A GAME THEORETICAL SEASONALIZATION MODEL OF PHYSICAL GUARANTEE FOR HYDROPOWER PLANTS

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Introduction

- In 2019, the hydraulic energy generated was 422.8 TWh, which represented 64.9% of the total (651.3 TWh) of the Brazilian electric matrix.
- Physical guarantee represents the maximum energy that a power plant can commit in its contracts over the period of one year.
- Each generation plant has the flexibility to allocate and distribute its annual physical guarantee between months.
- This process is made once a year and is known as the seasonalization of the physical guarantee.

Introduction

- The seasonalization can cause mismatches between the contracts and the physical guarantee allocated, which can lead to shortages or surpluses that needs to be financially adjusted.
- The individual allocation can financially affect the system's result as the system's total shortages and surpluses are shared. The players need to maximize their payoffs but need to avoid losses in consequence of other player movements.
- The seasonalization process can be interpreted as a game as the individual decisions affect other players results and there is a set of strategies and payoffs for each player.
- This work proposes a model for the seasonalization of the physical guarantee using game theory tools and time series forecasting models to define the optimum allocation decision.

Energy Reallocation Mechanism

- Sometimes some regions will have more favorable hydrological conditions for hydraulic energy production than others.
- There is a mechanism for sharing the hydrological risks associated with the optimization of the dispatch in the centralized system.
- The dispatch prioritizes power plants that are under the more favorable hydrological conditions.
- It would not be fair for the plants to be remunerated for the production of energy, since the dispatch decision is not theirs.
- In this way, the revenue is not related to the individual plant generation.

Energy Reallocation Mechanism

- For each month, power plant revenue depends on:
  - Physical guarantee allocated.
  - Contracts.
  - System capacity to supply the physical guarantee allocated (GSF).
- GSF on month j, where η_j is the gross generation and Γ_j is the system physical guarantee.

$$GSF_j = \frac{\eta_j}{\Gamma_j}$$

- The surpluses and shortages are adjusted in the short-term market using the spot price (PLD) as a basis for calculation.

Energy Reallocation Mechanism

- For each month j, the power plant i payoff of is:

$$\pi_{ij} = (g_{ij} \times GSF_j - c_i) \times PLD_j \times h_j$$

Seasonalization decision (g_{ij}): How physical guarantee is distributed between months.

System component (GSF_j): How much of the total physical guarantee can be met by the system.

Individual component (c_i): How much of the energy contracted can be covered by the physical guarantee allocated.

Seasonalization Game

- Suppose a player allocate higher amounts of physical guarantee than that required by their contracts for the months with higher PLD trying to increase their payoffs on that months.

$$(g_{ij} \times GSF_j - c_i) \times PLD_j \times h_j$$

- Doing so, they seek to have a higher payoff but they control only the term g_{ij} of payoff equation.
- If the other players do the same movement, GSF (the system component) will fall bellow 1 for that month and maybe physical guarantee allocated will not be enough to fulfill the contracts and there will be a shortage.
- So, the players need to consider their movements and the movements of other players to maximize their payoffs.

Seasonalization Game

- We considered 3 strategies:
  - Strategy I: allocate the physical guarantee according to the contracts.
  - Strategy II: allocate maximum physical guarantee to the months with higher spot prices (PLD).
  - Strategy III: allocate the physical guarantee following the spot prices proportion.

$$g_{ij} = G_i \times \frac{PLD_j}{\sum_{z=1}^{n}(PLD_z)}$$

  - Where G_i is the total physical guarantee of player i.

Seasonalization Game

- Example:
  - Simplified 2 player game. Seasonalization process for 2 periods.
  - 3 strategies
  - Upper and lower physical guarantee limits for each plant

Description	**Value**	**Unit**
Total power plants capacity	100,000	Avg MW
Total physical guarantee	60,000	Avg MW
Player 1 - UHE1		
UHE1 Installed Capacity	50,000	Avg MW
UHE1 physical guarantee	30,000	Avg MW
UHE1 Contract	30,000	Avg MW
UHE1 Contract Selling Price	150	R$/MW hour
UHE1 Minimum allocation per period	10,000	
Player 2 - UHE2		
UHE1 Installed Capacity	50,000	Avg MW
UHE1 physical guarantee	30,000	Avg MW
UHE1 Contract	30,000	Avg MW
UHE1 Contract Selling Price	150	R$/MW hour
UHE1 Minimum allocation per period	10,000	

Seasonalization Game

- Payoff matrix (R$ MM):

		UHE2					
		I		III		II	
UHE1	I	0	0	-101	101	164	-164
	III	101	-101	0	0	312	-312
	II	-164	164	-312	312	0	0

- Nash equilibrium allocation (both players choose strategy III):

Player	Period 1	Period 2	Avg MW
UHE 1	22,222	37,778	30,000
UHE 2	22,222	37,778	30,000
PLD (R$/MW hour)	100	170	-

Seasonalization Game

- Strategy III – equivalent prices (R$ MM): PLD x GSF

Player	Period 1	Period 2	Sum
UHE 1	0	0	0
UHE 2	0	0	0
GSF	1.35	0.79	
EP	135	135	

- Strategy III will always be the Nash equilibrium as it is able to balance the gains of higher prices with the losses of lower GSF.
- Strategy I and II makes the player susceptible to the movements of the other players, causing undesirable negative payoffs.
- Strategy I specially, is a very common strategy among the players.

Game Application

- We chose a major player in the market to apply the optimization model.
- First, we adjust and applied a SARIMAX forecast model to forecast the energy load. The gross generation (η_j) for each month was estimated using the following equation:

$$\eta_j = \varepsilon_j - (\tau_j + \omega_j + \beta_j + \phi_j + s_j)$$

- Where: ε_j is the energy load; τ_j is the thermal generation; ω_j is the wind generation; β_j is the biomass generation; ϕ_j is the solar generation; s_j represents the generation of small hydroelectric plants.

$$GSF_j = \frac{\eta_j}{\Gamma_j}$$

Numerical Application

- Gross generation estimation (average MW):

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
ε	71,139	72,152	72,017	70,687	69,406	68,879	68,855	69,665	70,439	71,066	71,119	71,039
τ	10,901	8,139	8,152	6,190	6,273	6,982	7,206	7,974	8,418	8,070	7,619	6,802
ω	6,423	4,544	4,480	5,093	6,584	8,388	8,851	10,136	10,269	9,650	9,003	7,711
ϕ	824	760	798	771	783	816	843	922	1,027	970	950	968
β	1,790	1,760	2,150	3,929	4,902	5,286	5,520	5,628	5,548	5,215	4,586	2,959
π	1,511	1,527	1,548	1,397	1,306	1,193	1,011	883	884	1,060	1,303	1,447
η	49,690	55,422	54,889	53,307	49,558	46,214	45,424	44,122	44,293	46,101	47,658	51,152

- PLD expected values:

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
E(P)	255.48	206.30	179.50	165.74	142.68	161.54	202.48	207.25	221.74	233.68	219.20	151.66
h	744	672	744	720	744	720	744	744	720	744	720	744

Numerical Application

- Optimization function: seasonalized physical guarantee must be equal to the power plant total physical guarantee.

$$\sum_{j=1}^{12} \Gamma_j \times h_j - \sum_{i=1}^{k} (G_i) = 0$$

- Restrictions: equivalent prices must be the same.

$$GSF_j \times PLD_j = GSF_{j+1} \times PLD_{j+1}$$

$$g_{ij} \leq Power\ plant\ capacity$$

$$g_{ij} \geq Lower\ regulatory\ limit\ for\ the\ plant$$

Numerical Application

- Results for the system:

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Γ	77,530	69,827	60,172	53,958	43,183	45,593	56,171	55,846	59,982	65,792	63,800	51,152
GSF	0.64	0.79	0.91	0.99	1.15	1.01	0.81	0.79	0.74	0.70	0.75	1.08
EP	163.74	163.74	163.74	163.74	163.74	163.74	163.74	163.74	163.74	163.74	163.74	163.74

- Optimum results for the player:

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Γ	666	600	517	464	371	392	483	480	515	565	548	407
c	475	450	450	390	390	390	400	430	430	430	430	425
π	-9.15	3.62	2.88	8.11	3.79	0.82	-1.47	-7.86	-7,9	-5,9	-3,25	1,63

Numerical Application

- Results for the system:

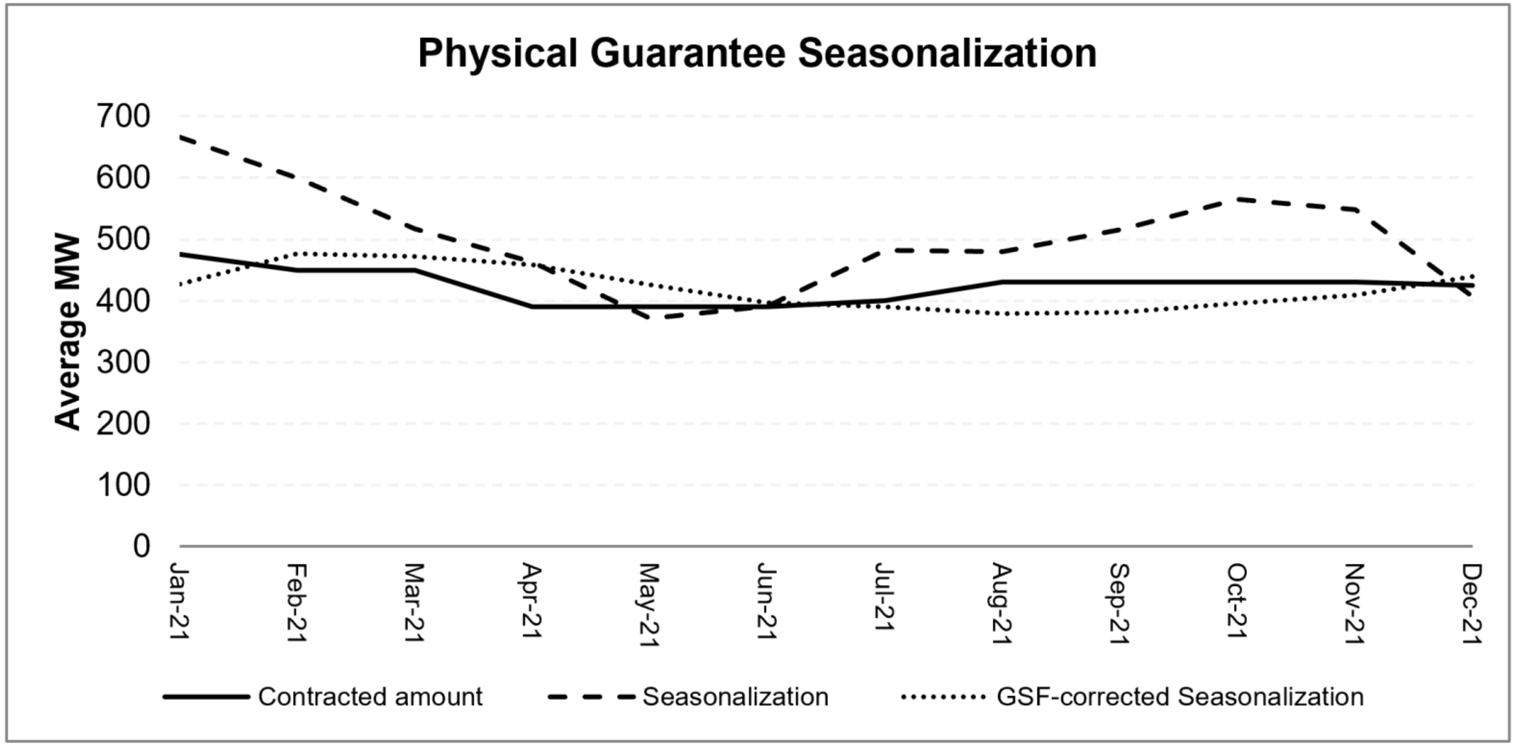

Figure 1: Seasonalization of physical guarantee decision for a major player in the market.

Conclusion

- The model was able to successfully support a major player seasonalization process for the year 2021.
- The model has a lot of potential to help the player to seasonalize their physical guarantee and optimize the results.
- The strategy proposed (strategy III) is the best strategy even for the most conservative players. We show that to seasonalize using only the contracts is not a strategy that protects the player from the movements of other players.

Contribution & Limitation

- **Main contribution:**
  - We brough a new approach and proposed a new model to support the seasonalization process. The model can optimize the financial results for the system and for the player, individually.

- **Limitation:**
  - The regulatory issue is still an important concern since the sector is undergoing several changes and the mechanisms for controlling and sharing risks may also undergo changes, which may imply the need for adjustments to the proposed model in the near future.

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