Otimização e energia: o case da PSR

Luiz Barroso

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PSR

COPPE-UFRJ, Novembro de 2021

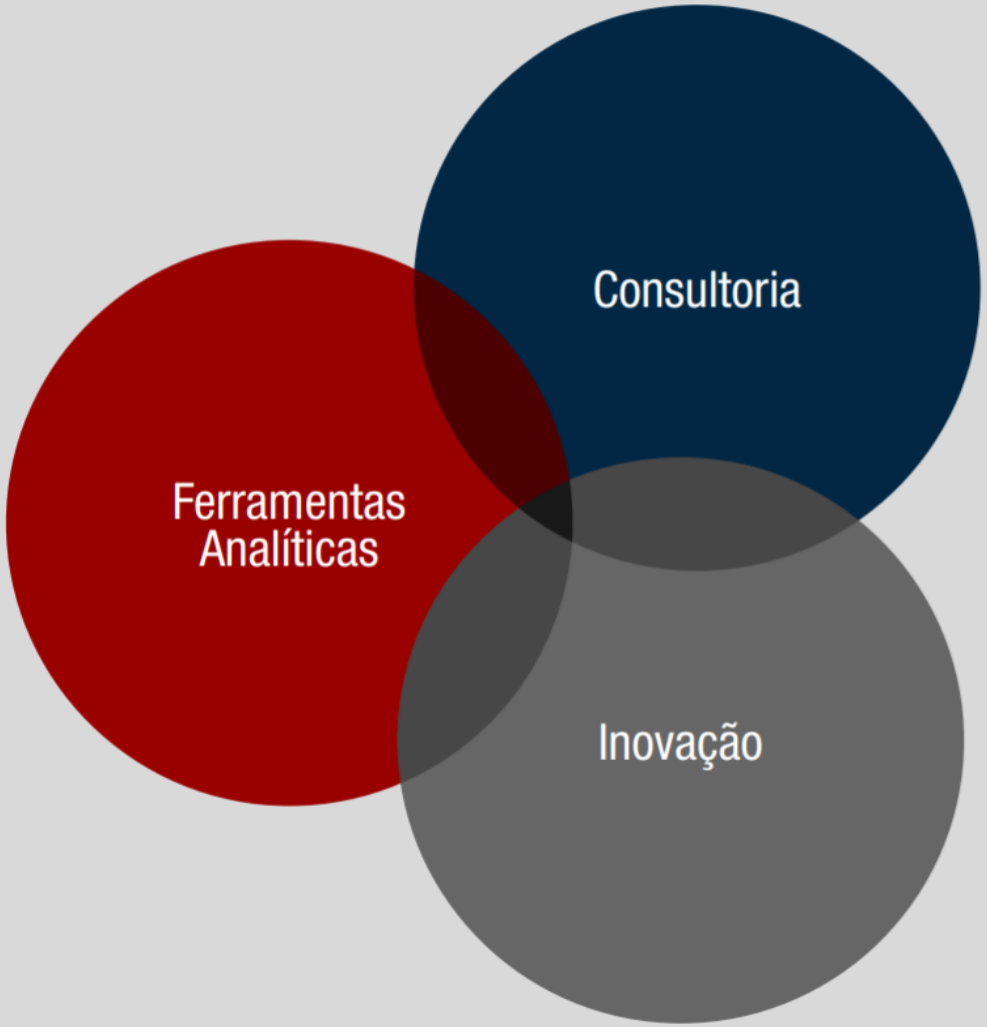
PSR

PSR integra estudos de consultoria, desenvolvimento de ferramentas avançadas de otimização e pesquisa de novas metodologias para sistemas de energia

Temos uma equipe de 100 pessoas formadas em otimização, sistemas de energia, estatística e ciência da computação e de dados

Trabalhamos em mais de 70 países em todos os continentes

A PSR integra estudos, ferramentas analíticas e inovação



Ferramentas Analíticas

Planejamento energético
Simulação probabilística horária
Otimização de portfolios físico-financeiros

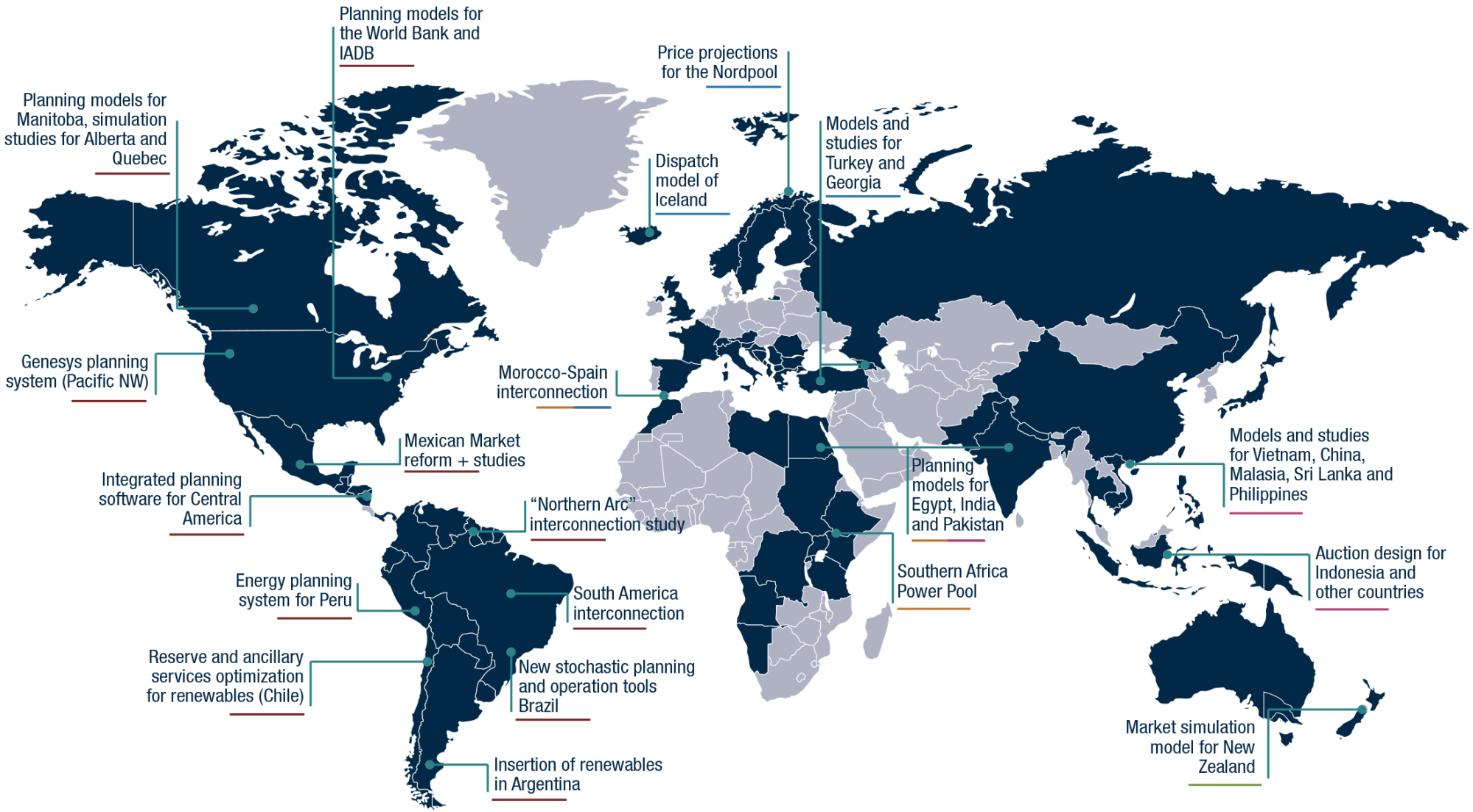
Consultoria

Avaliação e desenho de mercados
"Valuation" econômico-financeira
Estudos de planejamento e operação

Inovação

Projetos de P&D
Ensino e pesquisa acadêmica
Arquiteturas computacionais avançadas

A PSR atua em mais de setenta países de todos os continentes



Americas

All countries in South and Central America, United States, Canada and Dominican Republic

Europe

Austria, Spain, France, Scandinavia, Belgium, Turkey and the Balkans region

Asia

China (Shanghai, Sichuan, Guangdong and Shandong), India, Philippines, Singapore, Malaysia, Kirgizstan, Sri Lanka, Tajikistan and Vietnam

Oceania

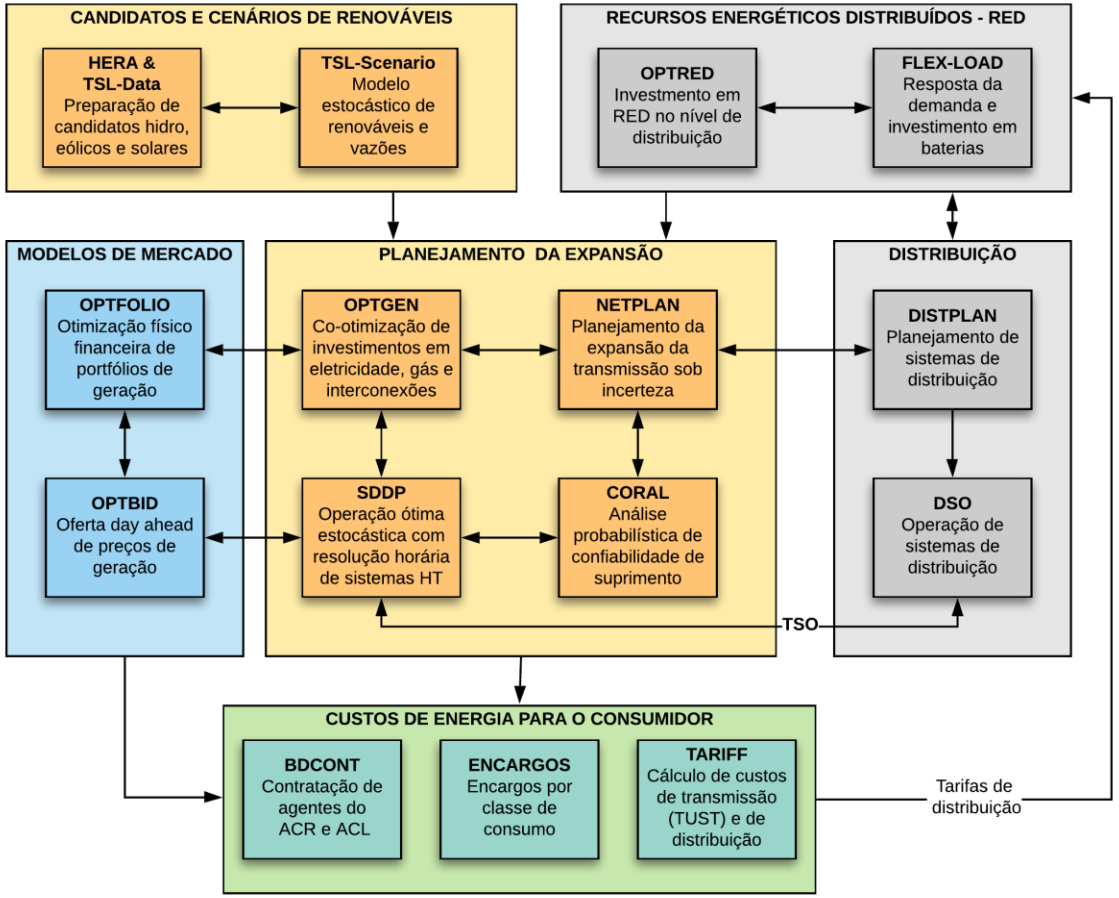
New Zealand

Africa

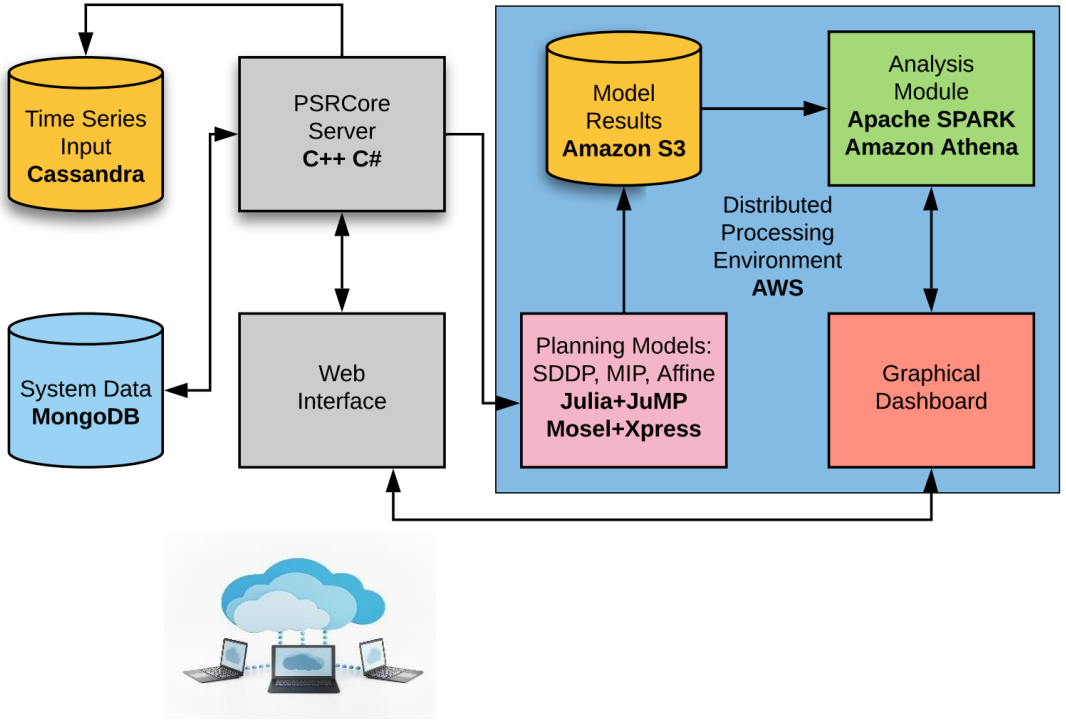
Morocco, Tanzania, Namibia, Egypt, Angola, Sudan, Ethiopia and Ghana

Liderança global no desenvolvimento de metodologias e ferramentas analíticas avançadas

Programação estocástica multi-estágio
Integrada com estatística + métodos de equilíbrio + MILP
Ambiente de processamento paralelo



Arquitetura baseada em nuvem, softwares open source
Big data (MongoDB, S3, Spark) +
Linguagem de programação (Julia / JuMP)



Base de clientes diversificada (amostra)

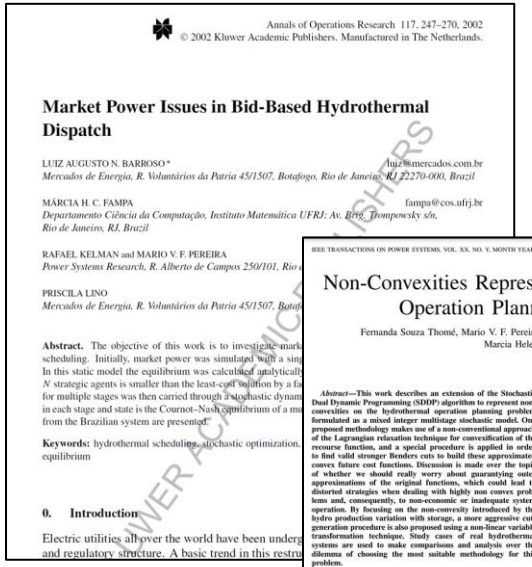
- **Investidores**: EdF international, Statkraft, Brookfield, BP, Shell, Equinor, CTG, Neoenergia (Endesa), CPFL (Stategrid).
- **Associações do setor elétrico brasileiro:** ABRADEE (Distribuição), APINE (Geração), ABRACEEL (Comercialização), ABEEÓLICA (Geração Eólica).
- **Fundos globais**: Blackstone, BlackRock, Carlyle Group, Lone Star, GEF.
- **Organizações multilaterais**: World Bank, Inter-American Development Bank (IDB), Organización Latinoamericana de Energía (OLADE), International Renewable Energy Agency (IRENA), Agência Alemã de Desenvolvimento (GiZ).
- **Agências de financiamiento privadas/multilaterais**: International Finance Corporation (IFC).
- **Organizações de Planejamento Regional**: Western Electricity Coordinating Council (WECC), Northwest Power Planning Council (NWPCC), Comisión de Integración Energética Regional (CIER), Ente Operador Regional (EOR).
- **Ministérios de Economía e Energia**, além de agências de planejamento e regulatórias: Brasil, Colombia, Egito, México, Marrocos, Peru, Vietnam.
- **Operadores do sistema** (ISOs/TSOs), Mercados Atacadistas de Energía e utilities públicas e privadas (geração, transmissão e distribuição) em dezenas de países em todo o mundo.
- **Empresas de consultoria**: Deloitte, IHS CERA, FTI Consulting.
- **Organizações Não-Governamentais**: The Nature Conservancy (TNC).

Além de uma qualificada equipe com formação avançada em engenharia, otimização, regulação, economia, sistemas de energia e TI / ciência de dados

A PSR e o PESC: longos e fortes laços!

- A PSR foi fundada na “escola do PESC”

- 20 ex alunos de doutorado do PESC
- 35 ex alunos da COPPE-UFRJ
- + 100 participações em co-orientações de teses
- + 200 participações em bancas de teses e dissertações
- Muitos alunos do PESC se tornaram colaboradores da PSR



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Market Power Issues in Bid-Based Hydrothermal Dispatch

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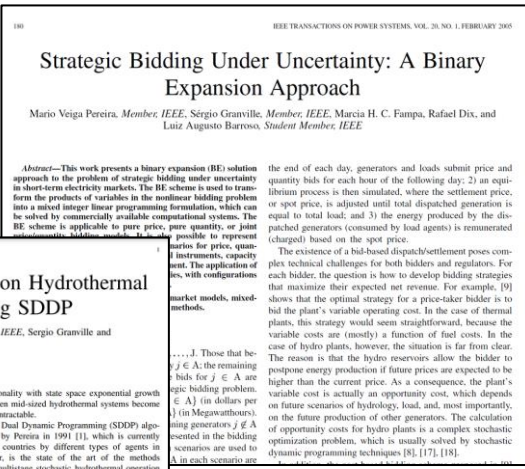
PRISCILA LINO
Mercados de Energia, R. Voluntários da Patria 45/1507, Bata

Abstract. The objective of this work is to investigate mark
scheduling. Initially, market power was simulated with a sim
In this static model the equilibrium was calculated analytically
N strategic agents is smaller than the least-cost solution by a fa
for multiple stages was then carried through a stochastic dynam
in each stage and state is the Cournot–Nash equilibrium of a mi
from the Brazilian system are presented.

Keywords: hydrothermal scheduling, stochastic optimization,
equilibrium

0. Introduction

Electric utilities all over the world have been underg
and regulatory structure. A basic trend in this restru



180 IEEE TRANSACTIONS ON POWER SYSTEMS, VOL. 20, NO. 1, FEBRUARY 2005

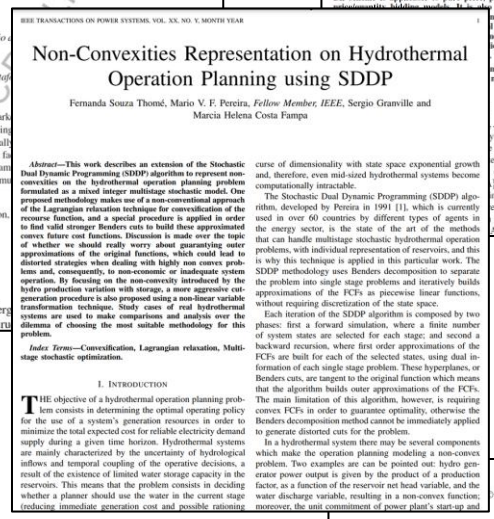
Strategic Bidding Under Uncertainty: A Binary Expansion Approach

Mario Veiga Pereira, *Member, IEEE*, Sérgio Granville, *Member, IEEE*, Marcia H. C. Fampa, Rafael Dix, and Luiz Augusto Barroso, *Student Member, IEEE*

***Abstract*—This work presents a binary expansion (BE) solution approach to the problem of strategic bidding under uncertainty in short-term electricity markets. The BE scheme is used to transform the products of variables in the nonlinear bidding problem into a mixed integer linear programming formulation, which can be solved by commercially available computational systems. The BE scheme is applicable to pure price, pure quantity, or joint**

the end of each day, generators and loads submit price and quantity bids for each hour of the following day; 2) an equilibrium process is then simulated, where the settlement price, or spot price, is adjusted until total dispatched generation is equal to total load; and 3) the energy produced by the dispatched generators (consumed by load agents) is remunerated (charged) based on the spot price.

The existence of a bid-based dispatch/settlement poses complex technical challenges for both bidders and regulators. For each bidder, the question is how to develop bidding strategies that maximize their expected net revenue. For example, [9] shows that the optimal strategy for a price-taker bidder is to bid the plant's variable operating cost. In the case of thermal plants, this strategy would seem straightforward, because the variable costs are (mostly) a function of fuel costs. In the case of hydro plants, however, the situation is far from clear. The reason is that the hydro reservoirs allow the bidder to postpone energy production if future prices are expected to be higher than the current price. As a consequence, the plant's variable cost is actually an opportunity cost, which depends on future scenarios of hydrology, load, and, most importantly, on the future production of other generators. The calculation of opportunity costs for hydro plants is a complex stochastic optimization problem, which is usually solved by stochastic dynamic programming techniques [8], [17], [18].



IEEE TRANSACTIONS ON POWER SYSTEMS, VOL. XX, NO. Y, MONTH YEAR 1

Non-Convexities Representation on Hydrothermal Operation Planning using SDDP

Fernanda Souza Thomé, Mario V. F. Pereira, *Fellow Member, IEEE*, Sergio Granville and Marcia Helena Costa Fampa

***Abstract*—This work describes an extension of the Stochastic Dual Dynamic Programming (SDDP) algorithm to represent non-convexities on the hydrothermal operation planning problem formulated as a mixed integer multistage stochastic model. One proposed methodology makes use of a non-conventional approach of the Lagrangian relaxation technique for convexification of the recourse function, and a special procedure is applied in order to find valid stronger Benders cuts to build these approximated convex future cost functions. Discussion is made over the topic of whether we should really worry about guarantying outer approximations of the original functions, which could lead to distorted strategies when dealing with highly non convex problems and, consequently, to non-economic or inadequate system operation. By focusing on the non-convexity introduced by the hydro production variation with storage, a more aggressive cut-generation procedure is also proposed using a non-linear variable transformation technique. Study cases of real hydrothermal systems are used to make comparisons and analysis over the dilemma of choosing the most suitable methodology for this problem.**

***Index Terms*—Convexification, Lagrangian relaxation, Multi-stage stochastic optimization.**

I. Introduction

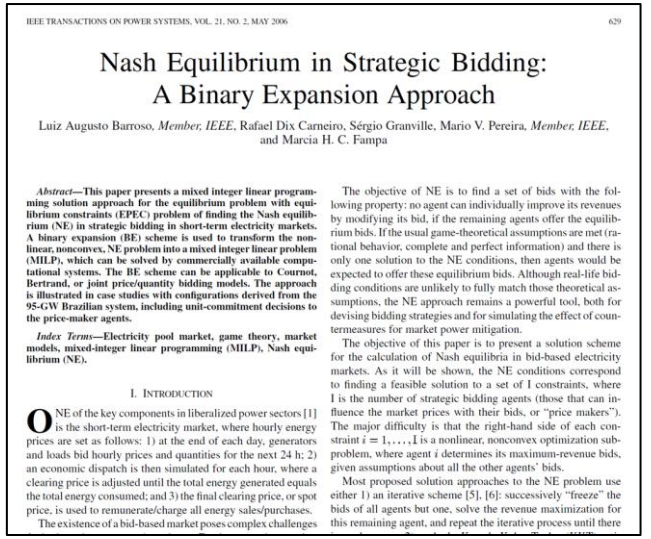
THE objective of a hydrothermal operation planning problem consists in determining the optimal operating policy for the use of a system's generation resources in order to minimize the total expected cost for reliable electricity demand supply during a given time horizon. Hydrothermal systems are mainly characterized by the uncertainty of hydrological inflows and temporal coupling of the operative decisions, a result of the existence of limited water storage capacity in the reservoirs. This means that the problem consists in deciding whether a planner should use the water in the current stage (reducing immediate generation cost and possible rationing

curse of dimensionality with state space exponential growth and, therefore, even mid-sized hydrothermal systems become computationally intractable.

The Stochastic Dual Dynamic Programming (SDDP) algorithm, developed by Pereira in 1991 [1], which is currently used in over 60 countries by different types of agents in the energy sector, is the state of the art of the methods that can handle multistage stochastic hydrothermal operation problems, with individual representation of reservoirs, and this is why this technique is applied in this particular work. The SDDP methodology uses Benders decomposition to separate the problem into single stage problems and iteratively builds approximations of the FCFs as piecewise linear functions, without requiring discretization of the state space.

Each iteration of the SDDP algorithm is composed by two phases: first a forward simulation, where a finite number of system states are selected for each stage; and second a backward recursion, where first order approximations of the FCFs are built for each of the selected states, using dual information of each single stage problem. These hyperplanes, or Benders cuts, are tangent to the original function which means that the algorithm builds outer approximations of the FCFs. The main limitation of this algorithm, however, is requiring convex FCFs in order to guarantee optimality, otherwise the Benders decomposition method cannot be immediately applied to generate distorted cuts for the problem.

In a hydrothermal system there may be several components which make the operation planning modeling a non-convex problem. Two examples are can be pointed out: hydro generator power output is given by the product of a production factor, as a function of the reservoir net head variable, and the water discharge variable, resulting in a non-convex function; moreover, the unit commitment of power plant's start-up and



IEEE TRANSACTIONS ON POWER SYSTEMS, VOL. 21, NO. 2, MAY 2006 629

Nash Equilibrium in Strategic Bidding: A Binary Expansion Approach

Luiz Augusto Barroso, *Member, IEEE*, Rafael Dix Carneiro, Sérgio Granville, Mario V. Pereira, *Member, IEEE*, and Marcia H. C. Fampa

***Abstract*—This paper presents a mixed integer linear programming solution approach for the equilibrium problem with equilibrium constraints (EPEC) problem of finding the Nash equilibrium (NE) in strategic bidding in short-term electricity markets. A binary expansion (BE) scheme is used to transform the nonlinear, nonconvex, NE problem into a mixed integer linear problem (MILP), which can be solved by commercially available computational systems. The BE scheme can be applicable to Cournot, Bertrand, or joint price/quantity bidding models. The approach is illustrated in case studies with configurations derived from the 95-GW Brazilian system, including unit-commitment decisions to the price-maker agents.**

***Index Terms*—Electricity pool market, game theory, market models, mixed-integer linear programming (MILP), Nash equilibrium (NE).**

I. Introduction

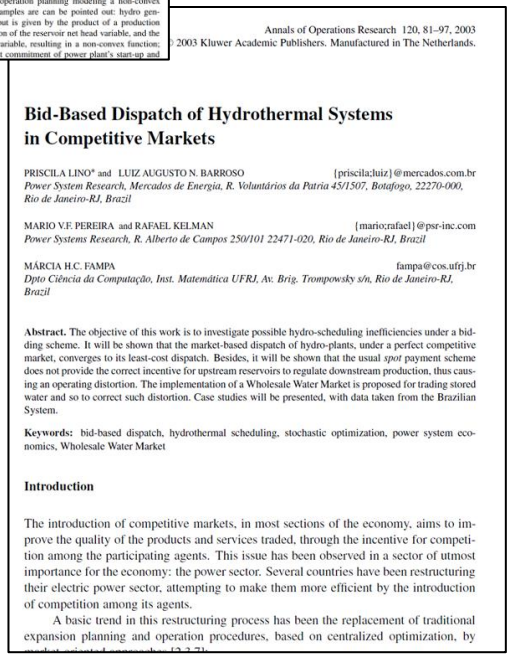
ONE of the key components in liberalized power sectors [1] is the short-term electricity market, where hourly energy prices are set as follows: 1) at the end of each day, generators and loads bid hourly prices and quantities for the next 24 h; 2) an economic dispatch is then simulated for each hour, where a clearing price is adjusted until the total energy generated equals the total energy consumed; and 3) the final clearing price, or spot price, is used to remunerate/charge all energy sales/purchases.

The existence of a bid-based market poses complex challenges

The objective of NE is to find a set of bids with the following property: no agent can individually improve its revenues by modifying its bid, if the remaining agents offer the equilibrium bids. If the usual game-theoretical assumptions are met (rational behavior, complete and perfect information) and there is only one solution to the NE conditions, then agents would be expected to offer these equilibrium bids. Although real-life bidding conditions are unlikely to fully match those theoretical assumptions, the NE approach remains a powerful tool, both for devising bidding strategies and for simulating the effect of countermeasures for market power mitigation.

The objective of this paper is to present a solution scheme for the calculation of Nash equilibria in bid-based electricity markets. As it will be shown, the NE conditions correspond to finding a feasible solution to a set of I constraints, where I is the number of strategic bidding agents (those that can influence the market prices with their bids, or "price makers"). The major difficulty is that the right-hand side of each constraint $i = 1, \ldots, I$ is a nonlinear, nonconvex optimization subproblem, where agent i determines its maximum-revenue bids, given assumptions about all the other agents' bids.

Most proposed solution approaches to the NE problem use either 1) an iterative scheme [5], [6]: successively "freeze" the bids of all agents but one, solve the revenue maximization for this remaining agent, and repeat the iterative process until there



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Bid-Based Dispatch of Hydrothermal Systems in Competitive Markets

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Abstract. The objective of this work is to investigate possible hydro-scheduling inefficiencies under a bidding scheme. It will be shown that the market-based dispatch of hydro-plants, under a perfect competitive market, converges to its least-cost dispatch. Besides, it will be shown that the usual *spot* payment scheme does not provide the correct incentive for upstream reservoirs to regulate downstream production, thus causing an operating distortion. The implementation of a Wholesale Water Market is proposed for trading stored water and so to correct such distortion. Case studies will be presented, with data taken from the Brazilian System.

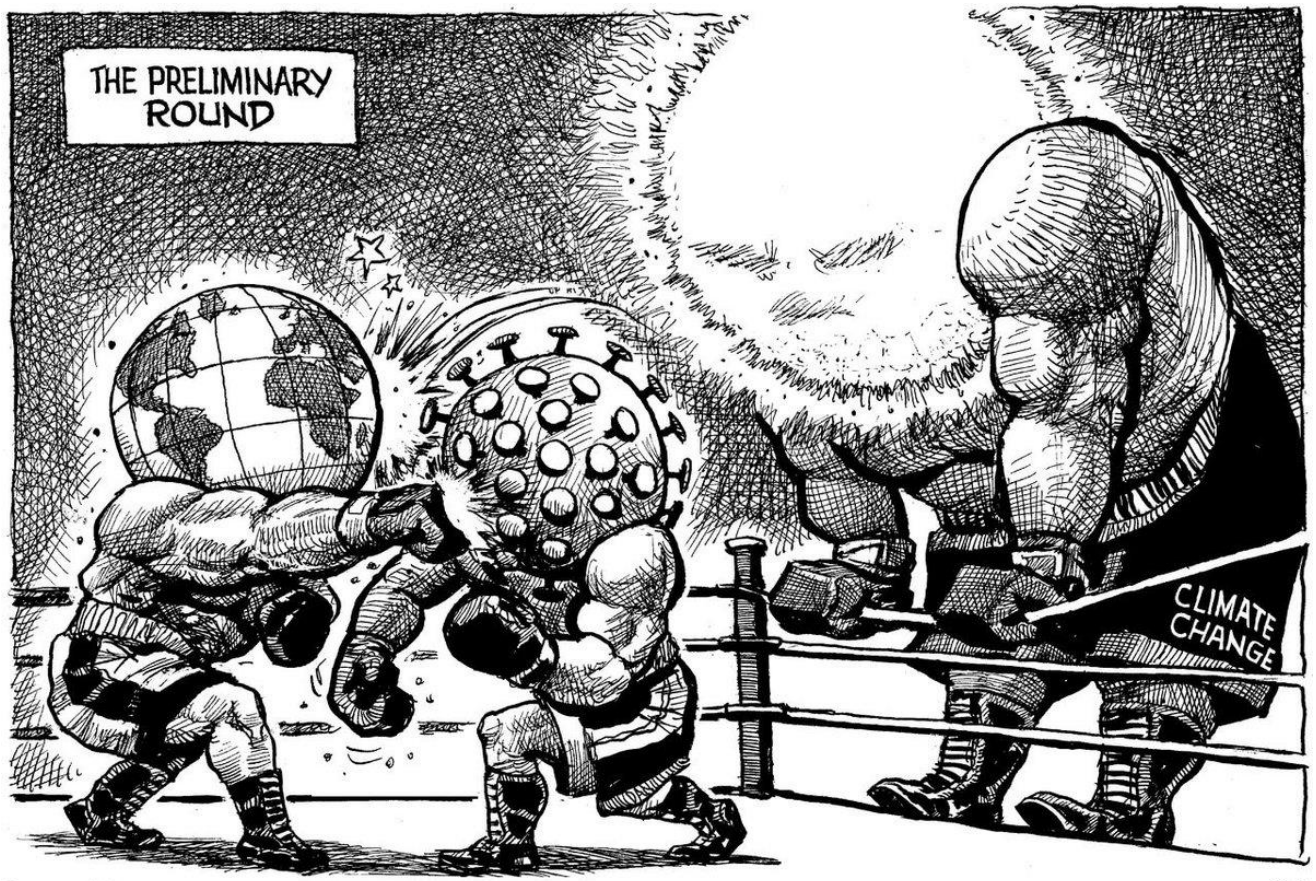
Keywords: bid-based dispatch, hydrothermal scheduling, stochastic optimization, power system economics, Wholesale Water Market

Introduction

The introduction of competitive markets, in most sections of the economy, aims to improve the quality of the products and services traded, through the incentive for competition among the participating agents. This issue has been observed in a sector of utmost importance for the economy: the power sector. Several countries have been restructuring their electric power sector, attempting to make them more efficient by the introduction of competition among its agents.

A basic trend in this restructuring process has been the replacement of traditional expansion planning and operation procedures, based on centralized optimization, by

Para o futuro: a agenda climática entrou na pauta da energia



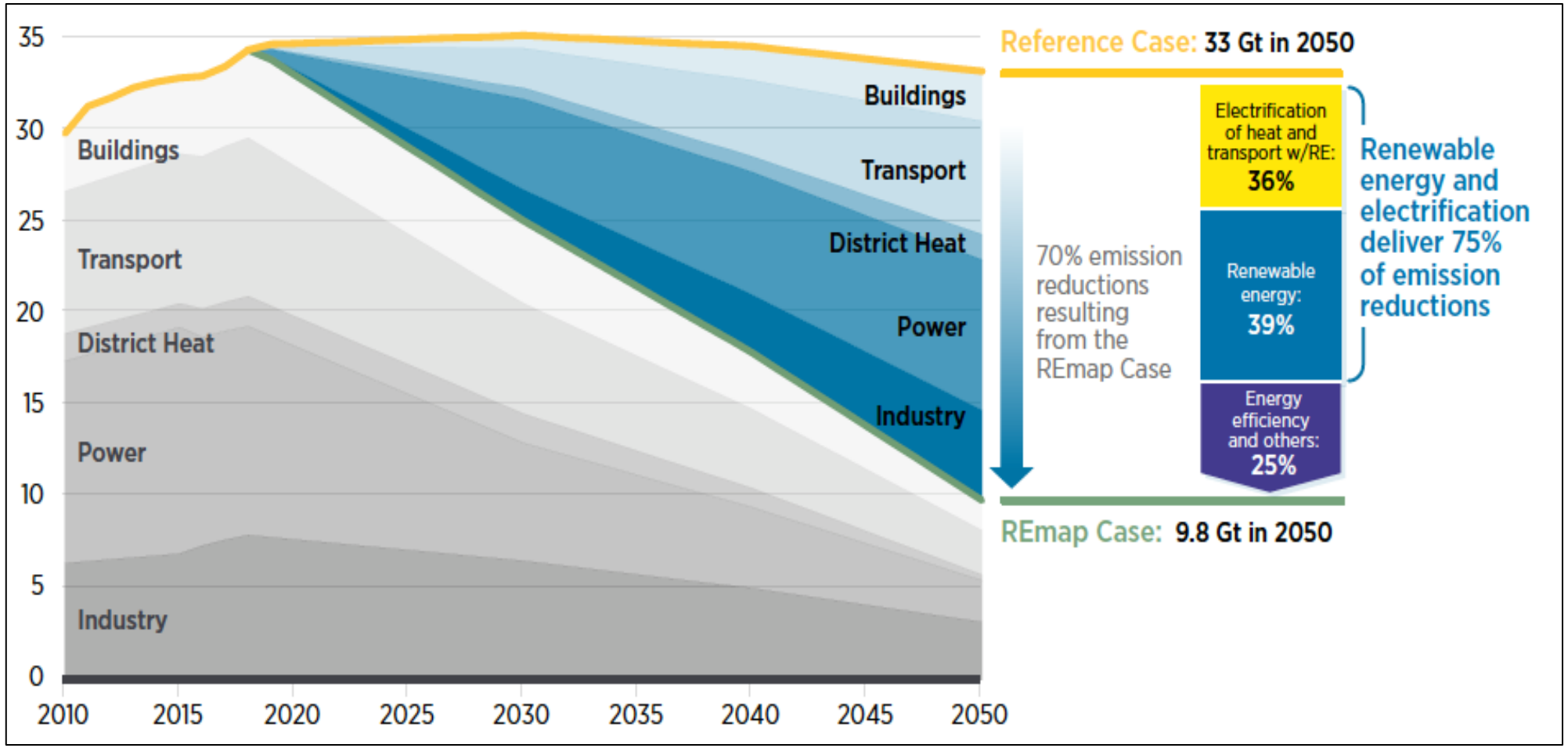
Economist.com Kal

Como podemos aproveitar a crise atual para evitar riscos climáticos adicionais e qual pegada de carbono podemos nos permitir durante e após a recuperação?

A recuperação econômica terá muitas iniciativas – e metas – de sustentabilidade

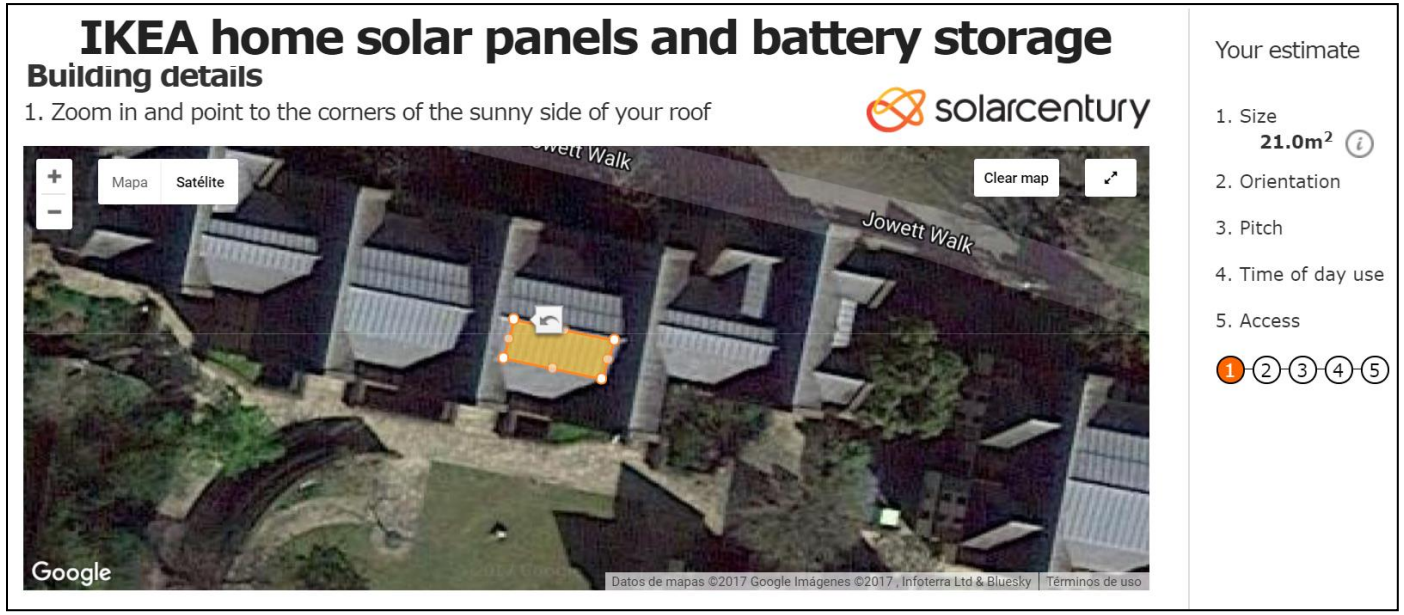
A energia renovável passou a ser diferencial competitivo

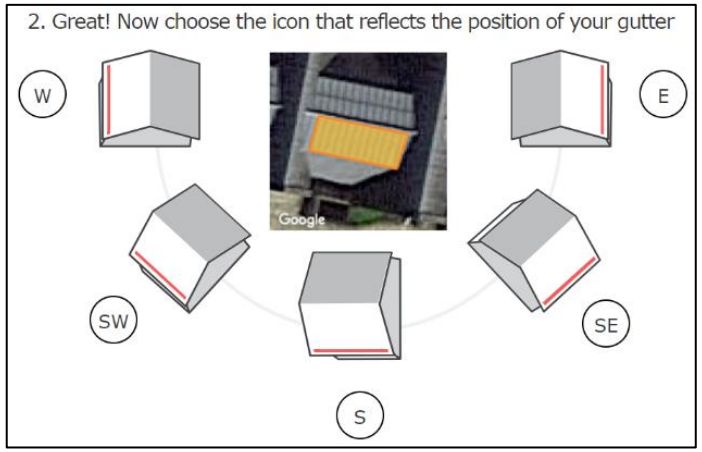
Estratégia básica dos “green deals”: eletrificação (renovável) da economia

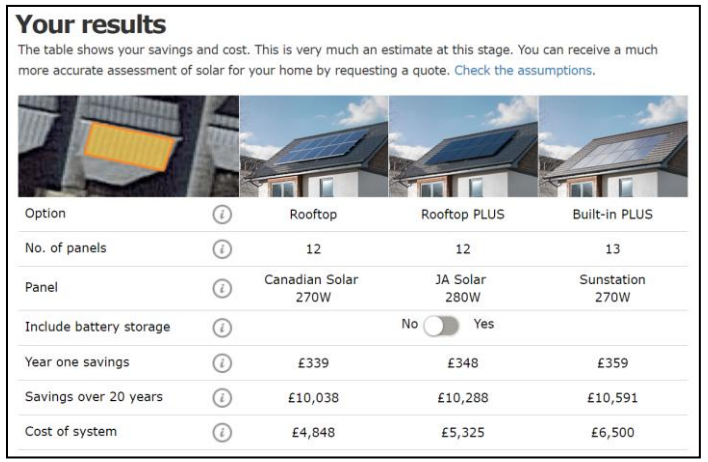


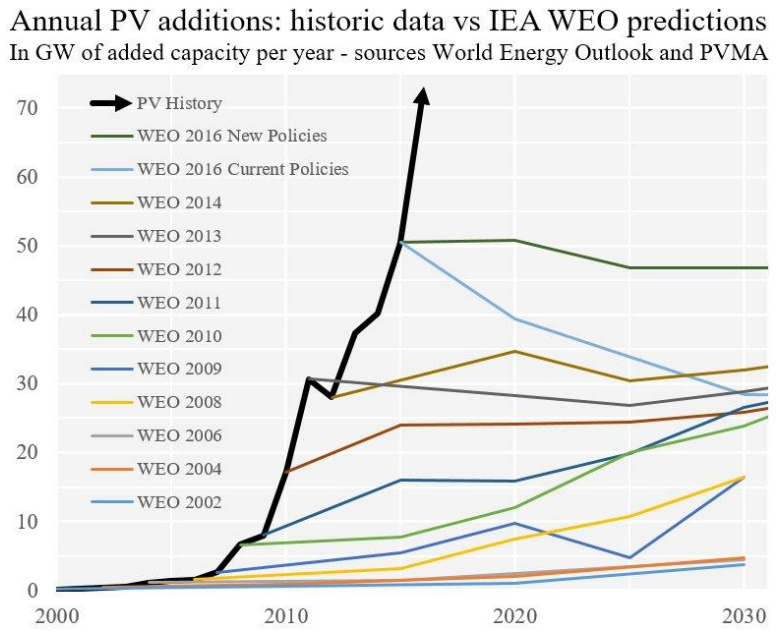
Fonte: Irena, 2019

Isto vem sendo impulsionada por avanços tecnológicos, como a geração distribuída









Pequena barreira de entrada, competitividade e rápido desenvolvimento têm gerado crescimento **exponencial**, levando o mercado livre a quem ainda não é livre

E novos modelos tarifários “engajam” o consumidor

Energy Monitor

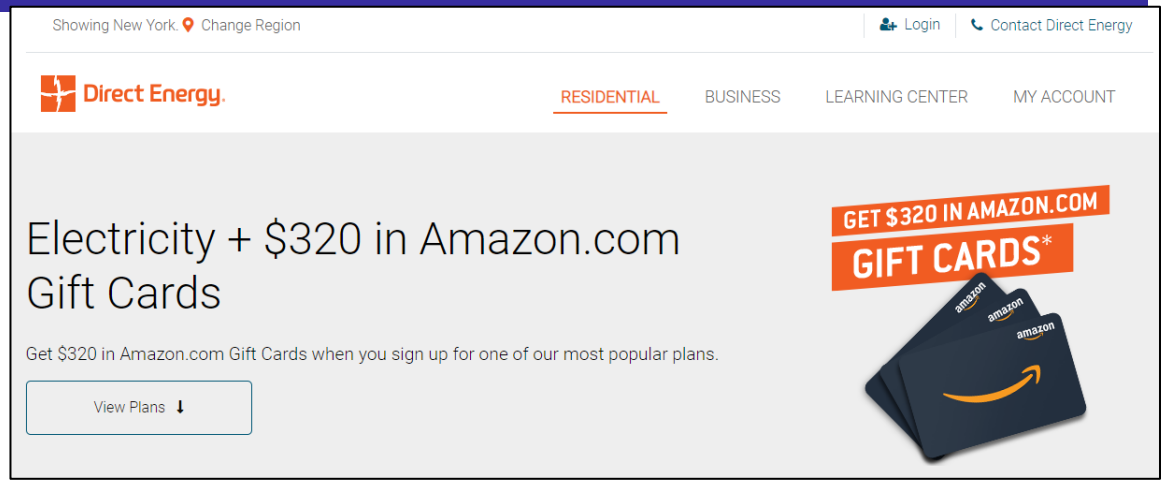
Take control of your energy bills

- After you’ve compared energy deals, we’ll keep an eye on prices*
- We’ll let you know when it’s time to switch and save. Again and again
- Another way we’re helping you save a lot by doing very little

Find out more

Gas & Electricity

Find the right deal and never overpay again

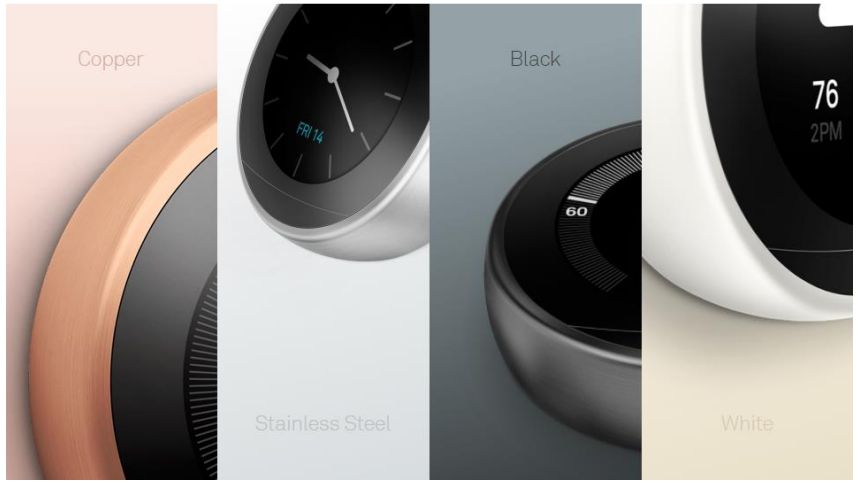


... que busca energia renovável por diversos objetivos

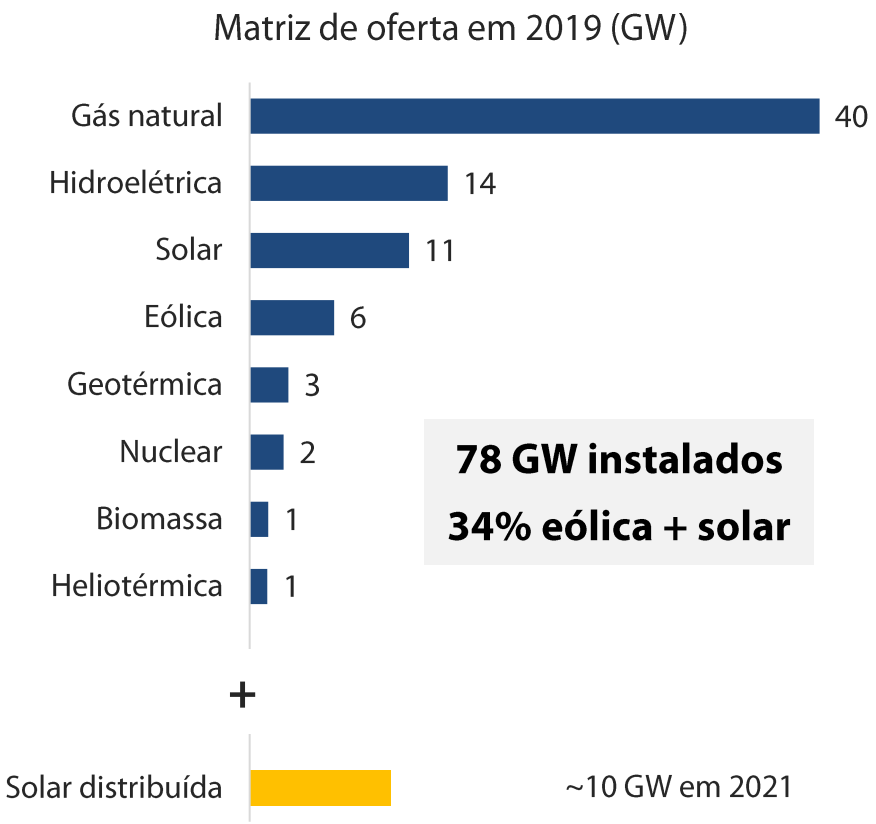
Motivação econômica

Motivação carbono/ambiental/social

“estilo de vida”/status

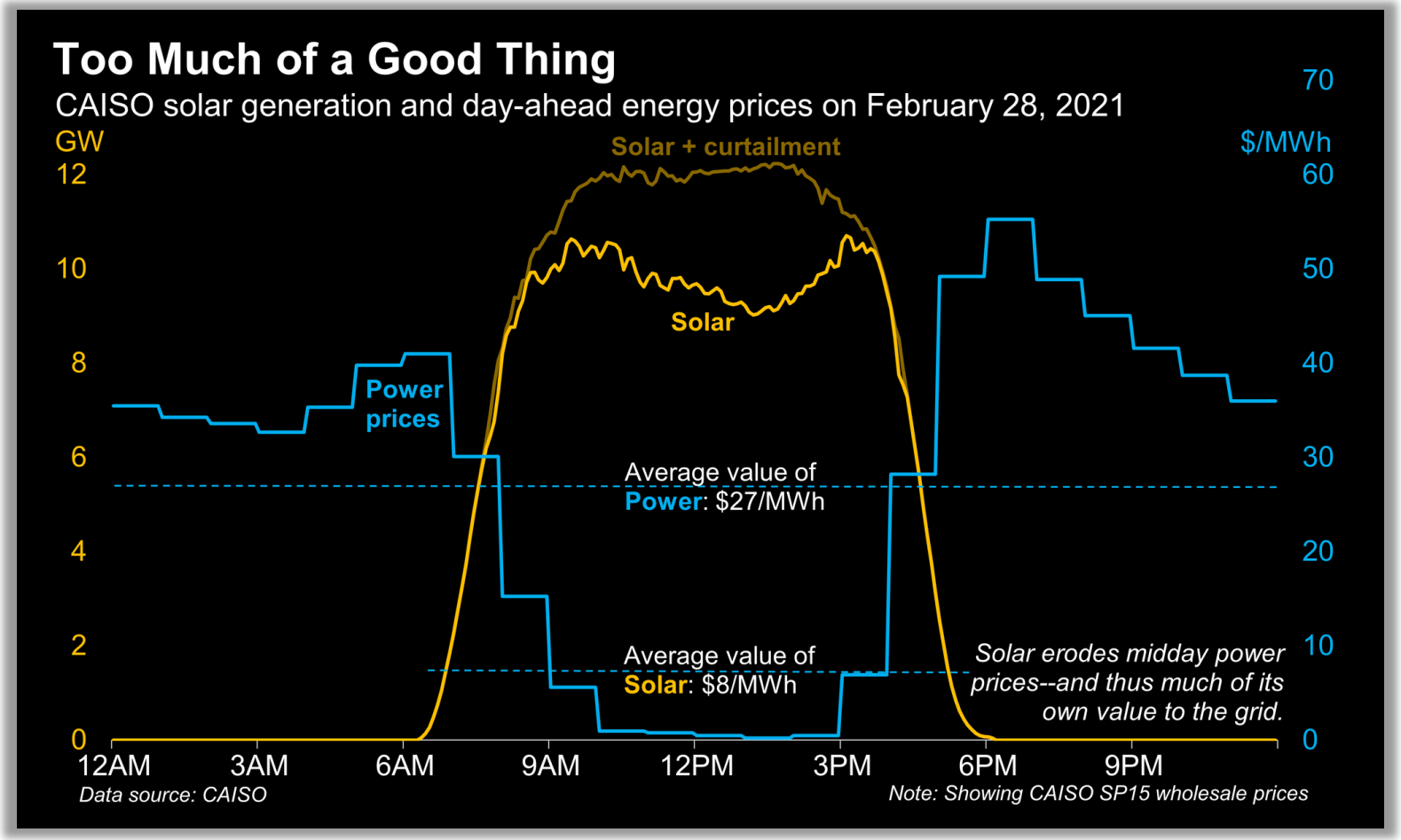


As renováveis impactam nos sistemas elétricos (nos preço horários, por exemplo)...

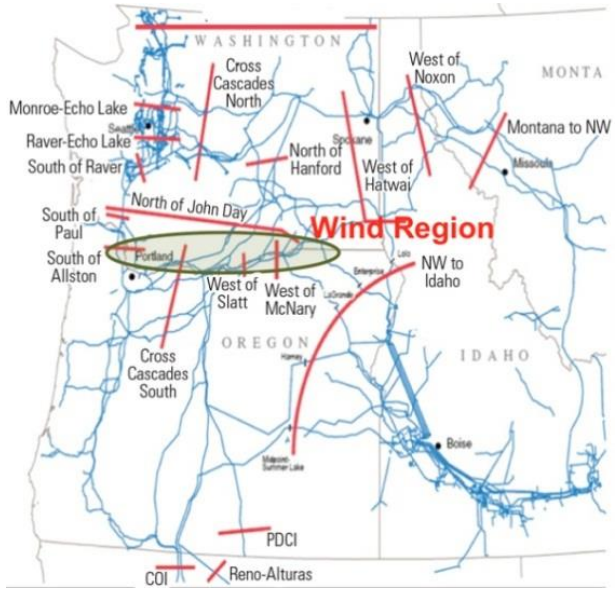


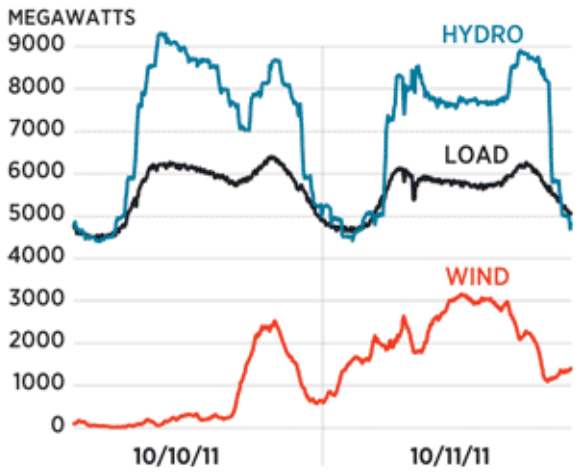
78 GW instalados

34% eólica + solar



Conflitos pelo uso da água se espalham





Where More Is Not Merrier: The Battle Between Wind and Water in the Pacific Northwest

By Kiran Kumaraswamy, ICF International

Bonneville Power calls for first wind shutdown of the season

By Christina Williams
Sustainable Business Oregon editor

Tweet | Recommend | Share | +1 | Email | RSS | Comments

Bonneville Power Administration ordered the temporary shutdown of wind farms in its system for a few hours early Sunday morning and again early Monday morning, marking the first time this year that the controversial practice has been tapped.

Bonneville calls for wind "curtailment" when periods of low electricity demand coincides with periods of strong wind and high water, which put more power on the grid than the system needs.

In all 10,100 megawatt hours of wind energy was curtailed over the two-day. Under new protocol filed by BPA to the Federal Energy Regulatory Commission this year, the wind energy operators will receive some compensation for the lost generation revenue.

Enlarge Image

With high-water season back, Bonneville Power Administration made its first curtailment order over the weekend, requiring wind energy operators to power down

bpa.gov

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Flexible spill agreement aims to benefit salmon and hydropower

December 18, 2018 Like 70 Tweet

Federal, State and Tribal partners have come together to develop an agreement on a key component of operating federal dams in the Columbia River Basin. Parties to the agreement have aligned on a flexible spring spill operation premised on achieving improved salmon survival while also managing costs in hydropower generation. Key supporters of the agreement are jointly issuing this statement:

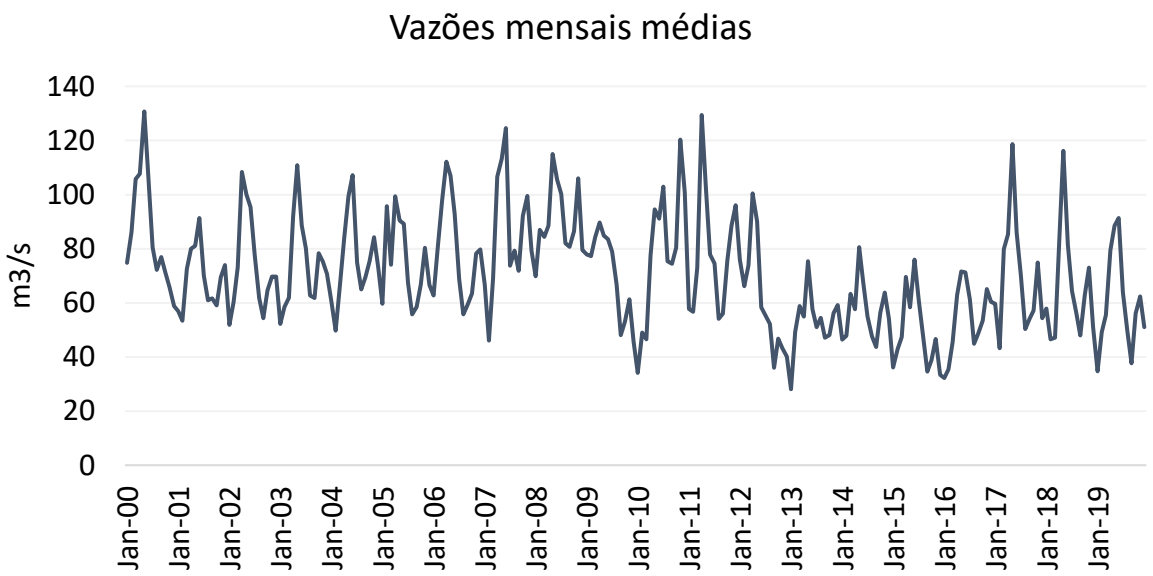
"Collaboration is key to this new approach to Columbia River system

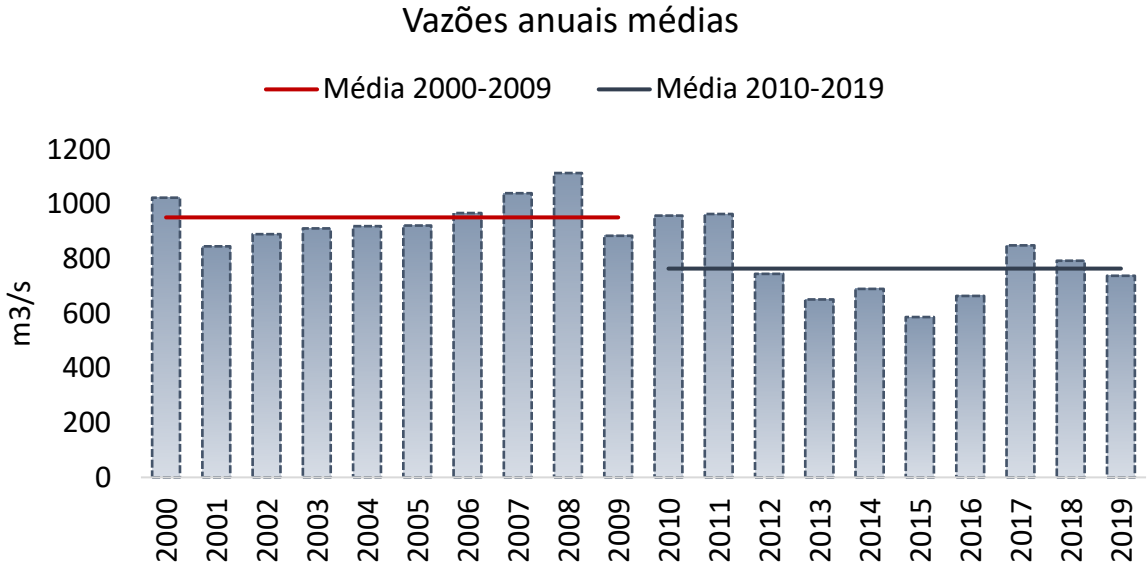
Conflitos no uso da água

(verte vento *vs.* verte água *vs.* salva o salmão)

E mudanças climáticas afetam as vazões nos rios

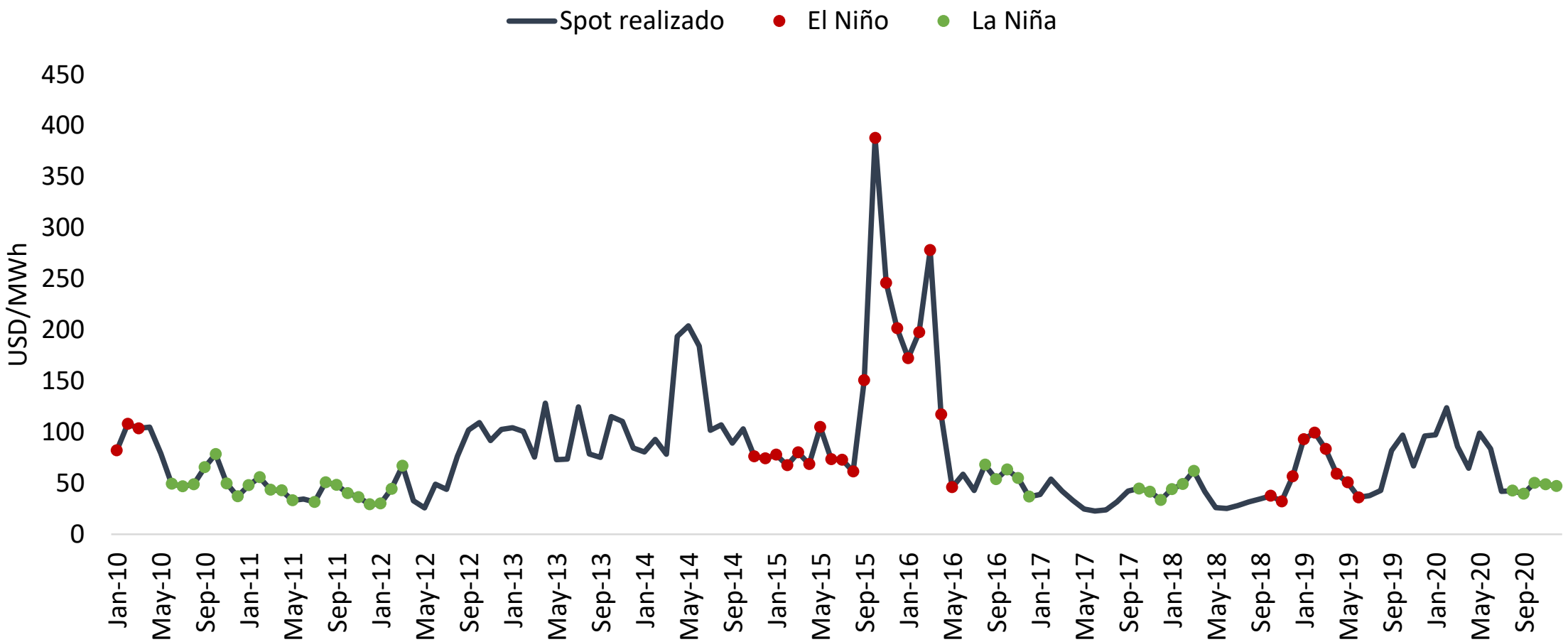
Colômbia: vazões históricas menores (~20%) nos últimos anos





Mudança climática afeta os preços de energia...

- Maior volatilidade de médio prazo, cuja magnitude depende da combinação da severidade do El Niño com efeitos do mix de geração (como indisponibilidade do gás) e de eventos pontuais, como a recente indisponibilidade de uma grande hidroelétrica



Otimização e energia: a complexidade da tomada de decisão aumentou

Problemas típicos de energia:

- Problema Geral de Planejamento Energético
- Problema de Operação: Despacho e Fluxo de Potencia Ótimo
- Problema de Tarifação e Custos Marginais da Transmissão
- Problema de Planejamento da Distribuição
- Tarifação e Custos Marginais
- Problemas de Mercado e de Comercialização
- Gestão de risco e otimização de portifólios
- Teoria dos Jogos

Típicos novos problemas de energia:

- Resiliência climática (mitigação/adaptação)
- Representação de novas incertezas
- Tomada de decisão em novas tecnologias
- Ações pelo lado do consumidor
- Integracão entre métodos de otimização formais com inteligência artificial

A maior lição para otimizadores: é fundamental especificar bem o problema a resolver

Em resumo...

- A PSR ilustra os benefícios de uma parceria entre universidade e industria; somos muito gratos a tod@s os professores e colegas do PESC
- Estes benefícios só devem aumentar, pois o ativo mais valioso para as empresas será a capacidade analítica e de inovação das pessoas
- A otimização, computação de alto desempenho e data science, que estão no núcleo do PESC, estão entre os instrumentos mais importantes para estas inovações

...algumas referências para as noites de insônia!

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