AURORA
ENERGY RESEARCH

Brazilian Market Outlook

Public Report

Agenda

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III. Central outlook and key drivers

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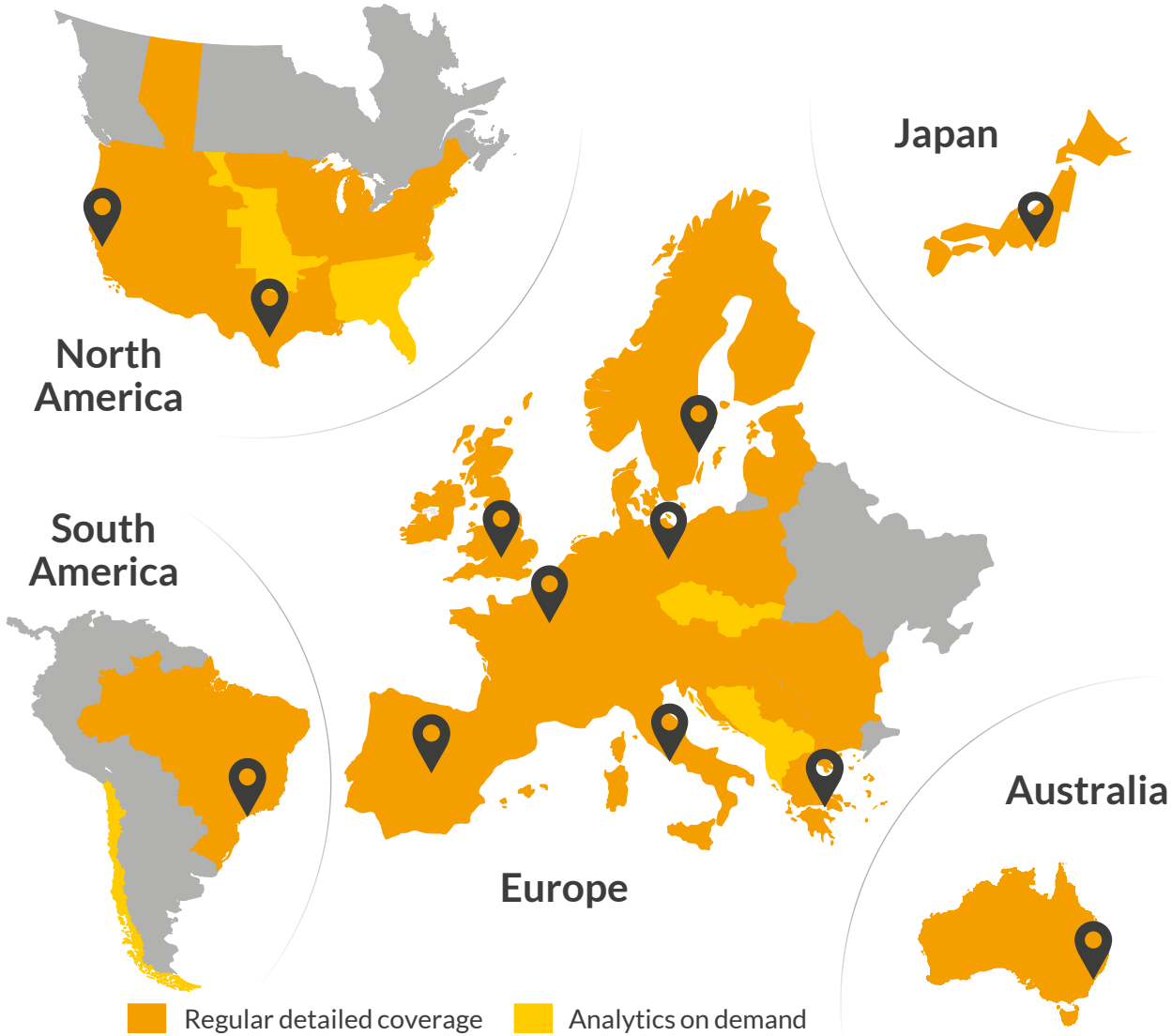
- Power markets
- Renewables
- Storage
- Electric vehicles
- Hydrogen H_2
- Carbon CO_2
- Natural gas



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Source: Aurora Energy Research

Our researchers

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The Brazilian government has been actively pursuing the approval of legal mechanisms towards a greener and more competitive power market

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2021

Adoption of hourly prices

- Until 2021, spot market was cleared on a weekly basis, based on three demand levels.
- In January 2021, Brazil adopted an hourly spot price (PLD), more accurately reflecting the real operation of the power system.

First capacity auction

- The first capacity auction contracted new and existing thermal, aiming to ensure security of supply.
- New mechanism sends a strong signal of commitment to liberalise the market.

2022

Subsidy reduction for distributed solar

- Law 14.300 created a new framework for distributed solar, gradually reducing grid tariff exemptions for new plants deployed from 2023.

Grid subsidy cut for renewables

- End of discounts for grid charges applicable to new renewable projects established by Law 14.120.

2023

Transmission auction

- ~6,200 kms of transmission lines auctioned mostly to expand interconnections between new renewables in the Northeast with demand in the Southeast.

Eletrobras privatisation

- Privatisation of the largest State-owned company, Eletrobras, expanding the role of private sector in the market.
- Law includes mandatory contracting of thermal capacity, with a first 753 MW auction to boost reliability in the North.

2024

Free market gradually opening

- Gradual opening started in 2018, but from January 2024 all high voltage consumers are eligible to shift to the free market.
- Congress is discussing draft-law 414/2021 to extend free market access to all low voltage customers, including residential, from 2028.

Energy sector tops Government's agenda

- R$ 540 billion will be allocated to decarbonise the economy as one of the main investment axes of the Growth Acceleration Program (PAC).
- In a COP28 context, the Brazilian congress approved significant advancements in its green agenda[1], aiming to attract new investments to the energy sector:
  - New offshore wind regulatory framework.
  - Legal framework for green hydrogen defining the criteria for categorising hydrogen as green, implementing financial incentives, and addressing organisational aspects.

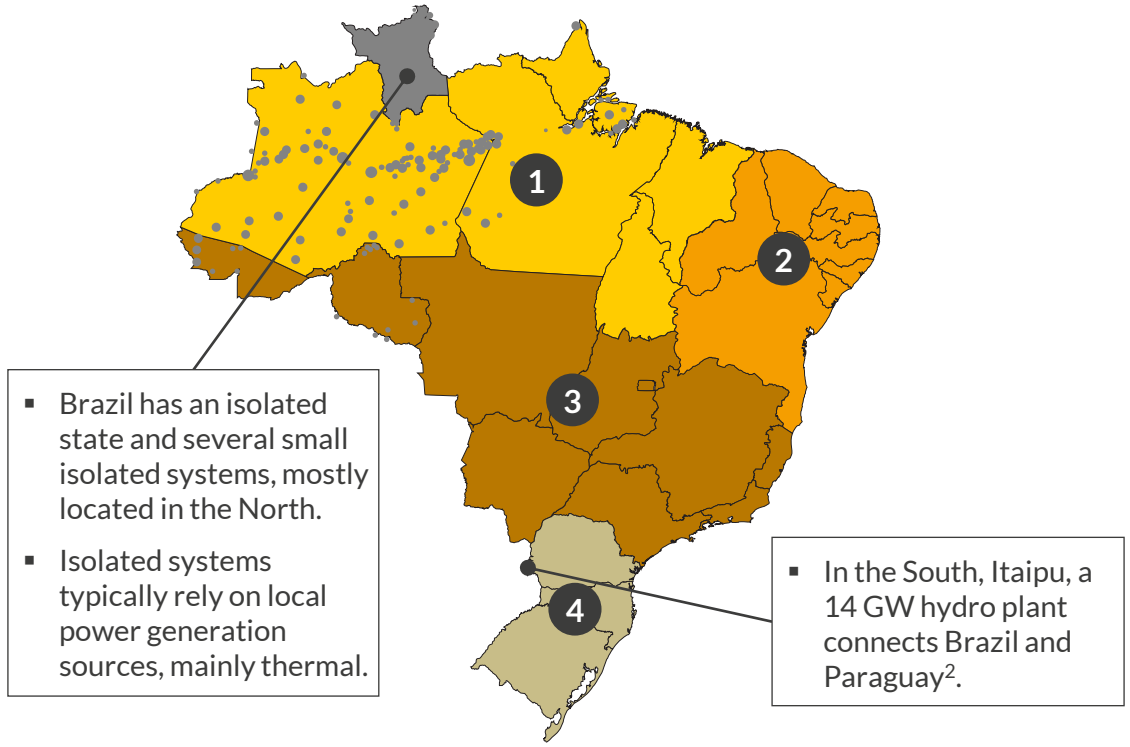
1) Approval must be obtained in both houses of Congress. The regulatory framework for hydrogen and offshore wind has been sanctioned in one parliamentary house and is currently awaiting approval in the other house.

Sources: ANEEL, MME

The Brazilian interconnected power system supplies over 99% of the country's demand and is divided in four submarkets

The Brazilian interconnected power system[1] supplies over 99% of the country's electricity demand. Although Boa Vista (Roraima) is the only state capital that is not connected, there are still 212 isolated systems across seven states. Brazil's most relevant international interconnection is with Paraguay via a 14 GW binational hydro plant[2].

Map of the Brazilian interconnected power system[3]



- Brazil has an isolated state and several small isolated systems, mostly located in the North.
- Isolated systems typically rely on local power generation sources, mainly thermal.

- In the South, Itaipu, a 14 GW hydro plant connects Brazil and Paraguay[2].

Market snapshot by 2022

Regions	Installed capacity GW	Share %	Annual demand TWh	Share %
1 North	27	15%	54	9%
2 Northeast	45	25%	98	16%
3 Southeast / Midwest	86	47%	348	57%
4 South	24	13%	103	17%
Isolated systems	1.2	1%	3.9	1%

1) "Sistema Interligado Nacional", or SIN. 2) Brazil is also interconnected with Argentina and Uruguay via 2.2 GW and 0.57 GW of transmission lines, respectively. Brazil operates at 60 Hz and Paraguay, Argentina and Uruguay at 50 Hz thus converters are required. There is also an interconnection with Venezuela and the Roraima grid, which is not part of the interconnected power system. 3) Grey areas are not connected to the power system.

Sources: Aurora Energy Research, ONS, EPE, ANEEL

Power system operations are updated on a rolling-horizon, starting at month level and resulting in day-ahead hourly prices

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Timeline for market operations

- Month

- Every month, the system operator updates the dispatch plan using the NEWAVE model, resulting in a monthly operational program.
- ONS plans operations and estimates hydro opportunity costs (i.e. water values) over a five-year period with monthly granularity.

- Week

- Each week of the month, ONS adjusts the operational plan for the year-ahead, planning the weekly operation and refining the calculation of hydro opportunity costs.
- ONS estimates system dispatch using the DECOMP model to calculate likely marginal costs for the week ahead.

D - 1

- On the day-ahead, ONS uses DESSEM to update dispatch, using previous models' outputs.
- Result is hourly level marginal cost (CMO).
- The Difference Settlement Price (PLD[1]) is calculated by the CCEE daily for each hour of the following day.
- **Financial:** on the day-ahead, CCEE identifies contractual imbalances (dispatch vs contracted), which are settled at the **PLD** .

D

- ONS **1)** manages supply and demand matching, **2)** solves transmission constraints, **3)** controls hydro reservoir levels, and **4)** ensures security of supply.
- ONS might dispatch differently from planning; energy dispatched in real-time is cleared at price set in the day-ahead market.

D + 1

- Analysis of actual dispatch vs planned day-ahead operations.

Planning operations | **Day-ahead operations** | **Real-time operations** | **Adjustments**

1) PLD, or, differences settlement price. See slide 12 for further details.

Sources: Aurora Energy Research, CEPEL, ONS

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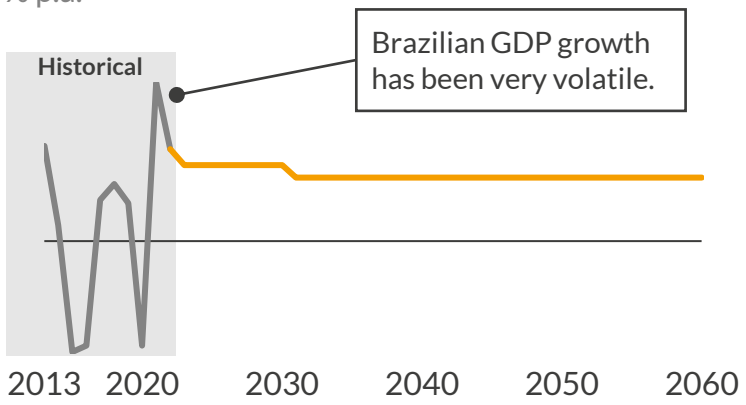
By 2060, electricity demand is forecasted to more than double from today's levels driven by population and economic growth

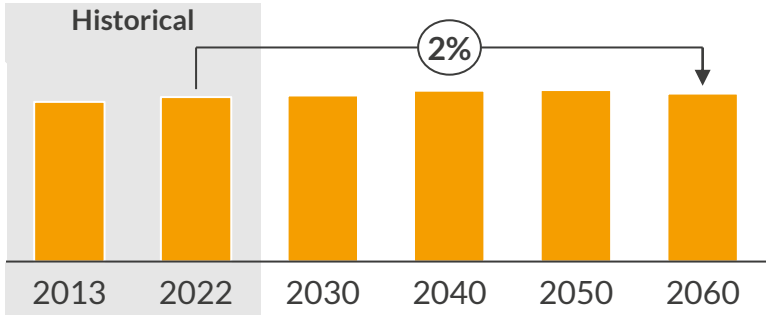
1 **GDP and population are the two key factors expected to drive electricity demand growth for Brazil going forward.**

2 **Demand growth is mostly driven by the residential sector, followed by industrial development and electrification.**

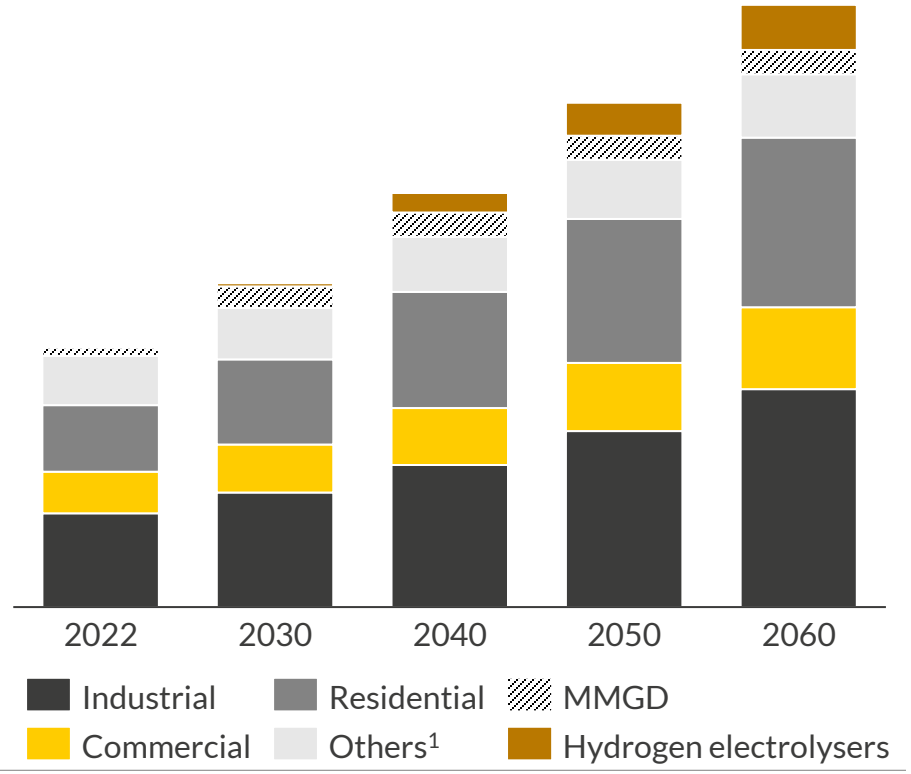
GDP growth
% p.a.



Population
Millions



Electricity demand
TWh



1) Agricultural growth of 3.5% p.a. for the last 10 years.

Sources: Aurora Energy Research, EPE, IBGE, IMF, Oxford Economics, 2022 Census

- By 2060, we expect demand to more than double when compared with 2022 demand levels. This increase is mostly driven by the residential sector, followed by industry.
- For the Industrial, Commercial and Residential sector, the key driver is GDP. The Residential sector also presents a strong correlation with population, which we have captured in our forecast.
- Hydrogen electrolysers will represent 7% of the total Brazilian demand by 2060. Based on the existing pipeline, these are expected to be in the Northeast.

Technological improvements will drive down costs for all renewables, with solar still at the forefront, decreasing by 26-29% by 2030

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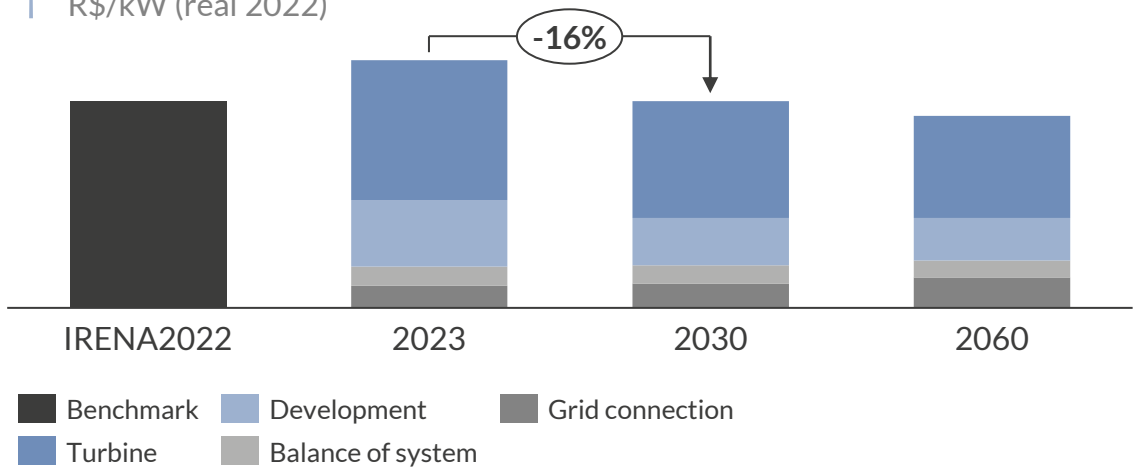
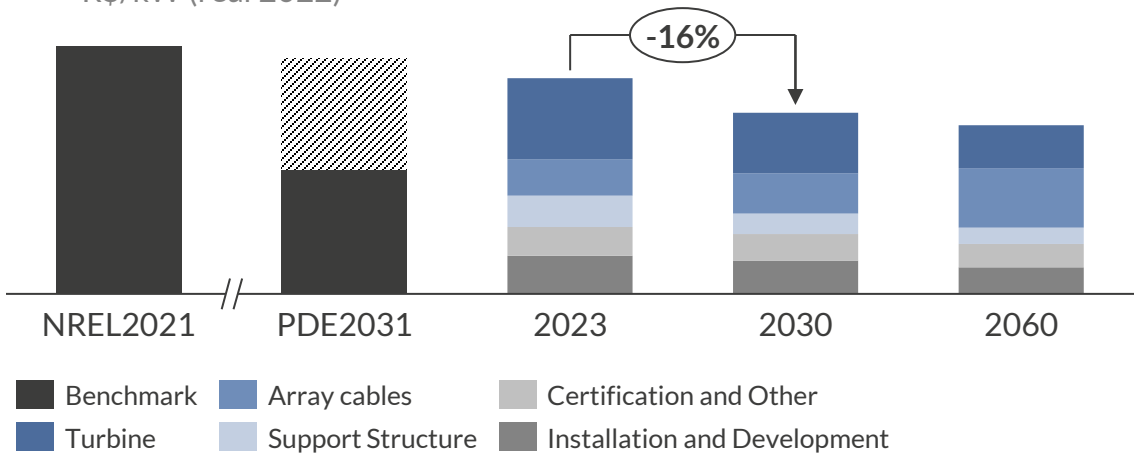
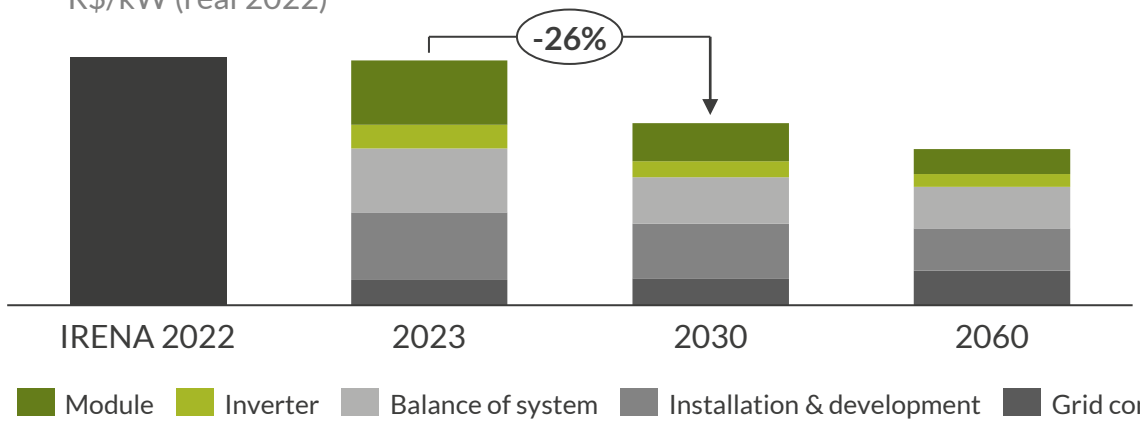
Utility scale onshore wind CAPEX costs
R$/kW (real 2022)



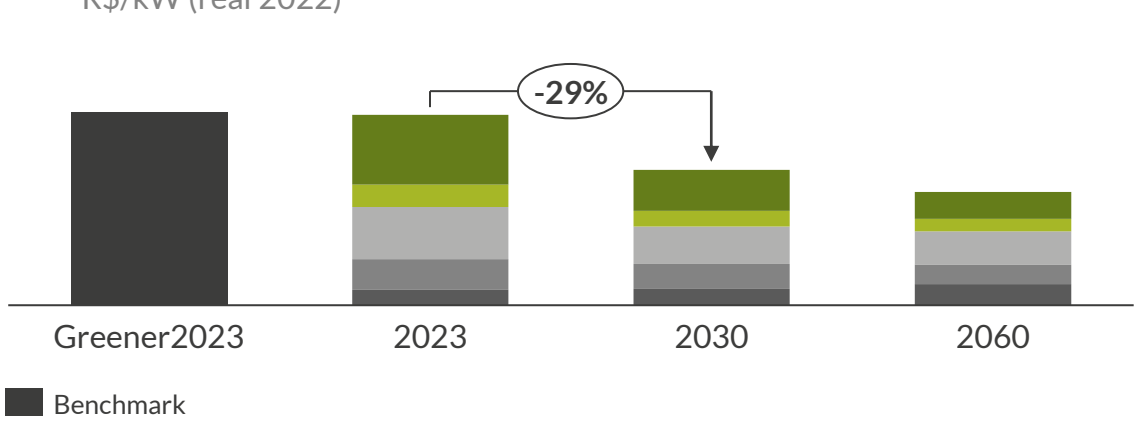
Utility scale fixed offshore wind CAPEX costs
R$/kW (real 2022)



Utility-scale tracking solar PV (single axis) CAPEX costs
R$/kW (real 2022)



Distributed solar PV (fixed axis) CAPEX costs
R$/kW (real 2022)



Source: Aurora Energy Research, IRENA, NREL, EPE, Greener

Brazil's solar potential is dispersed nationwide, while the Northeast boasts the highest load factor for both wind and solar

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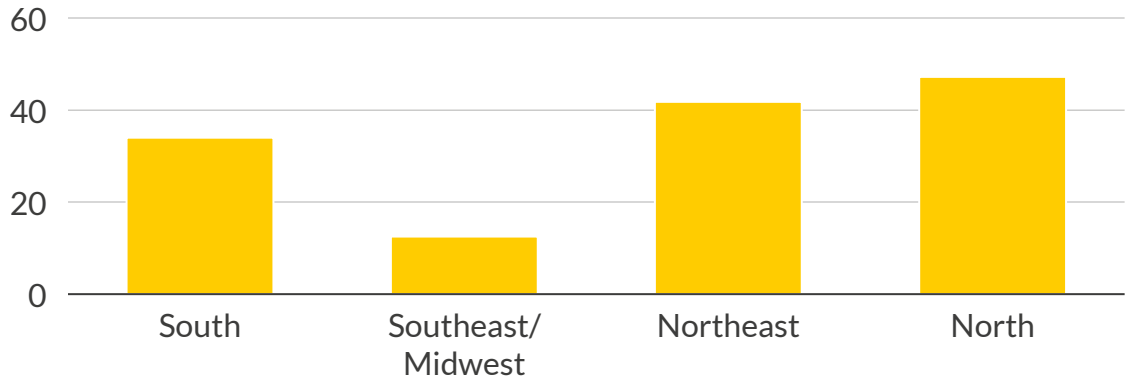
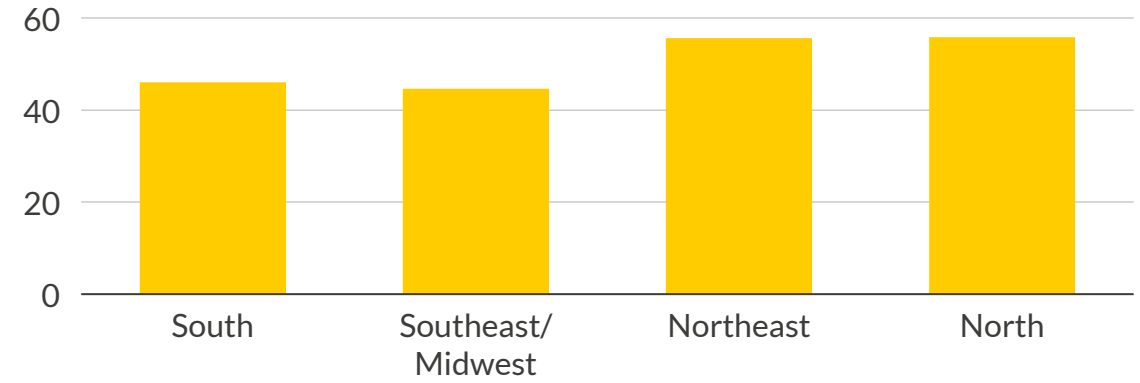
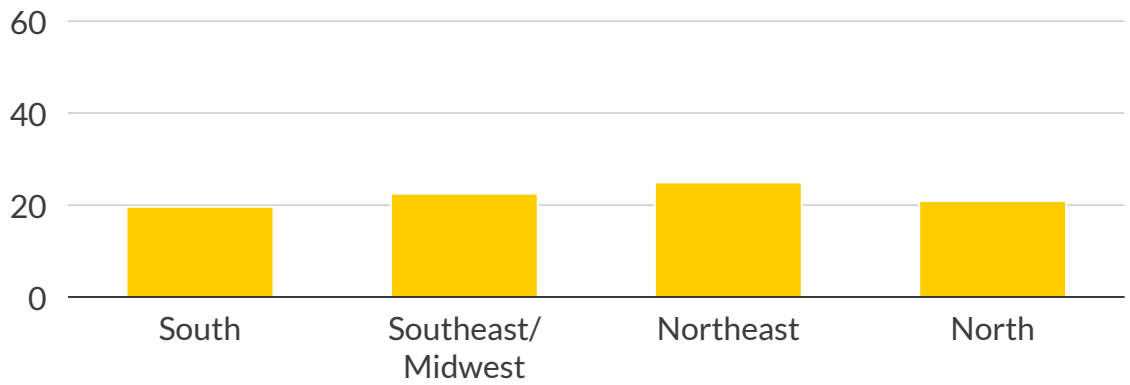
Utility scale onshore[1] wind load factors



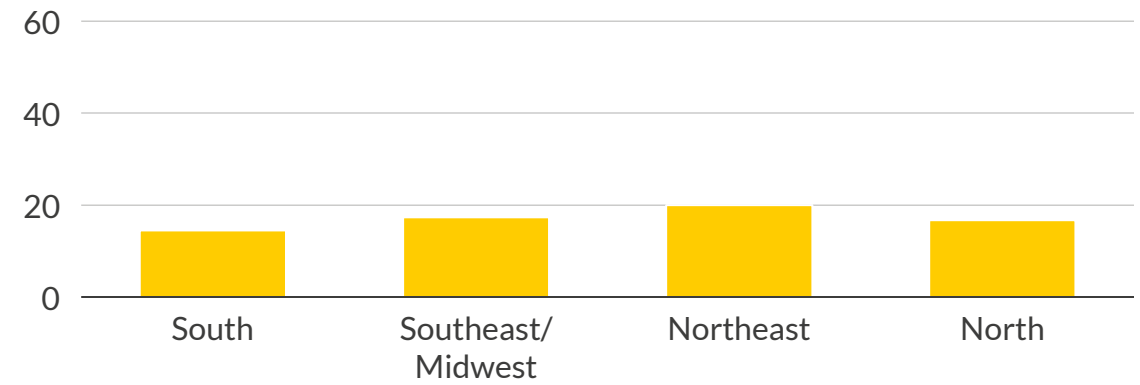
Utility scale fixed offshore wind load factors



Utility-scale tracking solar[2] PV (single axis) load factors



Distributed solar[2] PV (fixed axis) load factors



1) Onshore wind: based on measured wind speeds between 2018 and 2022, calibrated to expected technology deployment and turbine data. 2) Solar irradiation data provided by MERRA-2 database of NASA.

Source: AMUN, ANEEL, ONS, CCEE, Aurora Energy Research

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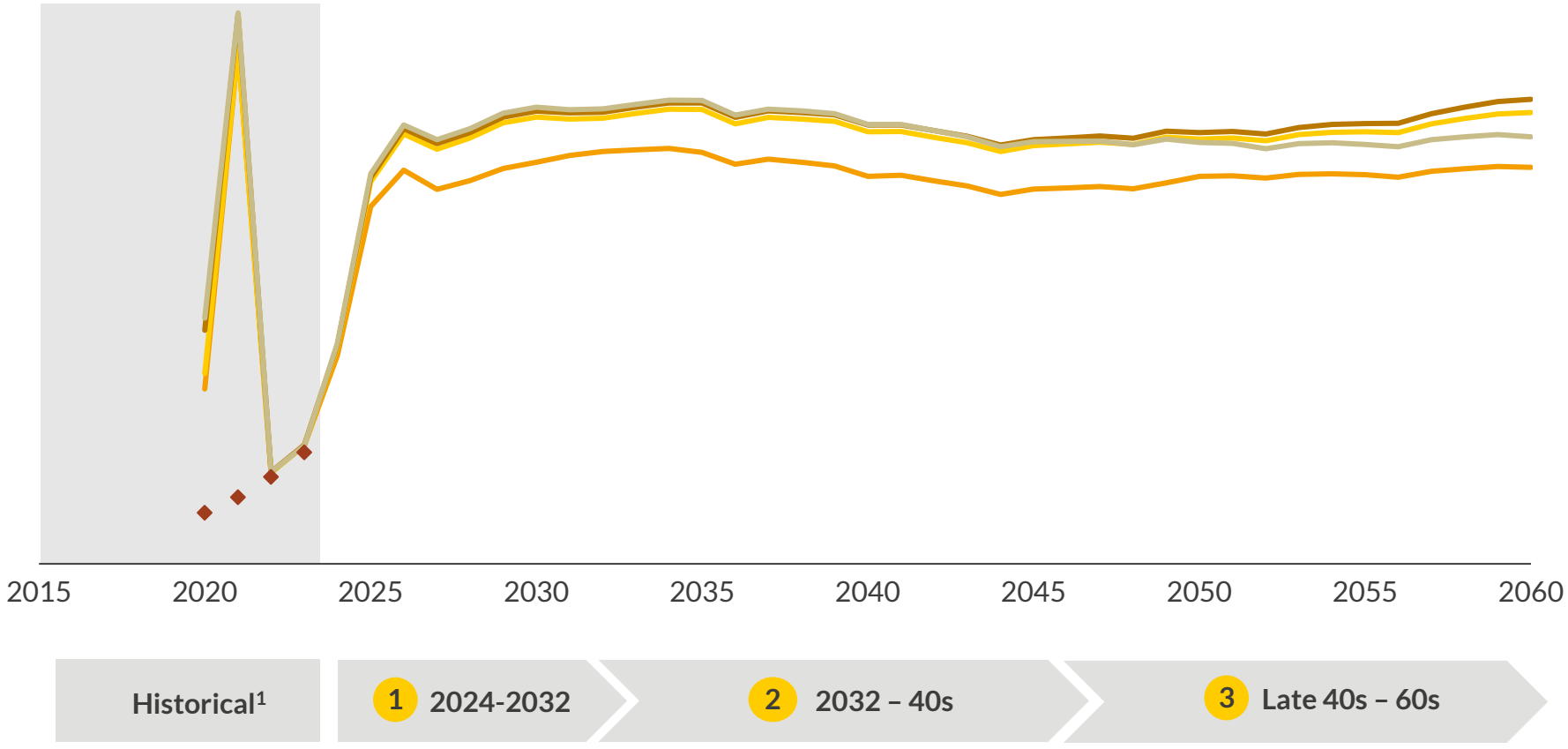
In our Central scenario, demand growth is offset by increasing renewable build-out, but transmission limits result in regional price divergence

Baseload price per Brazilian subsystem
R$/MWh (real 2022)



1) Historical data from ONS and CCEE. Considers IPCA as of November. For 2023, data until November 30.

Sources: Aurora Energy Research, ONS, CCEE.

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Outlook for baseload prices

1. In the short-term, prices rise from regulated floor price driven by an expectation of lower hydro inflows and slower pace of wind and solar projects deployment.
2. In the 2032-40s period, the acceleration of renewable deployment offsets price increases. Despite planned transmission upgrades, subsystem disparities persist.
3. In the long-term, rising divergence in prices across subsystems is driven by both uneven renewable growth and demand uptake.

Get key insights to make informed decisions and make the most of opportunities by getting in touch with **Priscila Vellano, Commercial Manager**

priscila.vellano@auroraer.com

Wind and solar drive the Brazilian capacity expansion leading to 80% of carbon-free generation by 2060, despite no new hydro build-out

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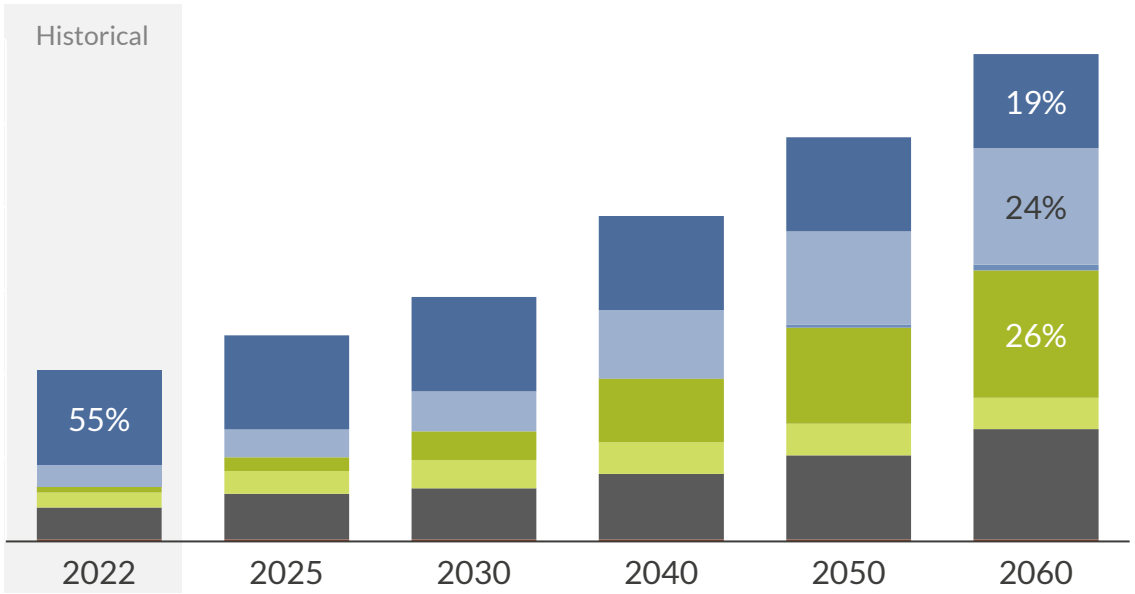
Installed capacity in Brazil

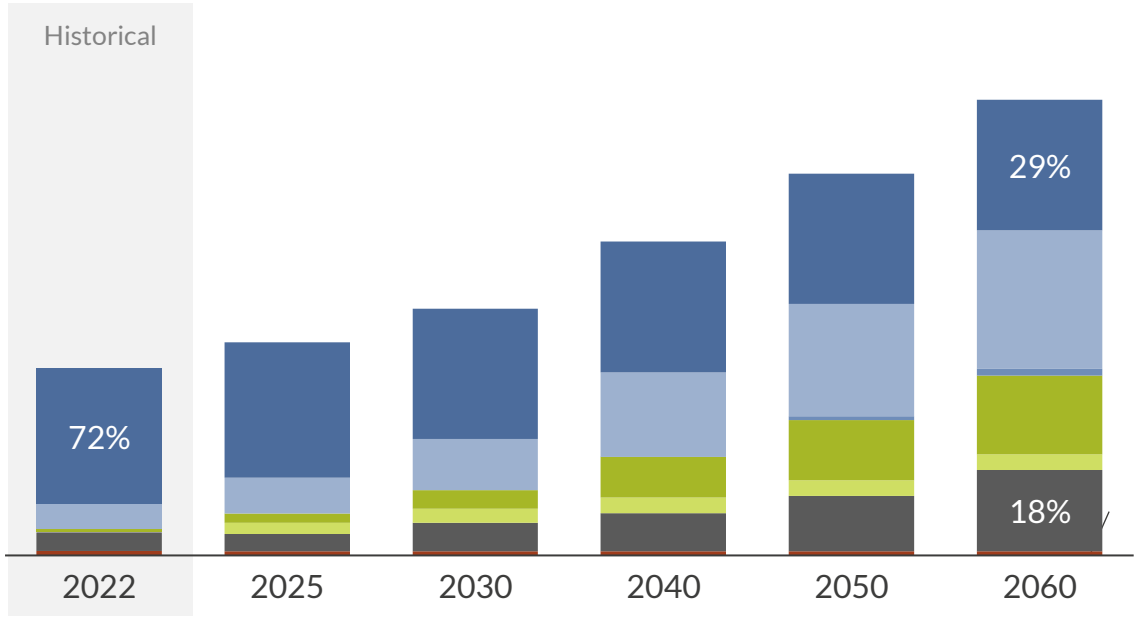
GW



- Installed capacity increases by about 200% within the forecast horizon, mostly driven by the growth of centralised renewables.
- With no new hydro build-out planned, its share in the capacity mix erodes to a third of its current share, while centralised wind and solar share rise sharply.
- Thermal plants play an enhanced role in ensuring security of supply, as the capacity mix evolves to include more intermittent renewables[1].

Generation[2] mix in Brazil

TWh



- Total electricity production more than doubles from 2022 levels, driven by growing demand over the 2024-2060 period.
- Renewables will constitute more than 80% of total generation by 2060, with hydro diminishing its central role in the generation mix.
- Thermal generation will continue to play an important role in the system, accounting for 18% of total generation by 2060.

Hydro | Onshore wind | Offshore wind | Centralised solar | Distributed solar (MMGD) | Thermal[3] | Nuclear

1) Wind and solar. 2) Historical generation mix does not include distributed solar (MMGD). 3) Thermal includes biomass, CCGTs, coal, oil, gas, and diesel.

Sources: Aurora Energy Research

As solar penetration increases in Brazil, a duck curve appears, lowering midday prices in 2050 below the lowest hourly average price of 2020

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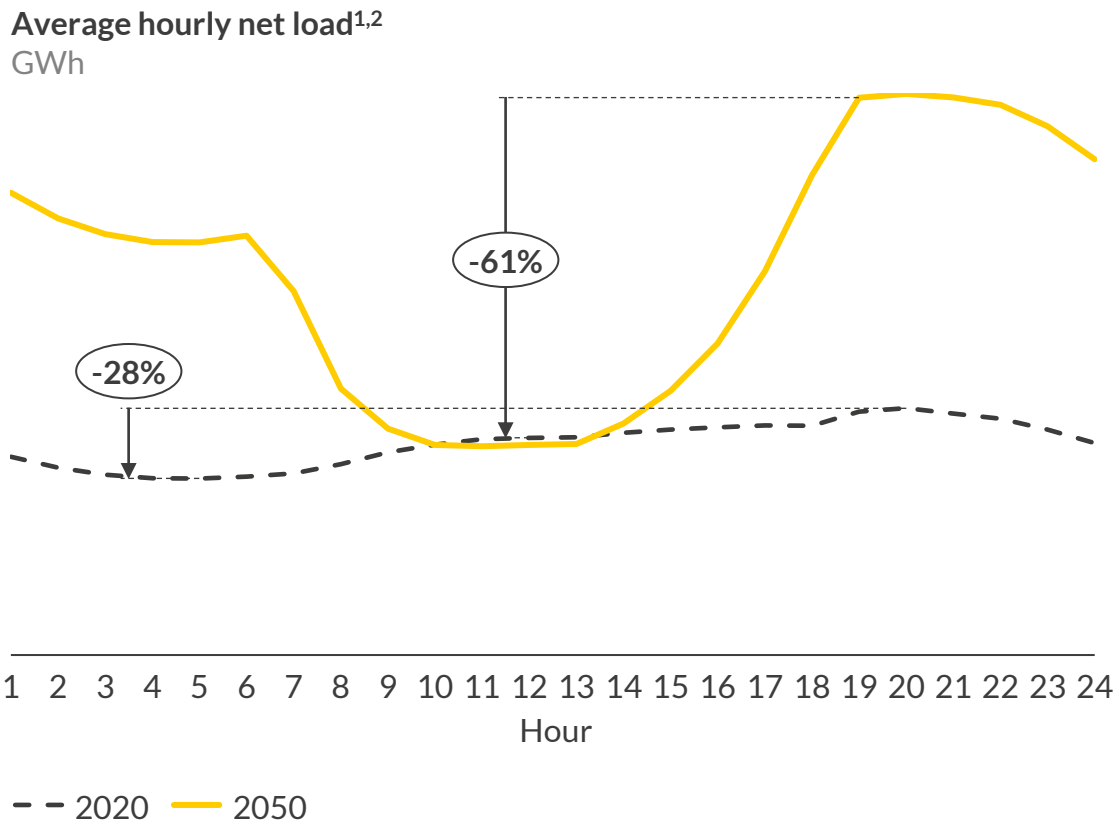
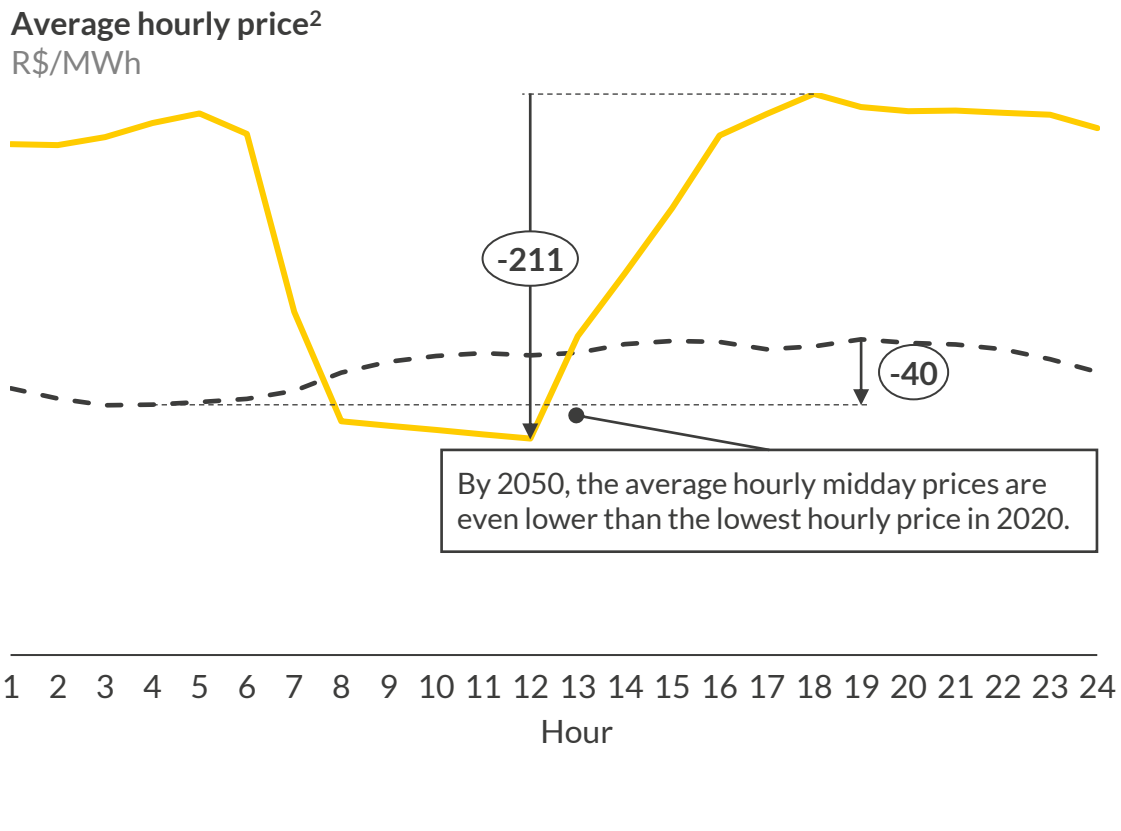
1 **In 2020, there are two load peaks: in the middle of the day and in the evening. By 2050, solar generation pushes down the net load in the middle of the day even as the net load spread increases for an average day.**

2 **The changes in net load shape shift the midday peak by 2020 to a peak in early morning by 2050. It also increases intraday volatility, with average daily spreads rising from R$40/MWh by 2020 to R$211/MWh by 2050.**



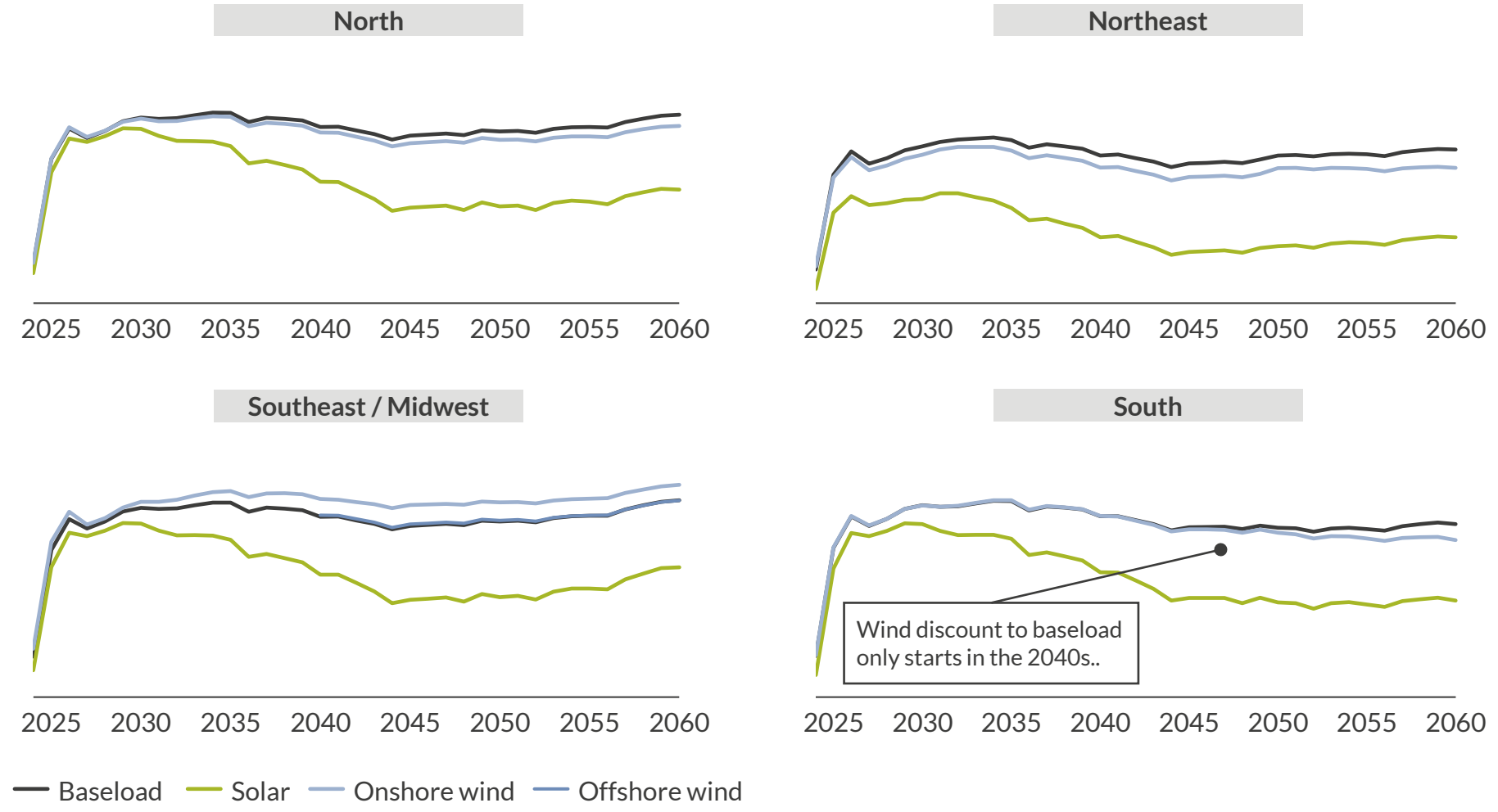


1) Net Load = Demand minus solar and wind generation. 2) Average over the year. Analysis shown for the Southeast/Midwest subsystem.

Sources: Aurora Energy Research, ONS.

Through 2060 and across all subsystems, capture prices for wind remain relatively close to baseload, but solar cannibalisation increases

Baseload and renewables capture prices[1]
R$/MWh (real 2022)



1) Capture prices are uncurtailed generation-weighted subsystem fleet average.

Source: Aurora Energy Research

- We see similar profiles across all subsystems with renewable capture prices following a similar trend to baseload prices.
- The level of cannibalisation for renewables increases from today's levels, due to the growth of renewable generation.

Solar PV

- Solar discount to baseload increases over time as large amounts of new installed capacity all generating at the same time cannibalises prices.
- From all the regions, the Northeast shows the largest discount to baseload.

Onshore wind

- For all subsystems, onshore wind capture price discount is much lower compared to solar.
- The Southeast/Midwest shows a premium to baseload price.

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Aurora designed Brazil-specific scenarios to explore a range of market uncertainties and sensitivities

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As per *Central* unless indicated	Capacity mix of the Brazilian system	Demand	Commodities	Technology		Policy
				Renewables	Hydro	Transmission upgrades
Central Scenario	▪ See section III.					
A Low (financing) Scenario	▪ Different capacity mix from Central scenario.	▪ Lower demand than in Central, assuming slower GDP growth[1].	▪ Lower commodity prices than in Central.	▪ Lower CAPEX for new assets.		
B Constrained transmission Sensitivity	▪ Same capacity build-out as Central scenario.					▪ Sensitivity to reflect impact of delays in network upgrades and inter-regional bottlenecks.
C Weather cycles Sensitivity	▪ Same capacity build-out as Central scenario.				▪ Sensitivity reflecting El Niño-Southern Oscillation cycles.	

1) Note that distributed solar (MMGD) and population growth are the same as in Central.

B If transmission upgrades fall short, Northeast wind projects could yield lower revenues than deploying the same asset in the South

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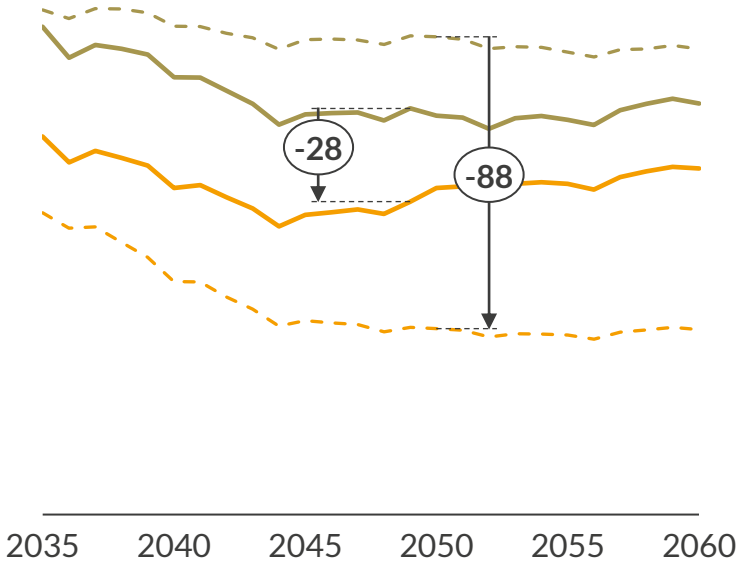
1 **Without transmission upgrades after the 30s[1], price divergence would average R$80/MWh, instead of R$30/MWh in the Central.**

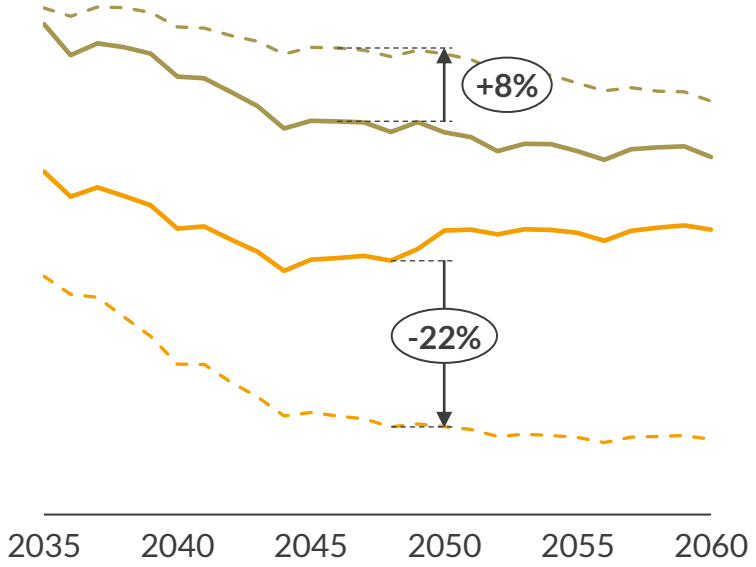
2 **Wind capture prices would drop by ~20% in the Northeast compared to Central, while the demand-heavy South would see a positive impact.**

3 **Consequently, unlike in the Central, expected revenues for a Northeast asset would be lower than for an asset in the South.**

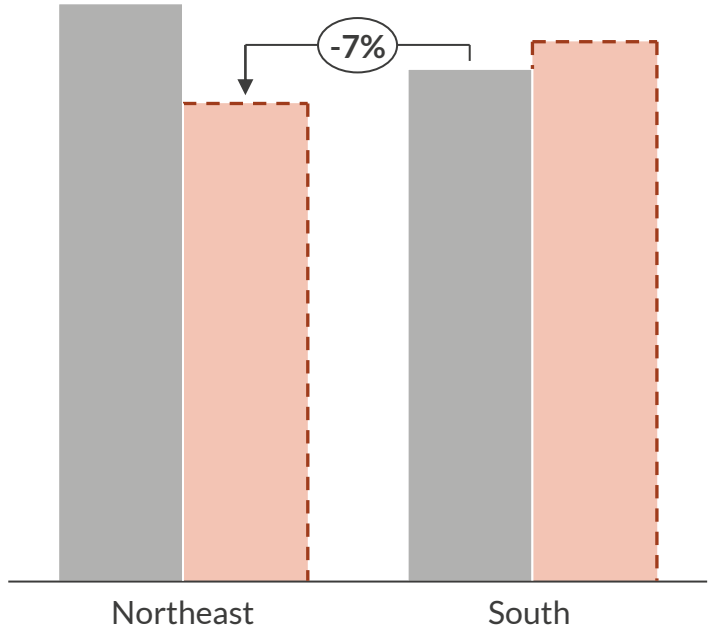
Baseload price per subsystem
R$/MWh (real 2022)



Wind capture price per subsystem
R$/MWh (real 2022)



Present value[2] of revenues for a wind project
mmR$



Central scenario | Constrained transmission sensitivity | Northeast | South

Central | Constrained transmission

1) In our Central scenario, we only assume there is a transmission upgrade across regions if economically viable, considering EPE assumptions on investment costs, lifetime, WACC for interregional interconnections. 2) Net present value of revenues discounted at 13% for a 400 MW wind project deployed in the Northeast (with a load factor of 45%) or in the South (with a load factor of 34%).

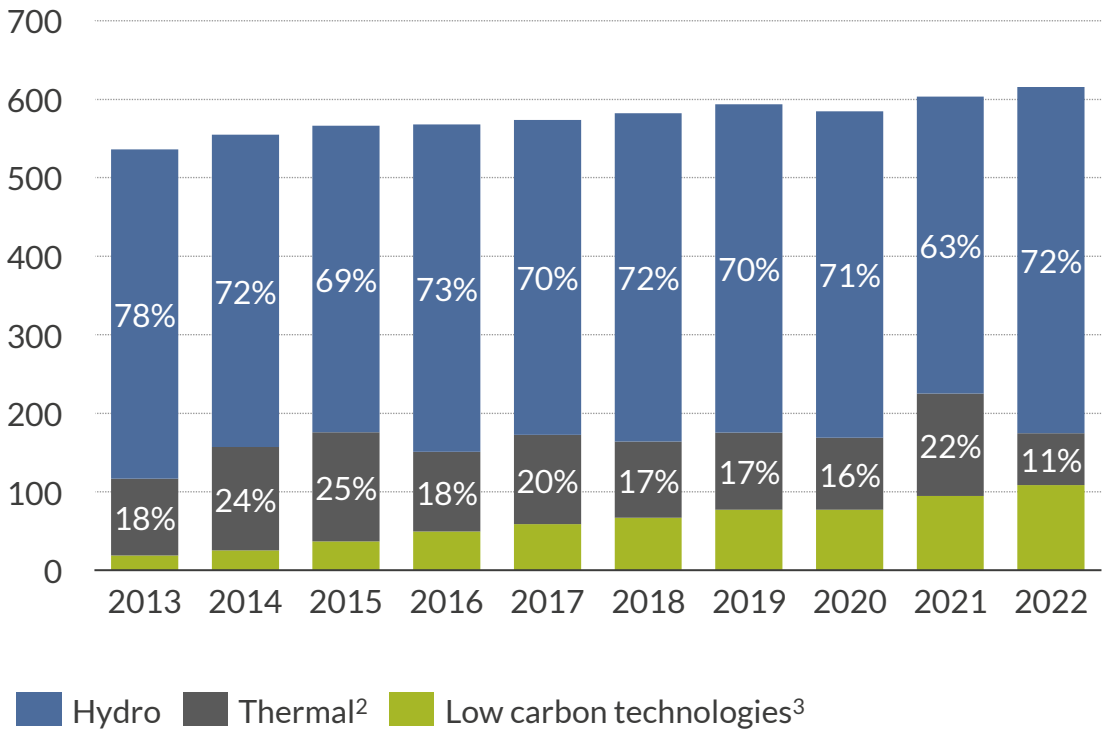
Sources: EPE

C Drawing upon historical data, we analysed an annually varying inflow sensitivity against our Central scenario

Historically, weather cycles with varying rainfall levels have affected each of the four Brazilian subsystems differently. Hydro inflows, which determine water availability for power generation, have exhibited significant year-on-year variations. In this sensitivity, rather than taking a P50 approach like in our Central scenario, Aurora uses historical cycles and analyses its impact in the evolving Brazilian power system.

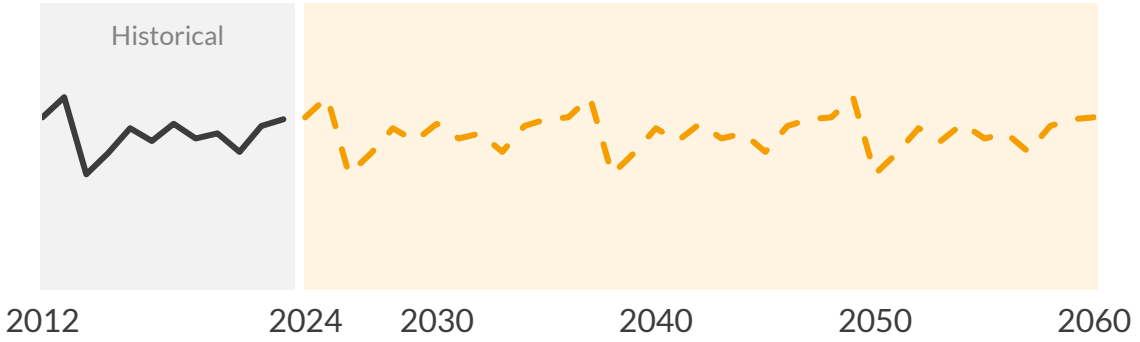
Generation mix for the Brazilian system over the last 10 years

TWh

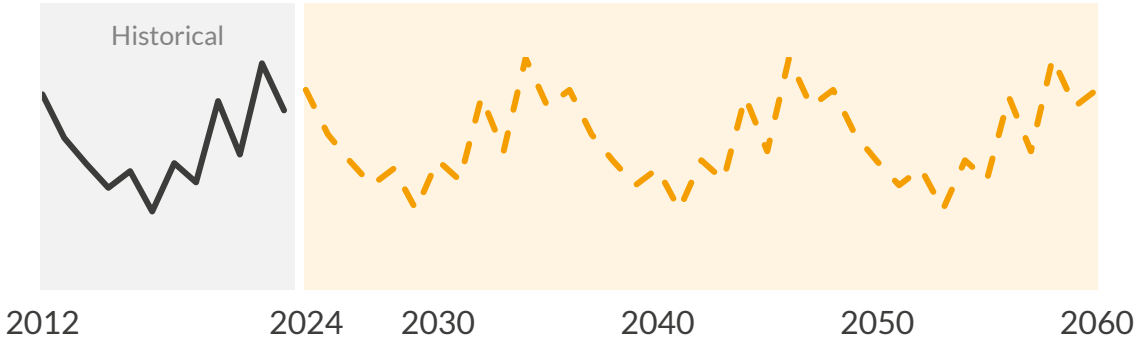


Inflows[1]

Southeast / Midwest subsystem



Northeast subsystem

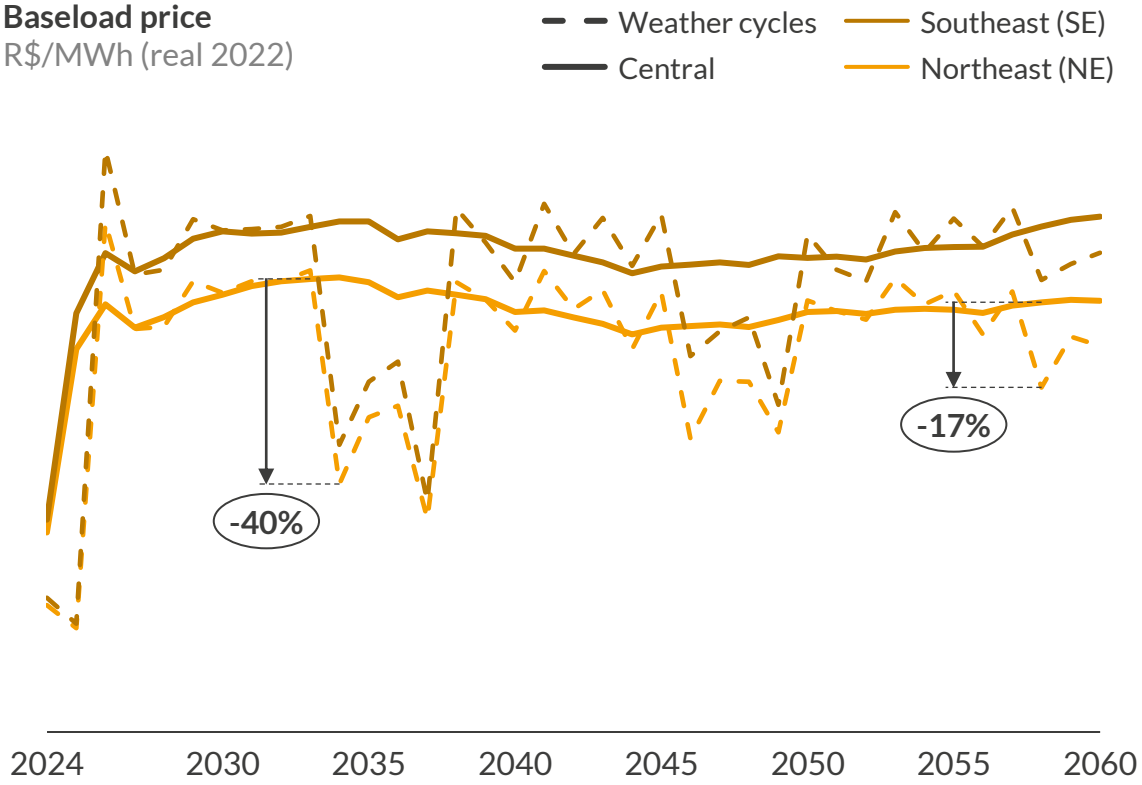


1) Relative to P50. Based on historical affluent natural energy of the hydro plants. 2) Thermal includes biomass, gas, coal, oil and diesel. 3) Low carbon includes solar PV, onshore wind and nuclear.

Sources: ONS

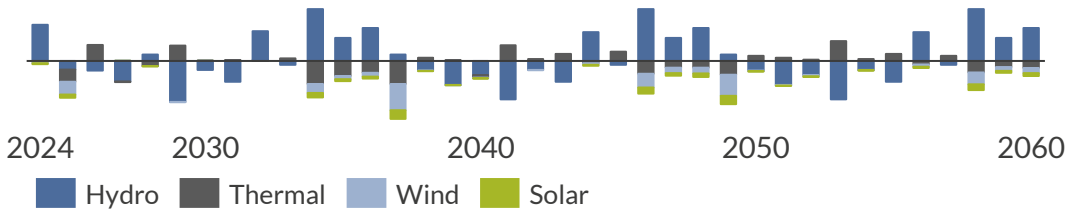
C Despite yearly changes in the generation mix in this scenario, the average price delta over the timeline is only 7% lower compared to the Central

Baseload price
R$/MWh (real 2022)



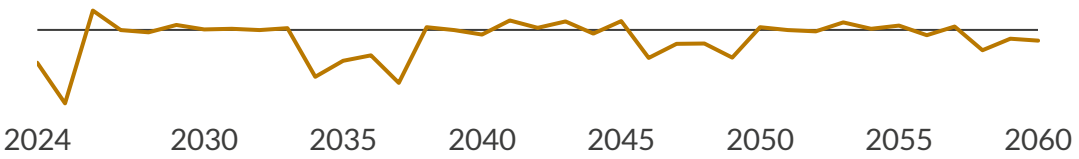
1 **In this scenario, variable inflows shift the generation mix, impacting dispatch and causing inter-annual price variations of up to R$120/MWh …**

Delta on generation[1]: Weather cycles relative to Central, TWh



2 **… yet, compared to Central, prices would be 7% lower over the timeline[2]; while showing a decreasing impact of inflow changes on prices.**

Delta in baseload prices[1]: Weather cycles relative to Central, %



- **PPAs strategic role**: in a market historically subject to weather cycles' unpredictability, securing stable long-term revenue streams is key.
- **Decreasing impact of hydro:** hydro's declining share in the mix translates into a lower impact of inflow variability on prices, signaling a positive trend for renewables.

1) Results shown for the Northeast subsystem. 2) 7% lower on average, and throughout the 2024-2060 timeline.

Sources: Aurora Energy Research

Key takeaways: Brazilian Market Outlook

1. Baseload prices rise from regulated floor price, with regional prices varying over time in line with uneven renewable growth and demand uptake across subsystems, and interconnections deployment.

2. Hydro share in the capacity mix erodes to a third of its current share, with capacity expansion primarily driven by solar and onshore wind.

3. The large growth in renewables will lead to intraday volatility in the baseload price and to the “cannibalisation” of revenues, resulting in different capture prices for wind and solar.

4. Aurora alternative scenarios analysis on the impact of weather cycles’ and on transmission network delays signals the importance of securing stable long-term revenues and having diverse portfolios.

Brazilian Power & Renewables Service:

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Take an in-depth look back at the past month's technology and market updates*

Forecast Reports & Data

Comprehensive market outlook reports and accompanying databooks, providing long-term price projections across different scenarios

Interactive EOS Platform

Explore scenarios through EOS, our dynamic and interactive online platform featuring a full library of comprehensive reports, datasets, and content, provided with company-wide access

Strategic Insights

Strategic Insight Reports

In-depth, thematic reports on topical issues

Policy Updates

Timely research notes on recent changes to policy and regulation, demonstrating the impacts and opportunities for market participants

Group Meetings

Group Meeting roundtable events with key market participants such as developers, investors, financiers, utilities, grid operators, and government officials

Analyst Support

Biannual workshops and support from our bank of analysts, including native speakers and on-the-ground experts

We work with a very broad range of clients … their constant challenge keeps us up on our toes and ensures our independence

AURORA

> *"Very excited to see Aurora investments in the country (Brazil). It is very good for us to bring a global expert to help us navigate these new times we have ahead of us"* **Igor Fonseca, Head of Power, Project Finance, Santander**

Santander

> *"With a vast expertise in the energy sector, Aurora has been promoting relevant discussions and providing valuable insights to our business in Brazil. Always grounded in data intelligence, it is helping companies to make strategic decisions towards the global energy transition"* **Rogério Jorge, CEO, AES**

aes

Power & utilities

fortum, FORSA ENERGY, edp, e·on, IBERDROLA, TESLA, Urenco, centrica, CALPINE, 50hertz, RWE, Ørsted, drax, enel, InterGen, uniper, EDF, Enea, Viridor, EnBW, UK Power Networks, ESB, axpo, sorgenia, Energa, Eneco, POLSKA GRUPA GÓRNICZA, SSE, nationalgrid, ukpowerreserve, ENGIE, Terna, VATTENFALL, Statkraft, enviva

Energy consumers

BASF We create chemistry, Port of Rotterdam, GLENCORE, Heineken, BOC Member of The Linde Group, MITSUBISHI POWER, umicore, SIEMENS, EVONIK INDUSTRIES, Google, ITM POWER Energy Storage | Clean Fuel, INEOS THE WORD FOR CHEMICALS, UPM, SALZGITTER AG Stahl und Technologie, Unilever, SNCF, SIMEC, AlzChem, DB, wieland, orange

Financial sector & investors

GREENCOAT CAPITAL, 北京控股有限公司 BEIJING ENTERPRISES HOLDINGS LIMITED, CIP, JLEN, Close Brothers Asset Finance, equitix, Allianz Global Investors, SOCIETE GENERALE, CaixaBank, Commonwealth Bank, Foresight, BARCLAYS, LLOYDS BANK, NatWest, Partners Group, MUFG, InfraRed Capital Partners, CPP INVESTMENT BOARD, ENERGY INFRASTRUCTURE PARTNERS, Marubeni, OCTOPUS INVESTMENTS, ONTARIO TEACHERS' PENSION PLAN, Legal & General, RBC, 中国投资有限责任公司 CHINA INVESTMENT CORPORATION, bluefield Partners LLP, NTR, mirova, UniCredit, COMMERZBANK, Moody's, DALMORE CAPITAL, Downing, RIVER STONE, National Australia Bank, HSBC, MACQUARIE

Oil & gas

ORLEN, Vitol, GASAG, equinor, eustream, OGE, SW//M Stadtwerke München, bp, snam, centrica, nationalgrid, Thyssengas, Naturgy, fluxys, Shell

Project developers

BELECTRIC, CanadianSolar, POLENERGIA, GreenFrog Power, solarcentury, brockwell energy, NEOEN, enlight, PACIFICO, tagenergy, BORALEX, British Solar Renewables, BayWa r.e., Good Energy, low carbon, BANKS Group, greentech, Invenergy, res power for good, bnrg, powercapital renewable energy, Anesco, HIVE ENERGY, TECHNIQUE SOLAIRE, EnergieKontor, lightsource bp, bp

Policy & regulation

Bundesnetzagentur, Bundesministerium für Wirtschaft und Klimaschutz, Ministerie van Economische Zaken en Klimaat, seai, Climate Change Committee, DRC Development Research Center of the State Council of the People's Republic of China, Roinn Cumarsáide, Gníomhaithe ar son na hAeráide & Comhshaoil Department of Communications, Climate Action & Environment, European Climate Foundation, European Commission, HM Treasury, Energy Regulatory Office, JETRO Japan External Trade Organization, National Audit Office, Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, NATIONAL INFRASTRUCTURE COMMISSION, AEMO, LOW CARBON CONTRACTS COMPANY, Electricity Settlements Company, Department for Business, Energy & Industrial Strategy

Source: Aurora Energy Research


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