PSE BR 2026

Flexible electrification in Brazil: an emerging strategy to mitigate renewable energy curtailment and reduce operational costs

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Why does Brazil need demand flexibility?

- High levels of non-dispatchable renewable energy, thermal generators' contractual inflexibility, and inflexible demand;
- There are times with high generation and low demand, leading to curtailment;
- The average centralized wind and photovoltaic (PV) curtailment in 2025 was 4.25 GW or a total of 37.2 TWh (20.7% of total energy generated by these sources) [1];
- Brazil consumed 45.1 to 49.2 TWh monthly in 2025 [2];
- Flexible electrification means electrifying industrial energy demands and adjusting their operation in time to respond to electricity availability and costs.

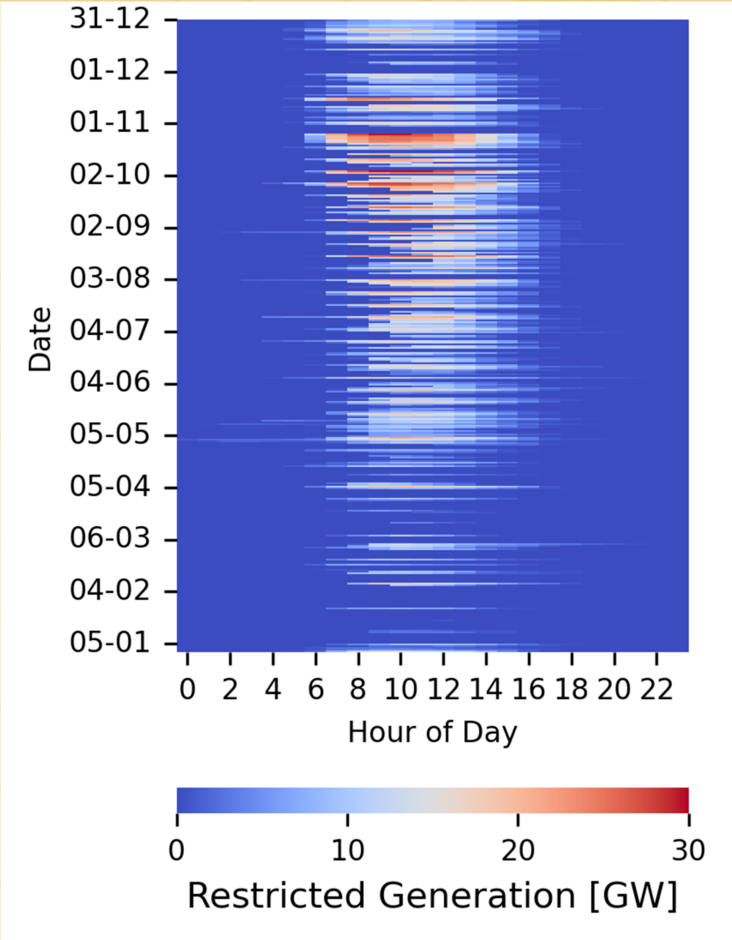
[1] - ONS: Acompanhamento das restrições de geração eólica e fotovoltaica, https://www.ons.org.br/Paginas/faq_curtailment.aspx, 2026.
[2] - EPE: Consumo mensal de energia elétrica por classe (regiões e subsistemas), https://www.epe.gov.br/pt/publicacoes-dados-abertos/publicacoes/consumo-de-energia-eletrica, 2026.

Objective

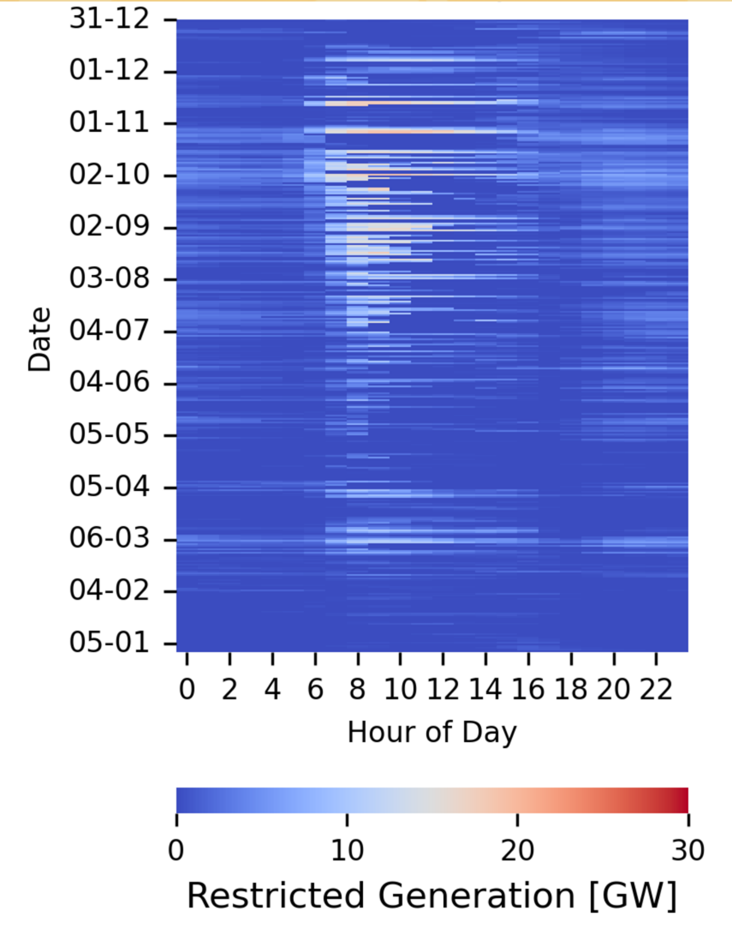
- Assess whether the temporal patterns of curtailment and electricity prices in Brazil indicate favorable conditions for flexible industrial electrification.
- Publicly available ONS and CCEE data for 2025 were aggregated into hourly profiles to analyze curtailment, turbinable discharge and electricity prices.

When does curtailment happen?

Lack of energy demand



Grid reliability

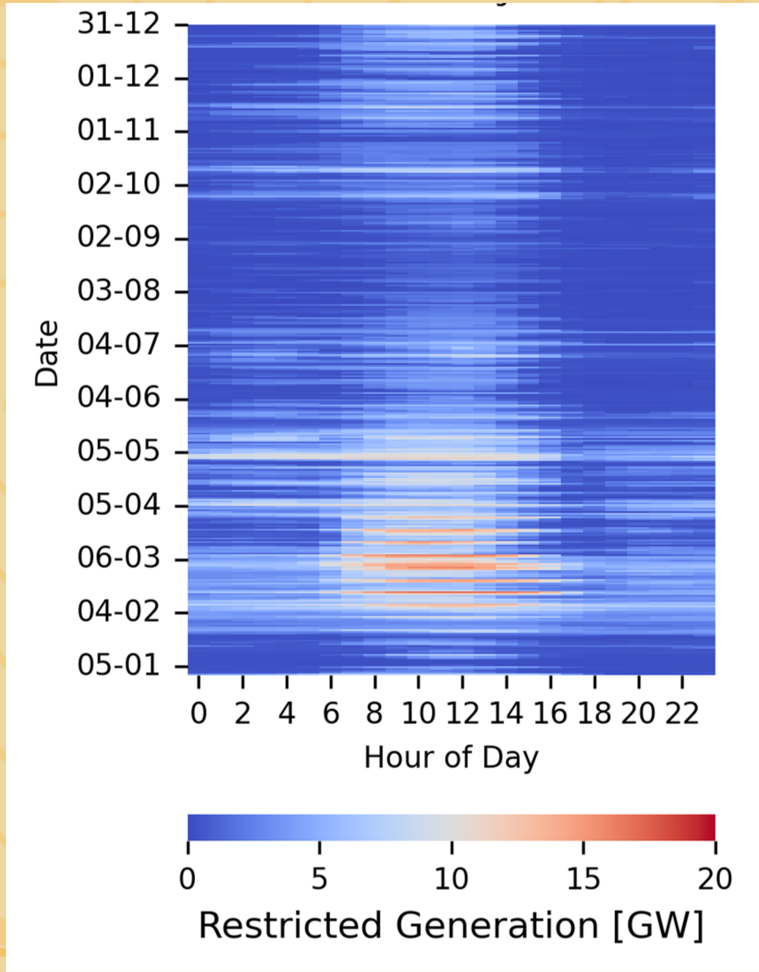


- Lack of energy demand [1]: Most common during daylight hours
- Grid reliability [1]: Most common during the wind season (July-October)
- Demand-related curtailment could potentially be mitigated by increasing flexible consumption during surplus periods. Grid-reliability curtailment, however, may also depend on the geographical location of the load and transmission constraints.

[1] - ONS: ONS Open Data Portal, https://dados.ons.org.br/, 2025

Renewable surpluses also constrain hydropower operation

Turbinable discharge [1]

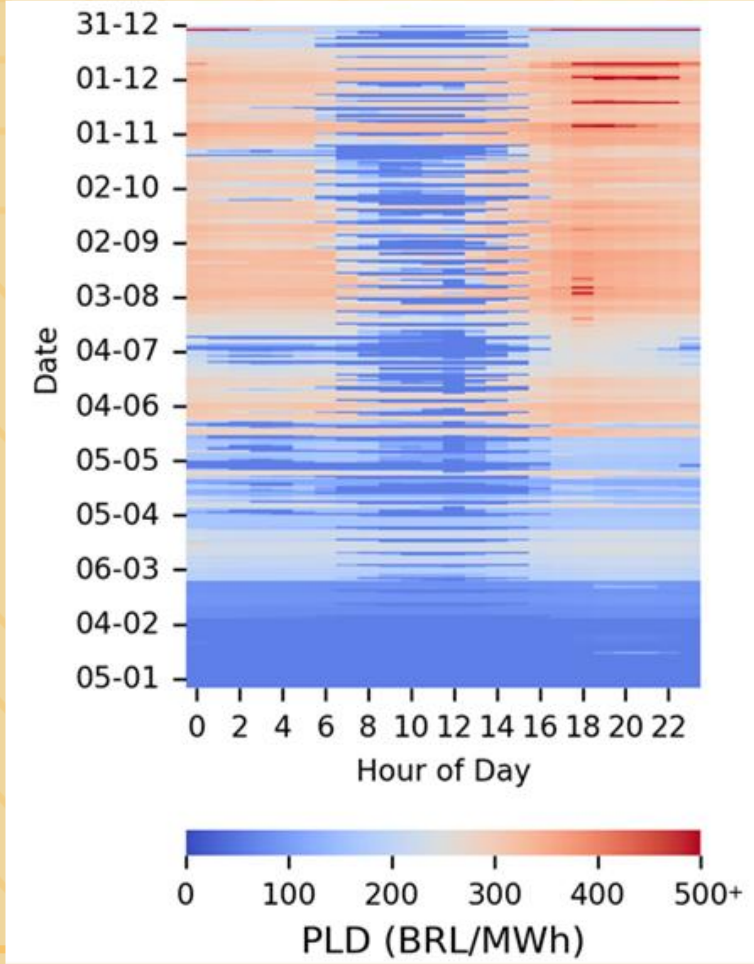


- Turbinable discharge: most common around the end of the rainy season (January - May);
- Mostly concentrated in the North subsystem due to run-of-river (fio d'água) hydropower;
- More prominent during daylight hours due to PV overproduction and minimum river flow constraints;
- 21.0 TWh of hydropower generation was discharged in 2025 (not quantified in the ONS curtailment report).

[1] - ONS: ONS Open Data Portal, https://dados.ons.org.br/, 2025.

Renewable surpluses tend to lower the PLD

Price of liquidation of differences [1] (color scale capped at 500 BRL/MWh)



- The price of liquidation of differences (before taxes) acts as a spot price in the Brazilian free electricity market;
- Prices during daylight hours tend to be much lower when curtailment occurs;
- The PLD is calculated by CCEE using the NEWAVE, DECOMP and DESSEM models developed by CEPEL, based on the marginal operating cost.

[1] - CCEE: Dados abertos CCEE, https://dadosabertos.ccee.org.br/dataset, 2026.

Hours with curtailment tend to have lower costs

Table 1. Quartiles of maximum daily price spreads in the Southeast-Centerwest subsystem.

Quartile	Price Spread (BRL/MWh)	Price Spread (%)
Minimum	0	0
25%	42.57	15.8
50%	169.11	156.2
75%	261.98	440.2
Maximum	1105.19	1418.2

Distribution costs also present price differences through the day

- Distribution tariffs are divided into peak and off-peak hours (horas de ponta e fora de ponta), increasing price differences;
- Peak hours lasts 4 hours of workdays (e.g. 18:00-21:00, depending on the distribution utility);
- Tariffs according to the connection-point voltage are available at [1].

Table 2. An example of tariffs applied to industrial consumers.

Group	Voltage (kV)	Off-peak capacity cost (BRL/kW)	Peak capacity cost (BRL/kW)	Distribution charges (BRL/MWh)
A3a	44	29.47	65.43	119.38

[1] - https://portalrelatorios.aneel.gov.br/luznatarifa/basestarifas

Illustrative example

Table 3. Costs for an industrial consumer with an average load of 2.75 MW

Annualized cost type	Cost (Million BRL)
Distribution capacity	4.838
Distribution charges	3.606
Energy	6.910
Total	15.354

Emerging technologies

- Storage:
    - Mechanical: pumped-storage hydropower, compressed air, etc
    - Electrochemical: lithium-ion batteries, flow batteries, etc
    - Chemical: hydrogen and other synthetic fuels
    - Thermal: cold or heated fluids may be stored for later hours
- Electrification:
    - Using electricity for heating, e.g., heat pumps that use low-temperature waste heat and electricity to achieve higher temperatures
    - Heat pumps can achieve a coefficient of performance greater than one.

Emerging technologies

- Electrification and Storage:

  E.g. heat pumps are used during low-electricity-cost hours and the thermal fluids are stored for higher-price hours

- Partial load operation:
  - Processes with high electricity intensity may be oversized to take advantage of lower prices
- Multiperiod optimization:
  - Solving a sequential optimization problem over a finite time horizon in which time t is influenced by times in $\tau < t$

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Preliminary illustrative example with batteries

Table 4. Costs for an industrial consumer with an average load of 2.75 MW with batteries (16.9 MWh) and without batteries

Annualized cost type	Without batteries (Million BRL)	With batteries (Million BRL)	Difference (Million BRL)
Distribution capacity	4.838	2.473	-2.365
Distribution charges	3.606	3.682	+0.076
Energy	6.910	6.409	-0.501
Capital	-	1.052	+1.052
Total	15.354	13.616	-1.738

Conclusions

- Curtailment in Brazil is an emerging problem and emerging technologies may add to the solution;
- Intraday cost variability creates load-shifting opportunities;
- Multiperiod process systems engineering models are needed to quantify when flexibility and/or electrification are economically advantageous.

Acknowledgements

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