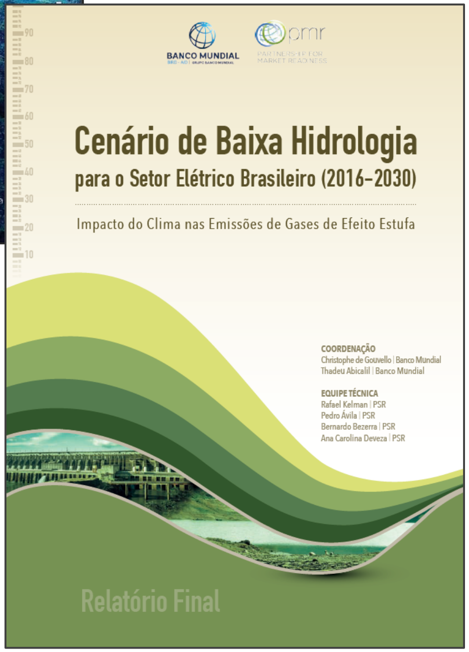
Our relative storage capacity is decreasing.



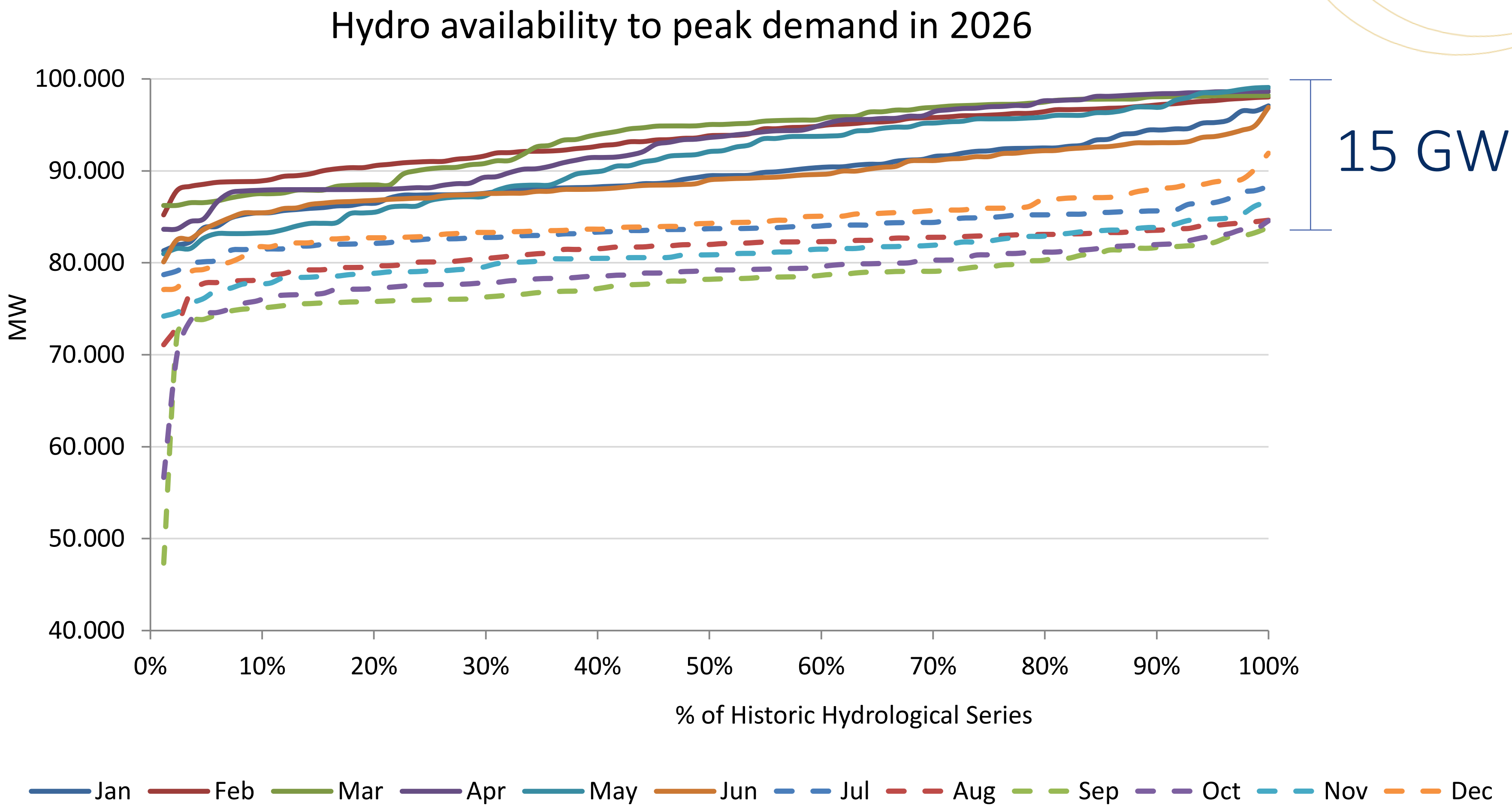
Climate change adaptation

- Studies of impacts on supply/demand of electricity are of key importance
  - Hydrology changes might affect flexibility supply;
  - Demand profiles might change.



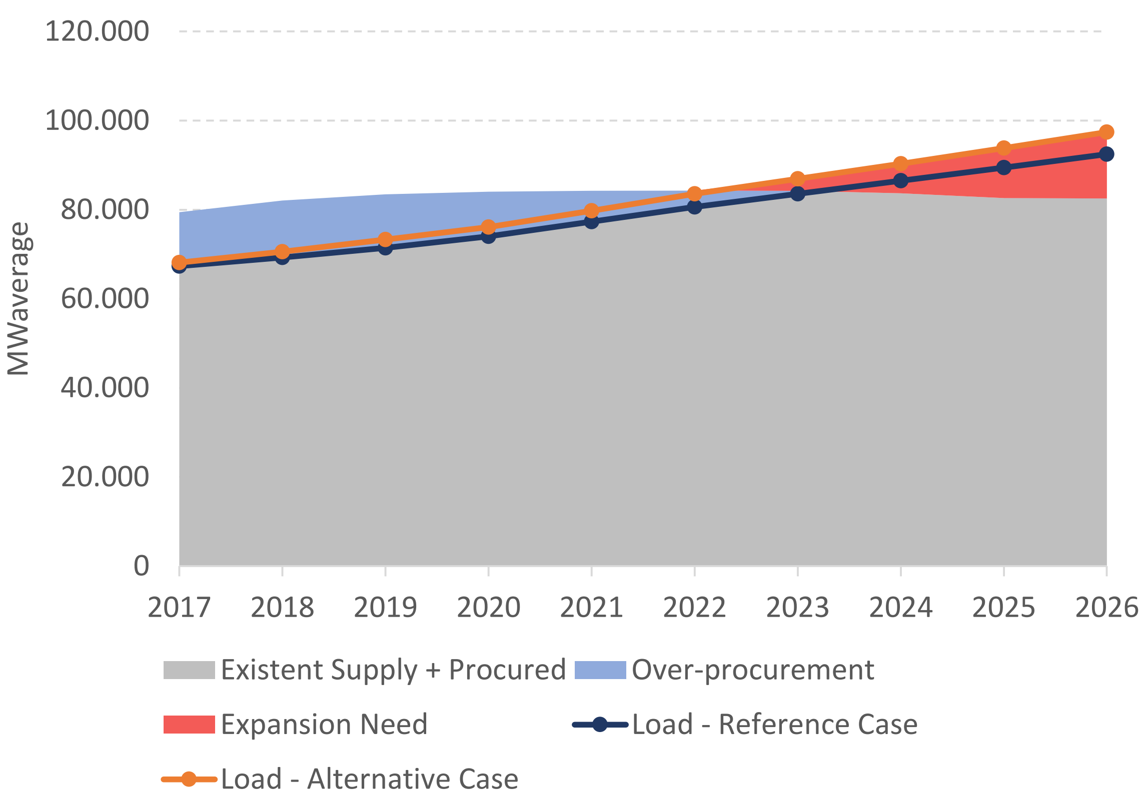


Less water -> less head -> less power



The recovery of our economy will demand new investments to meet load growth

GDP Growth Rate	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2017 - 2026
Source Case	0,5%	1,8%	2,1%	2,7%	2,8%	2,8%	2,9%	3,0%	3,0%	3,0%	2,5%
Alternative Case	1,7%	2,8%	3,1%	3,2%	3,5%	3,5%	3,5%	3,5%	3,5%	3,5%	3,2%



Need for new supply in the 10-year horizon: ≈10,000 – 15,000 MWa

≈ 2-3x Portugal

(2014). Source: EIA

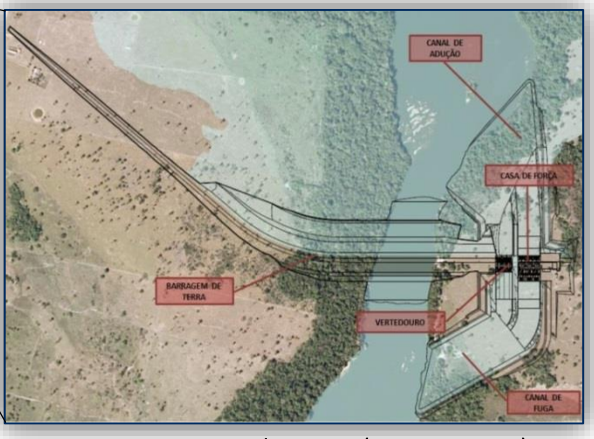
Note: Projected distributed generation is subtracted from the load forecast.

The majority of our hydro potential is located in the Amazon region

Several social and environmental barriers that hinder the development of new projects

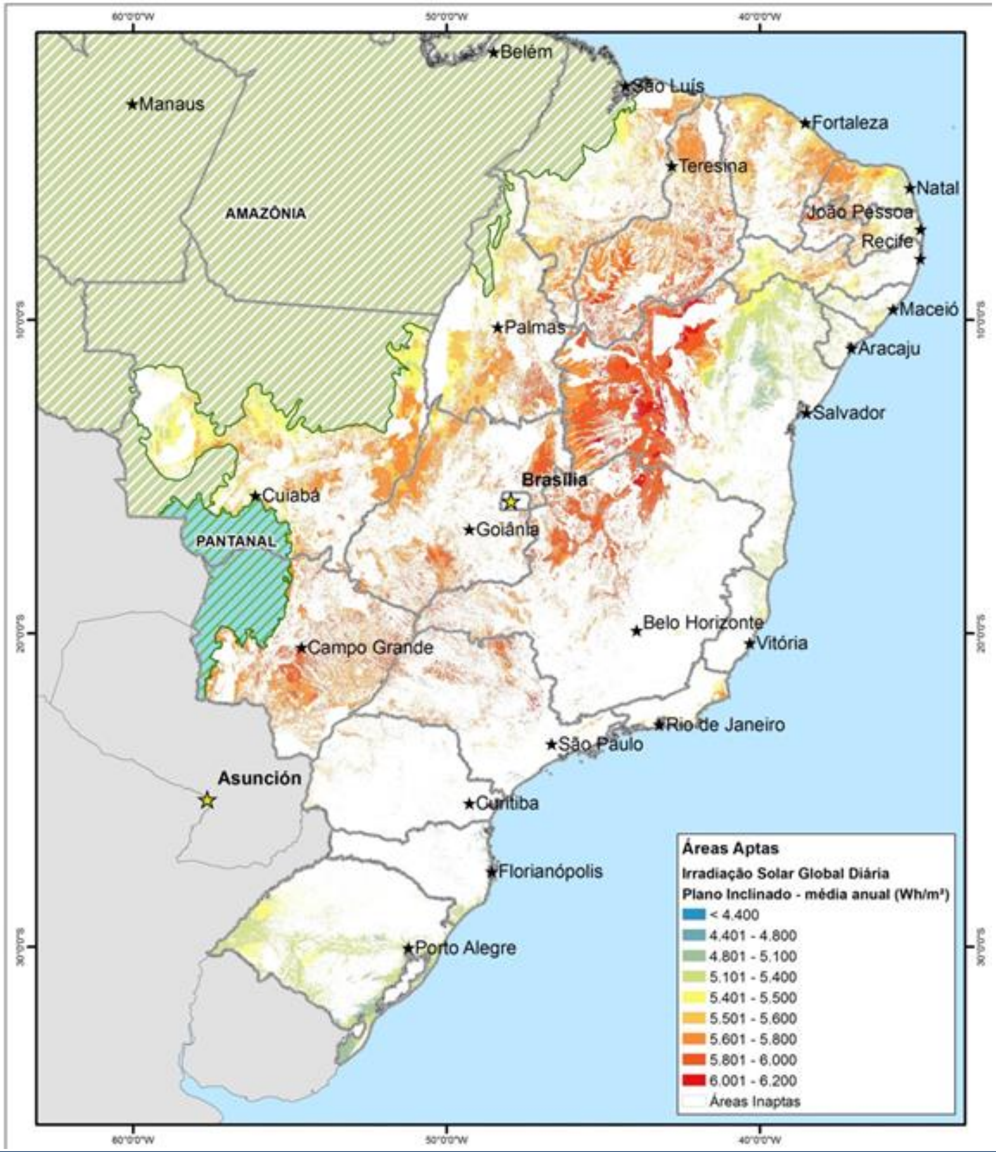
Hydro Region	Remaining Potential (MW)	%
Amazônica	33.278	64%
Atlântico Leste	807	2%
Atlântico Sudeste	1.194	2%
Atlântico Sul	327	1%
Paraguai	38	0%
Paraná	2.952	6%
Parnaíba	615	1%
São Francisco	1.839	4%
Tocantins-Araguaia	7.952	15%
Uruguai	2.865	6%
Total	**51.868**	**100%**

EPE studies (2017)



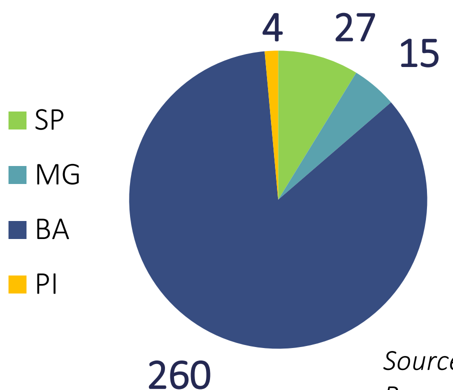
UHE Castanheira (140 MW)

Brazil has an enormous PV technical potential



Excluding areas with native vegetation:

Irradiation (Wh/m².dia)	Technical Potential(GWp)
4400-4800	24
4800-5100	747
5100-5400	4.803
5400-5500	2.618
5500-5600	3.406
5600-5800	10.101
5800-6000	6.513
6000-6200	307



Source: EPE – Book "Energia Renovável", 2016

And Wind potential as well

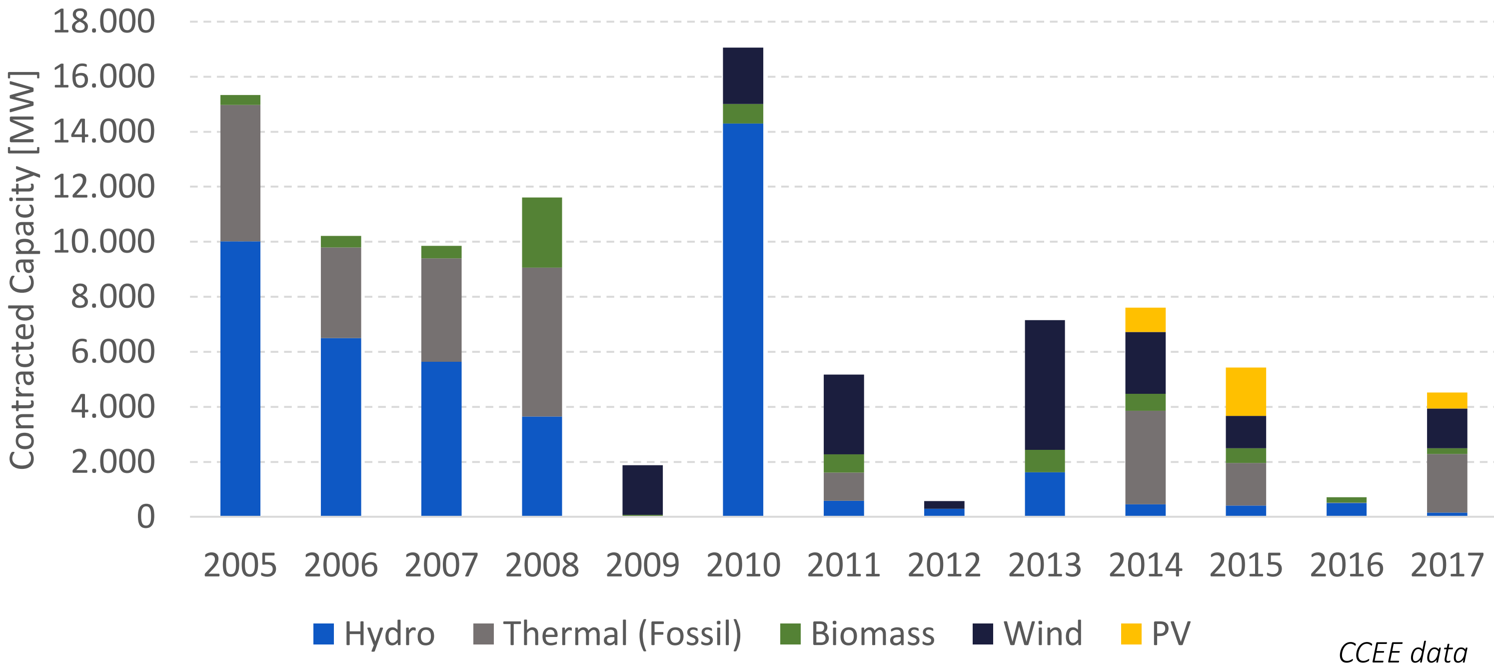
Height	100 m		150 m	
Potential by State (>7m/s)	Capacity (GW)	Annual Energy (GWh)	Capacity (GW)	Annual Energy (GWh)
Alagoas [2008]	0.6	1,340	-	-
Bahia [2013]	70	273,500	195	766,500
Espírito Santo [2009]	1.1	2,397	-	-
Minas Gerais [2010]	39	92,076	-	-
Paraná [2007]	3.4	9,386	-	-
Rio de Janeiro [2002]	2.8	8,872	-	-
Rio Grande do Norte [2003]	27	69,293	-	-
Rio Grande do Sul [2014]	103	382,000	245	911,000
São Paulo [2012]	0.6	1,753	-	-
Total	247	839,277	440	1,677,500

Source: Prepared by EPE, multiple sources

Photo by Sam Forson

Integration of wind & solar is changing the demand/supply of short-term flexibility…

- Recent expansion via auctions of long-term PPAs for regulated market (“half” of the story, since wind has also expanded for the deregulated market):



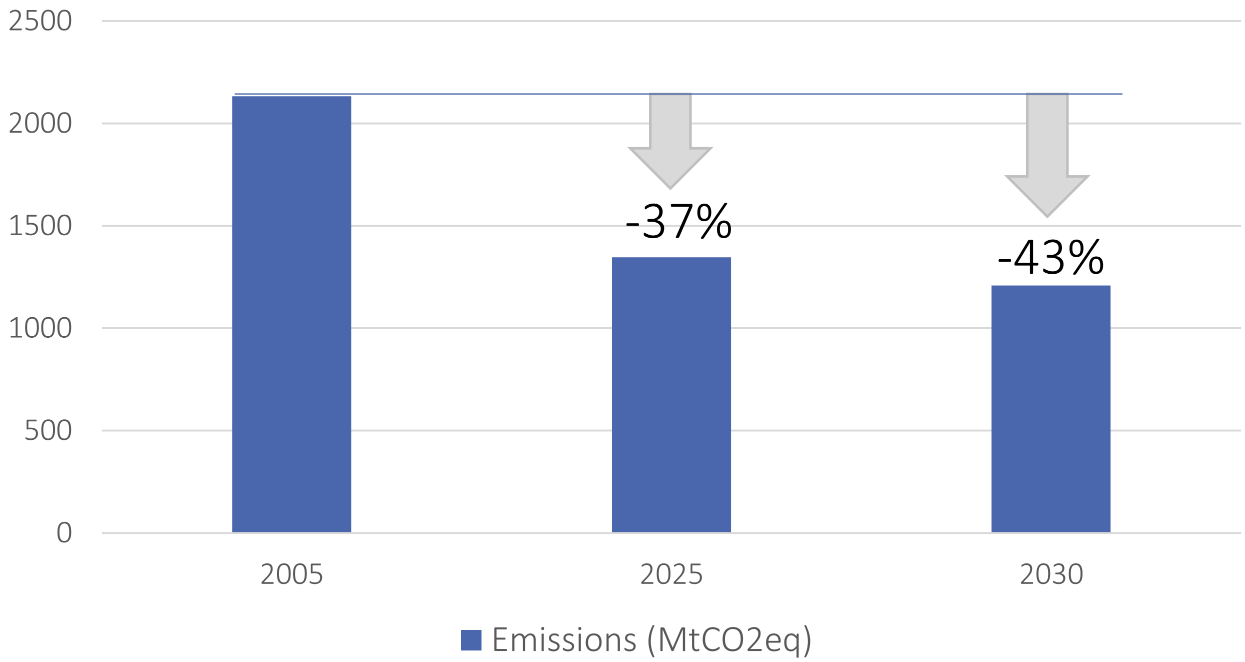
CCEE data

- Wind and solar: 8.5% of Brazilian installed capacity in 2018…
  - … and shall exceed 11% of installed capacity in 2021.

Brazilian Nationally Determined Contribution (NDC)

Limit the temperature increase to 2 °C
above to pre-industrial levels

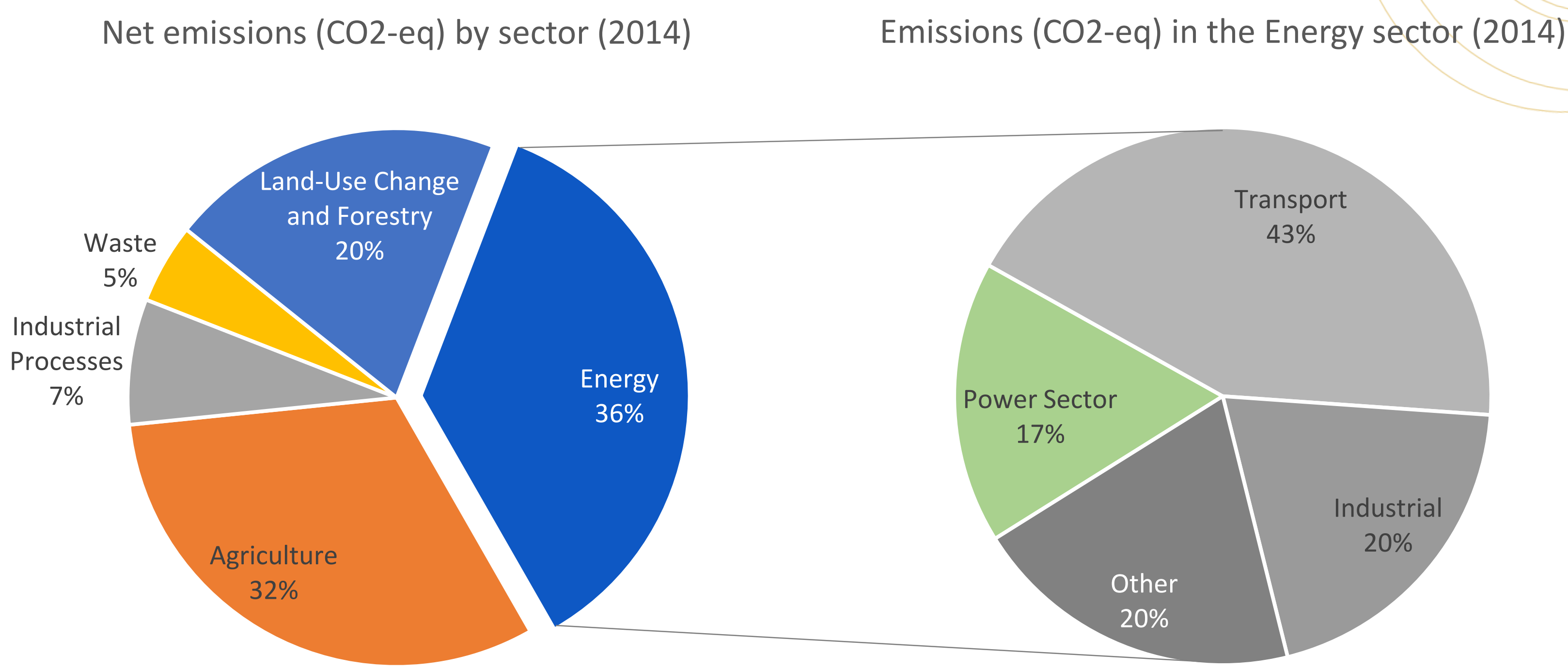
Global Commitment



Brazilian Commitment

Brazil's NDC is economy wide and therefore is based on flexible pathways to achieve the 2025 and the 2030 objectives.

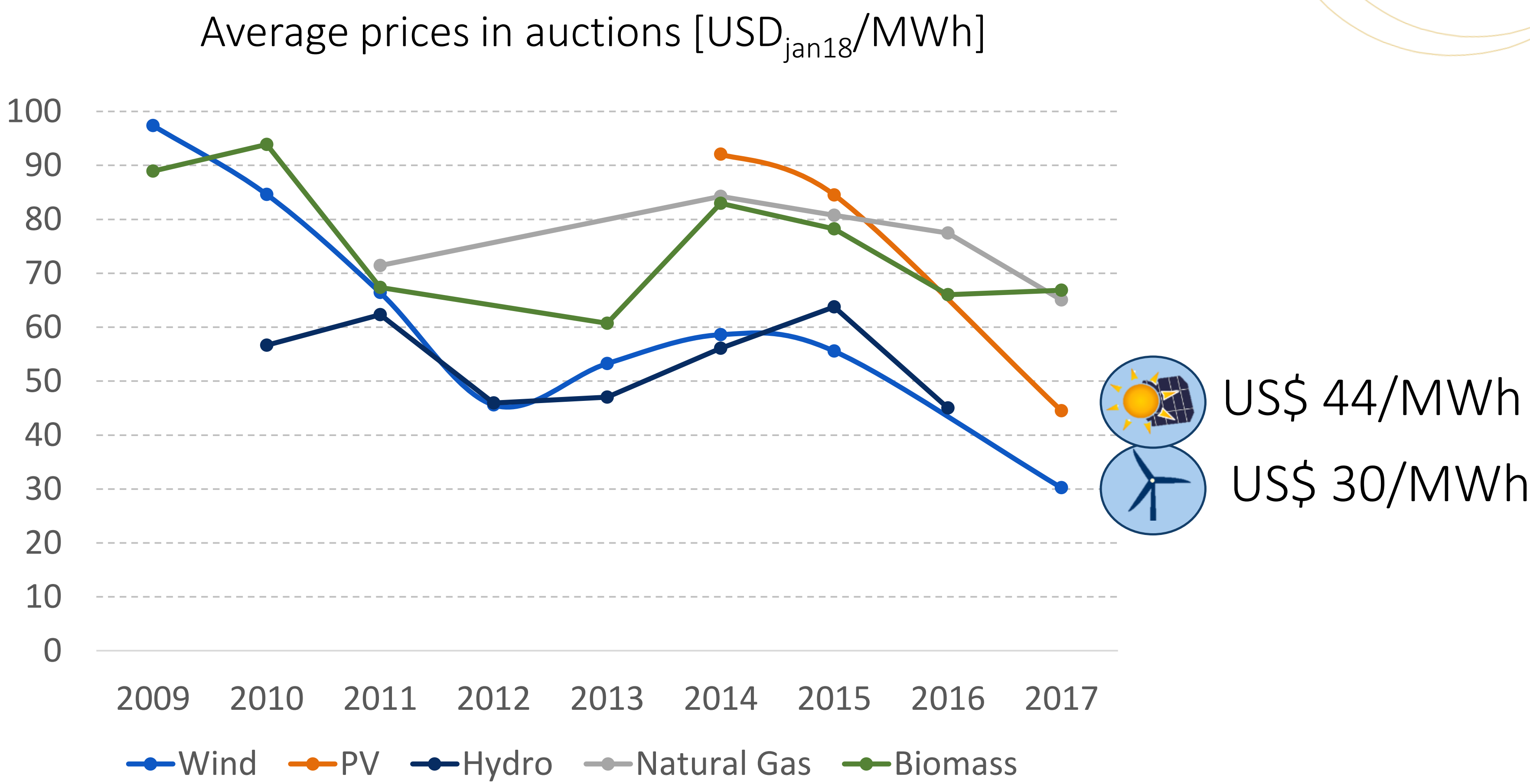
The Brazilian power sector has a low contribution to total emissions



Power Sector Emissions = 36% x 17% = 6%

Source: Emissions by sector - SEEG Brazil. Energy sector emissions calculated from BEN and EPE data.
Note: CO2 equivalent by sector calculated based on GWP-AR2.

Cost reductions are driving the increase of wind and PV in our mix



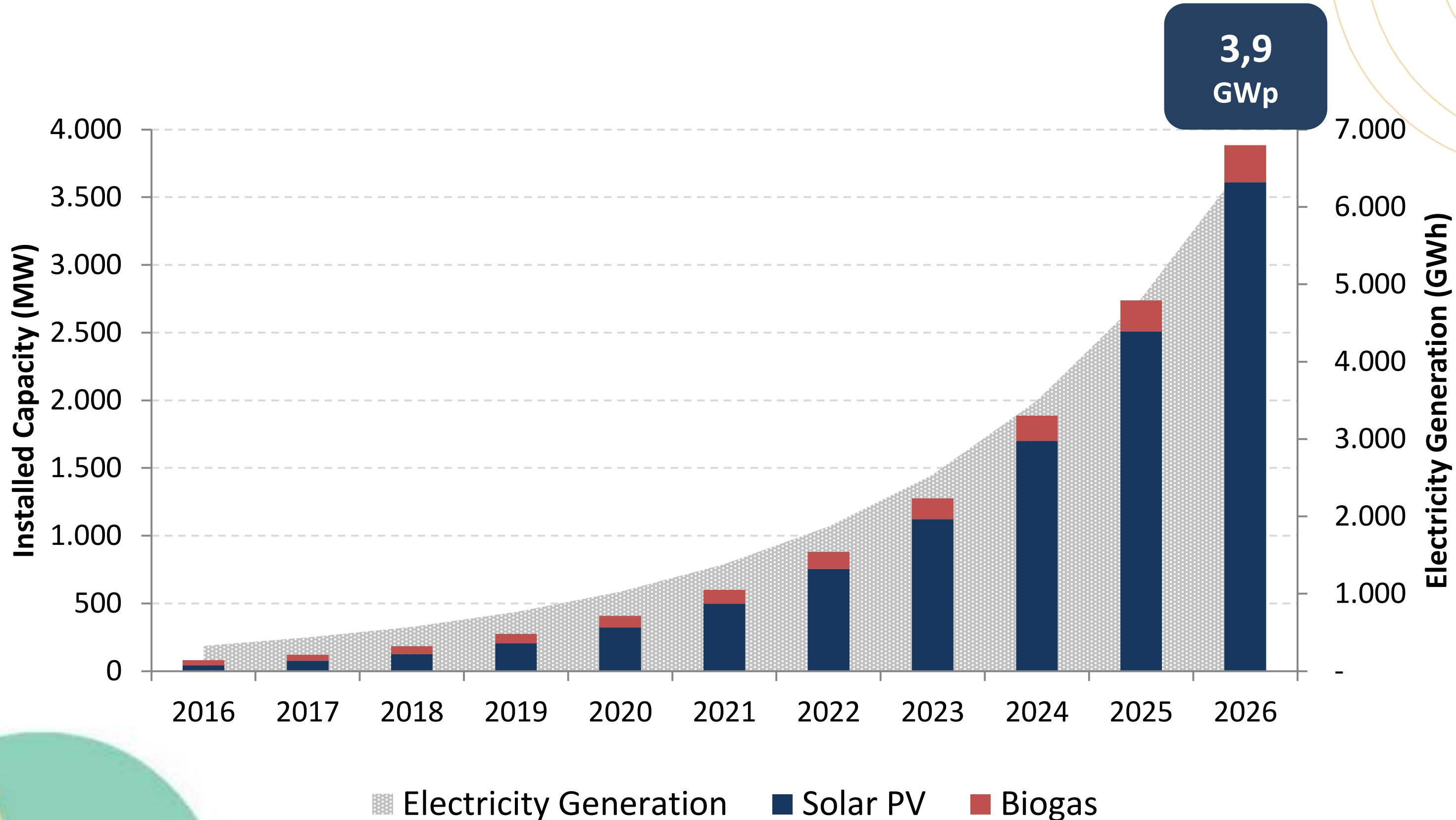
CCEE data

PV and Wind registered a huge amount of projects for the next A-4 auction (Apr/18)

- 2 New Electricity Auctions to be held in 2018.
  - "A-4" auction: supply to begin in January 2022 (scheduled for April, 4th).
  - "A-6" auction: supply to begin in January 2024 (TBA until March, 30th).
- "A-4" auction with 4 "products":
  - Wind; solar PV; biomass-fired thermal; and small hydro

Source	Number of Projects Registered	Registered Capacity (MW)	Price Cap (US$/MWh)
Wind	931	26,198	78
Hydro	3	114	88
Solar	620	20,021	95
Biomass	28	1,422	100
Total	**1,672**	**48,713**	**-**

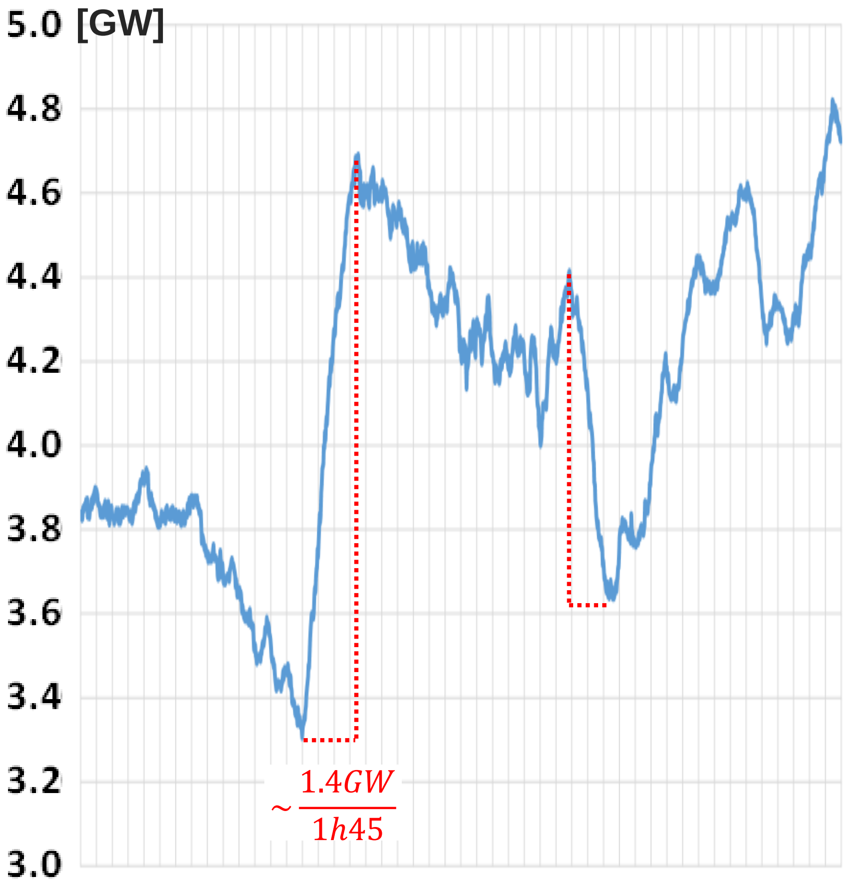
Small-scale Distributed Generation Forecast (PDE 2026)



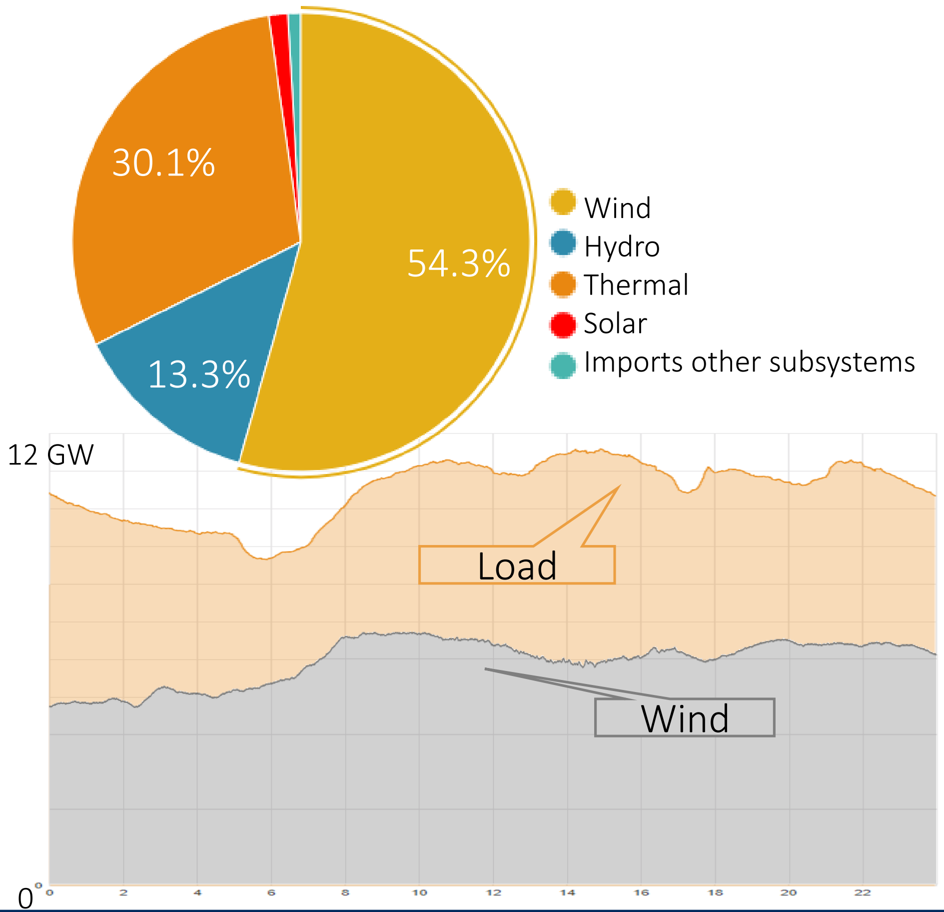
800 thousand buildings with solar PV by 2026

The Northeast has already been giving us a sample of challenges in this context

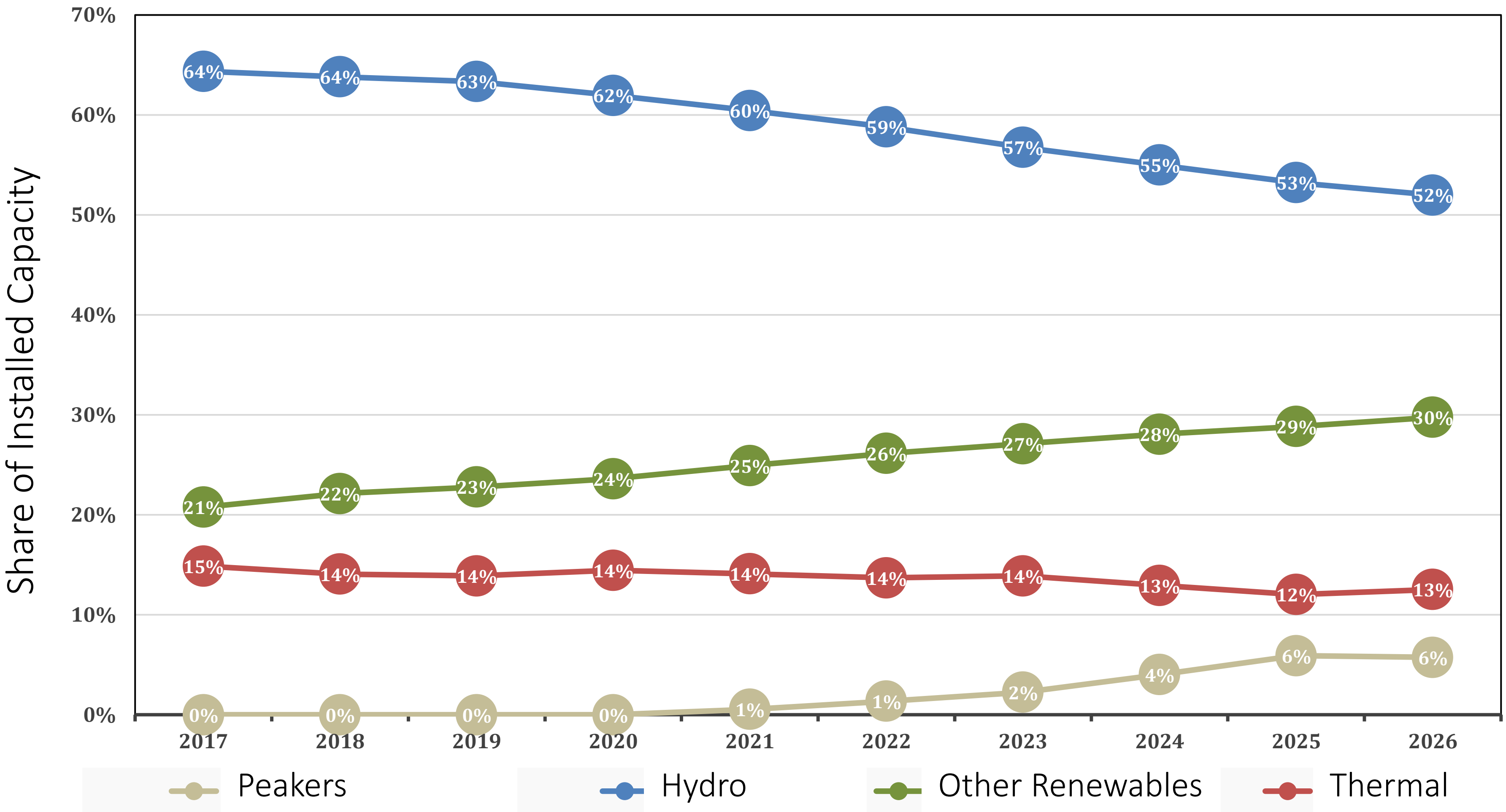
- Ex.: wind gen. NE (June 26, 2017):



- Daily supply mix in Northeast (Oct/4)

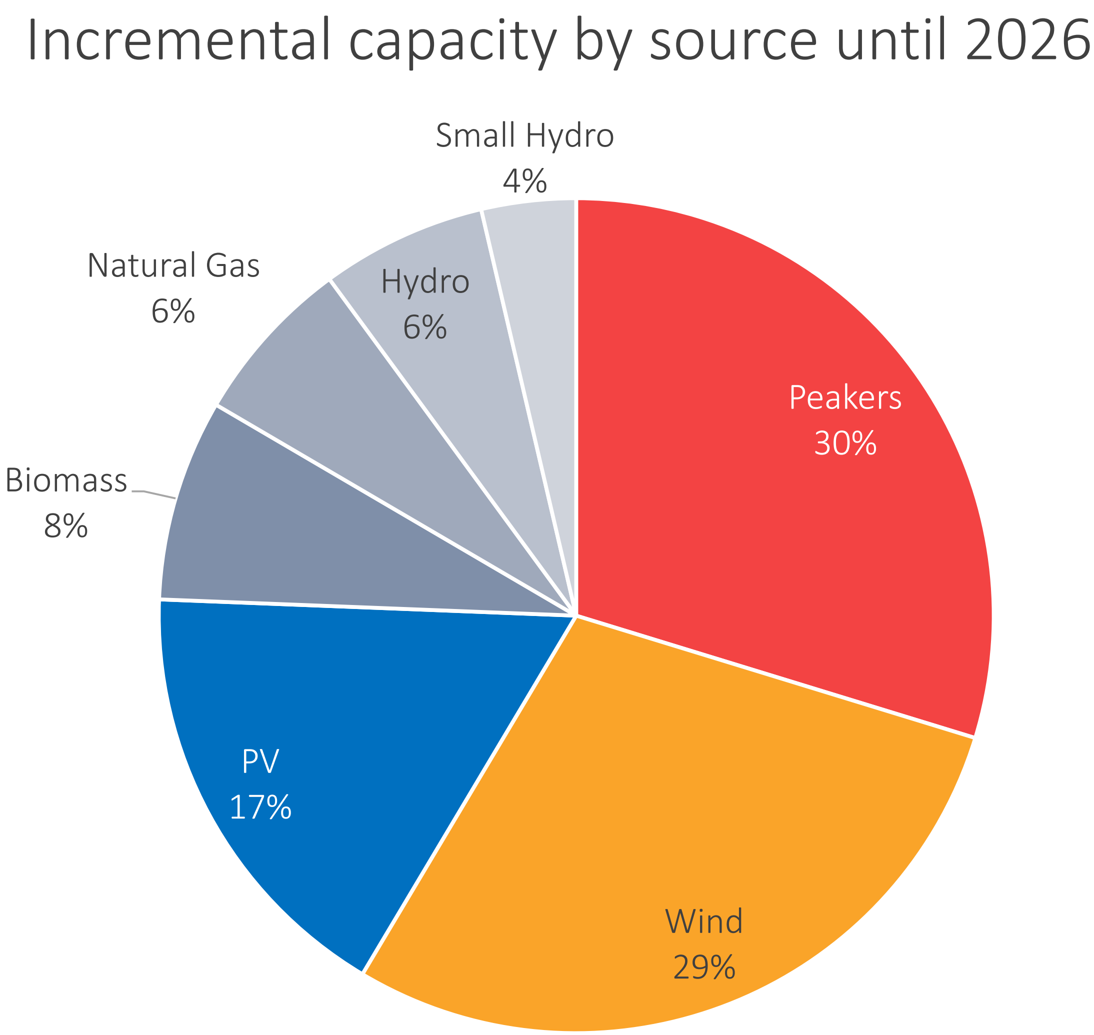


PDE 2026: Summary of Results - Source Case



The diminishing share of hydroelectric and the increase of variable renewables requires solutions to provide flexibility.

“Peakers” will demand a lot of investments in the next years

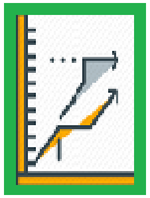


Note: excludes plants already contracted.

Alternatives to cope with the increasing share of variable renewables in the Brazilian system

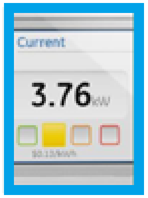
Main alternatives

Flexible Generation

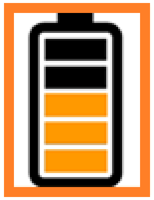


Generation Forecasts

Grids



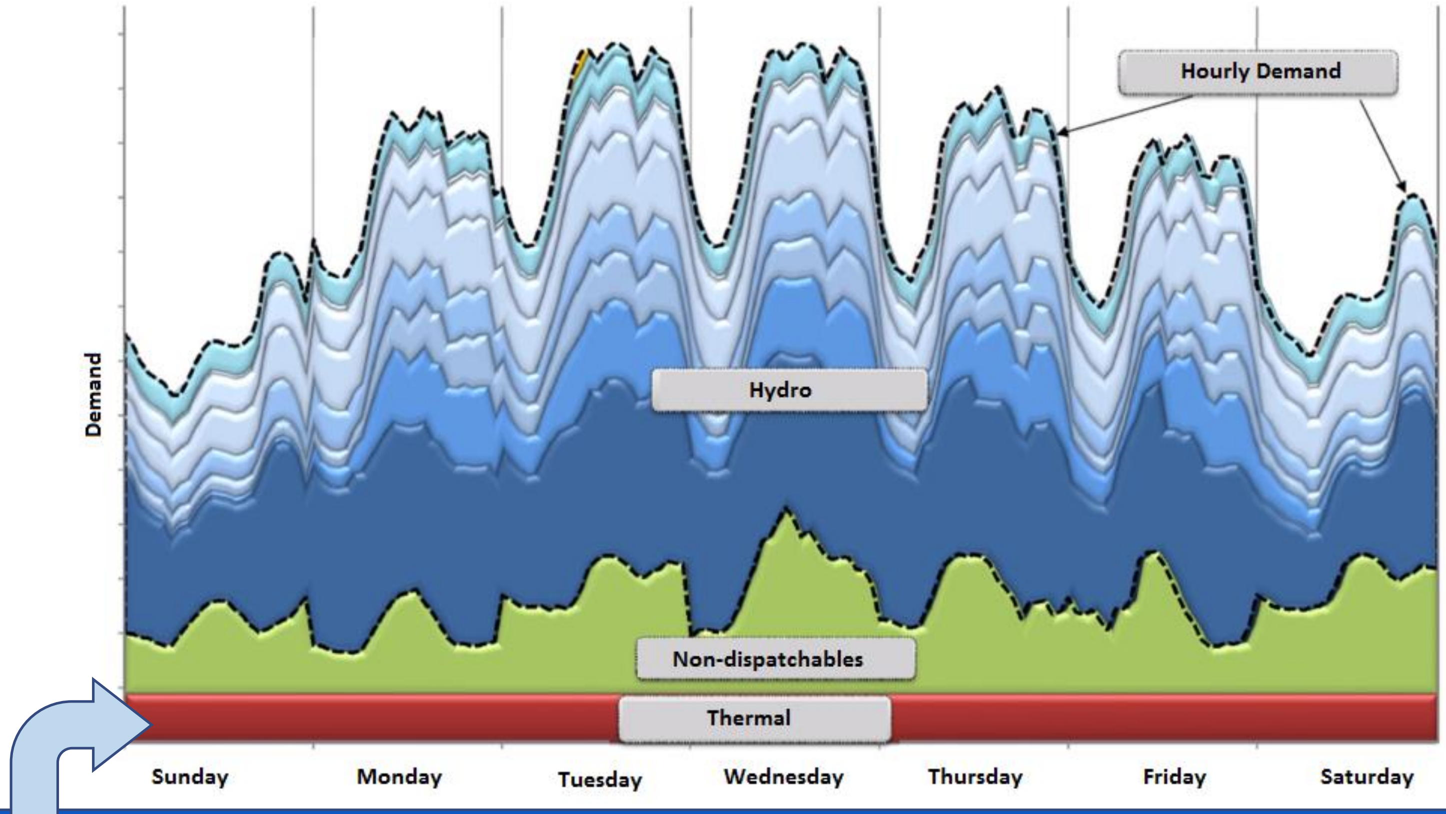
Demand-Side Management



Storage

First of all, we already have a good source of flexible generation – How to make a better use of it?

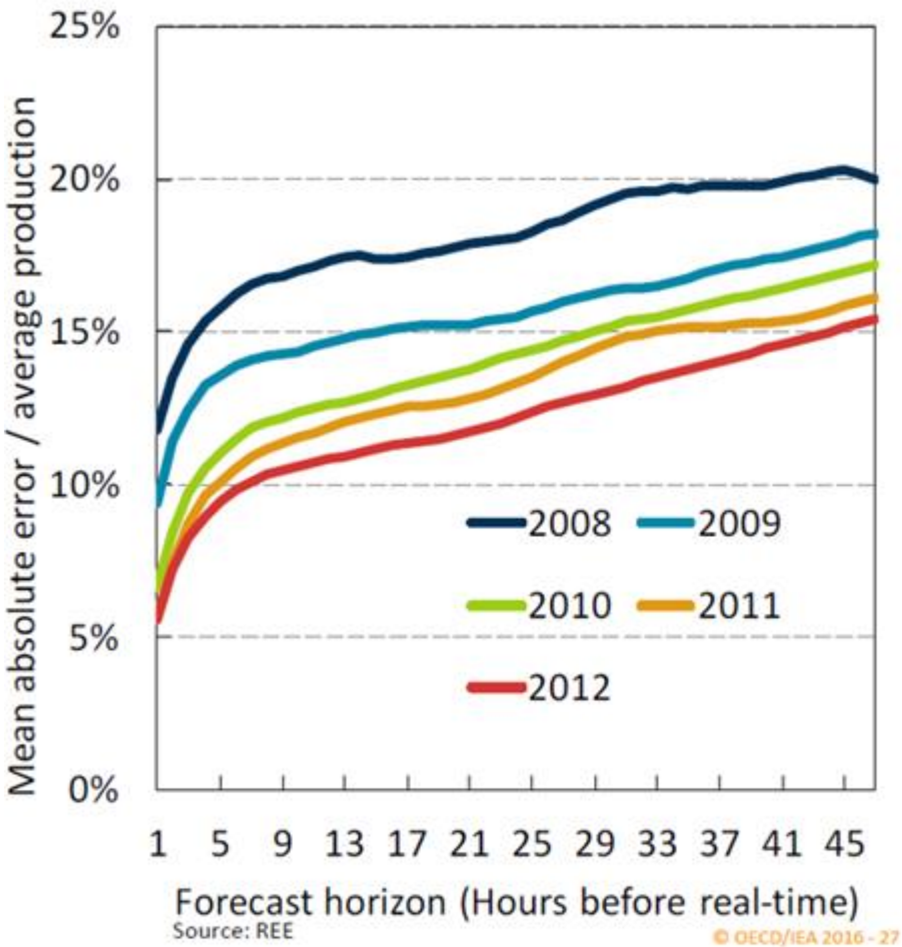
Example of a hourly energy balance



Increase the thermal generation might be a good alternative to take advantage of our existing hydro capacity

Improvements in the generation forecasts

Example of improvements in the accuracy of Wind forecasts in Spain



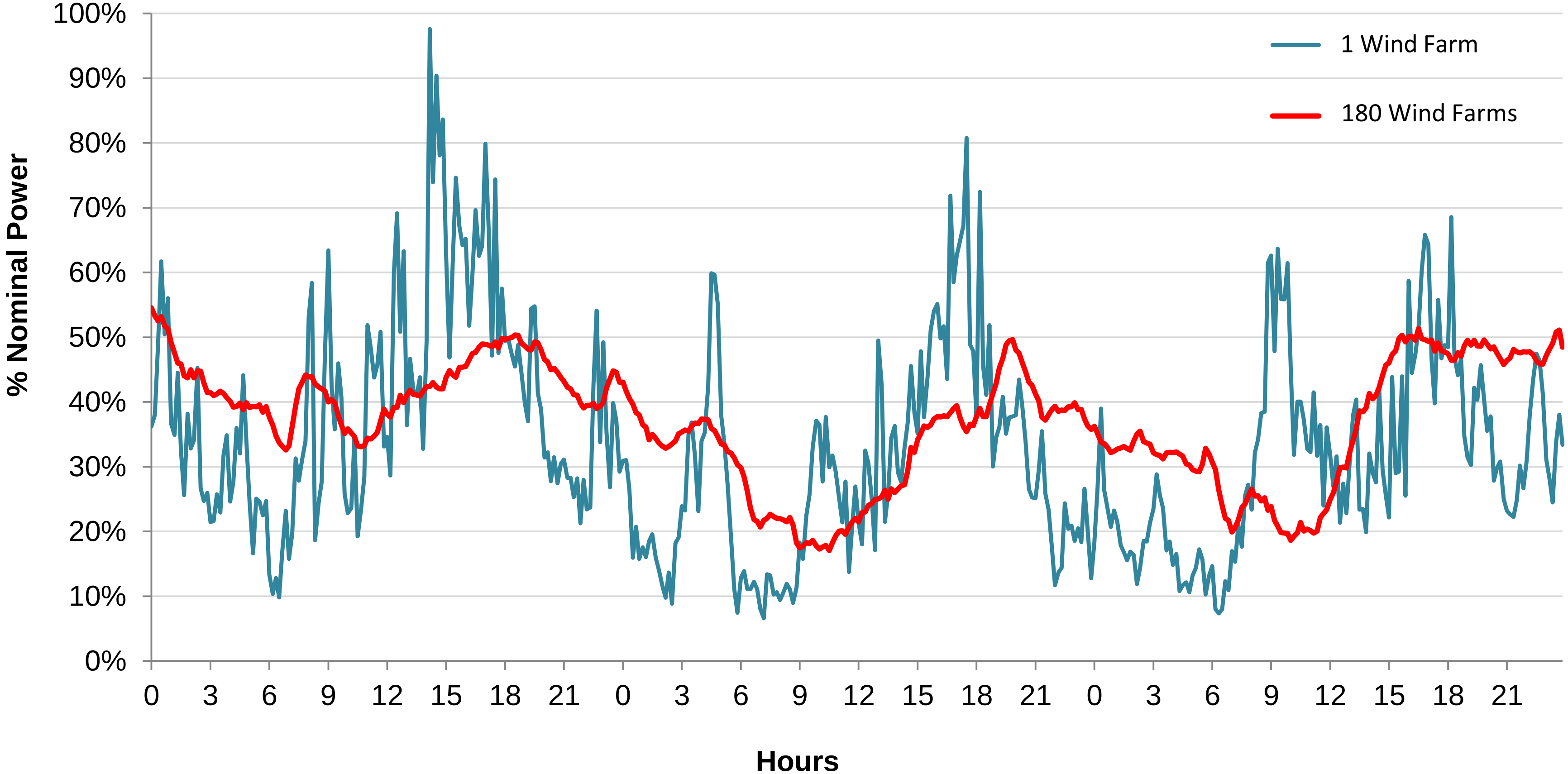
Anemometric Measurement Monitoring System: since 2011, EPE collects wind and climate measurement data from all auctions' winning wind farms in Brazil;

! Lacking a similar system for PV.

ONS launched last year a new model to forecast the wind generation in Brazil.

Aggregation of Power Plants can help to reduce variability

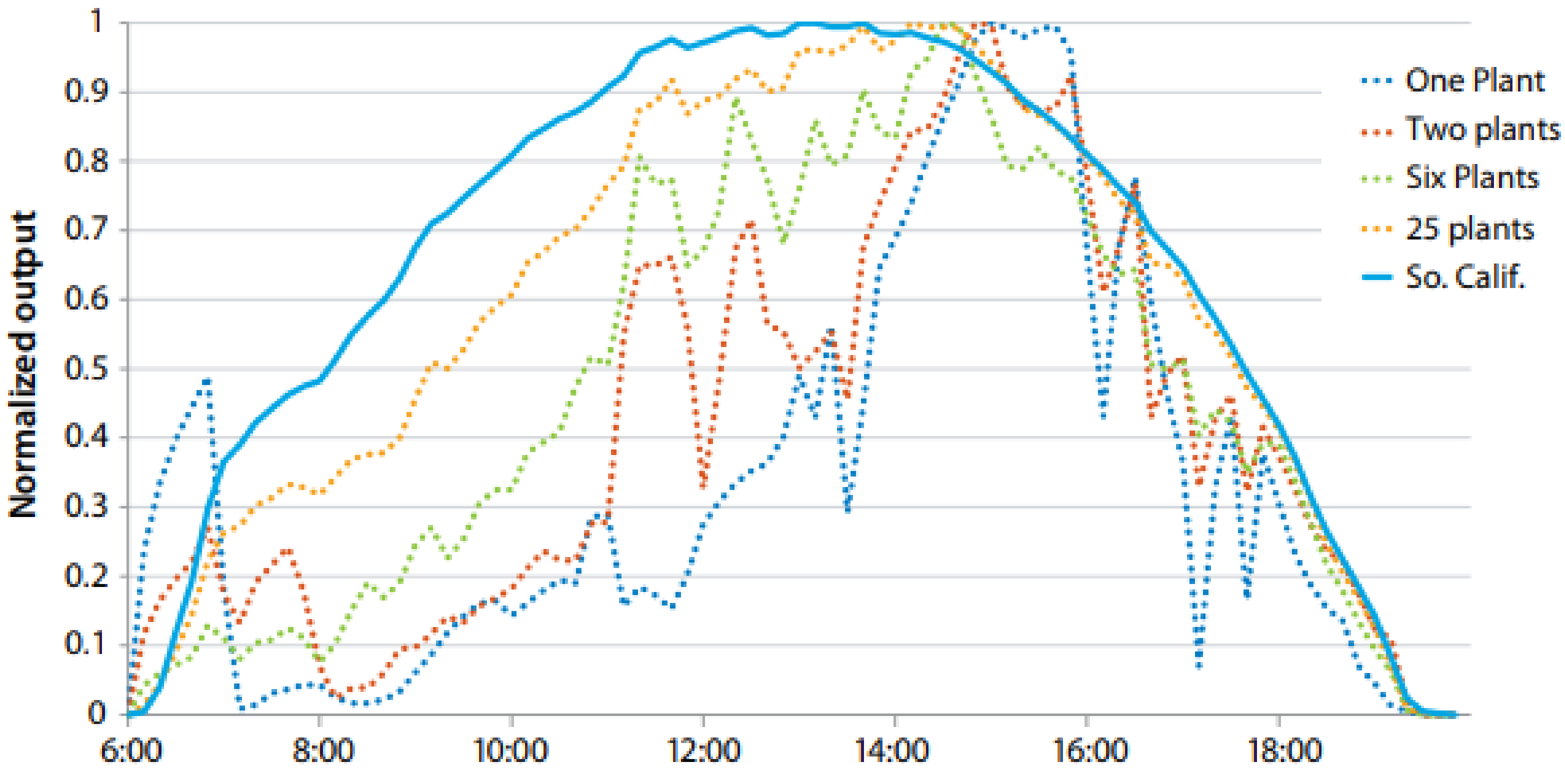
Example for Wind in the Northeast



Source: EPE, 2017

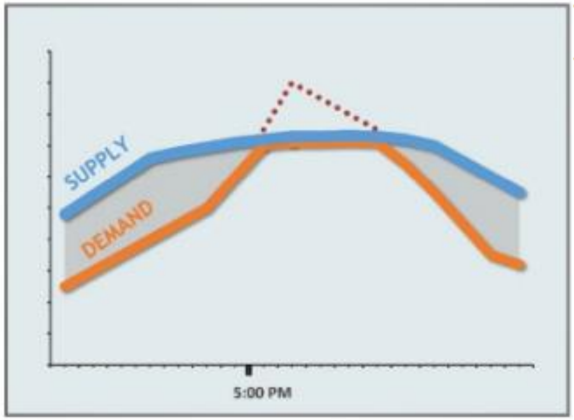
Aggregation of Power Plants can help to reduce variability

Normalized power output for increasing aggregation of PV in Southern California for a partly cloudy day



Source: NREL, 2013

Demand Response Pilot Programme



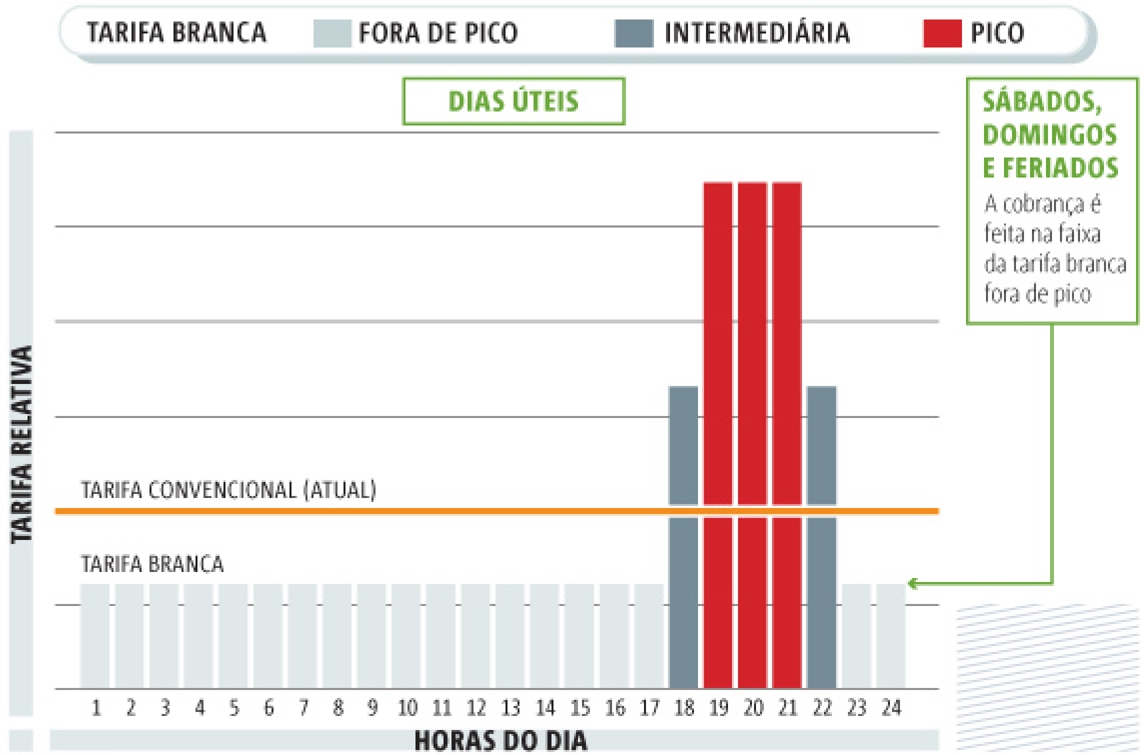
- Approved in November, 2017;
- Valid until June, 2019;
- Valid only in the North and Northeast subsystems;
- Only for large consumers (free consumers, partially free consumers and consumers whose energy purchase contracts follow the precepts established in art. 5 of Law 13.182/2015).
- Demand response can be used to:
    - Operating reserve;
    - Peak power;
    - Frequency regulation.

Time of Use (ToU) tariffs for retail customers

- Started in 2018;
- Three different rates during weekdays (peak, shoulder and off-peak);

! Not mandatory.

It may lead only customers who do not need to change their load profile to migrate to ToU tariffs → less revenue to the utility → tariff increase for other customers.



Public hearing on low-voltage tariffs

SUPERINTENDÊNCIA DE GESTÃO TARIFÁRIA

Nota Técnica nº 46/2018-SGT/ANEEL
Brasília, 02 de março de 2018

MODELO TARIFÁRIO DO GRUPO B

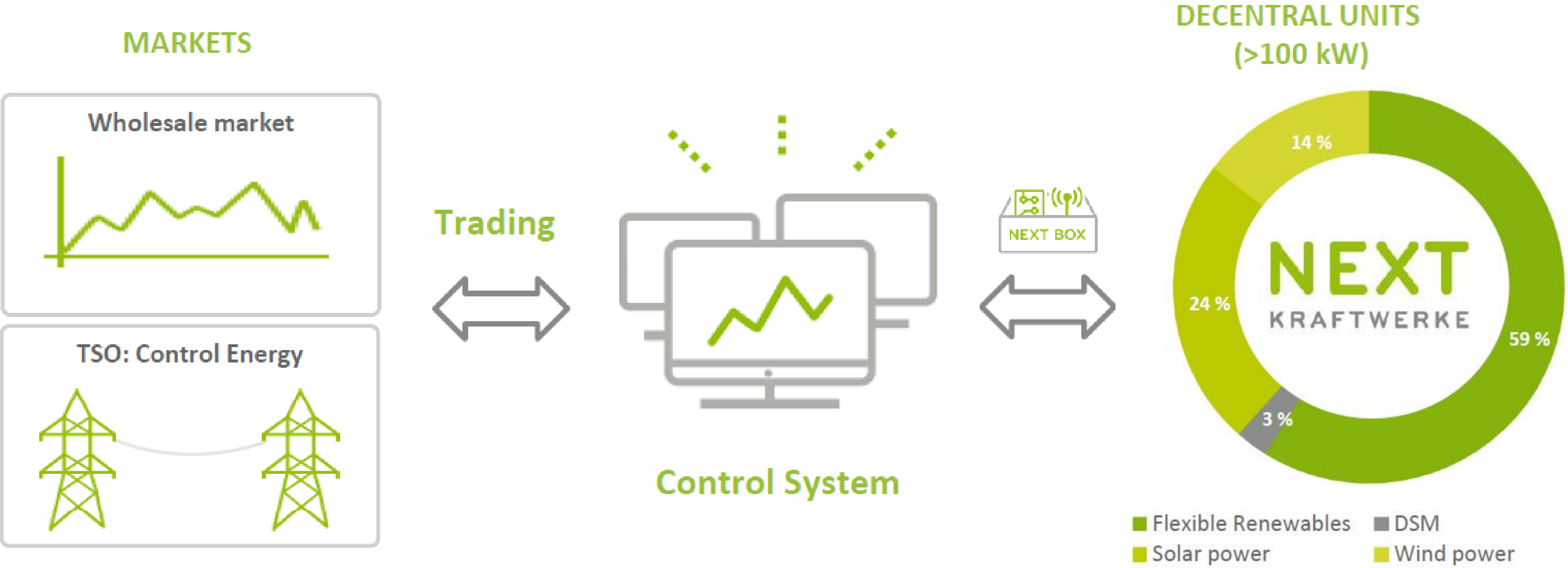
CONSULTA **PÚBLICA**

Agência Nacional de Energia Elétrica
Superintendência de Regulação Econômica
SGAN 603 / Módulo "J" – 1º andar
CEP: 70830-030 – Brasília – DF
Tel: + 55 61 2192-8814

ASSINADO DIGITALMENTE POR DAVI ANTUNES LIMA, ROBSON KUHN YATSU
DIEGO LUIS BRANCHER,ANDRE MEISTER
CÓDIGO DE VERIFICAÇÃO: 2F3D2B6200443084 CONSULTE EM http://sicnet2.aneel.gov.br/sicnetweb/v.aspx

Open to contributions until May 11, 2018

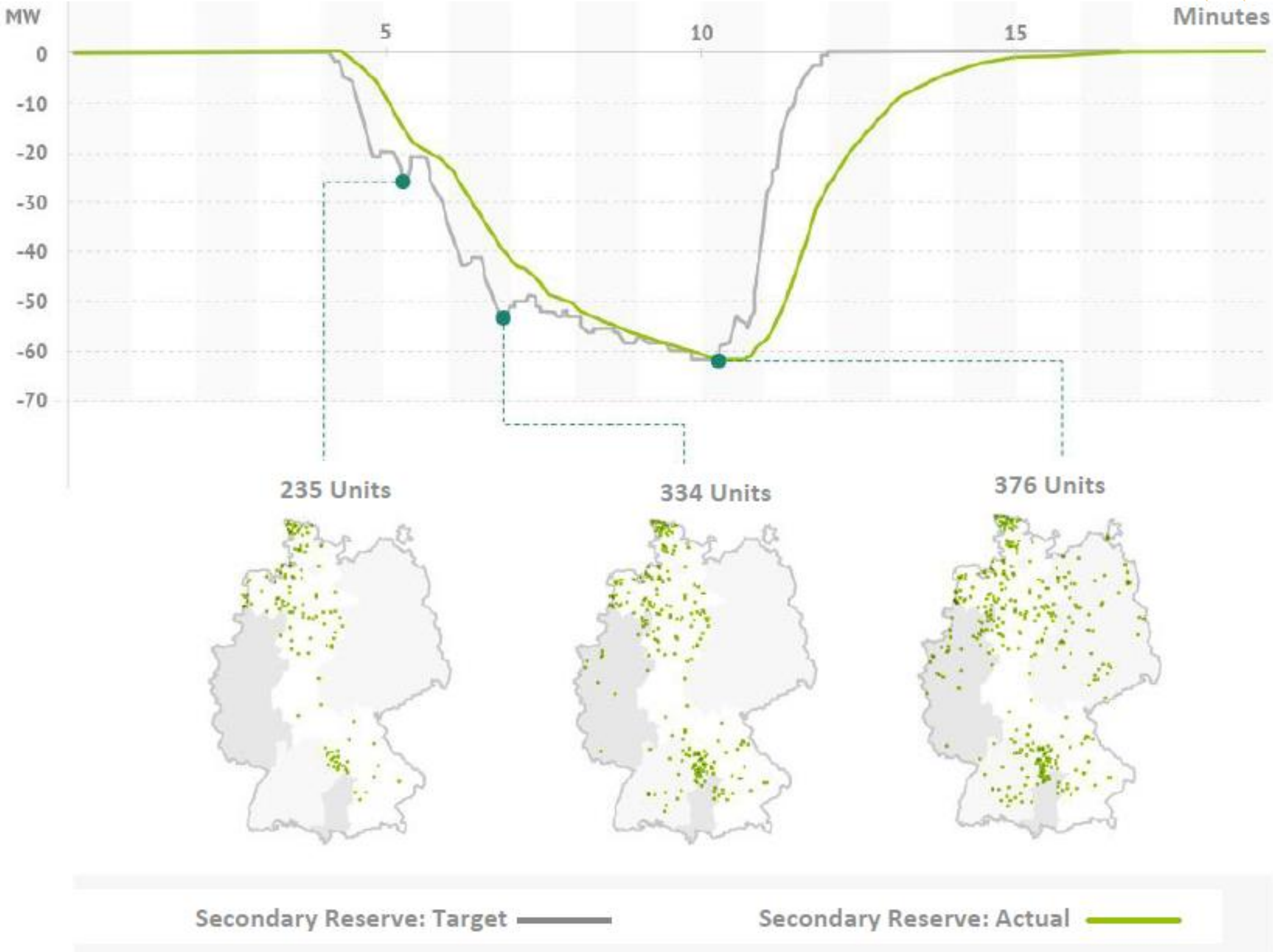
Alternatives to provide flexibility: Virtual Power Plants



- Control system as collector of all the information transmitted by the Next Boxes and the electricity system.
- Through the central control system, the units are controlled, started up and shut down
- Trading department monetizes the electricity and the flexibility

Source: Next Kraftwerke

Alternatives to provide flexibility: Virtual Power Plants



Source: Next Kraftwerke

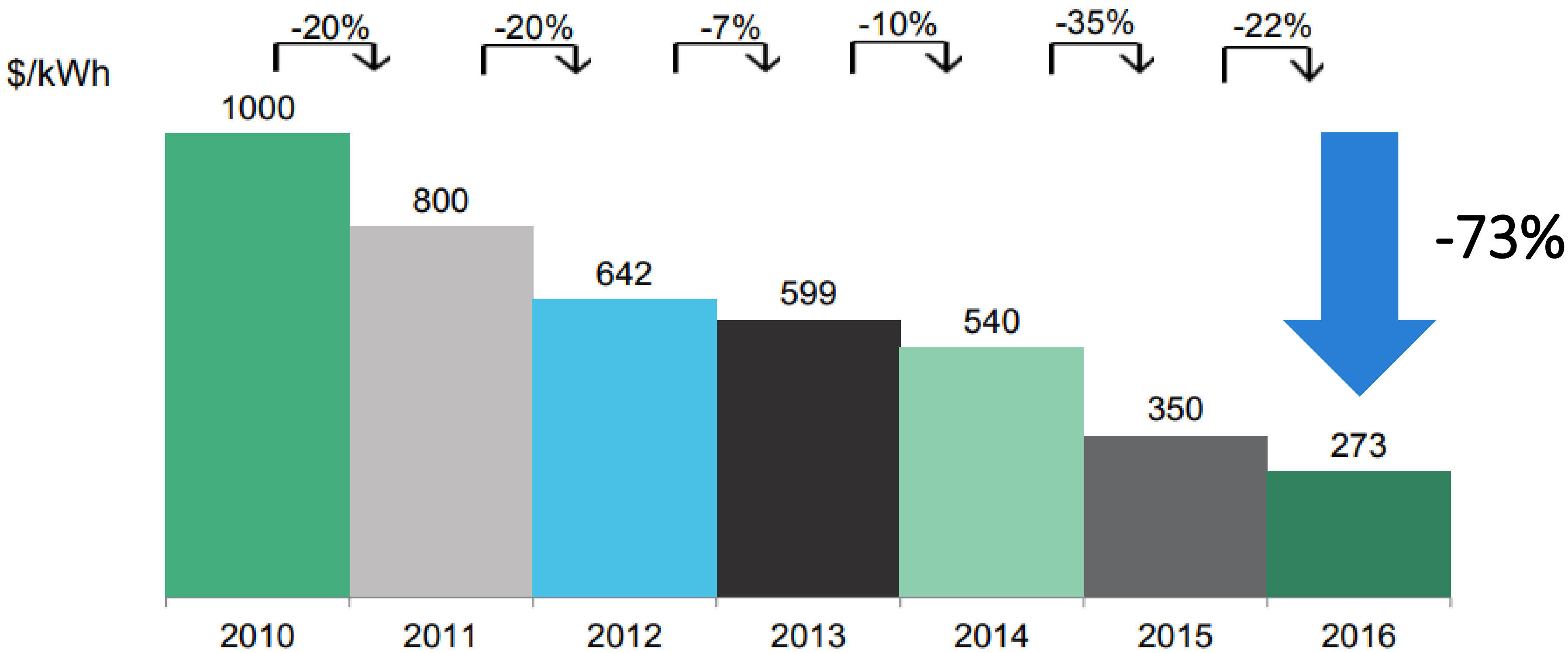
Storage Initiatives

- Strategic R&D project #21:
  - 23 projects were approved;
  - Widely spread across the country;

- Battery Storage Auction in Roraima (isolated system):
  - 70 MW/35 MWh -> significant size
  - Mainly to avoid blackouts when the connection with Venezuela is lost. -> But also will foster the storage industry in Brazil;
  - Approved by MME in June, 2017;
  - Technical specifications were detailed by EPE and ONS.

Batteries are a great promise.

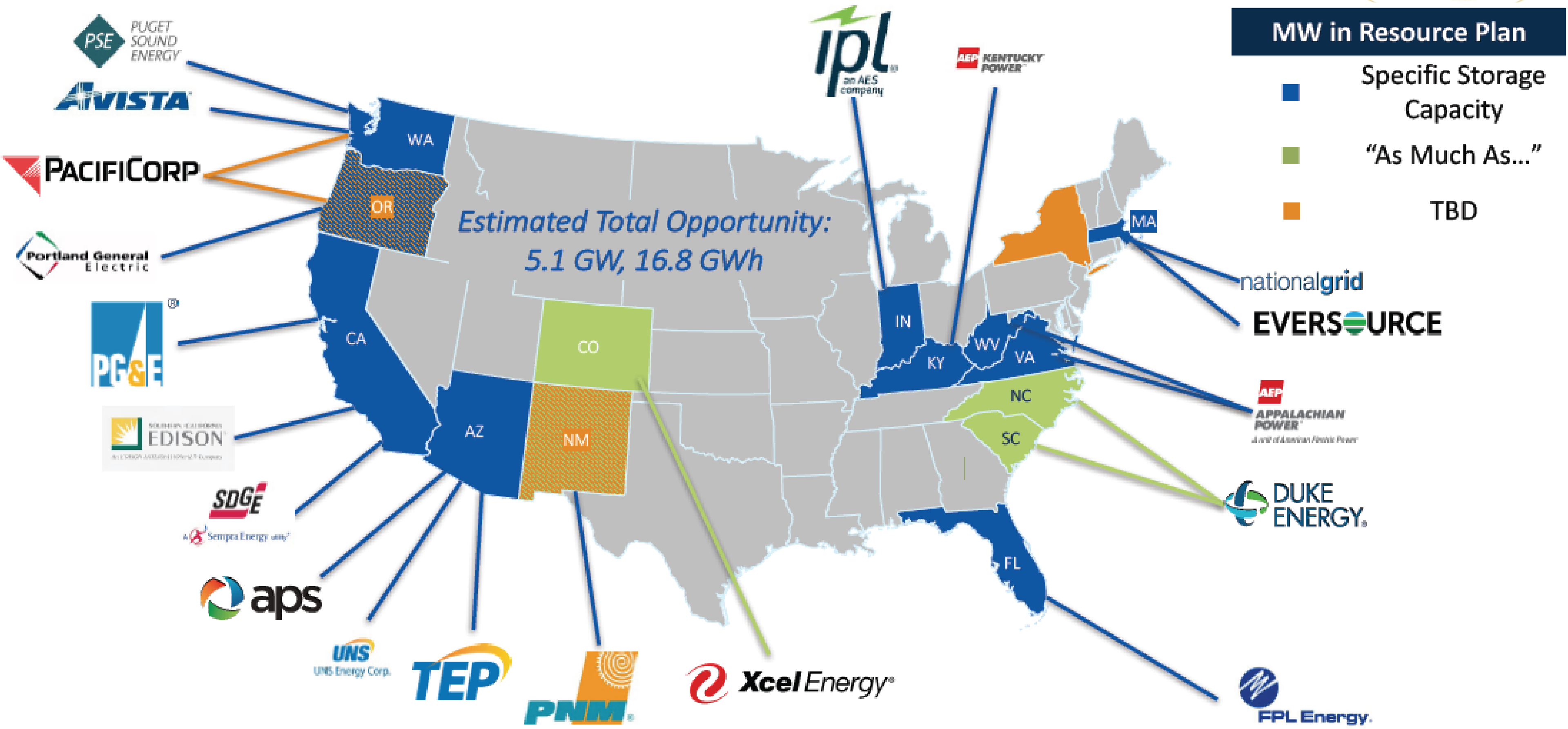
BNEF lithium-ion battery price survey, 2010-2016



Source: Bloomberg New Energy Finance. *https://data.bloomberglp.com/bnef/sites/14/2017/07/BNEF-Lithium-ion-battery-costs-and-market.pdf*

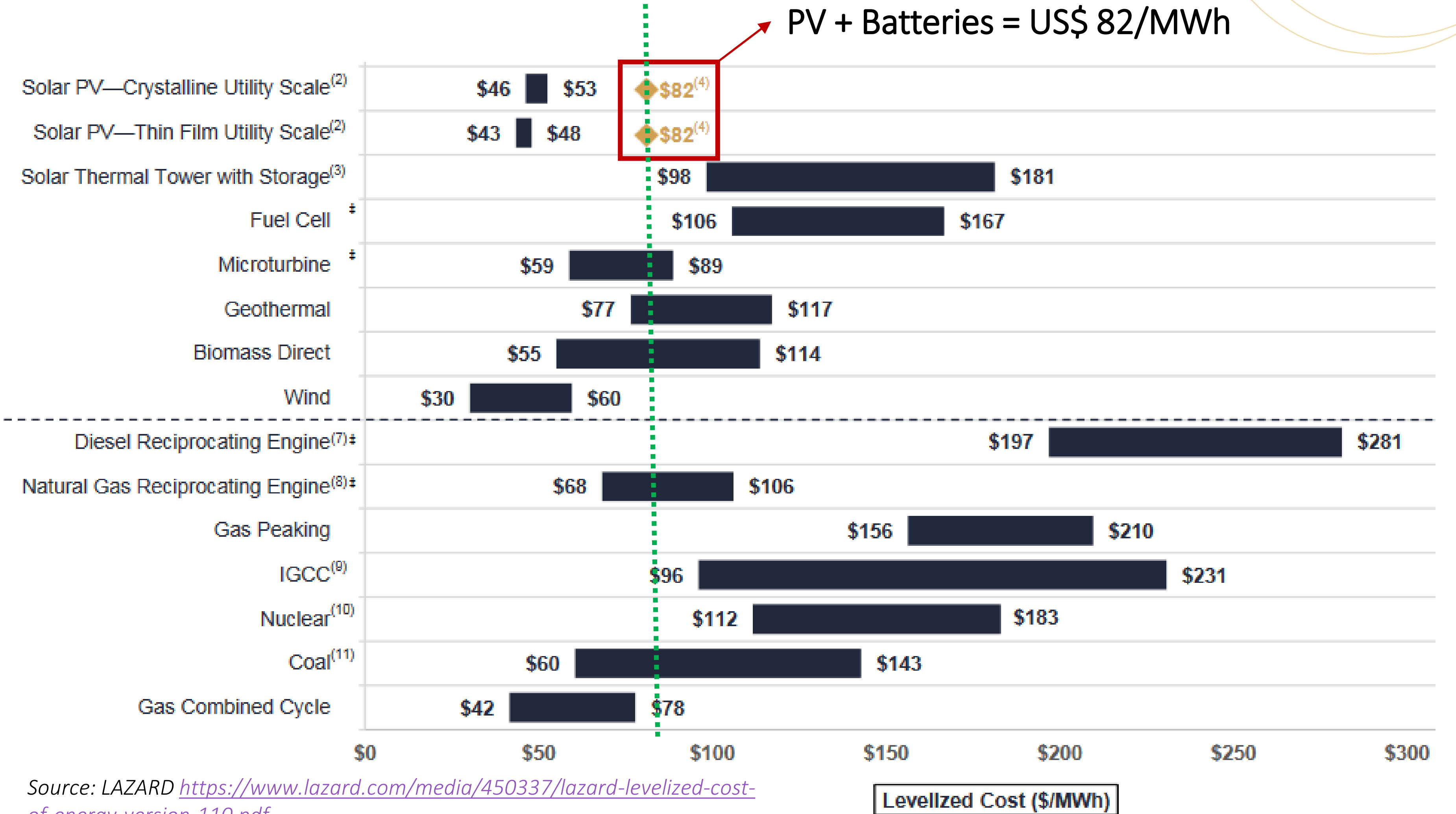
Indeed, many utilities in the US are considering batteries in their plans.

Storage Modeled, Eligible or Mandated in Utility Integrated Resource Plan (MW)



Source: GTM Research

Solar + Batteries is becoming a competitive source



Source: LAZARD https://www.lazard.com/media/450337/lazard-levelized-cost-of-energy-version-110.pdf

"Solar + Batteries" PPAs are being signed at reasonable prices

- **Updated: Tucson Electric signs solar + storage PPA for 'less than 4.5¢/kWh'**

  Source: Utility Dive, May 23, 2017

  Subsidized price. The estimate for unsubsidized price is around US$ 0,09/kWh (https://www.utilitydive.com/news/how-can-tucson-electric-get-solar-storage-for-45kwh/443715/)

- **Hawaii co-op signs deal for solar+storage project at 11¢/kWh**

  Source: Utility Dive, January 10, 2017

“Solar/Wind + Batteries” PPAs are being signed at ~~reasonable~~ very low prices

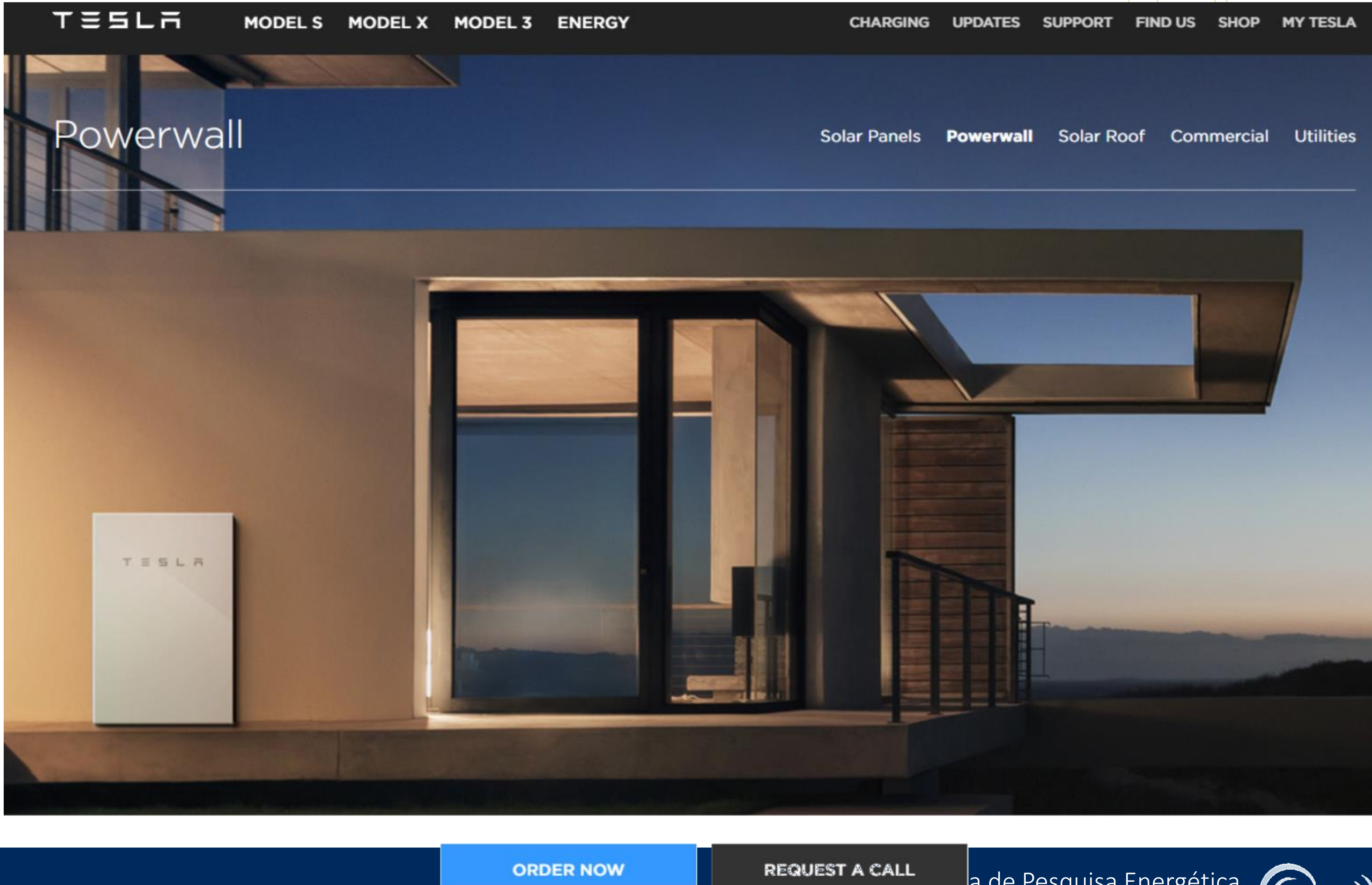
- **Xcel Attracts ‘Unprecedented’ Low Prices for Solar and Wind Paired With Storage**

  Bid attracts median PV-plus-battery price of $36 per megawatt-hour. Median wind-plus-storage bids came in even lower, at $21 per megawatt-hour.

  - Projects are due to go online by 2023
  - In 2023, the U.S.' federal solar Investment Tax Credit is due to drop from 30 percent to 10 percent

Source: GreenTech Media, January 8,, 2018

Behind-the-meter batteries might contribute as well



But... What if consumers decide to go off grid?

O interesse em sair do grid, segundo buscas no Google

Source: Google Trends

What will the future be like?

“Difficult to see. Always in motion is the future..” – Yoda.

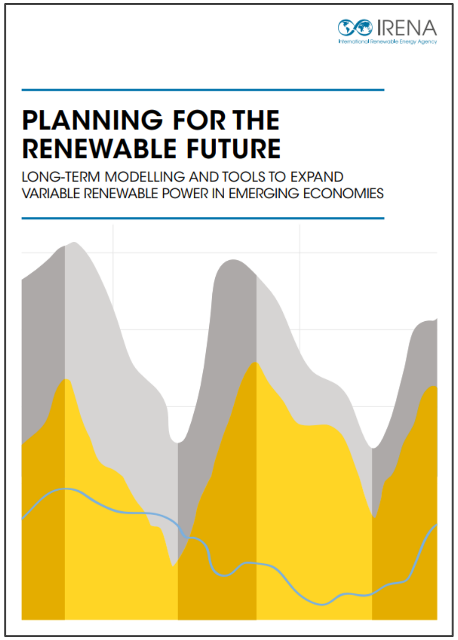
“As for the future, your task is not to foresee it but to enable it. – Antoine de Saint-Exupéry

How EPE is adapting to this new era?

Improving our models

Goals:

- Improve time resolution (hourly);
- Improve the integration between generation and transmission studies (e.g. increase spatial resolution by adding more subsystems);
- Improve the uncertainties representation of renewables;
- Detailed operation;
- Improve the representation of storage technology;



EPE approved the acquisition of a planning software/toolkit

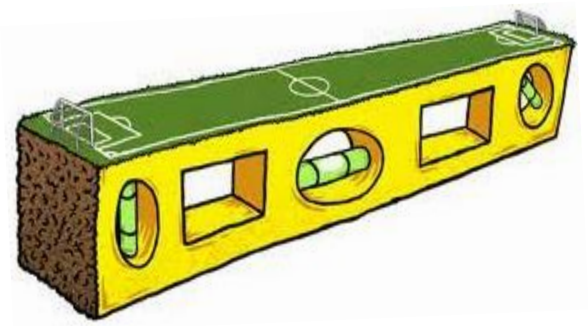
How EPE is adapting to this new era?

Changing our perspective

Interpretation of expansion plans as instruments to subsidize the design of policy and regulatory frameworks

- Sensitivity analysis
- Impact Assessment

Help to create a level playing field



MME has just released a Bill project to modernize the electricity regulatory framework

- Released on February 9th, built upon more than 200 contributions under a public consultation process

- The main proposals take into account:
  - From weekly to hourly wholesale prices;
  - Capacity/Energy splitting;
  - Improvement of price formation mechanism:
    - Tight pool to loose pool;
  - Less barriers to access the free market;
  - Locational signals in the grid fees:
    - Transmission: mandatory;
    - Distribution: to be assessed;

- Next step is the submission of the project to the congress for a wide discussion with the society

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Projeto de Lei de Modernização e Abertura do Mercado Livre de Energia Elétrica

Publicação: 09/02/2018 | 14:58
Última modificação: 09/02/2018 | 15:02

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G+

O Ministro de Minas e Energia Fernando Coelho Filho encaminhou à Presidência da República a proposta de Projeto de Lei de Modernização e Expansão do Mercado Livre de Energia Elétrica. A proposta de aprimoramento do marco legal do setor elétrico reflete o encerramento da Consulta Pública Nº 33, instaurada em 5 de julho de 2017, que teve mais de duas mil interações e recebeu 209 contribuições.

Os objetivos da proposta são o de atrair investimentos e tornar este mercado mais eficiente, de forma a reduzir custos de energia elétrica e aumentar a competitividade da economia brasileira.

Para alcançar esses objetivos, a proposta, que está alinhada com o documento "Princípios para Reorganização do Setor Elétrico Brasileiro", objeto da Consulta Pública nº 32, de 2017, prevê: (i) o aumento da liberdade de escolha do consumidor de energia elétrica; (ii) mecanismos para que a expansão do mercado livre de energia elétrica ocorra de forma virtuosa; (iii) que os atributos das fontes alternativas passem a ser valorados na expansão da oferta de energia elétrica utilizando critérios de mercado; (iv) que eventuais subsídios sejam justificados por critérios econômicos, sociais e ambientais; e (v) a alocação dos custos de segurança do sistema elétrico de forma isonômica entre os usuários.

Reforçando o compromisso deste Ministério de diálogo com todos os segmentos da sociedade brasileira, a proposta traz ainda temas para detalhamento e estudos, tais como o desenvolvimento de bolsas de energia, o aprimoramento dos mecanismos de garantia e formação de preços, a redução de custos para a implantação de medidores inteligentes e a abertura do mercado livre para o segmento residencial.

Os documentos integrantes da proposta podem ser acessados aqui.

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Extra: modelling details

Expansion Planning Steps

Investment Decision Model

Computational model for investment support: transparency and reproducibility.

Detailed Investment Problem | Simplified Operation

Expansion adjustments and operation simulation

Simulation with Newave Model by CEPEL: Evaluates the operation of the system in order to detail future conditions of load balance.

Operation fine-tuning

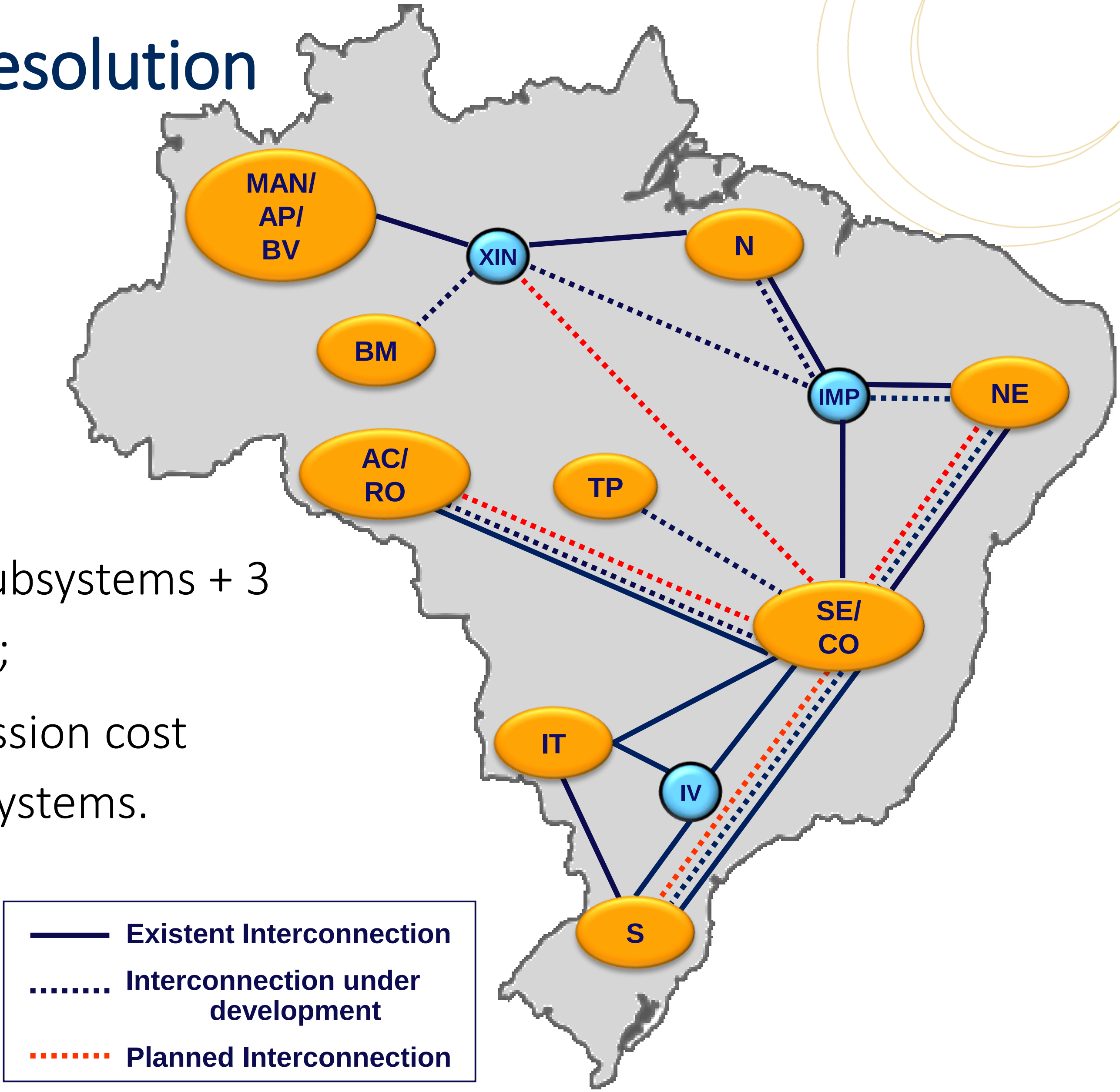
Peak demand and hourly supply check

Investment Decision Model

Objective Function: minimize the sum of costs for all periods

- Fixed Cost (Expansion)
  - O&M
  - Charges
  - Investment
  - Cost of Capital
- Variable Cost (Operation)
  - Thermal Dispatch
  - Deficit

Model Spatial Resolution



- 9 interconnected subsystems + 3 transmission nodes;
- Associated transmission cost between each subsystems.

Investment Decision Model: Main Characteristics

➢ Electricity balance constraints

Monthly or quarterly balance (depending on the timeframe) , which considers:

- Individualized generation scenarios for each Hydro Plant;
- Merit Order Dispatch for Thermal Power Plants;
- Generation estimate for sources not centrally dispatched (Wind, solar, biomass and small hydro)
- Plants are modeled with minimum load levels

➢ Peak demand balance constraints

Power capacity balance considers:

- Loss in Hydro Plants due to reservoir depletion;
- Unavailability of Thermal Power Plants;
- Hourly data for Wind Power Plants;
- Maximum Instantaneous Power and Operating Reserve.

Representation of sources not centrally dispatched

<table>
<tr><td rowspan="2">Contribution</td><td colspan="3">Energy Balance</td><td>Capacity Credit</td></tr>
<tr><td>In Operation</td><td>Procured</td><td>New Plants</td><td>All Plants</td></tr>
<tr><td>Wind</td><td rowspan="4">Based on verified generation</td><td rowspan="2">Seasonal Physical Energy Guarantee</td><td rowspan="2">Capacity Factor based on auctioned projects</td><td>P95 of the hours at which maximum demand has occurred</td></tr>
<tr><td>PV</td><td>Do not contribute</td></tr>
<tr><td>Biomass</td><td colspan="3" rowspan="2">Average monthly generation value based on plants in operation</td></tr>
<tr><td>Small Hydro</td></tr>
</table>

Wind Capacity Credits

Region	jan	feb	mar	apr	may	jun	jul	ago	sep	oct	nov	dec
South	5%	4%	12%	5%	3%	3%	5%	4%	10%	12%	7%	6%
Northeast	34%	20%	9%	11%	15%	26%	31%	42%	32%	44%	27%	23%