TransitionZero

System-level impacts of 24/7 Carbon-Free Electricity (CFE)

Results for Malaysia 🇲🇾

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We gratefully acknowledge the contributions of colleagues across TransitionZero—both current and former—who supported this work through communications, analysis, modelling infrastructure, and operational coordination. These include Alice Apsey, Ollie Bell, Duncan Byrne, Khandekar Mahammad Galib, Matthew Gray, Michael Guzzardi, Tim Haines, Anna Hartley, John Heal, Simone Huber, Thomas Kouroughli, Alex Luta, Aman Majid, Grace Mitchell, Irfan Mohamed, Joe O’Connor, Sabina Parvu, Abhishek Shivakumar, Stephanie Stevenson, Isabella Söldner-Rembold, Dan Welsby, and Joel Yap.

Acknowledgements

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Our methodological approach is focused on the assessment of system-level costs and benefits of 24/7 Carbon-Free Electricity (CFE) procurement in Japan, India, Singapore, Taiwan, and Malaysia. It draws on a robust body of literature and cutting-edge modelling tools.

TU Berlin and affiliated researchers:

- *Riepin, I., & Brown, T. (2022). System-level impacts of 24/7 carbon-free electricity procurement in Europe. Zenodo.* https //doi.org/10.5281/zenodo.7180098
- *Riepin, I., & Brown, T. (2023). The value of space-time load-shifting flexibility for 24/7 carbon-free electricity procurement. Zenodo.* https //doi.org/10.5281/zenodo.8185850

Princeton University (ZERO Lab):

- *Xu, Q.,Manocha, A.,Patankar, N., and Jenkins, J.D., System-level Impacts of 24/7 Carbon-free Electricity Procurement, Zero-carbon Energy Systems Research and Optimization Laboratory, Princeton University, Princeton, NJ, 16 November 2021.*
- *Xu, Q., & Jenkins, J. D. (2022). Electricity System and Market Impacts of Time-based Attribute Trading and 24/7 Carbon-free Electricity Procurement. Zenodo.* https //doi.org/10.5281/zenodo.7082212

International Energy Agency (IEA):

- *Regional insights and sectoral analyses*
- *IEA (2022), Advancing Decarbonisation through Clean Electricity Procurement, IEA, Paris.* www.iea.org/reports/advancing-decarbonisation-through-clean-electricity-procurement

Our in-house modelling leverages PyPSA (Python for Power System Analysis), an open-source framework for simulating and optimizing energy systems. This platform enables high-resolution, hourly modelling of decarbonised power systems, adapted for our country-specific analyses. We are grateful to all contributors in the open modelling community, whose tools and insights strengthen the analytical foundation for achieving global CFE goals.

We thank the reviewers who provided valuable feedback and insights that were invaluable during the development of this work and in shaping the final report.

Contribution to and review of this study does not imply an endorsement by either the individual or their organisation. Any mistakes are our own.

Table of Contents

Matthew Gray
Co-founder & CEO
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Foreword

Malaysia assumed the 2025 ASEAN Chairmanship with a clear signal for its power sector agenda: regional clean energy cooperation, cross-border grid integration, and decarbonisation. This leadership comes as Malaysia deepens its own energy transition, committed to peaking emissions around 2040 and achieving net zero by 2050. As a fast-industrialising economy with a growing export base and a grid dominated by coal and gas, the country faces both opportunities and challenges as it prepares for a power system with more solar and battery.

This transition could be supported by **24/7 carbon-free energy (24/7 CFE)** procurement at scale — ensuring that the country's high-value exports, especially from manufacturing and heavy industry, are powered by electricity that is genuinely clean at all hours. As policymakers and corporate buyers align with the upcoming revisions to the Greenhouse Gas Protocol (GHGP), two critical questions emerge: what is 24/7 CFE, and what would it take to make it real for Malaysia?

24/7 CFE means matching every hour of electricity consumption with generation from carbon-free sources. This is a fundamental shift away from annual certificate-based accounting, which allows clean energy claims even when fossil generation fills the grid. Hourly matching is especially relevant for Malaysia's corporate procurement schemes, which have been met with much interest but require refinement still, particularly in relation to high wheeling charges. For system planners, 24/7 procurement would be new but it would support long-term system optimisation: reducing peak fossil use, guiding storage investments, and ensuring that clean supply grows in step with demand.

Our analysis shows that 24/7 CFE can be a **'no regrets' strategy** for Malaysia's grid and its clean industrial future. We find that **reaching 80% hourly CFE in Peninsular Malaysia and 90% CFE in Sarawak** can reduce emissions intensity more sharply than annual matching. At the system level, these cleaner procurement pathways could save the country **up to US$ 710 million annually**, 6% higher than those achieved under conventional annual matching approaches. Plus, they align directly with Malaysia's role in promoting clean energy leadership under ASEAN's current agenda.

We also recognise that Malaysia is actively exploring the future role of **clean dispatchable power**, including gas-fired generation with Carbon Capture and Storage (CCS), and early-stage co-firing of hydrogen or ammonia. While our modelling includes these technologies, we found that their long-term viability remains highly sensitive to fuel price, technology cost, and availability of infrastructure. These solutions will need to be evaluated carefully alongside maturing alternatives, including long-duration storage and regional grid imports, which may offer more robust and cost-effective pathways to clean firm capacity.

We hope this analysis supports Malaysia's energy planners, regulators, and corporate leaders in navigating the shift to 24/7 carbon-free electricity—and informs future policy as the country leads ASEAN through one of its most pivotal energy transitions to date.

About TransitionZero

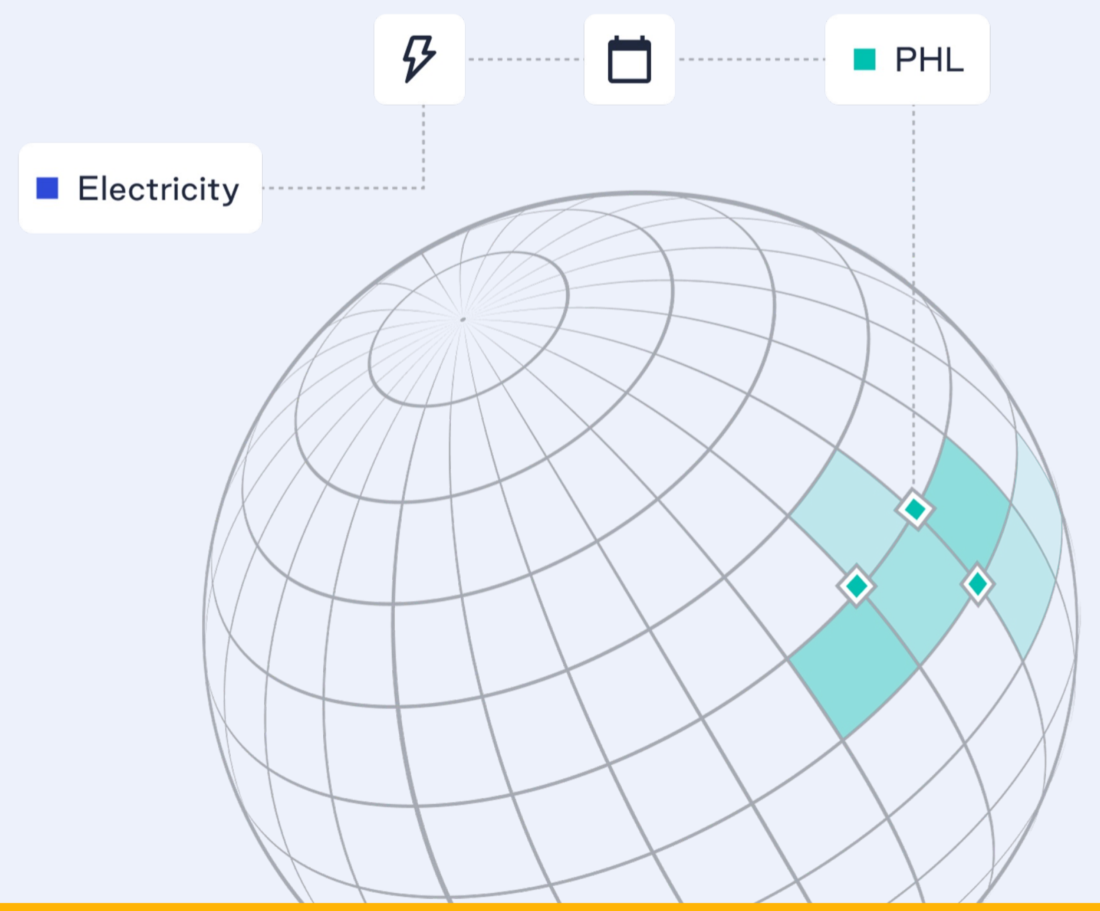
Open software, data and insights for energy transition planning

We help governments and their partners plan for the transition to clean, and more reliable electricity

Visit our website

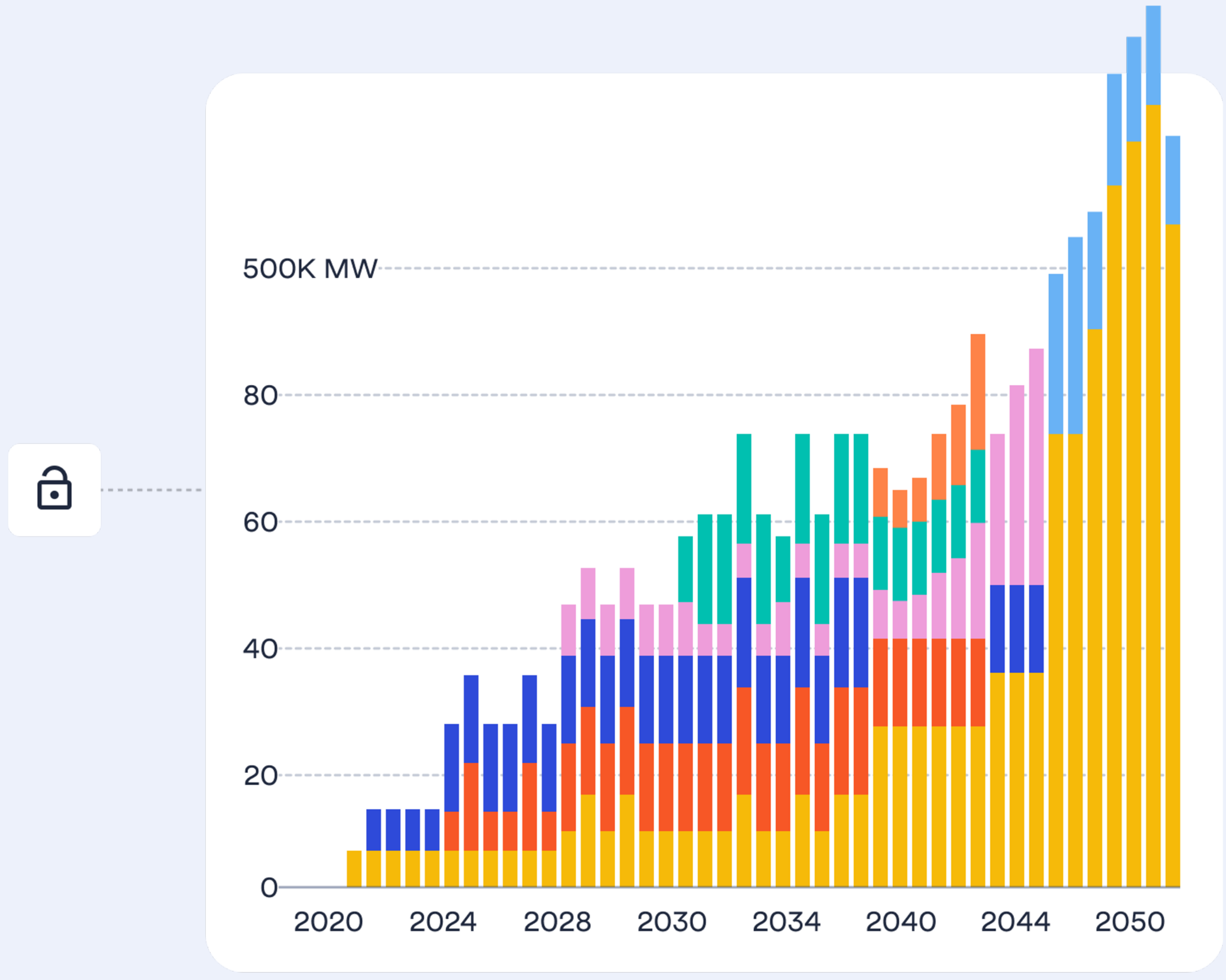
Accessible software

Our accessible system modelling software and technical training enables more efficient, effective energy transition planning.



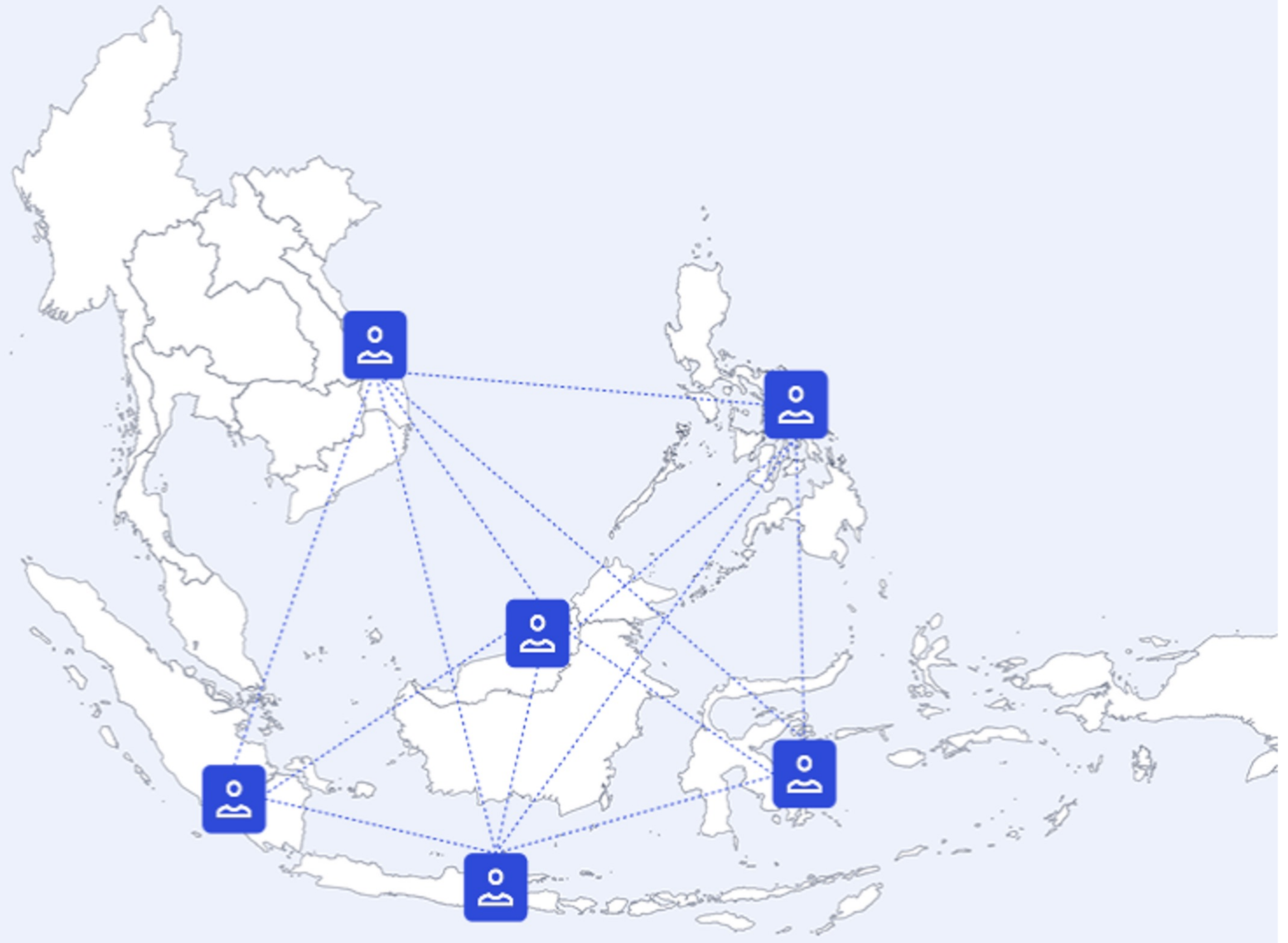
Open data

Combining AI with in-country expertise, our open datasets support high-quality system modelling.



Market analysts

Our analysts help decision-makers build the skills and knowledge they need to better understand energy transition risks and opportunities.



Funded by Sequoia Climate Foundation, Google.org, Bloomberg Philanthropies, Quadrature Climate Foundation

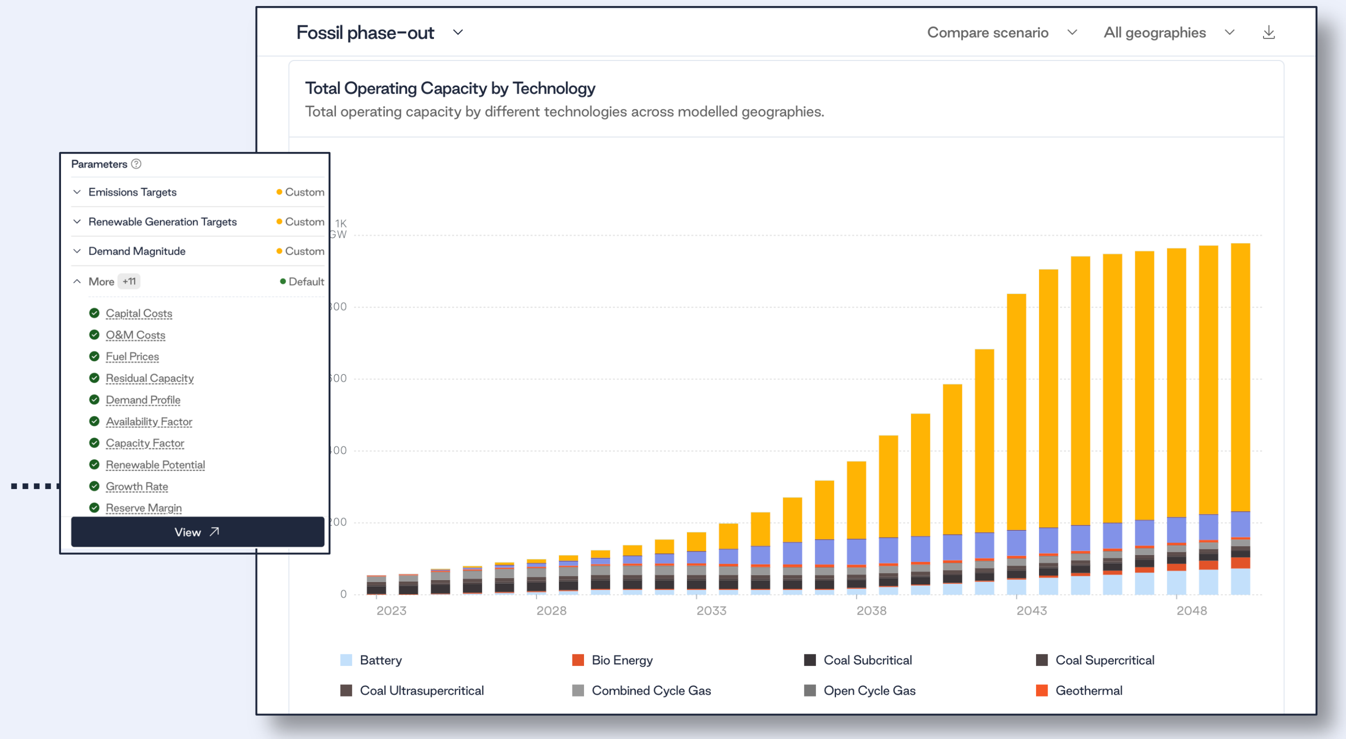
TransitionZero products

Our software and data products make energy transition planning more accessible and transparent

Explore products

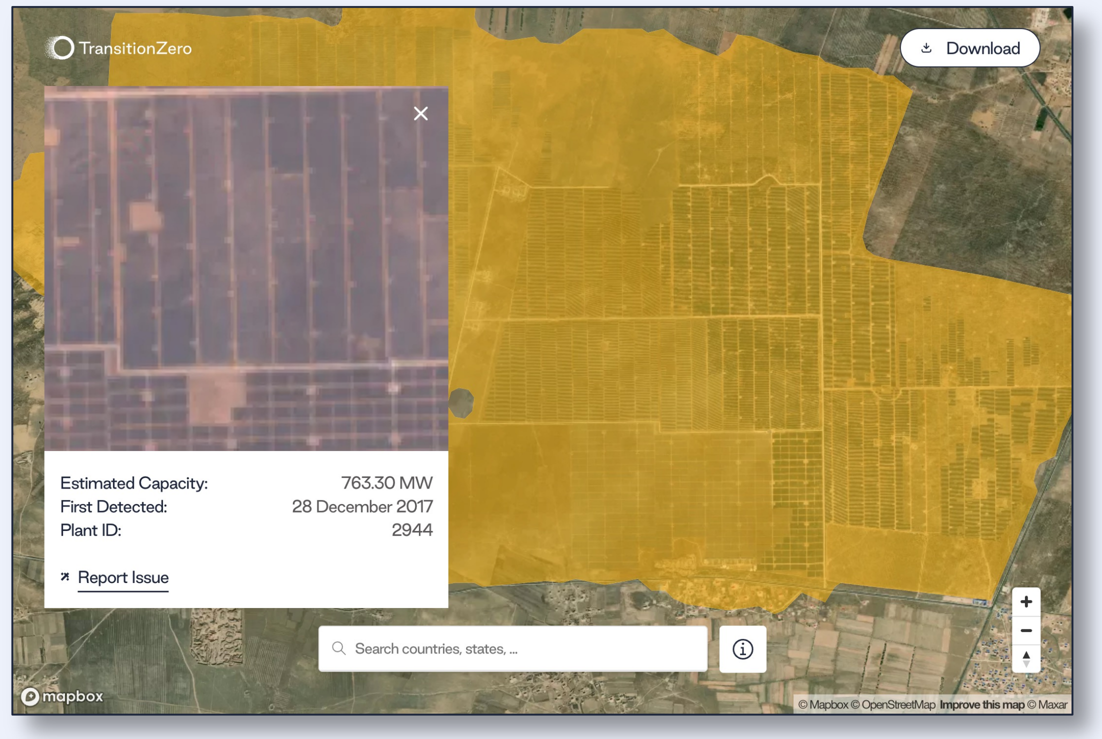
Scenario Builder

TZ-SB is free, no-code modelling platform that allows analysts working on energy transition planning to build, run, and analyse results from electricity system models – quickly, transparently, and at scale.



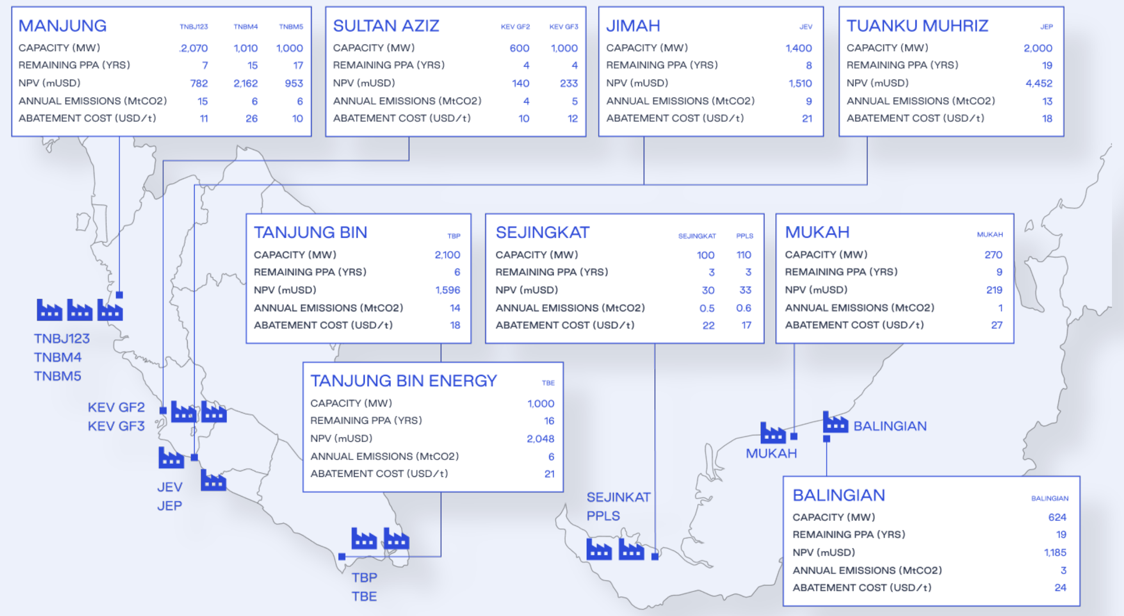
Solar Asset Mapper

TZ-SAM is an open access, asset-level dataset of solar facilities, powered by machine learning and geospatial data. Updated quarterly, the dataset contains over 26,353 km² of solar across 200 countries.



Coal Asset Transition Tool

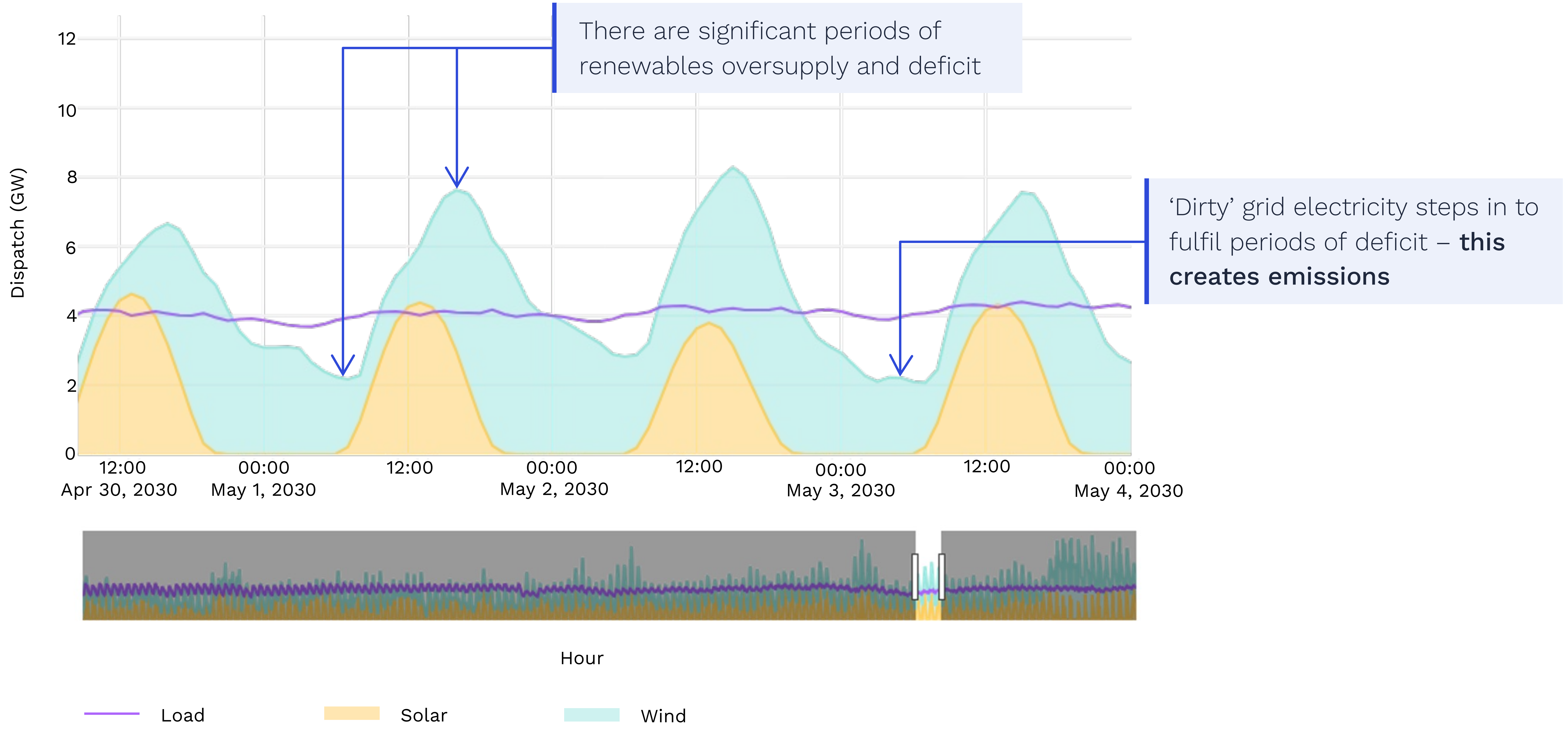
TZ-CAT is an open data product that supports the refinancing and replacement of coal plants in an affordable, just way. TZ-CAT is currently available for the Philippines, Indonesia, and Malaysia.



Background to Carbon Free Electricity (CFE)

Power consumers are grappling with mismatches between the generation and consumption patterns of clean electricity

What does an annual matching regime look like?

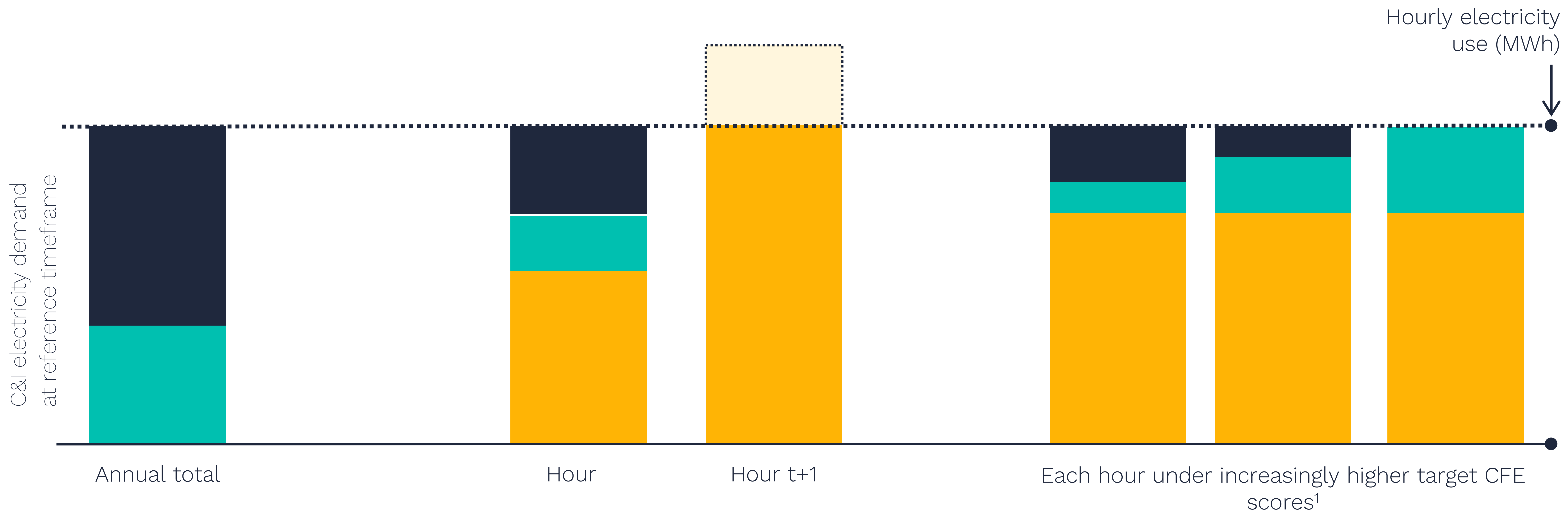


Key points

- Commercial and industrial (C&I) consumers face pressures to reduce their consumption of polluting electricity.
- Reliance on 100% annual matching through renewables PPAs results in cycles of oversupply and deficit, where only some hours truly benefit from CFE.
- When there is a deficit between procured clean energy and demand, consumers must rely on carbon-emitting system electricity.
- Matching consumption to generation hour by hour ('24/7 CFE') seeks to maximise CFE reliance round the clock.

Shifting guidance on emissions reporting

The GHG Accounting Protocol is evolving, requiring companies to report Scope 2 emissions based on hourly accounting



Situation 1:
Do nothing

C&I consumer's electricity consumption is met only by the regional grid, which is for the most part carbon-based.

Situation 2:
Annual matching (current common practice)

C&I consumer's electricity consumption is only partially matched, resulting in either a shortfall or an oversupply of CFE.

Situation 3:
24/7 CFE

Electricity use is fully matched with CFE. We can use a blended approach, in which some of the demand is matched by a PPA, while the remainder can be imported from the grid, provided it meets CFE threshold.

Key points

- A consumer's CFE score is the average of Situation 3 across all hours of the year.
- Principles that CFE should meet are to be locally sourced (from the same grid zone), time-matched (ideally hour by hour), and resulting from additional investments.
- CFE includes, by definition, a commitment to technological neutrality.

Carbon-based grid supply
CFE from grid supply
CFE PPA consumed
Excess CFE PPA (not counted towards CFE score)

[1] Note that at 100% CFE C&I consumers can rely on the grid only if the grid itself is also 100% CFE. A grid that features emitting generators can also be relied upon if the consumers seek to reach a lower CFE score.

How is Carbon Free Electricity measured?

The CFE score includes PPA-procured generation, and the cleanliness of the wider grid

- The CFE Score is a percentage score which measures the degree to which each hour of electricity consumption is matched with carbon-free electricity generation. We follow the methodology set out by Google[1].
- This is calculated using both carbon free electricity provided by through PPA contracts, as well as CFE coming from the overall grid mix. It is calculated as:

$$\text{CFE Score \% (h)} = \frac{\text{Contracted CFE MWh} + \text{Consumed Grid CFE MWh}}{\text{C\&I Load MWh}}$$

where:

$$\text{Contracted CFE MWh} = \text{Min (C\&I Load MWh, CFE Generation MWh)}$$

$$\text{Consumed Grid CFE MWh} = [\text{C\&I Load MWh} - \text{Contracted CFE MWh}] \times \text{Grid CFE \%}$$

- The Grid CFE % is calculated by looking at the what percentage of the generation comes from carbon free sources. In the case of Malaysia, this is an hourly CFE % score for 2 of the 3 main grids –Peninsular Malaysia and Sarawak– where significant C&I growth is expected.
- The contracted CFE score is capped at 100%, even if there is excess CFE that is exported back to the grid.

An example calculation

Participating C&I load =	*100 MWh*
Contracted CFE generation =	*65 MWh*
Grid Imports	*100 - 65 = 35 MWh*
Grid CFE	*45%*
CFE Score =	*[65 + (35 x 0.45)] ÷ 100 = 81%*

Here, the participating C&I consumer has a load of 100 MWh which is participating in CFE/round-the-clock matching.

In this example hour, they have procured 65 MWh of clean generation through PPAs (e.g. some combination of solar and batteries) and must import the remaining 35 MWh from the grid to meet the load.

The grid at that hour has a CFE score of 45% (i.e. only 45% of generation is from CFE sources). This results in an overall CFE score for the C&I consumer of 81% in that hour.

[1] Google 2021, "24/7 Carbon-Free Energy: Methodologies and Metrics"

Key questions

Stakeholders need to better understand the implications of this shift

What are the implications in markets with high levels of fossil generation when a significant share of C&I consumers shift from annual to hourly matching?

What are the costs and benefits of hourly matching at the system level, i.e. the Malaysia power sector and the actors involved in generation, storage, transmission, and distribution?

What other implications of hourly matching are there for both the wider system and C&I consumers?

To what extent are nascent technologies (storage or innovative thermal generation) needed for higher shares of hourly matched CFE?

To what extent can different conceptions of additionality and a wider palette of CFE technologies affect system-wide costs and benefits?

Technology palettes

We explore how additionality and technological choice affect system costs and benefits arising from greenfield investments

Technology	Palette 1[3]	Palette 2	Palette 3
Onshore wind and solar	✓	✓	✓
Battery storage	✓	✓	✓
Long-duration energy storage[1]	✗	✓	✓
Gas with CCS	✗	✗	✓
H_2/NH_3 co-firing	✗	✗	✓

[1] *Pumped storage hydro and Redox flow batteries are grouped under this option for Singapore and Malaysia. Liquid air storage is the technology made available in our Japan, Taiwan and India models.*
[2] *For H_2/NH_3 only generation from the non-fossil share is accounted as CFE (10% and 20% respectively). For CCS we consider a 70% CO_2 capture rate, with the remaining 30% of unabated generation not accounted for as CFE.*
[3] *We have not considered onshore wind for Singapore, following feedback from stakeholders.*

Wider technical scope should lower system costs

- The 'brownfield' capacity mix in our Reference Scenario will include CFE sources of low additionality (pre-existing nuclear, hydro, renewables plants, as well as pumped and battery storage) and CFE plants likely to be built under business-as-usual conditions – all of which will contribute to the CFE score of the local grid.
- In our annual and hourly matching scenarios, C&I consumers can procure additional generating capacity in the 'greenfield' through PPAs with technologies restricted to these palettes.
- Palette 3 also considers generation from innovative thermal plants[2] as additional emissions, as such plants have imperfect capture rates and cannot be said to be 100% CFE. For each such plant we implement a CFE generation ratio that is fixed at all time steps:

Asset class	CFE share[3]
Coal-ammonia co-firing	20%
Gas-hydrogen co-firing	10-30%
CCS	70%

Executive summary

From annual RECs to hourly matching

Safeguarding Malaysia's competitive edge

- Malaysia currently offers one of the more diverse range of corporate clean electricity procurement options in Southeast Asia, including net energy metering for rooftop solar, green electricity tariff, virtual and direct PPAs. Continuous improvements in the regulatory frameworks represent a notable achievement for a regulated, vertically-integrated power market, positioning Malaysia as an attractive destination for C&I consumers with sustainability commitments.
- The existing framework has facilitated the use of renewable energy certificates (RECs) with annual matching as the primary instrument for corporates to account for and achieve Scope 2 decarbonisation targets.
- Momentum is building around hourly matching as the next benchmark in corporate emissions accounting and reporting – reflected in the ongoing revision of the GHG Protocol's Scope 2 Guidance . Malaysia will need to take the next step and evaluate the implications and pathways for its utilities and power markets if corporates begin adopting this standard at scale.
- Malaysia has significant renewable energy potential, with abundant solar resources across its three grid regions. However, the pace of solar deployment has been constrained by Tenaga Nasional Berhad's (TNB) cautious approach and grid limitations in Peninsular Malaysia, as well as restricted market access for independent power producers in Sarawak. There is considerable scope to expand corporate PPAs.
- Taking early and proactive steps in facilitating C&I consumers' adoption of the hourly matching is essential to help Malaysia stay ahead of the curve amidst growing regional competition.

Key Policies & Targets

2 AVAILABLE CORPORATE PPA SCHEMES

- Corporate Renewable Energy Supply Scheme (CRESS);
- Corporate Green Procurement Program (CGPP), quota-based

1 GREEN TARIFF PROGRAMME

- Green electricity tariff (GET), quota-based

1 ROOFTOP SOLAR SCHEME

- Net Energy Metering (NEM) programme, quota-based

269 GW SOLAR TECHNICAL POTENTIAL

- Only 2% of which has been deployed

Sources: Malaysia Energy Commission, PETRA, TNB

An overview of our study approach

How we modelled carbon free electricity in Malaysia in 2030

An hourly dispatch model was created for 2030 to represent the three grid zones of Malaysia and its cross-boundary interconnectors with neighbouring Thailand, Singapore, and Indonesia. We tested different clean electricity policies to see the impact of these interventions on costs, emissions and other key system metrics.

Our step-by-step process is as follows:

01

The 2030 grid and associated capacity were developed by incorporating both existing infrastructure and planned additions. We cycle through each grid zone and allocate a portion of demand to C&I consumers participating in clean electricity matching. While the CFE matching is calculated at the grid zone level, the aggregated participation corresponds to 5% of Malaysia's estimated overall electricity demand in 2030.

02

This 5% of demand – 13 TWh for Peninsular Malaysia and 2 TWh for Sarawak– is modelled following either an annual matching or an hourly matching scheme (testing between 70-100% hourly CFE). C&I consumers procure PPAs from additional clean generators to supply this clean electricity, which are built and optimised by our model.

03

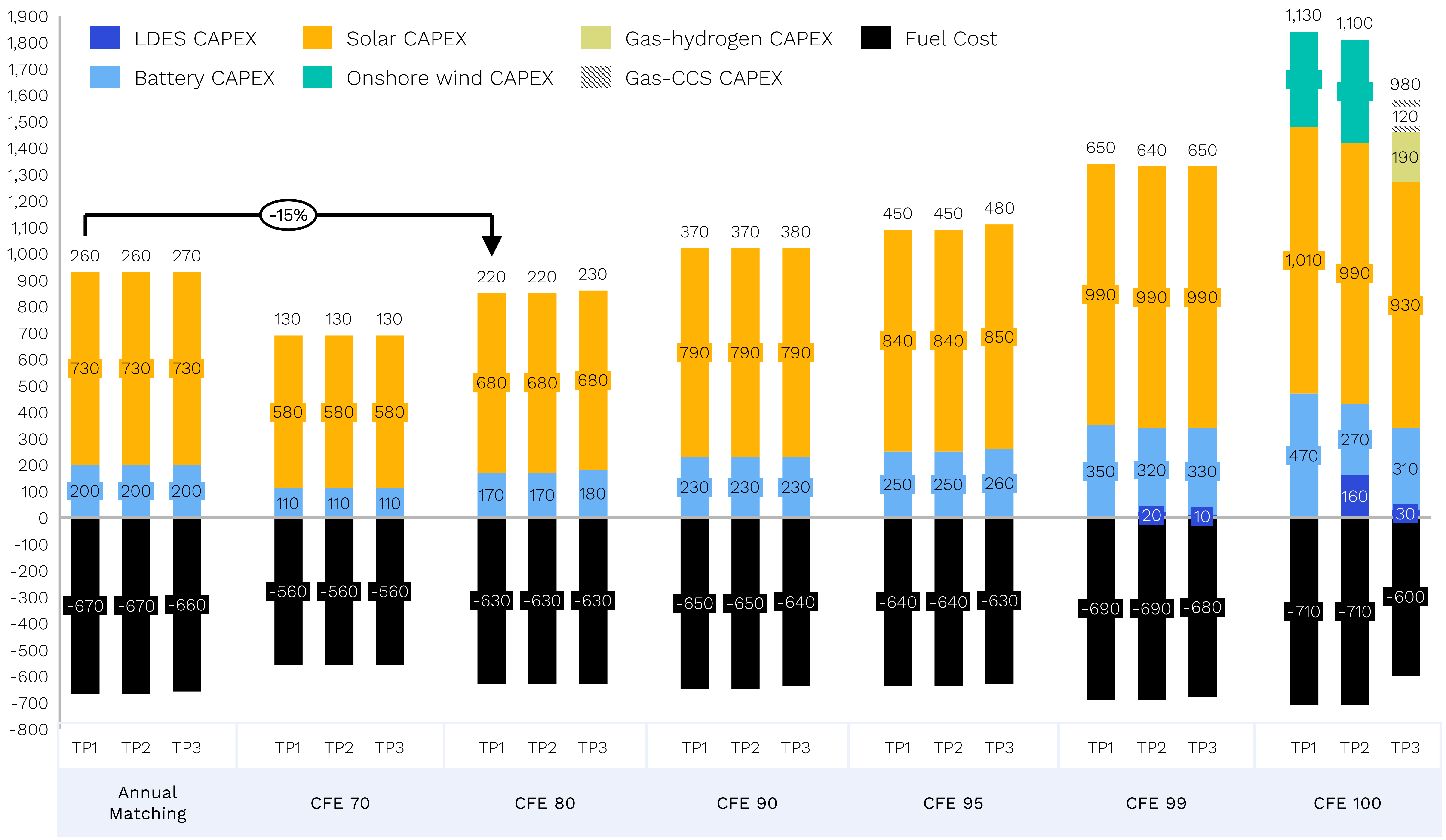
We aggregate grid zone level results to assess the nationwide impact of these schemes for both the C&I consumers as well as the wider Malaysia power system, and the actors involved in generation, storage, transmission, and distribution.

Sabah is modelled to trade with Sarawak but not considered to be participating in CFE.

Savings under hourly matching start at US$560 million

Round-the-clock carbon free electricity brings net system benefits over annual matching

Costs/savings to the Malaysia power sector in 2030 (million US$)



Source: TZ modelling

Notes

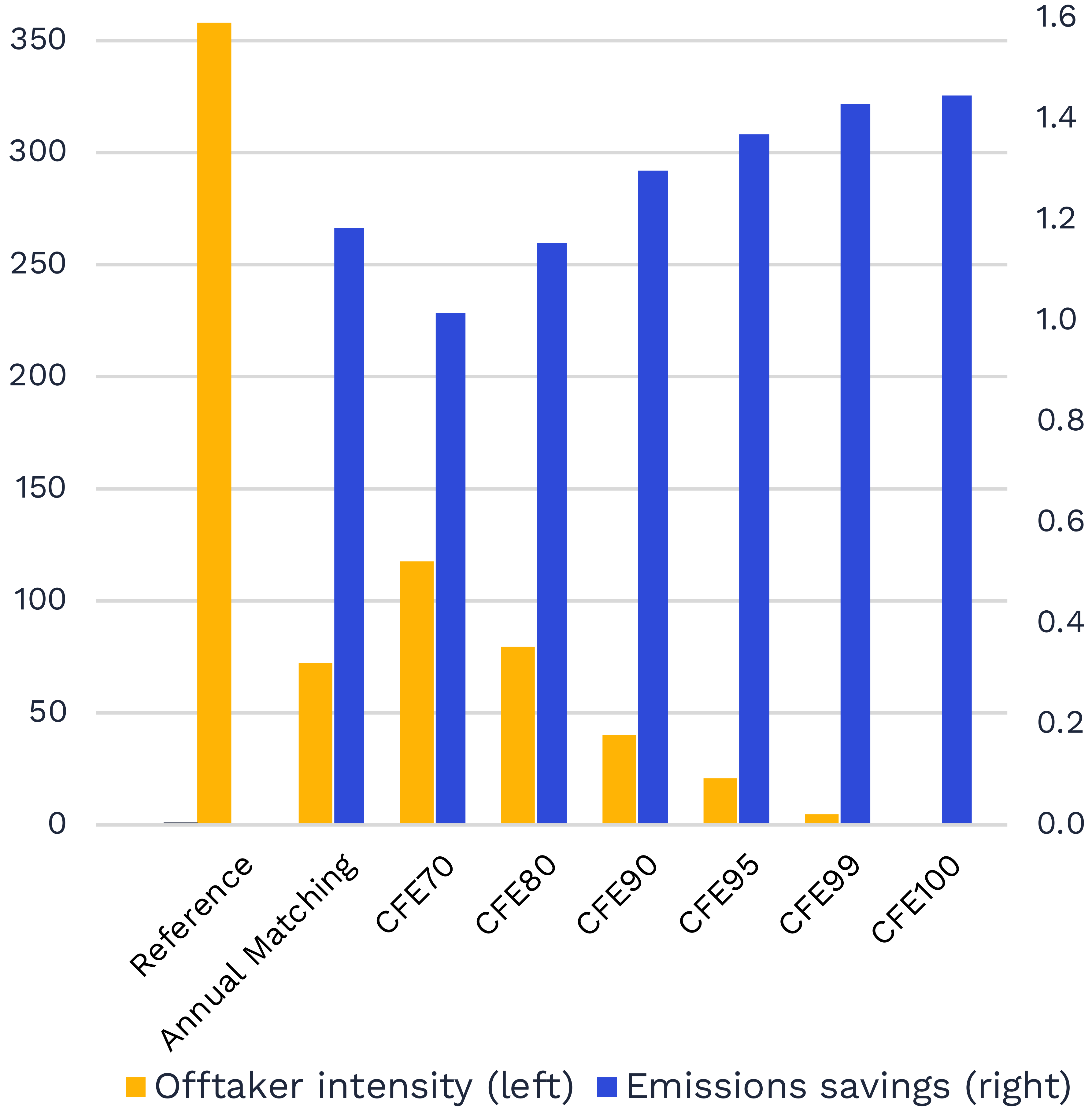
1. **24/7 CFE by 2030 can be delivered at a lower system cost than annual matching.** Achieving clean firm electricity every hour of the year for participating C&I consumers is more cost-effective compared to annual matching, while also reducing emissions and fuel costs across the system. At 80% CFE in Peninsular Malaysia and 90% CFE in Sarawak these benefits can be achieved at lower net system costs than annual matching.
2. **Savings to the grid increases with higher CFE targets, ranging from US$560 to 710 million in avoided fuel cost.** Annual matching savings potential is capped at US$670 million. Operational cost savings are achieved through increased clean C&I procurement and the sale of excess C&I generation to the main grid. The low and steadily decreasing costs of solar-plus-battery storage make it increasingly feasible to use renewables to displace some high-cost LNG and coal, but Malaysia will need to enact mechanisms to enable revenue-earnings for the sale of excess power from C&I consumers.
3. **The net system cost of 80% CFE for the whole of Malaysia is 15% cheaper than annual matching.** It has both lower capital costs and higher avoided fuel costs than annual matching with total system cost amounting to US$56 million.
4. **Long-duration storage (LDES) is not deployed.** C&I demand is met by abundant and relatively low-cost clean firm options (e.g. hydropower, biomass) and purchases from the high hydro capacity grid, which fill multi-hour gaps more cheaply than building expensive 1-hour LDES. However, this may change with day or week-long storage assumptions.
5. **The alternative palettes enter only in 100% CFE.** Gas CCS and gas-hydrogen co-firing results in more gross grid emissions cuts due to lower renewable build-out. Net reductions are further limited by off takers' responsibility for residual CCS emissions. Coal-ammonia is an option but does not appear to be deployed to meet CFE in any of the matching regimes.

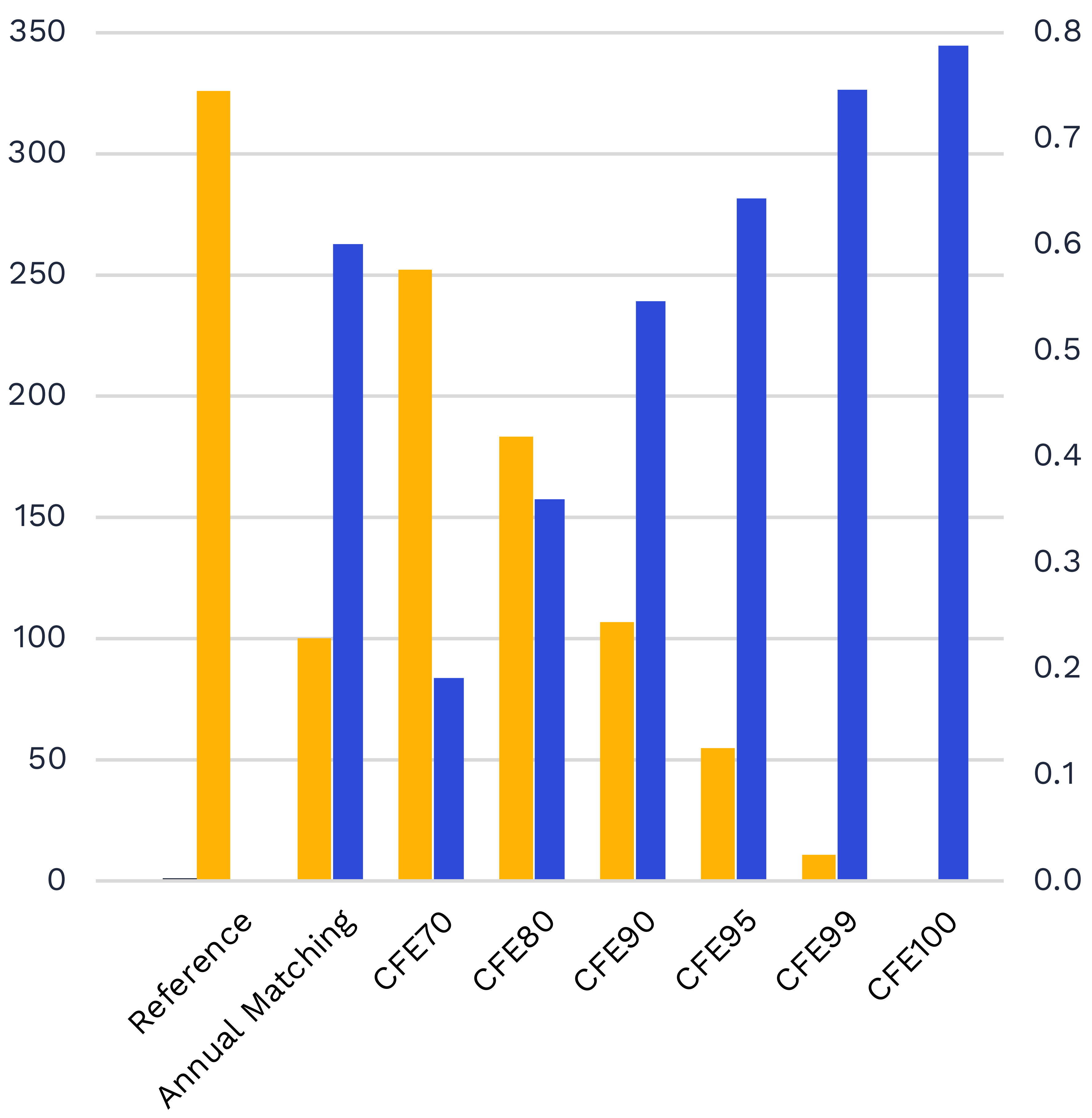
[1] *System costs comprise all capital, operational, and fuel expenditure of the grid, including C&I assets.*

Total abatement cost potential is lower for hourly matching

CFE has the potential to drive emissions reduction

C&I consumer emissions intensity (gCO_2/kWh) and emissions savings ($MtCO_2e$) for TP1





Source: TZ modelling

Notes

1. **At lower CFE scores, annual matching achieves greater nationwide emissions reductions than CFE.** Emissions reduction of annual matching optimises at 80% CFE in Peninsular Malaysia and 90% CFE in Sarawak. This is because of the substantial sales of CFE from overbuilt assets back to the grid, and partly because 70-90% CFE requires lower capacity buildout than under the annual matching scenario.
2. **System-wide emissions consistently fall as matching stringency increases, allowing hourly CFE to deliver greater abatement over time.** At 90% CFE, hourly matching cuts 24% more emissions than under annual matching in Peninsular Malaysia and 95% at 95% in Sarawak. By 100% CFE, hourly matching delivers nationwide emissions savings of nearly 2.76 $MtCO_2e$, 25% more than the 2.2 $MtCO_2e$ that annual matching achieves.
3. **The final 10% of decarbonisation drives steep cost increases.** Adding onshore wind or CCS cover hardest-to-match hours, but the marginal cost per added MW decreases at higher CFE scores.
4. **The emissions intensity of C&I consumers is strongly influenced by the cleanliness of the underlying grid.** Since emissions in the Greenfield come from power purchased from the main grid where gas generation is prominent, regions with cleaner grids see lower emissions. Unlike solar, hydro generation in Sarawak is not limited to daylight hours, making it more effective in reducing reliance on brownfield imports.

In focus: Peninsular Malaysia

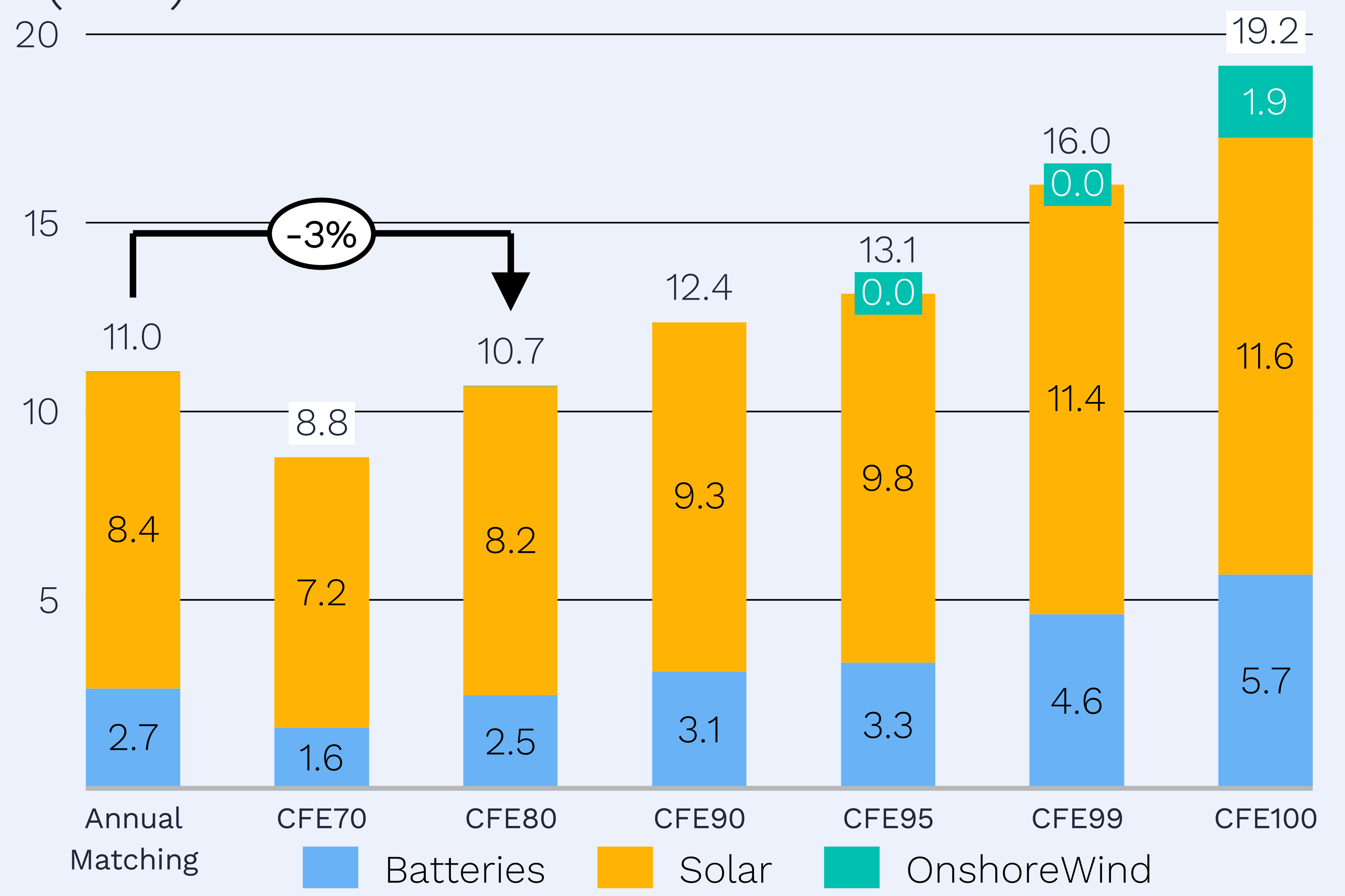
80% CFE can be met with less solar and batteries, and at US$20 million less net system cost than annual matching

1. **More efficient procurement strategies can reduce buildout needs.** Building 8.2 GW of solar and 2.5 GW of battery capacity to meet 80% CFE would cost C&I consumers US$791 million in capital and operational costs. This is 3% cheaper than annual matching, as well as 3% lower in terms of capacity requirements.
2. **CFE can deliver benefits to all consumers on Peninsular Malaysia's gas-dominant grid.** Fuel cost savings are equivalent to US$600 million annually at 80% CFE if participating C&I consumers are able to sell their excess renewable capacity back to the main grid. This would achieve a net system cost of US$20 million less than annual matching. Avoided fuel cost can rise to US$650 million annually under 100% CFE but is capped at US$620 million for annual matching.
3. **Solar-plus-battery is the optimal renewable energy (RE) resource in Peninsular Malaysia.** Batteries increase the hours when C&I off-takers can rely on their solar PPA resources to achieve CFE. These hybrid solar and battery systems start becoming necessary at the highest CFE scores, where the grid can no longer be completely relied on for hourly matching. Reaching 90-95% CFE involves a buildout of 12.4 to 13.1 GW, enabling much higher clean coverage in comparison to annual matching.
4. **100% CFE sees the introduction of other technologies to meet the hardest to reach hours.** Onshore wind (1.9 GW) is introduced to offset solar shortfalls during early mornings and evenings, increasing procurement cost by 38%. In a scenario when 2.2 GW of LDES becomes available, solar capacity requirements are reduced by 5%. When gas CCS and gas-hydrogen become available, 14% less solar capacity is needed to meet 100%.
5. **Solar is the backbone of Peninsular Malaysia's CFE portfolios, with batteries complementing to smooth output.** Grid procurement and sales balance shifts gradually. At lower CFE scores, corporates can rely on the grid. By 99-100% CFE, grid reliance shrinks, indicating near full independence from fossil-based power.
6. **Average PPA costs remain in the US$65–69/MWh range up to 95% CFE, showing affordability at high clean levels.** PPA costs would spike at full hourly matching, hitting US$110.4/MWh with the introduction of onshore wind to balance the system and avoid procuring from Peninsular Malaysia's gas-heavy grid. These are modelled optimised generation per unit costs, and do not yet account for corporate wheeling fees, which are considered prohibitively high in Malaysia. Currently, corporate PPA wheeling fees (System Access Charges for CRESS) are approximately US$9/kwh for solar only projects and US$5/kwh for solar +BESS projects.

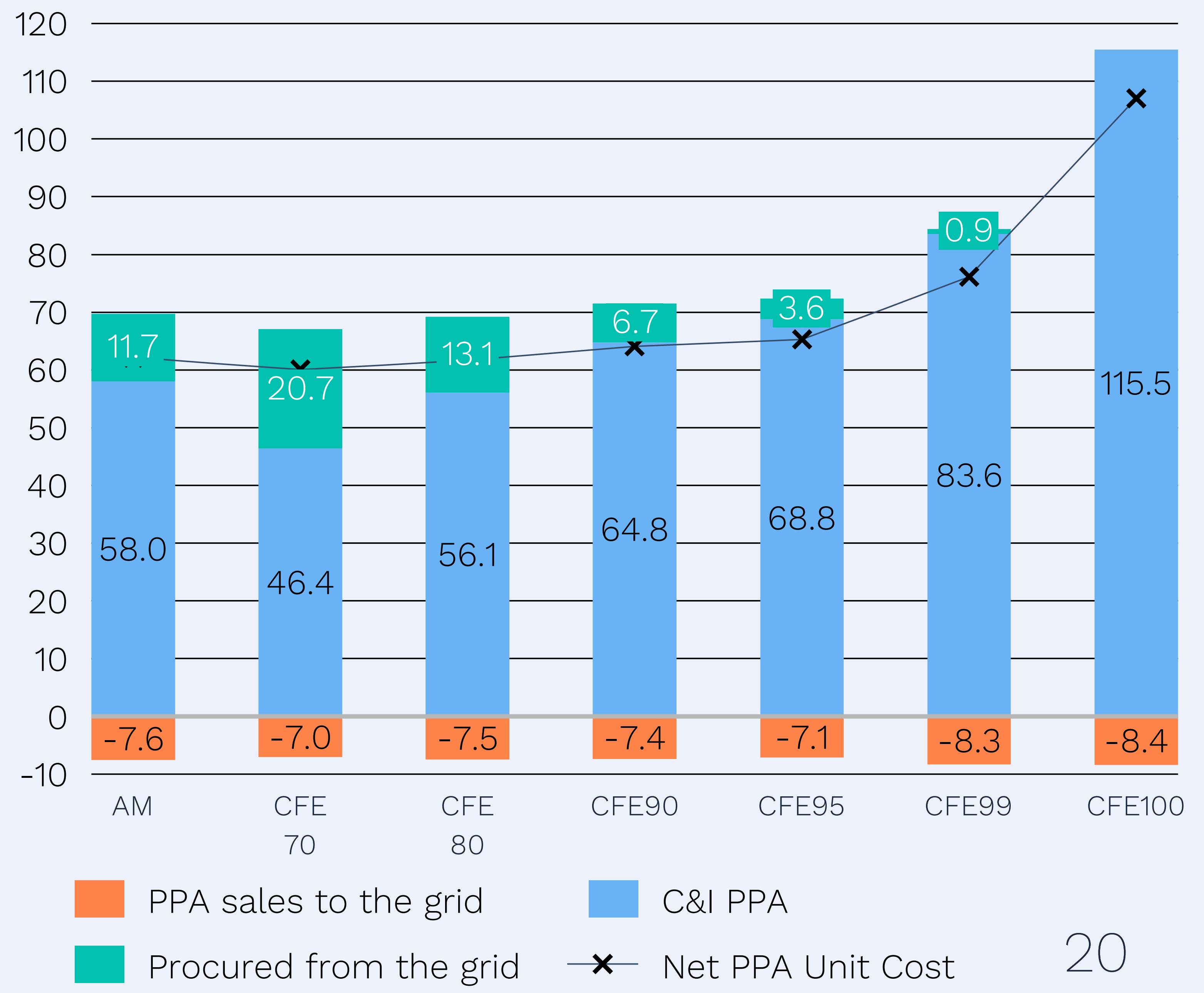
Source: TransitionZero modelling

Peninsular buildout in 2030

Capacity build-out for participating C&I (GW)



PPA Cost (US$/MWh)



In focus: Sarawak

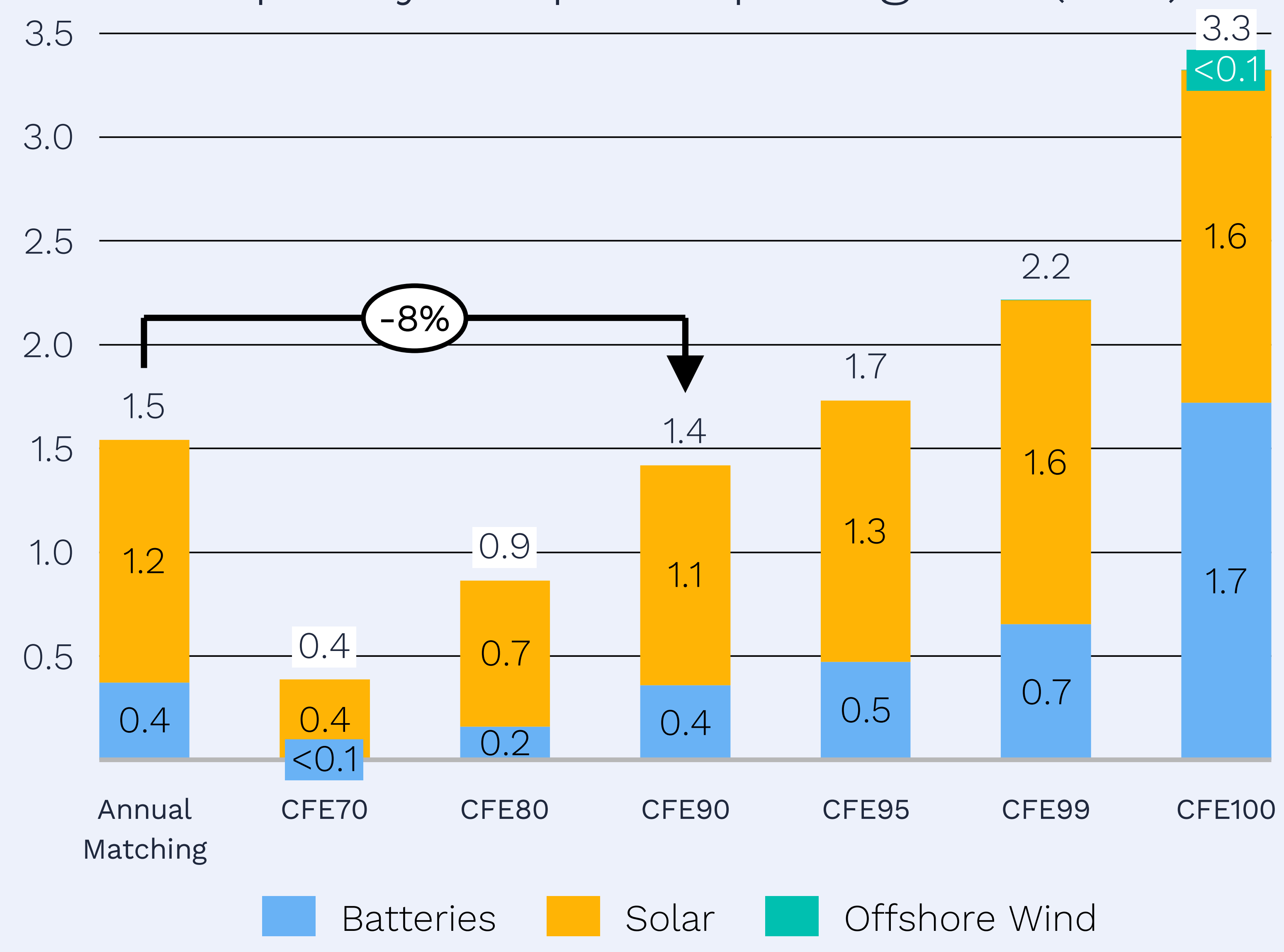
90% CFE can be met with just 1 GW of solar and 350 MW of batteries and save nearly US$44.2 million per year

1. **Sarawak's hydro-dominant grid makes it ideal for hourly matching.** From 70% to 90% CFE, participating C&I consumers accounting for 3% of Sarawak's total demand can rely on the grid to meet at least half of their hourly CFE needs. These lower CFE hourly matching regimes require less new renewables capacity build out than under annual matching.
2. **90% CFE can be met easily with the Sarawak grid's hydro-based power.** Sarawak requires only modest buildout, as participating C&I consumers can rely on the main grid in lower matching regimes. 90% CFE would entail building just 1.1 GW of solar paired with 350 MW of batteries. This would be equivalent to US$101 million in system cost – 8% less than annual matching, whose benefit is capped at 1.2 GW of solar. Even at 95% CFE, estimated buildout is equivalent to only 1.7 GW of solar-plus-batteries.
3. **90% CFE in Sarawak saves US$5 million in net cost to the system in comparison to annual matching, mainly due to fuel cost savings of US$44.2 million annually**. Assuming a 20-year useful life, procurement costs remain modest across most scenarios, with the relative US$/MWh generation expenses for hourly matching ranging US$16–62/MWh. This does not yet account for wheeling charges imposed by the utility. From 90% to 100% CFE, costs for C&I consumers doubles to US$107.2/MWh, as they're no longer able to rely on the grid for clean power.
4. **The emissions intensity of C&I consumers is strongly influenced by the cleanliness of the underlying grid.** Since emissions are largely driven by power purchased from the main grid, regions with cleaner grids see lower off-taker emissions. Hydro generation in Sarawak allows participating C&I consumers to procure power from the grid at night. At 70% CFE, approximately 65% of their demand can be met by grid-based power.
5. **Reaching near-full CFE requires substantial battery storage.** From annual matching (0.4 GW) to CFE 90 (0.4 GW) and even to CFE 99 (0.7 GW), the additional battery storage capacity requirements are relatively minor. Solar capacity is capped at 1.6 GW by 99% CFE, but to meet 100% an extra 1 GW of storage is needed to cover more hours with clean energy, bringing total CFE capacity to 3.3 GW and doubling procurement costs.
6. **CFE an efficient pathway to corporates' goals.** For corporates in Sarawak, achieving high CFE scores requires far less investment and buildout than in other regions, making it a uniquely cost-effective location for green industrialisation.

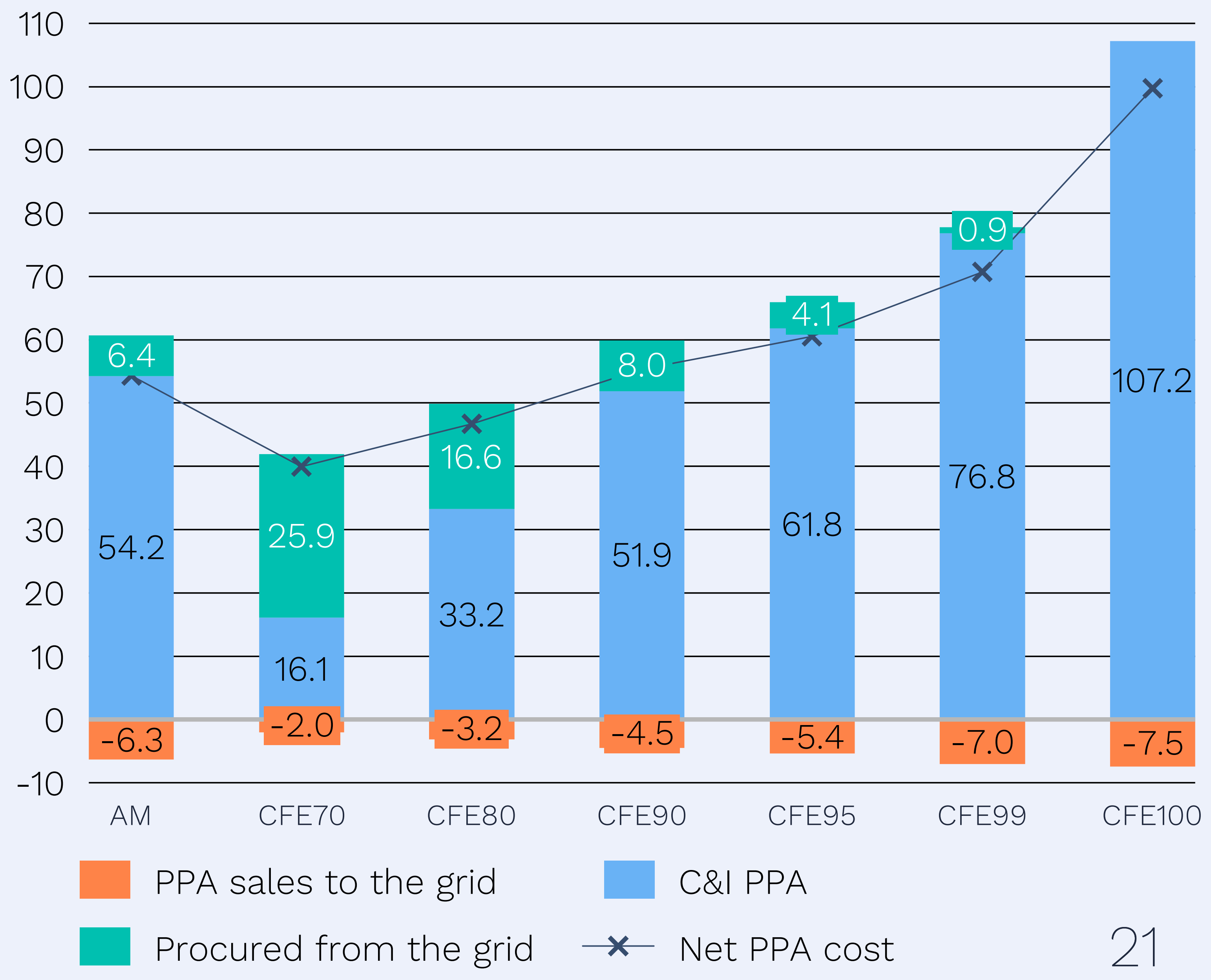
Source: TransitionZero modelling

Sarawak buildout in 2030

PPA capacity for participating C&I (GW)



PPA Cost (US$/MWh)



Policy guidance

Optimal targets and flexible sell-back can unlock both corporate and national decarbonisation wins for Malaysia

01

Accelerating solar deployment by supporting corporate procurement

Malaysia has set a target for 7GW of solar capacity by 2030. Our modelling shows that meeting decarbonisation goals will require more than three times this amount. By raising near- and medium-term solar targets — especially in Peninsular Malaysia — policymakers can support the investment needed to expand generation and upgrade grid infrastructure.

Raising subscription limits under schemes such as CRESS and allowing the CGPP to be uncapped or continue with higher quotas, would encourage more businesses to invest in solar energy. This would help ensure that solar growth supports wider efforts to decarbonise the energy system.

02

Enabling IPPs and corporate renewable deployment

Issuing regulations in Sarawak to allow for independent power producers and establishing clear frameworks for corporate PPA schemes with third-party grid access can unlock private-sector investment.

In Peninsular Malaysia, piloting provisions within CRESS schemes that would allow C&I consumers to sell their excess clean power would support investment in corporate PPAs, help contribute to system-level decarbonisation, and align corporate procurement with tangible emissions reductions.

03

Deepening regional connectivity and interconnection

Expanding cross-border power trading with neighbouring countries can strengthen Malaysia's role as Southeast Asia's future renewable trading hub, while improving the economic viability of domestic solar assets.

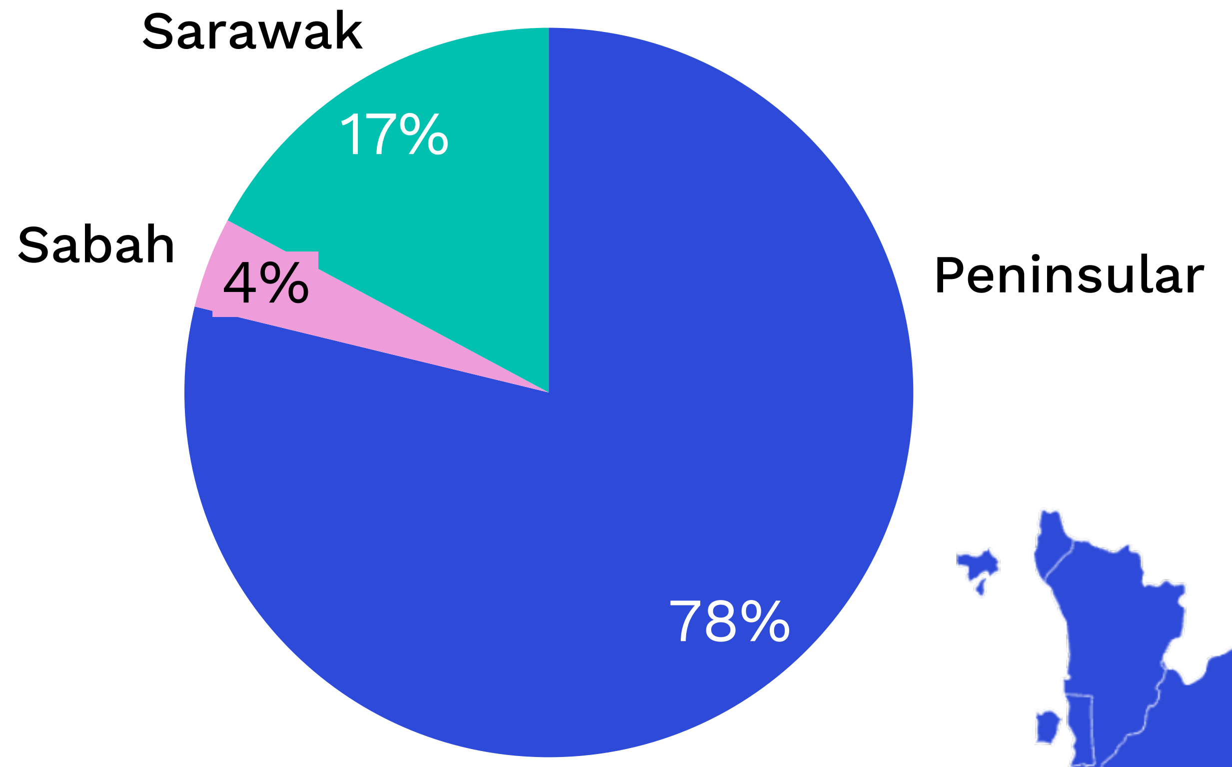
Another TransitionZero report on CFE in Singapore showed that increasing power trade between Singapore and Malaysia could reduce gas generation in both countries.

Advancing ASEAN power trading frameworks, including mutual recognition of green attributes, would build trust in regional markets and accelerate renewable energy deployment across borders.

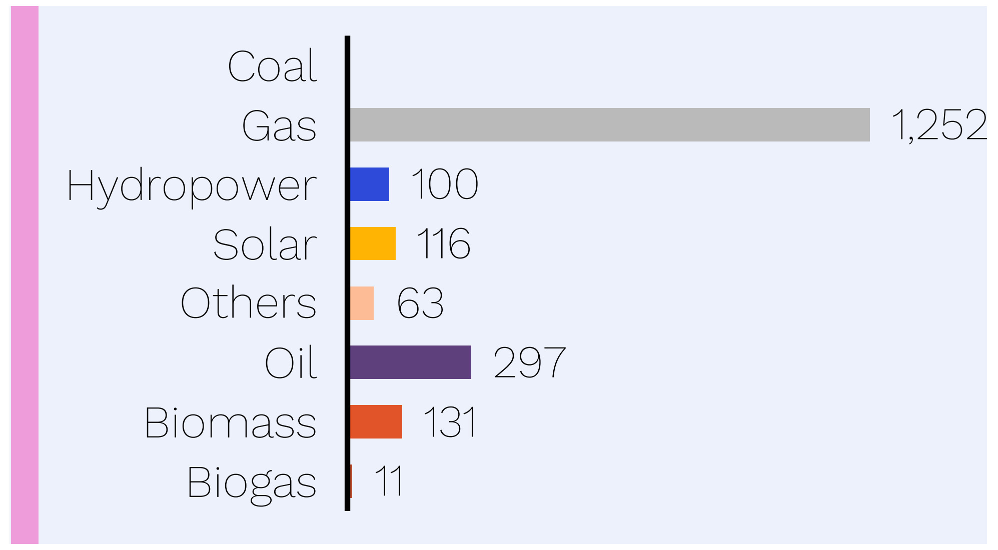
Overview of Malaysia's power market

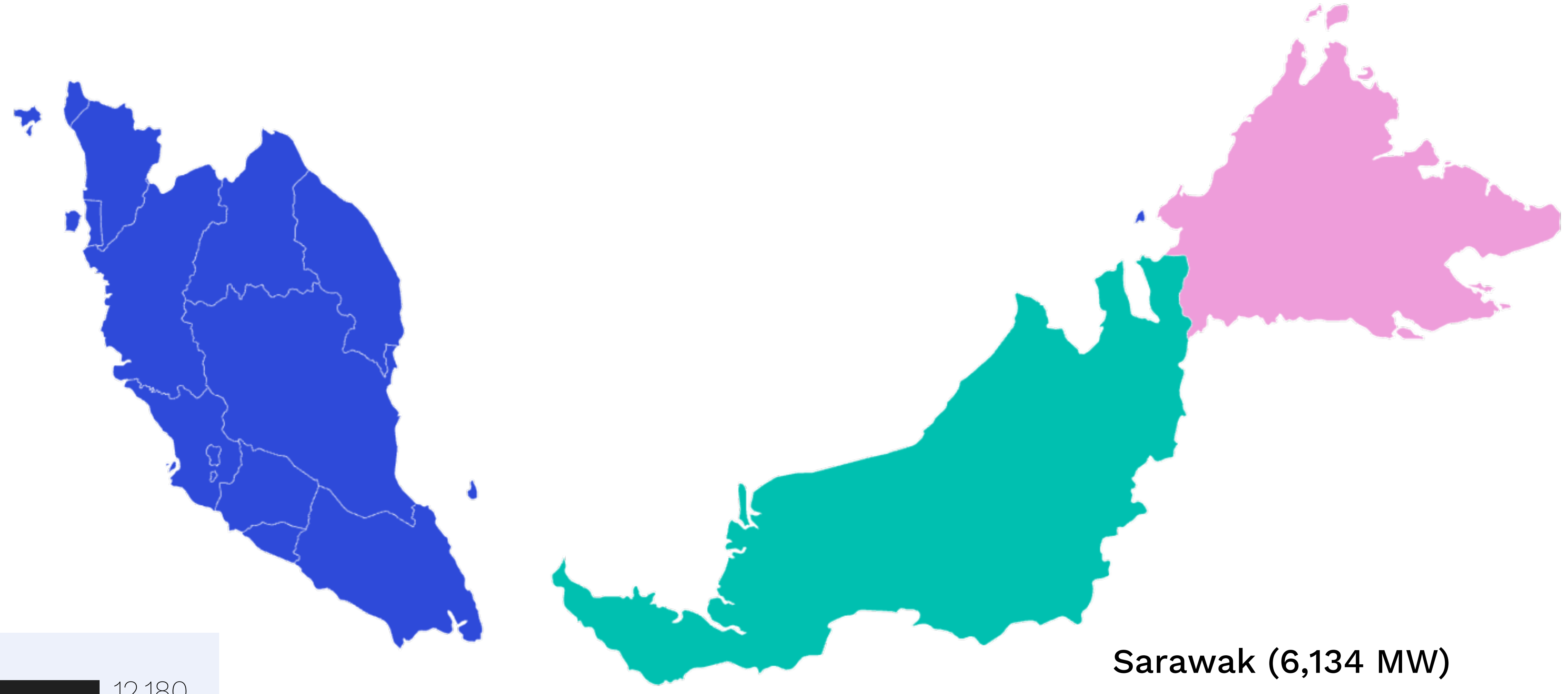
Overview of the Malaysian power sector

Capacities by grid zone as of 2023 (GW)

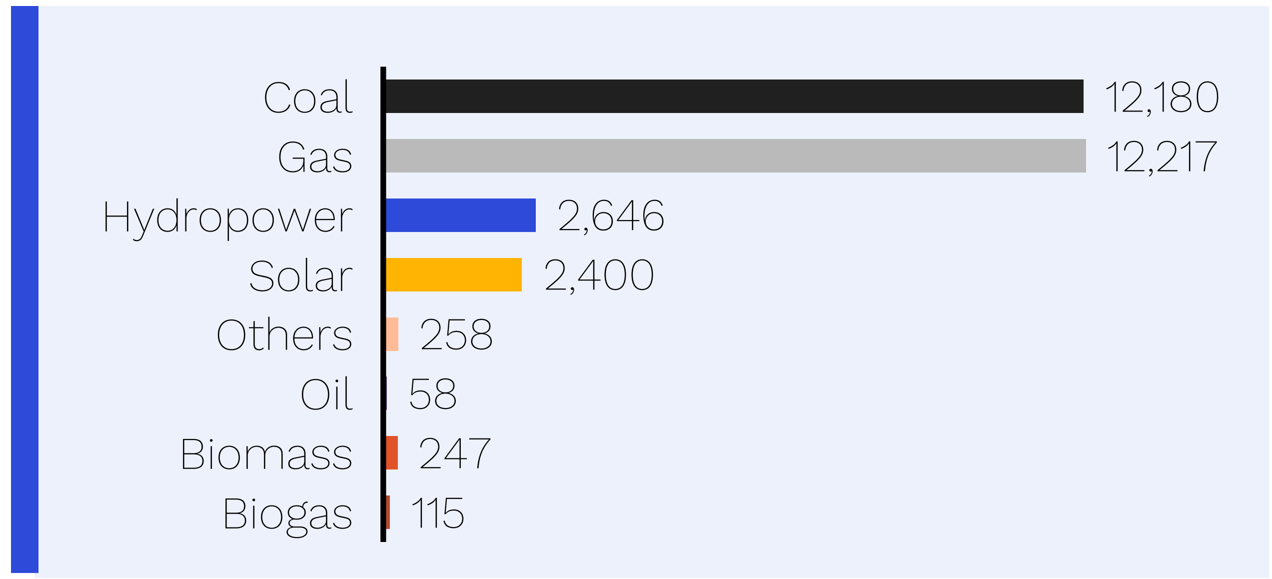


Sabah (1,970 MW)

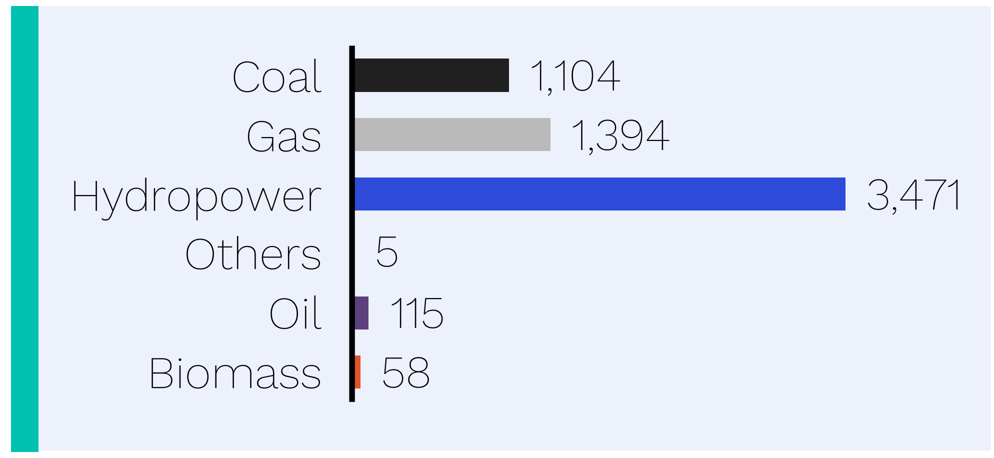




Peninsular Malaysia (30,121 MW)



Sarawak (6,134 MW)



This map is for illustrative purposes only and does not imply an endorsement of geographical boundaries by TransitionZero or its partners.

Source: Malaysia Energy Commission, TransitionZero (2025)

Notes

- Malaysia's power system is divided into three independent grids: Peninsular Malaysia, Sarawak, and Sabah. Peninsular Malaysia is the largest and serves as the main load centre.
- Each grid reflects its resource base: hydropower dominates in Sarawak, gas power in Sabah, while Peninsular Malaysia relies on a more diverse and import-dependent generation mix. In 2023, total RE capacity share was 19%.
- The electricity market is highly regulated and dominated by three vertically-integrated state utilities: Tenaga Nasional Berhad (TNB), Sarawak Energy Berhad (SEB), and Sabah Electricity (SESB), each servicing one grid.
- Regulatory authority is split across regions. Sarawak has maintained full autonomy over its energy sector since 1963, while Sabah assumed full regulatory control in 2024. As a result, power sector regulations there are different from those applied in Peninsular Malaysia.
- While Sabah is modelled to 2030 and trades power with Sarawak, it is not considered to be participating in CFE due to limited projected firm C&I demand in 2030.

Regulatory and Market Structure (1/2)

Regulatory and Market Structure (2/2)

Source: TransitionZero (2025)

Corporate clean energy procurement in Peninsular Malaysia

While unavailable in Sarawak and Sabah, Peninsular Malaysia offers C&I consumers various options to directly access and procure clean electricity

2016

Net Energy Metering (NEM) scheme

NEM allows consumers, including businesses, to install rooftop solar systems on their premises and export excess power to the TNB grid on a 'one-on-one' offset basis.

Three rounds have been introduced to date, with a combined quota of 3.5 GW.

Under the last round, NEM 3.0, the allocated quota for C&I customers is 1.7 GW, with registration open until 30 Jun 2025. The offset period is 10 years. As of June 2025, 70% of the quota has been subscribed.

2021

Green Electricity Tariff (GET) programme

This is subscription-based green tariff scheme by TNB that allows consumers to purchase solar and hydroelectric power directly through their electricity bill. Subscribers receive Malaysia Renewable Energy Certificates (mRECs) at the end of the year.

The GET quota for 2025 is set at 6.6 TWh.

Starting 1 July 2025, GET premium rates for C&I consumers will range from 3-5 sen/kWh, a reduction of up to 83% from previously. The premium is applied on top of the standard applicable tariff rates.

2022

Corporate Green Power Procurement (CGPP) programme

CGPP is essentially a mechanism of **virtual power purchase agreement** that allows C&I consumers, specifically manufacturing or service companies, to procure green electricity from new solar plants via a contract-for-difference.

As of October 2023, the programme's 800MW quota was fully subscribed, with 32 successful applicants. No new subscription rounds have been announced for 2025.

2024

Corporate Renewable Energy Supply Scheme (CRESS)

This mechanism allows businesses to directly source renewable energy from developers via TNB's open grid network.

A 'system access charge' is levied by TNB for electricity wheeled through its grid network. As of 1 July 2025, this is set at 20 sen/kWh for firm output, and 40 sen/kWh for non-firm output.

Three CRESS deals — all involving data centres as off-takers — have been reported as of June 2025, with a combined capacity of 1.3 GW.

2025

GET Greenpath programme

This is an enhanced version of the GET scheme that helps consumers within bulk-metered premises, such as data centres or commercial tenants, to subscribe to green electricity.

An extra admin fee of 0.2 sen/kWh is charged on top of the GET rates.

Subscription is open from 1 August 2025.

Solar Accelerated Transition Action Programme (Solar ATAP)

The programme, set to launch in December 2025, succeeds the NEM scheme and is expected to feature enhanced terms to further incentivise rooftop solar adoption.

Note: 100 sen = 1 ringgit Malaysia
Source: Malaysia Energy Commission, SEDA, PETRA

A comparison between C&I retail and clean electricity tariff structures in Peninsular Malaysia

TNB standard tariff of on-grid electricity (effective July 2025)

Monthly bills include four components as illustrated above. Rates increase with higher voltage connection levels. C&I consumers can opt between general and time-of-use tariff rates.

Note: Figures in boxes are examples of C&I high-voltage general tariffs.

GET premium tariff

C&I consumers pay an additional GET premium on top of the standard retail tariff to get certified clean electricity.

CGPP tariff

C&I consumers pay a two-component tariff: the TNB standard tariff, and the CGPP settlement tariff which is the difference between the CGPP tariff agreed with the RE generator and the actual System Marginal Price (SMP) in each half-hour time frame.

CRESS tariff

Under this mechanism, C&I consumers pay the RE generator the tariff agreed upon in their PPA (called the Bilateral Energy Supply Contract). In case the C&I demand exceeds the amount supplied by the RE generator, the balance of supply is purchased from TNB at the standard retail tariff.

Note: 100 sen = 1 ringgit Malaysia
Size of boxes not proportional to the corresponding costs.
Source: TNB, Malaysia Energy Commission

Methodology

How we modelled CFE in Malaysia

Key modelling design features

How Malaysia is represented in the TZ CFE study

Relevant Parameters

- **Year of analysis:** 2030.
- **Time steps:** 8760 hours/year, i.e. hourly.
- **Modelling framework:** PyPSA open-source linear optimisation of dispatch in copper-plated zones without intra-zone power flows.
- **Nodes & Interconnectors:** A 3-node model, representing Peninsular Malaysia (MYSPE), Sarawak (MYSSK), Sabah (MYSSH). MYSPE is interconnected with Singapore (SGP) and the South of Thailand (THASO), while MYSSK can trade power with MYSSH and Kalimantan, Indonesia (IDNKA)
- **CFE demand:** Projected national demand, plus increased growth from emerging sectors. Only Peninsular Malaysia and Sarawak have assigned CFE demand.
- **CFE demand profile:** Proportional to overall demand profile in each grid region.

Explore the full methodology

A detailed explanation of our modelling assumptions and methodology, along with other TransitionZero CFE country reports, is available at: www.transitionzero.org/cfe

Common inputs

Our models utilise the full suite of inputs required for power systems modelling

Technology

- Capacities
- Maximum build-constraints
- Renewable profiles
- Efficiencies
- Emissions factors

Financial

- Cost of capital
- CAPEX
- OPEX (FOM/VOM[1])

Demand

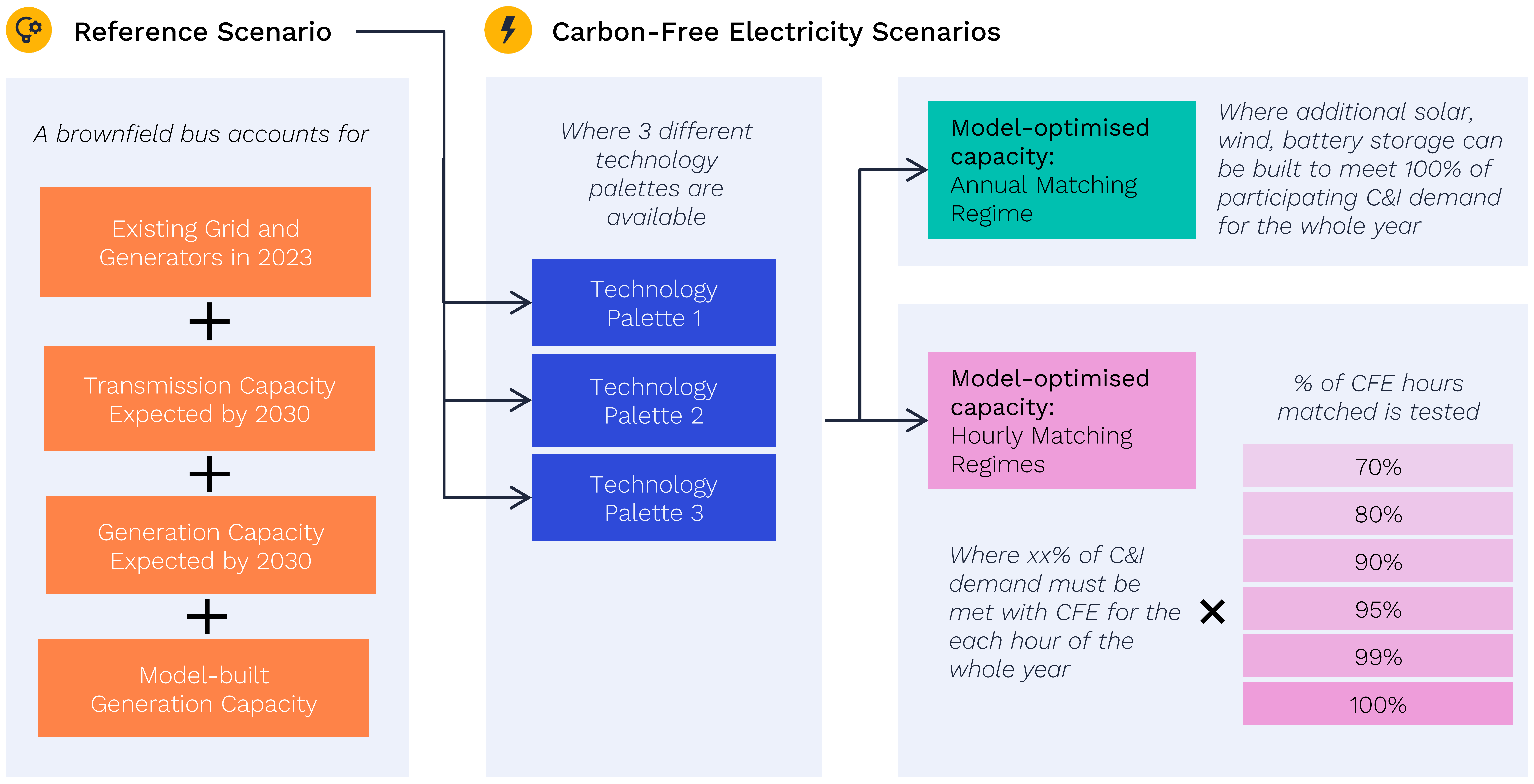
- Nodal hourly demand
- Commercial & industrial demand

National policies [2]

- Planned expansions
- Capacity mix targets
- Decarbonisation targets
- Transmission plans

[1] *VOM also covers here fuel costs and carbon penalties.*
[2] *We will apply a delay of up to 5 years on policies that do not seem realistic, in consultation with our Working Group partners.*

We run three sets of scenarios to test both supply and demand for CFE in 2030



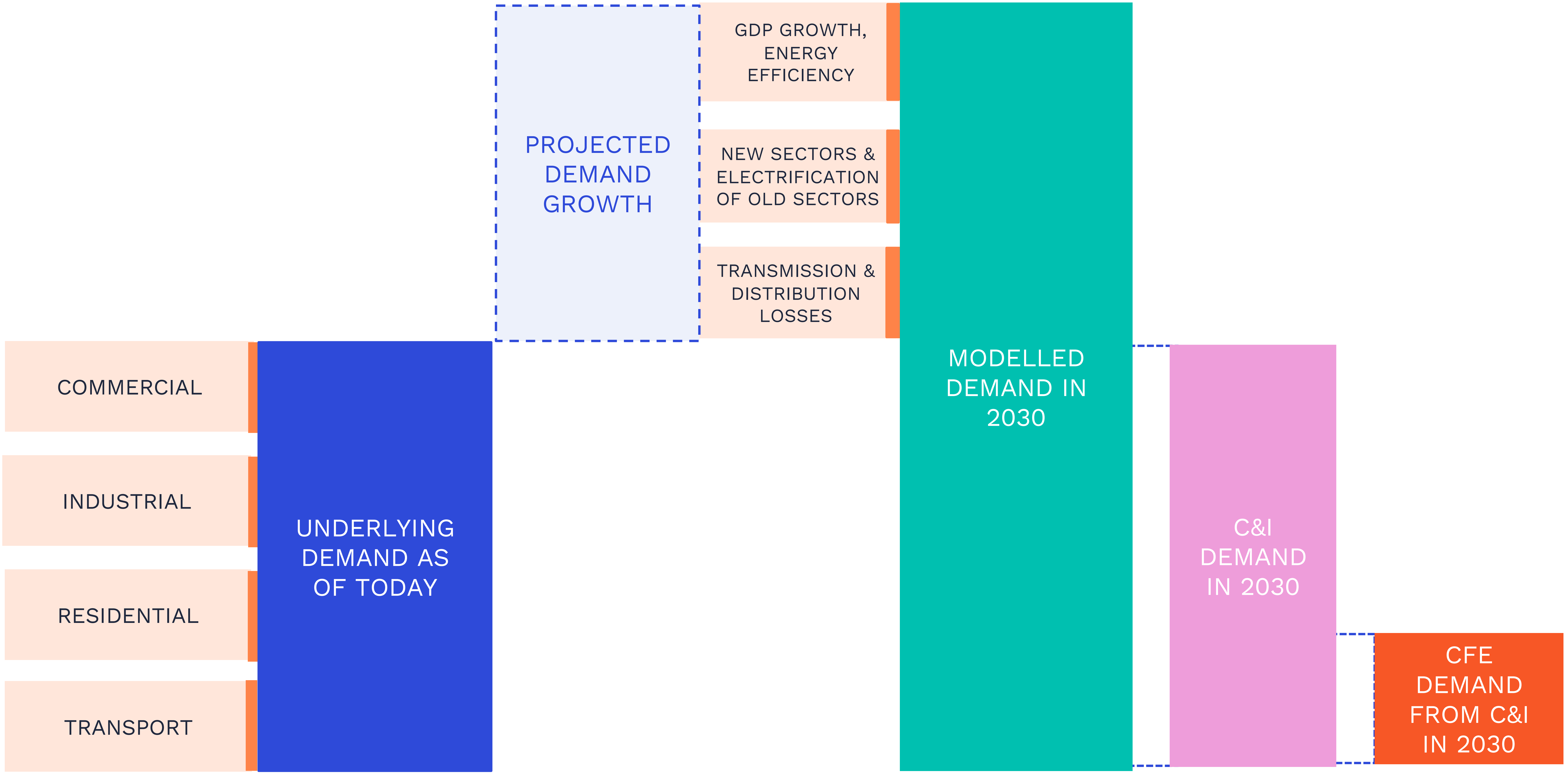
Notes

- CFE scenarios meet the participating C&I demand either on an annual or an hourly basis by building additional capacity (equivalent to procuring additional capacity through PPAs).
- Before modelling any CFE scenarios, we run a Reference scenario, allowing new-build on the brownfield bus only.
- For each technology palette the first CFE scenario is the Annual Matching Regime, which we run only once.
- We then run Hourly Matching Regimes starting with a CFE share of 70% and then rising to 100% for a total of 6 runs (see infographic on left).
- The total number of runs per grid region is 22, made up of 1 Reference Scenario and 7 matching regime runs each for each technology palette.

Demand in 2030

Our model considers demand for both conventional electricity and CFE

Illustration of components contributing to modelled final demand



[1] Bottom-up in-house projection done for Japan only.

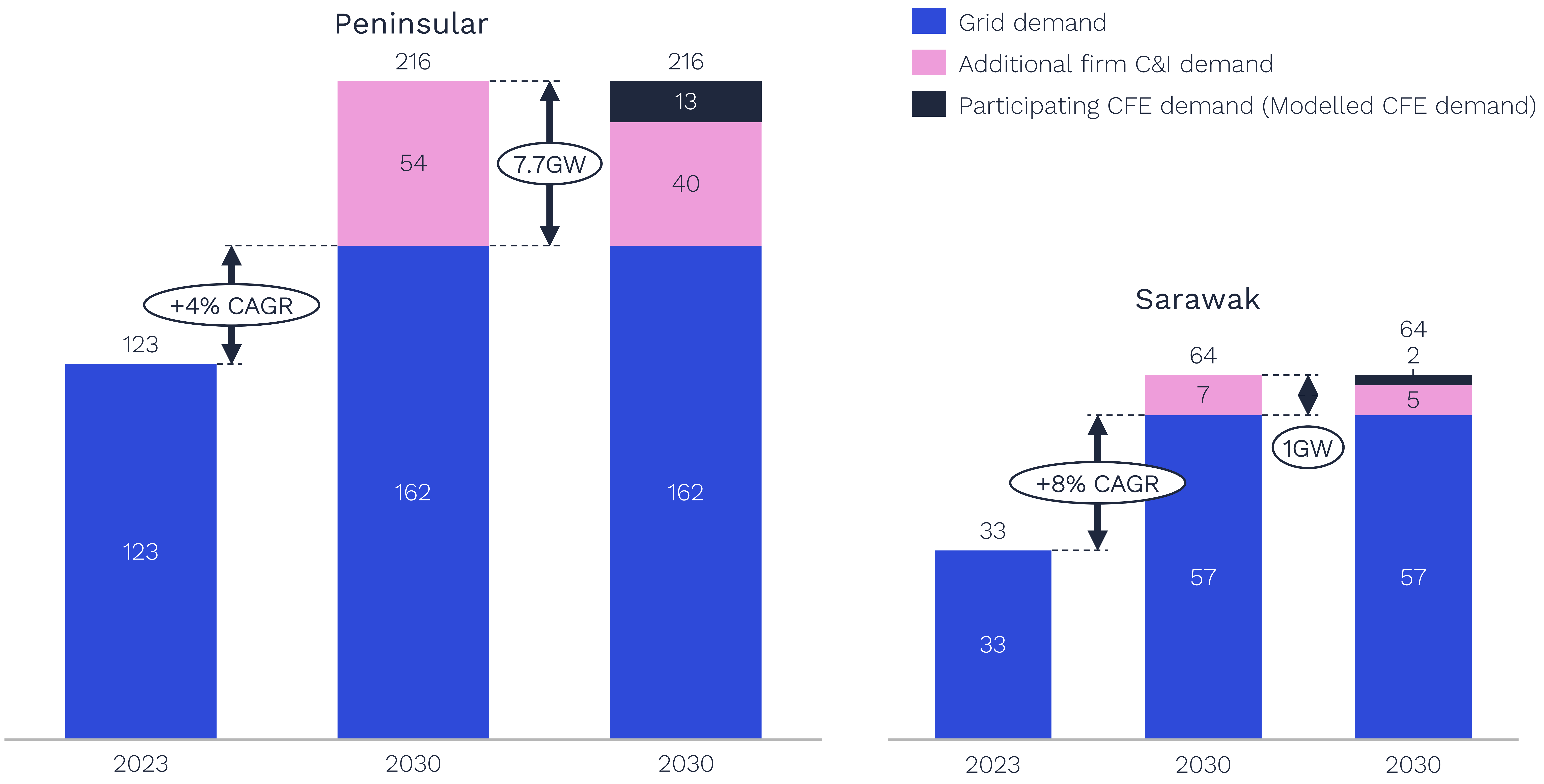
Notes

- Our demands for 2030 account for several sources of change from the present – either explicitly through in-house modelling[1] or by incorporating projections made by local authorities.
- In our Reference Scenario, the model only seeks to meet demand from all sectors.
- In our CFE scenarios, we expect that a certain share of C&I consumers switch to consuming only CFE, thereby triggering PPA developers to build new capacities.
- To reflect changes in electricity consumption, we incorporated incremental demand beyond GDP-linked growth, accounting for emerging high-load activities and firm C&I demand.
- Actual CFE demand depends on the CFE% targeted in each Hourly Matching Regime. For Malaysia, only Peninsular Malaysia and Sarawak are assumed to be participating in 24/7 CFE.

Market	**CFE volume** [TWh]	**CFE %** [relative to 2030 demand]
India	122 TWh	5%
Japan	29 TWh	3%
Malaysia	14 TWh	5%
Singapore	3.5 TWh	4%
Taiwan	16 TWh	5%

Demand assumptions for 24/7 CFE in 2030

Demand by grid (TWh)



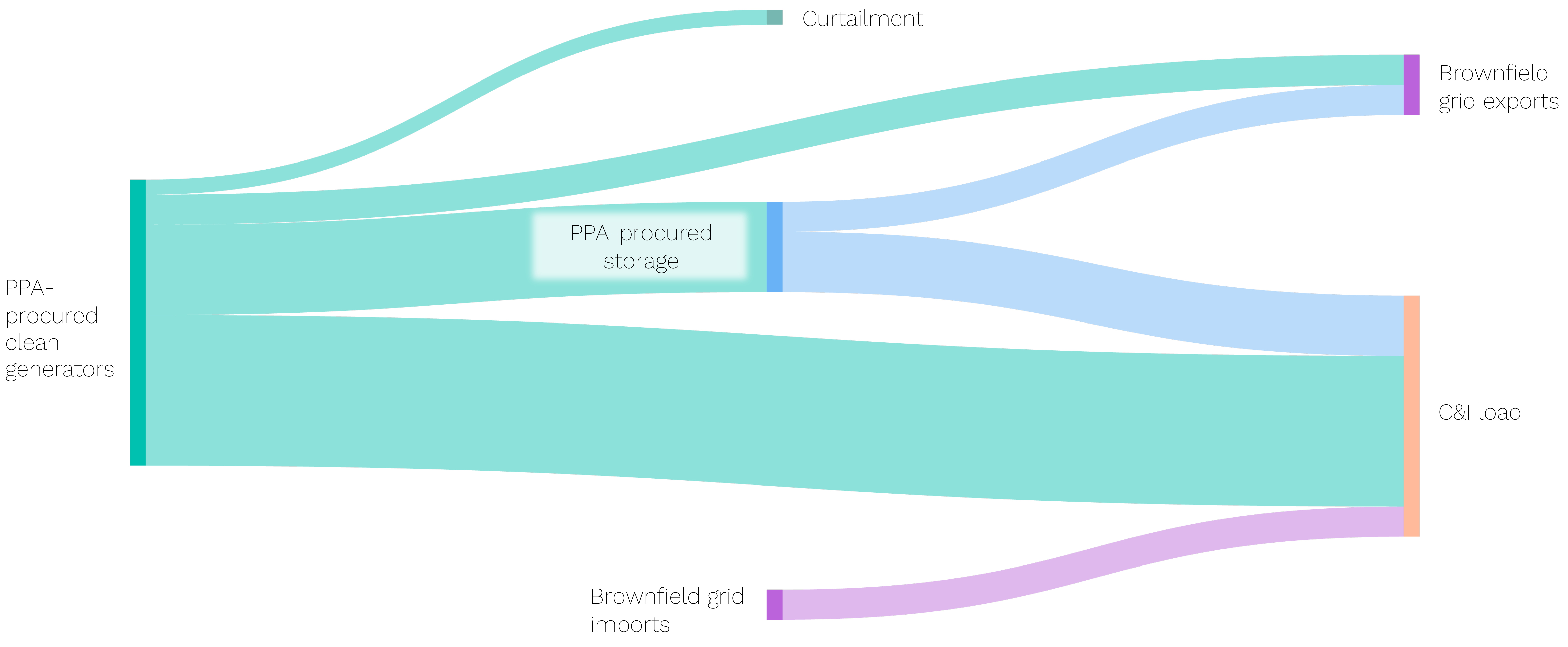
Source: TNB and Sarawak official statistics for 2023 data, TransitionZero for 2030 projections

Notes

- Demand growth assumptions differ by region, considering the pace of economic expansion and targeted increases in firm C&I load.
- Total electricity demand in Peninsular Malaysia is expected to grow by 4% a year between 2023 and 2030. In addition, PETRA aims to add 7.7GW of firm C&I demand by 2030.
- In Sarawak, overall electricity demand is forecast to rise by 5% a year by 2030. Our model estimates an additional 1 GW of demand from firm C&I demand.
- For both regions, we assume 25% of projected firm C&I demand — **13TWh in Peninsular Malaysia and 2TWh in Sarawak** — will participate in 24/7 CFE procurement.
- In practice, various sectors of the economy may take part in a 24/7 CFE scheme. Actual CFE demand could vary, depending on market development, uptake by consumers such as hyper-scalers, and supporting policies.

Energy flows and costs for the C&I load

Sankey diagram showing indicative energy flows between clean generators, storage units, the grid, and the C&I load



Relevant formulas

- In calculating the unit cost of electricity supplied to the C&I consumer, the C&I consumer could handle the grid imports themselves, and the PPA manager handles the PPA supply and export revenue from excess supply. This would lead to the following unit cost calculation:

$$\text{Unit cost} = A \times \frac{\text{capex + opex + grid export revenue}}{\text{C\&I load} - \text{grid imports} + \text{grid exports}} + (1\text{-}A) \times \frac{\text{grid import costs}}{\text{grid imports}}$$

$$\text{Where } A = \frac{\text{C\&I load - imports}}{\text{C\&I load}}$$

- This splits the electricity supply into the two components which come from the PPA supply and the grid respectively, which are then weighted by the proportion by which they supply the C&I load.

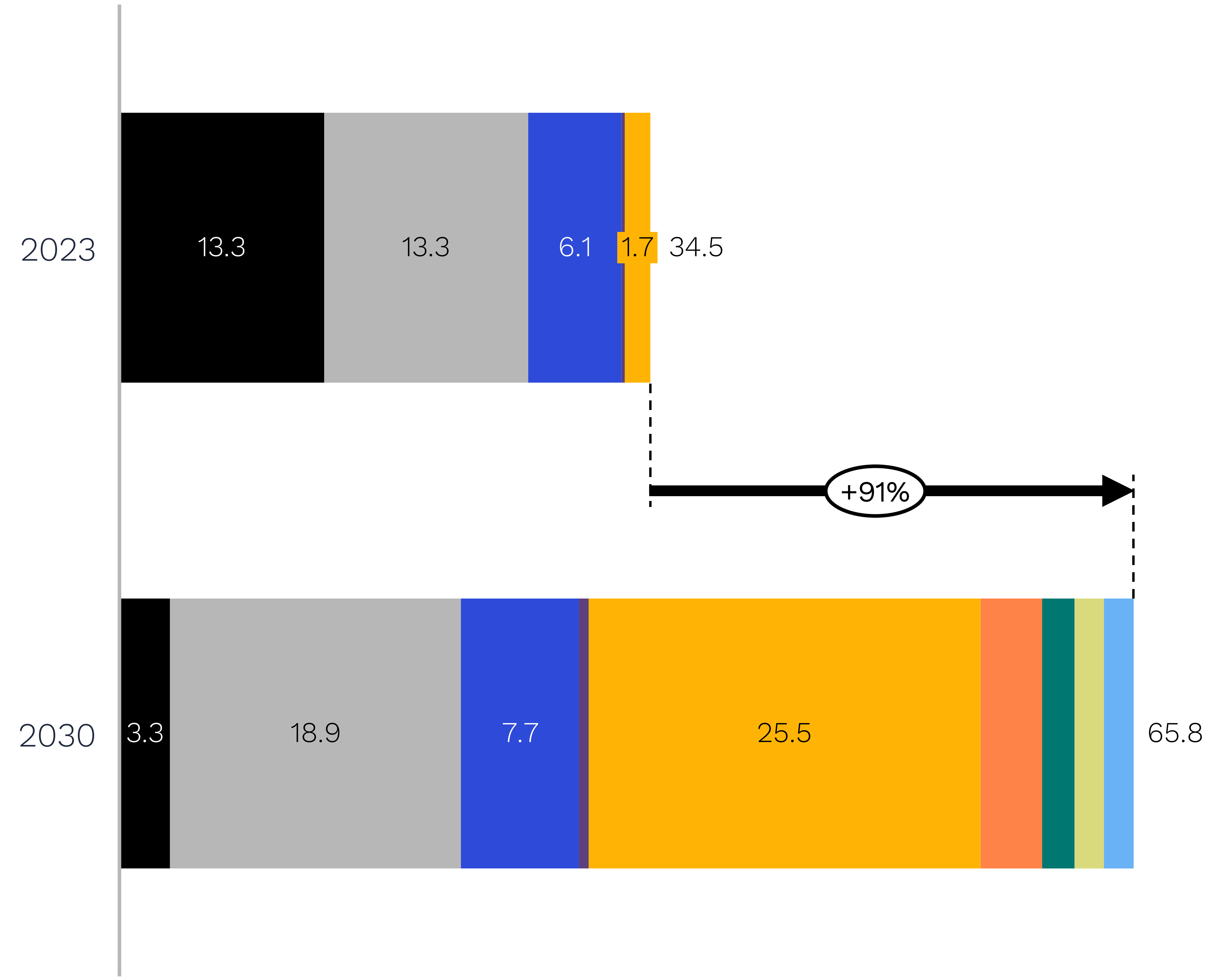
Reference Scenario results

Overview of the 2030 modelled results
for the grid regions

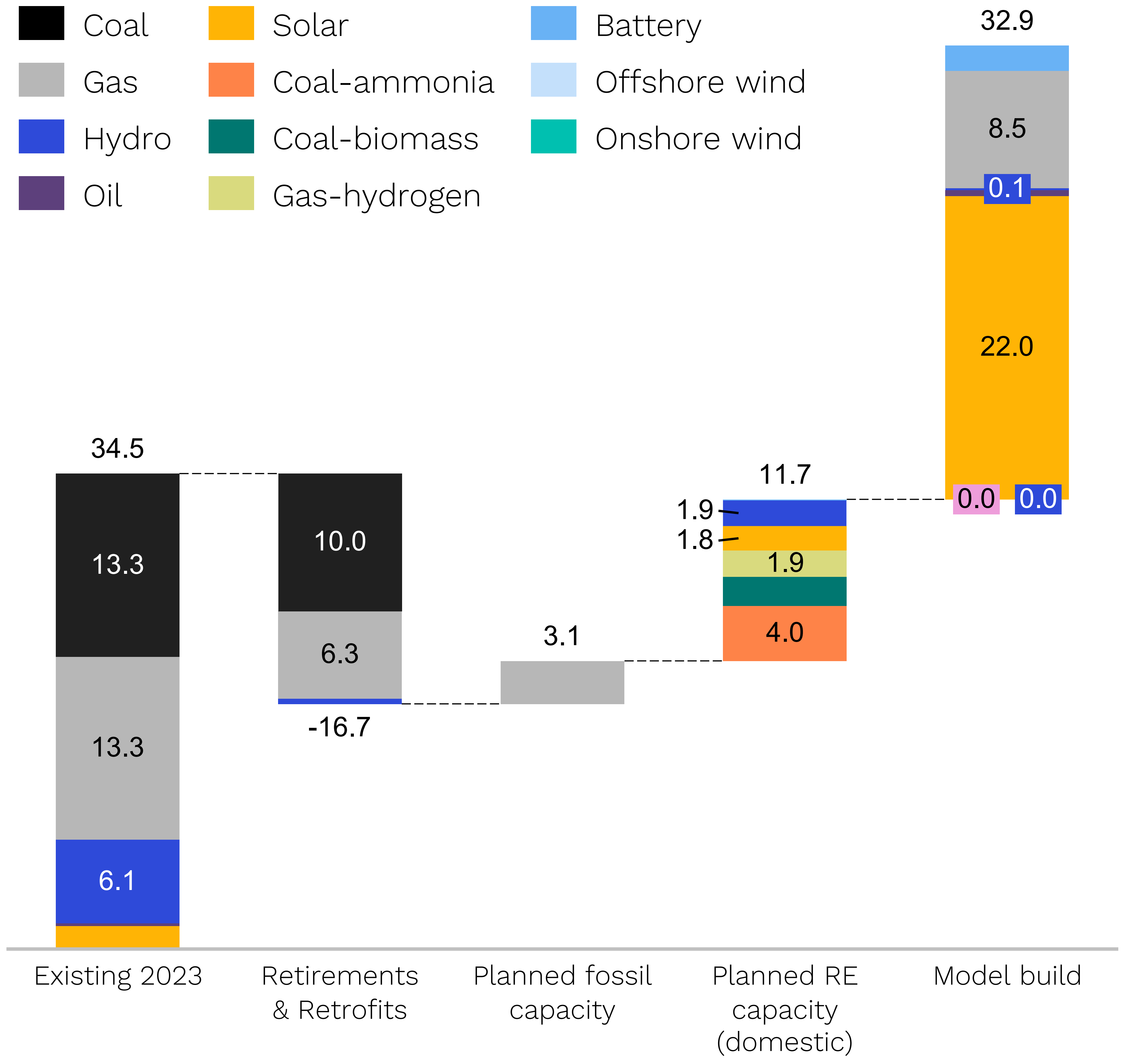
Generator & Storage Capacities in 2030 (1/2)

Our analysis starts with the composition of each grid system before any CFE demand

Installed capacities (GW)



Breakdown of 2030 installed capacities in Malaysia power system, including Sabah (GW)



Notes

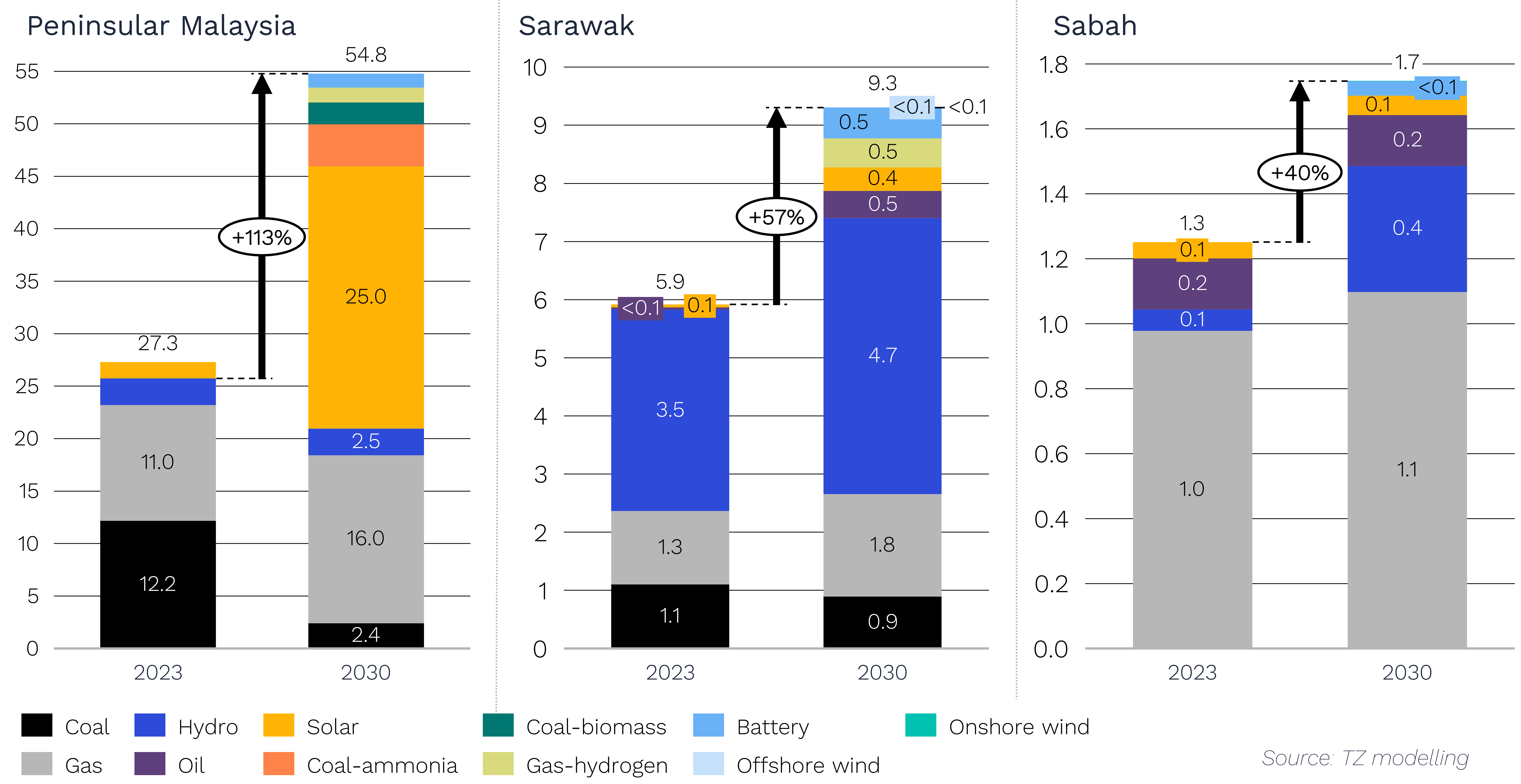
- The increase in installed capacity to 2030 is primarily driven by new solar and gas capacity, aided by government plans and decarbonisation targets.
- Our dispatch model integrates capacity already planned by developers and optimises for any additional capacity required beyond these installations.
- Using an 8% discount rate, the model favours solar deployment to meet the country's future demand and decarbonisation goals, resulting in an unprecedented growth in the technology to service demand on the main grid.
- The model projects over 8 GW of new gas plants to ensure grid reliability and sufficiency. This takes into consideration 16 GW of coal and gas plants scheduled for retirement or conversion into blending technologies, and the country's 'no new coal' policy.

Source: Malaysia National Energy Transition Roadmap; TransitionZero modelling

Generator & Storage Capacities in 2030 (2/2)

Capacity deployment mirrors each region's resources availability and energy priorities

Installed capacities by grid region (GW)



Source: TZ modelling

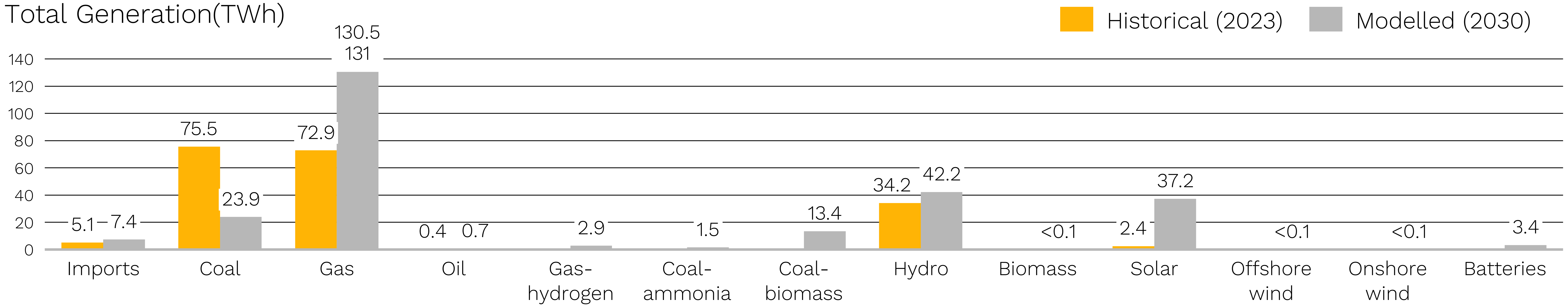
Notes

- Installed capacity rises across all regions by 2030. Peninsular Malaysia sees the most dramatic increase, more than doubling its installed capacity to 54.8 GW in 2030. Sarawak expands from 5.9 GW to 9.3 GW, a 57% increase. Sabah's capacity grows more modestly to 1.74 GW, a 40% increase.
- Solar becomes the largest source of new capacity in Peninsular Malaysia, growing from a small base to 25 GW by 2030 — nearly half of the region's total installed capacity.
- Hydro remains the backbone of Sarawak's power system, retaining its large share and expanding capacity by 1.2 GW by 2030.
- In Sabah, hydro and batteries are the main additions. Hydro installations in particular quadruple to allow for more clean power.
- Coal's share of installed capacity declines sharply in the Peninsular grid, falling from 12.2 GW to 2.4 GW due to planned retirement and repurposing. Sarawak shows a similar downtrend, though coal's initial role is smaller in this region.
- Gas retains a large share of Malaysia's capacity, especially in Peninsular Malaysia and Sabah.
- Battery storage and wind (both onshore and offshore) start appearing in the capacity mix. Fuel blending technologies like coal-ammonia and gas-hydrogen are introduced in small volumes, signalling early-stage diversification.

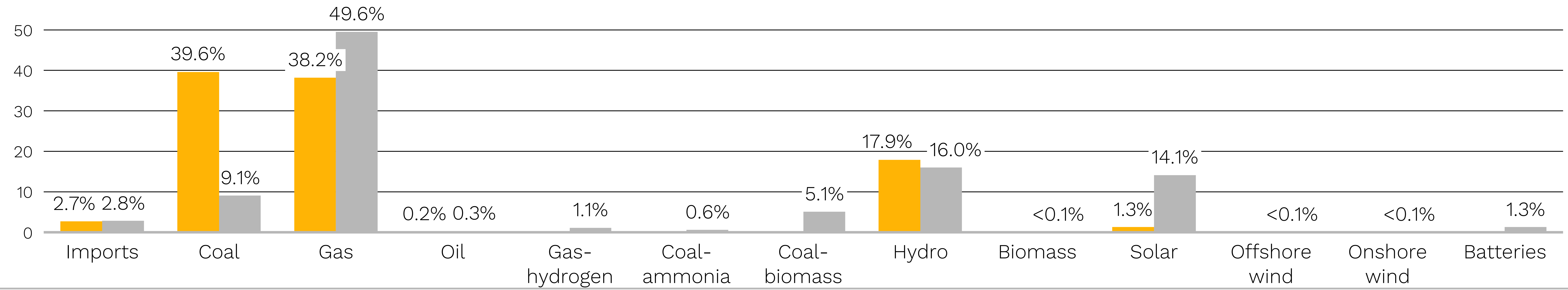
Malaysia-wide generation mix in 2030

Gas dominance, solar surge, and early-stage thermal innovation shape the system's evolution

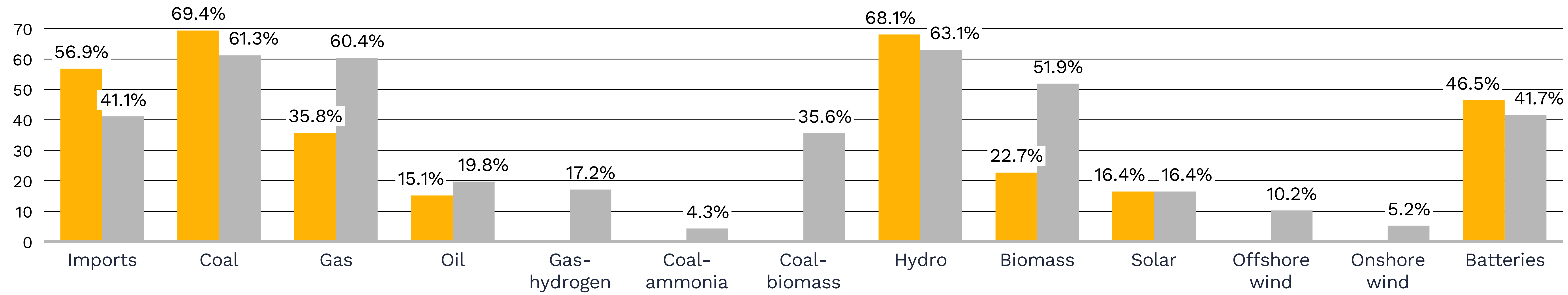
Total Generation(TWh)



Generation share per technology (%)



Capacity factor per technology (%)



Notes

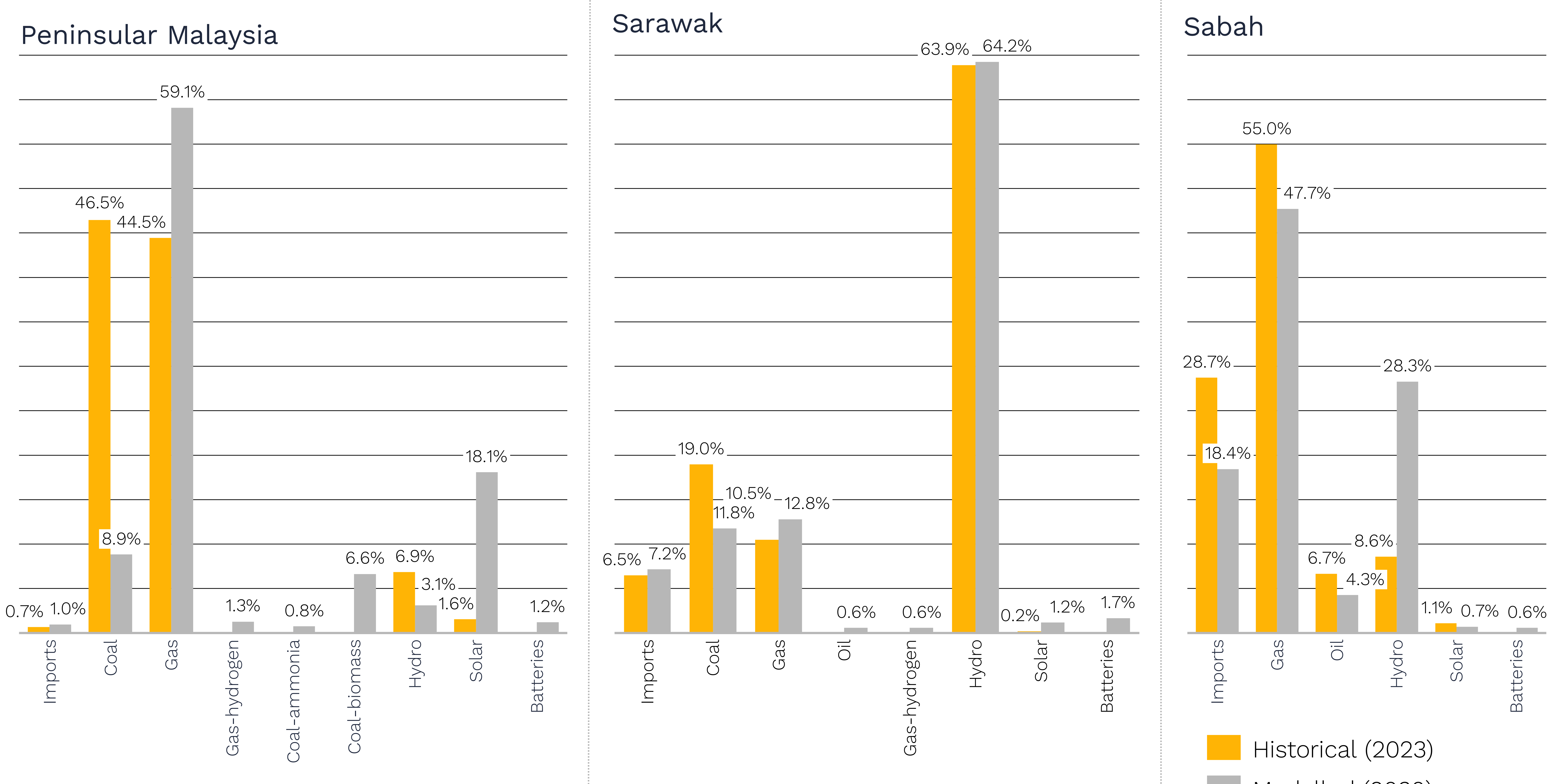
- Our model was calibrated with 2023 data to reflect actual generation patterns for technologies reported by Malaysia's three utilities: Tenaga Nasional Berhad (TNB) for Peninsular Malaysia, Sarawak Energy for Sarawak, and Sabah Electricity Sdn Bhd (SESB) for Sabah.
- Gas remains Malaysia's largest electricity source, as national plans prioritise the retirement and retrofitting of coal plants. In Sarawak, hydro retains its dominant role in the generation mix.
- RE's share of total generation increases from 19% to 30%, driven mainly by the rapid expansion of solar, which is modelled to grow from 2.4 TWh to 37 TWh — becoming the third-largest power source nationally and overtaking coal.
- Coal-fired generation drops by 30 percentage points if the 3.6 GW of coal capacity retire as planned by 2030. The remaining coal plants operate at slightly lower capacity factors (69% in 2023 to 61% in 2030) and gas capacity factor nearly double due to both increased demand and lower coal generation.
- With an 8% discount rate, the deployed utility-scale solar exceeds Malaysia's 2030 capacity target, triggering greater battery storage deployment and utilisation.
- Co-firing technologies contribute 5% of national generation by 2030, reflecting Malaysia's push for innovative thermal solutions. However, utilisation on these plants remains relatively low.

Source: TZ modelling

Power dynamics in 2030 by grid region

Gas dominance, solar surge, and early-stage thermal innovation shape the system's evolution

Share of Total Generation by grid zone (%)



Source: TZ modelling

Notes

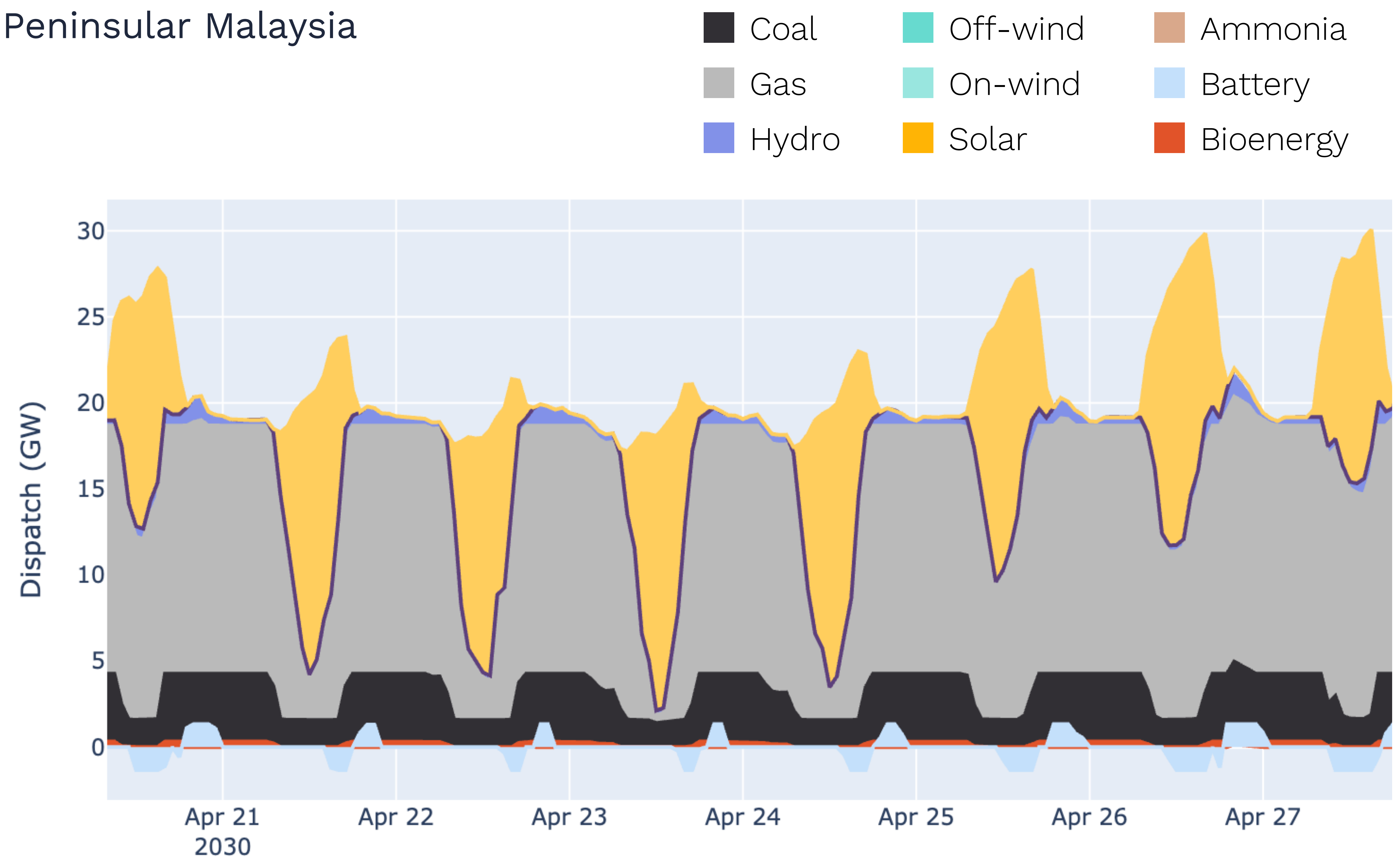
- **Peninsular Malaysia**: plans to retire and retrofit existing coal plants lead to a substantial decline in coal's contribution to the power mix. To meet a projected 75% increase in regional electricity demand by 2030, gas, solar, and blending technologies scale up. Cross-border imports, particularly from Thailand, maintain their contributions to system reliability and balancing supply.
- **Sarawak**: hydropower will continue to dominate Sarawak's generation mix, but its share declines by 13% due to increased electricity imports from Indonesia and Sabah. Batteries also see an increased role with 8.5% share in generation to support solar integration.
- **Sabah:** hydro capacity grows 20 percentage points, reducing the shares of imports and gas generation from 29% to 18% and from 55% to 48%, respectively.
- **Participating CFE regions:** Peninsular Malaysia starts with a baseline CFE score of 24.9%, while Sarawak begins at 65%. Aggregated up, this puts Malaysia's national base CFE score at approximately 30%.

Sample of hourly generation in 2030

The unique grid operation patterns of each region shapes the opportunities and challenges for achieving 24/7 CFE

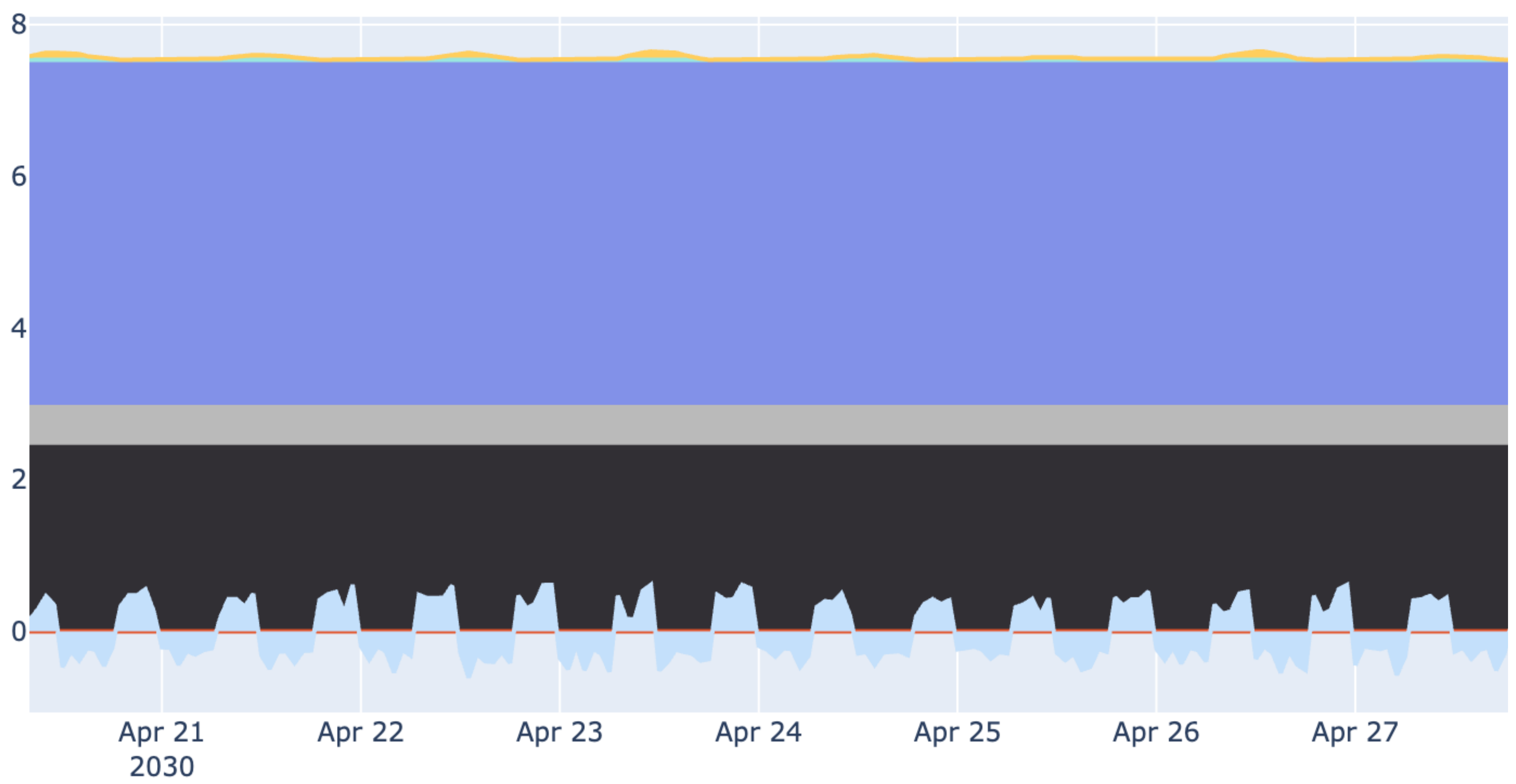
Hourly generation by fuel type during a high demand sample period in 2030

Peninsular Malaysia



- Solar generation in Peninsular Malaysia comes in mid-day to complement gas and hydro generation, which ramp up in the evenings

Sarawak



- Hydro dominance provides a steady, clean baseload that increases the ability of 24/7 CFE contracts, especially ones relying on solar and batteries, to tap into the grid

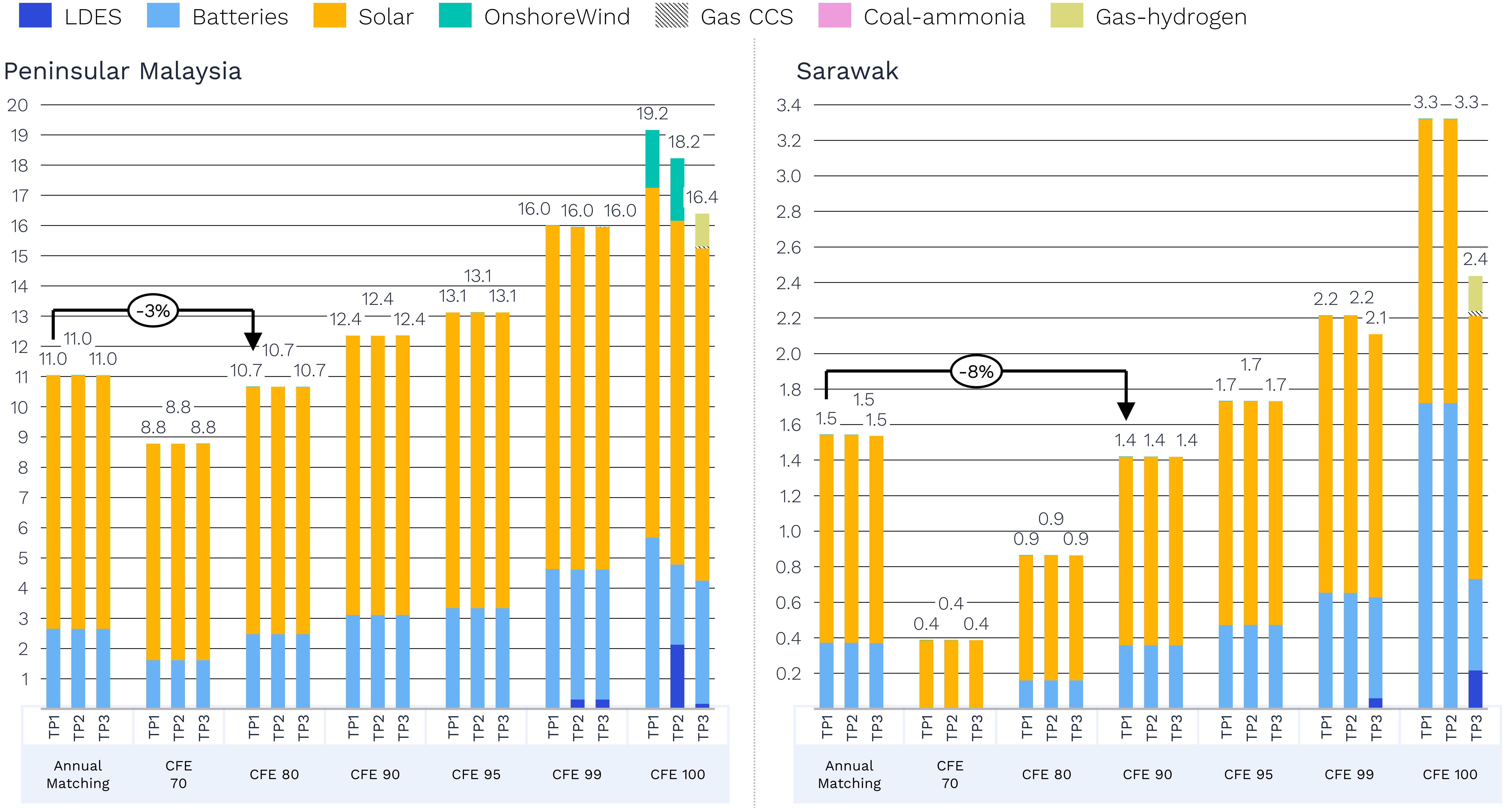
Modelling Results

Deep-dive analysis into CFE findings in Peninsular Malaysia and Sarawak

What capacity is built for CFE ?

Solar-plus-battery deployment can deliver hourly matching for Malaysia

Greenfield capacity build out (GW)



Notes

- The two participating CFE grid regions of Malaysia have different optimal CFE scores because their power systems, renewable resource availability, and grid interconnections differ significantly.
- **Sarawak's** hydropower-dominated system can reach 90% CFE with 1 GW solar and 0.4 GW batteries to meet similar benefits to annual matching, but at 8% less capacity.
- **Peninsular Malaysia**, with its higher projected participating CFE demand and a grid dominated by gas, can reach 80% CFE using 8.2 GW of solar and 1.6 GW of batteries reach — 3% less capacity than the annual matching.
- Solar PV and battery storage dominate capacity additions across all matching regimes in **both** regions, reflecting their cost competitiveness, scalability, and suitability for flexible deployment.
- Moving from 95% to 100% CFE will require batteries to grow exponentially, particularly in Sarawak, to provide load-shifting for the hardest-to-reach hours.
- Alternative technologies enter only for the last 1% of CFE. In **Peninsular Malaysia**, 1.9 GW of onshore wind features at to offset solar shortfalls and if LDES is available, it reduced total batteries needs by 0.5 GW. The integration of CCGT-gas blending and gas-CCS reduces total installed capacity by 14% in comparison to TP2. In **Sarawak**, 100 MW gas-hydrogen with 216 MW LDES replace firming from lithium-ion batteries.

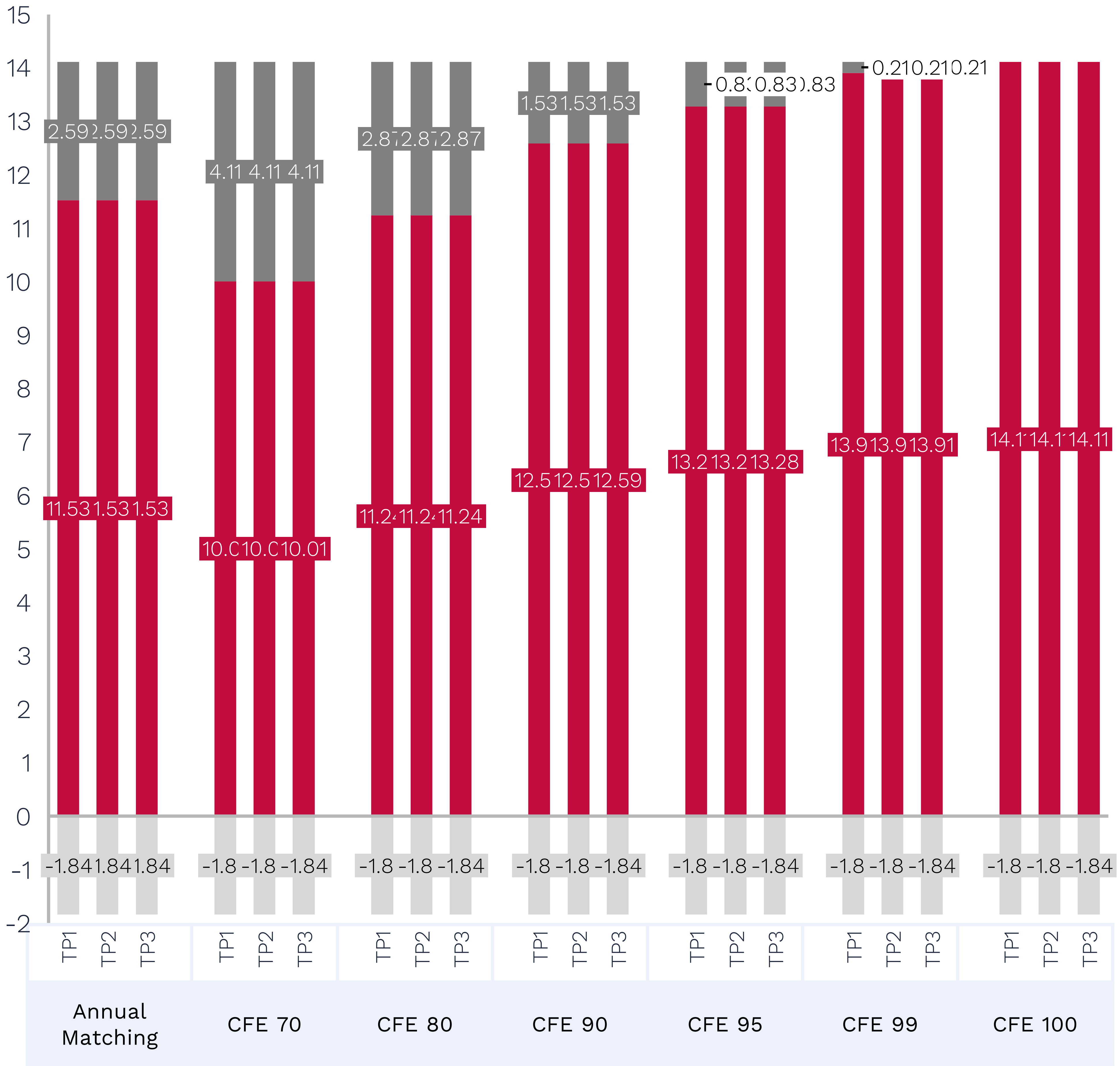
To what degree can participating CFE consumers rely on clean power from the grid?

Malaysia's hourly matching potential delivers strong benefits across regions

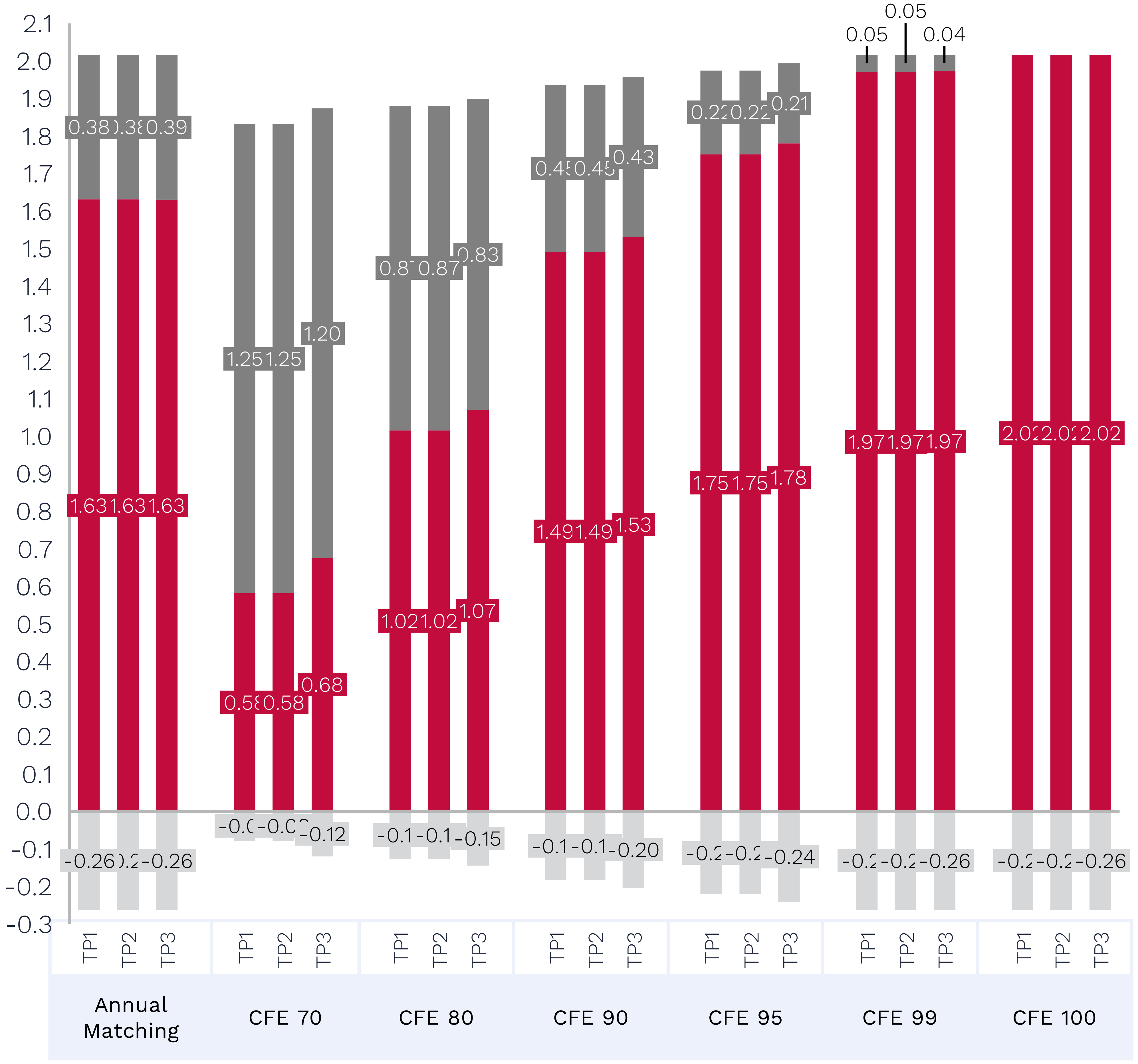
C&I procurement mix (TWh)

Grid supply Excess C&I PPA

Peninsular Malaysia



Sarawak



Notes

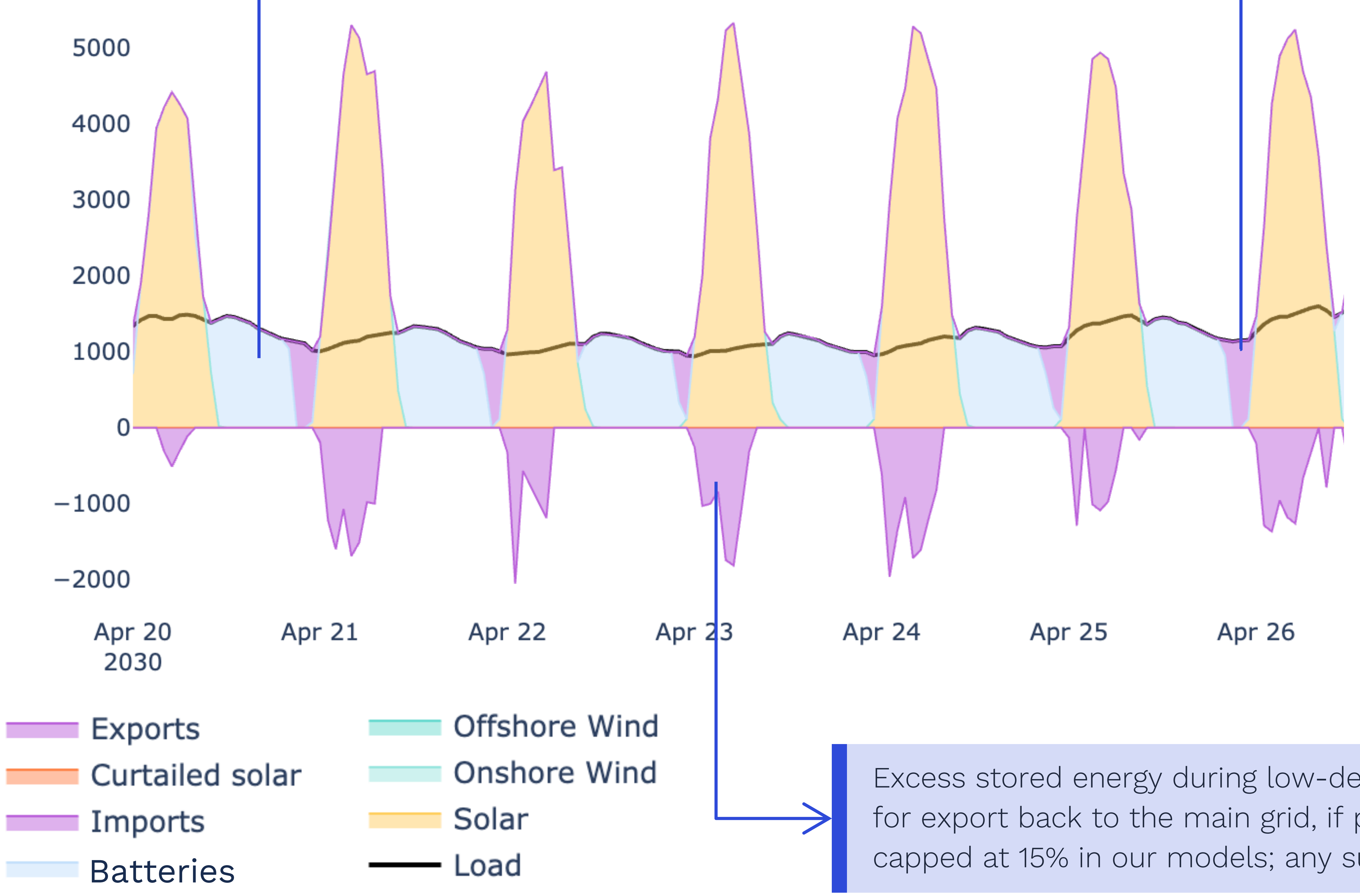
- Under lower hourly matching regimes, C&I consumers can source part of their electricity needs from the grid, though this declines sharply at 95% CFE and ceases entirely at 100% CFE. This coincides with an exponential increase in direct PPAs and clean capacity needed to achieve full self-sufficiency.
- In **Peninsular Malaysia**, under both annual matching and lower hourly matching target, 20–30% of electricity used to meet CFE comes from the grid. At 90% CFE, this share falls to 10%.
- For **Sarawak**, over 70% of power needed to meet 70% CFE can be met by grid-based electricity, with just 0.6TWh of PPA generation needed. Even at 90% CFE, a quarter of supply comes from the grid with much of the electricity consumed.
- **Peninsular Malaysia** consistently sees high excess C&I generation sold back the grid, maximising at 1.84TWh across all scenarios. In **Sarawak**, sell-back increases as C&I consumers must overside their systems to meet higher CFE; though it only reaches annual matching levels at 99% hourly CFE.
- This highlights the need for a sell-back framework to enable C&I consumers to generate revenue from surplus power and to help Malaysia unlock corporate investment while avoiding curtailment of excess generation.

Examination of clean energy supply to C&I consumers

Sample hourly dispatch at 80% CFE using Technology Palette 1 (MW)

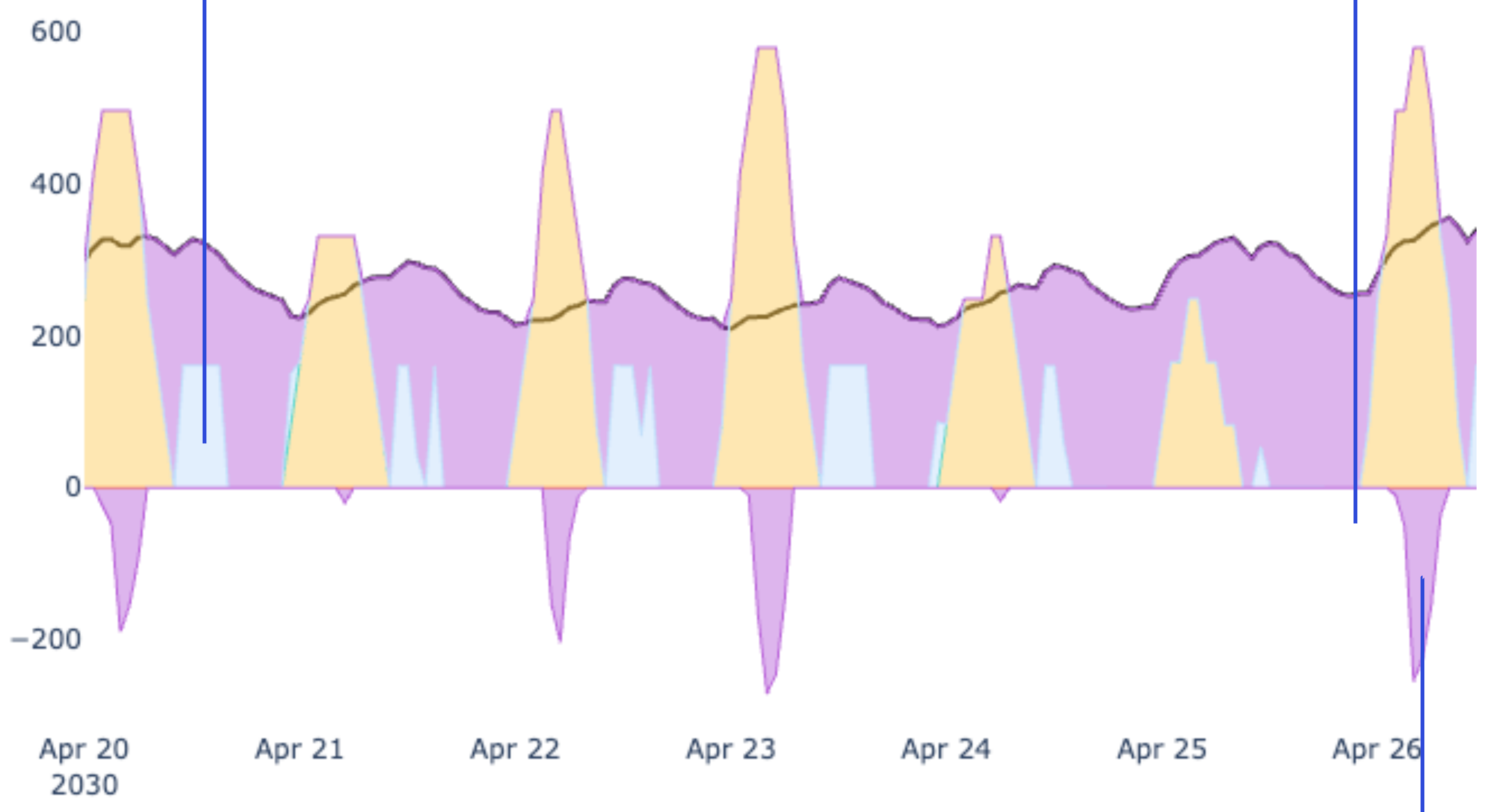
Peninsular Malaysia

Battery storage is primarily used to meet evening and early morning demand, bridging the gap between solar generation cycles.



Sarawak

At 80% CFE, imports from the Brownfield are required primarily in the early morning hours—just before peak solar generation begins.



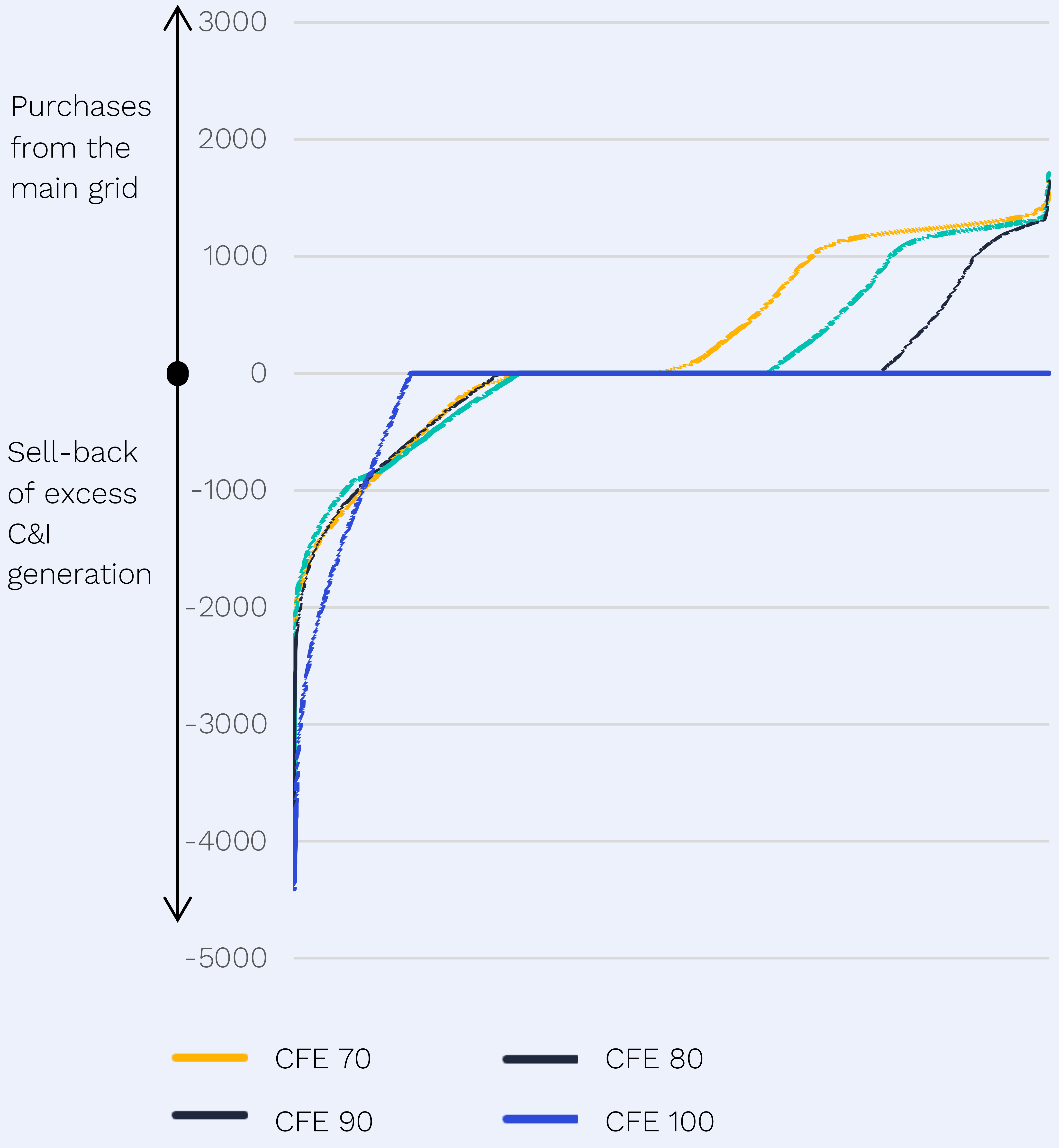
Excess stored energy during low-demand periods presents a significant opportunity for export back to the main grid, if policy permits greater sell-back flexibility. This is capped at 15% in our models; any surplus beyond this limit is curtailed.

Clean energy targets reshape trade between grids

Imports, exports, and system flexibility evolve with higher CFE targets

- The greenfield CFE system can partially depend on electricity purchased from the main grid. Under hourly matching, the carbon intensity of the grid directly influences overall CFE performance.
- A 15% sell-back cap — applied for both annual and hourly matching — restricts the system's ability to balance supply and demand solely through grid interactions between the greenfield and brownfield.
- The cap was set to ensure that new greenfield build is focused on matching hourly consumption rather than overbuilding for profit. Since Malaysia currently does not account for the sales of excess corporate PPA generation to the grid, the cap was set at 15% — lower than the 20% used in previous studies — to reflect real market constraints.
- At lower CFE targets, purchases from the grid are more frequent and larger in volume, indicating greater flexibility in trading electricity with the main grid.
- As CFE ambition increases, both the frequency and magnitude of grid purchases decrease. At 100% CFE, C&I consumers become self-sufficient.
- Sell-back is highest at 100% CFE because achieving full hourly matching forces an overbuild of clean generation and storage to cover every possible hour of demand. This surplus capacity inevitably produces excess electricity in many hours, leading to larger volumes of clean power sold back to the grid.
- Across all scenarios, purchases from the Peninsular Malaysia grid peaks at 1,500 MWh, highlighting an ongoing need for backup capacity. In contrast, sell-back can occasionally exceed 3,000 MWh, though such events occur in fewer than 1% of hours.

Flow duration curve in Peninsular Malaysia for Technology Palette 1 (MWh)

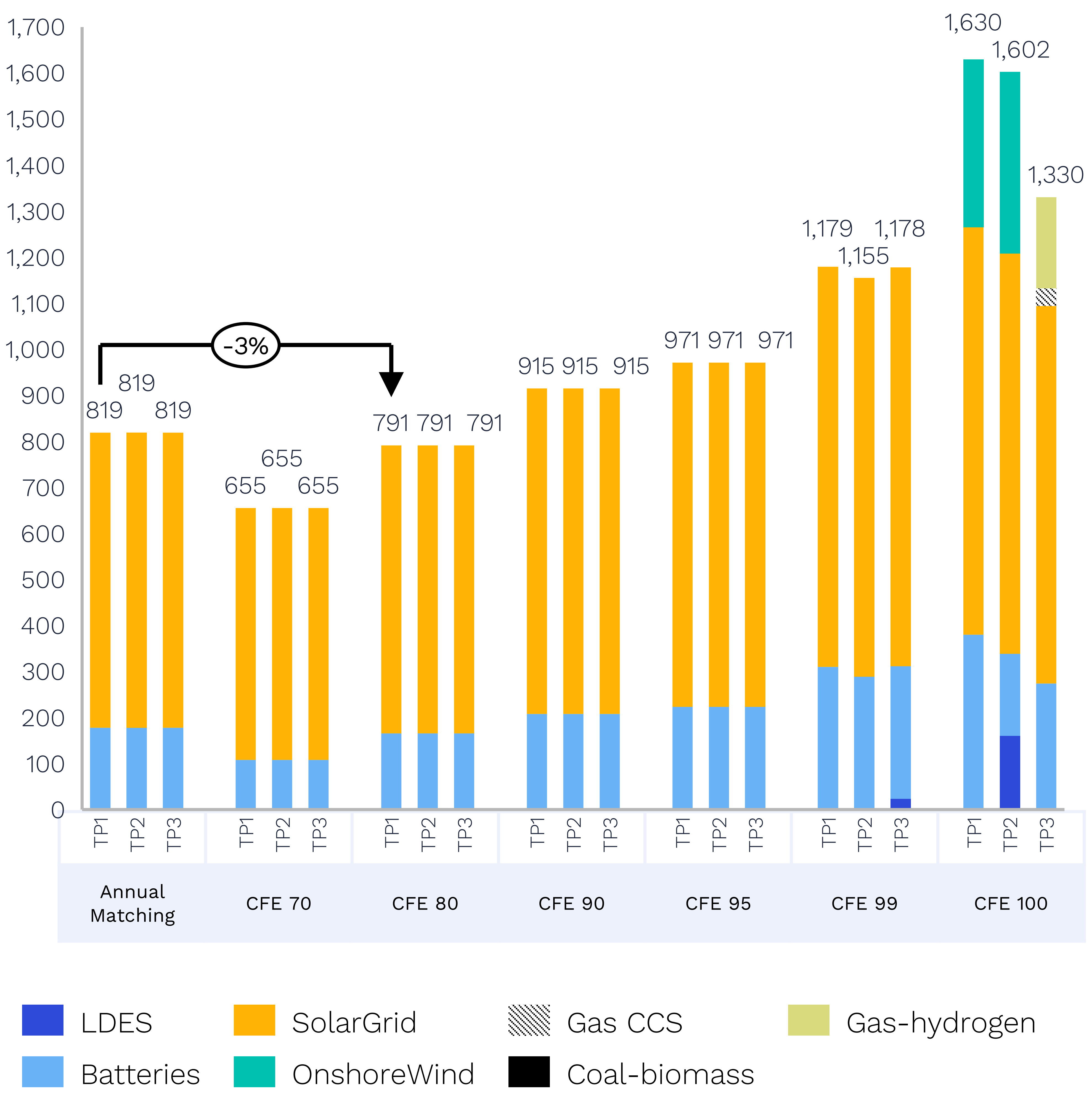


Source: TZ modelling

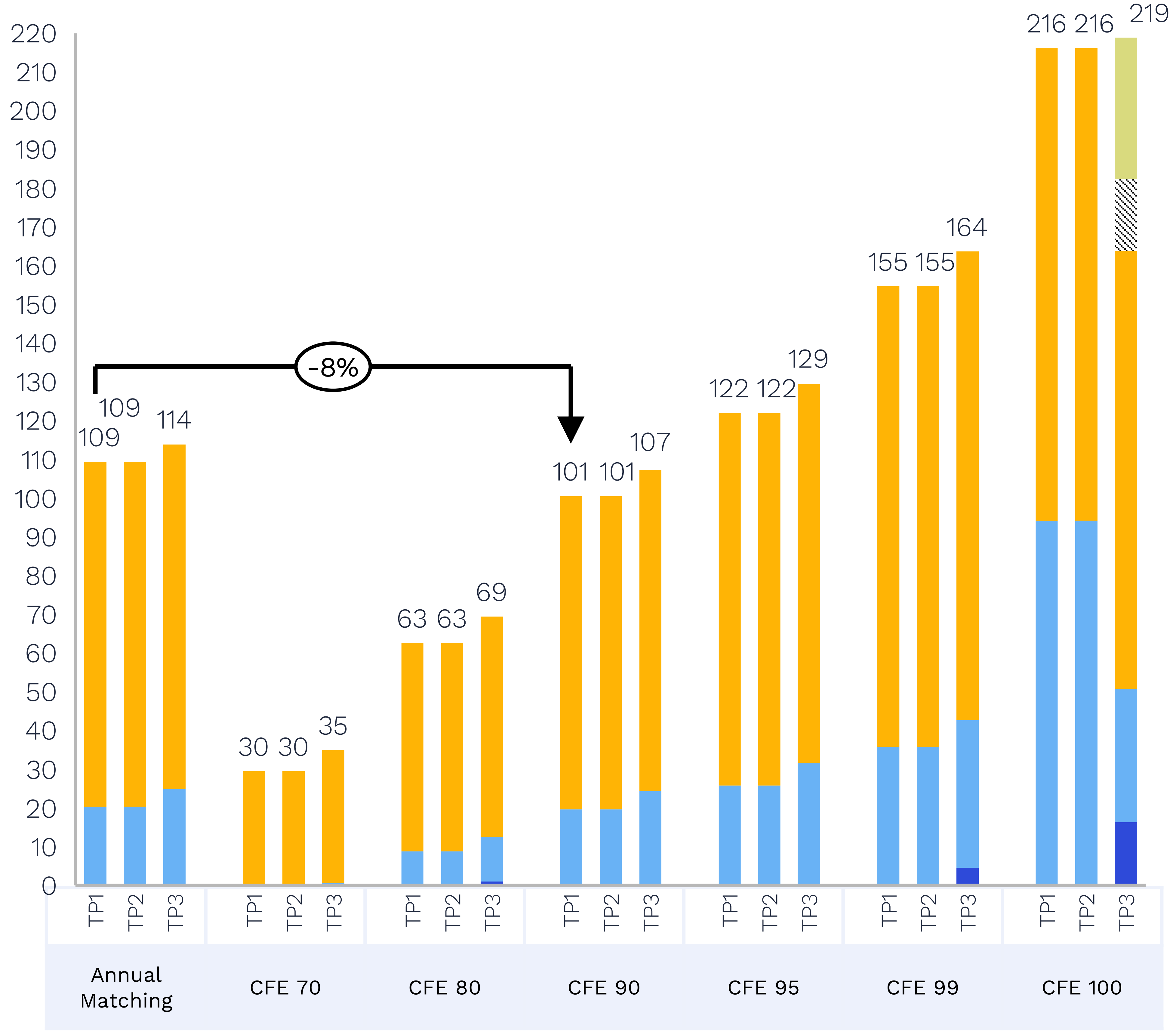
High CFE targets come with high trade-offs

Technology choices and regional grid conditions significantly shape total system costs

Greenfield procurement cost in **Peninsular** (million US$)



Greenfield procurement cost in **Sarawak** (million US$)



Source: TZ modelling

Notes

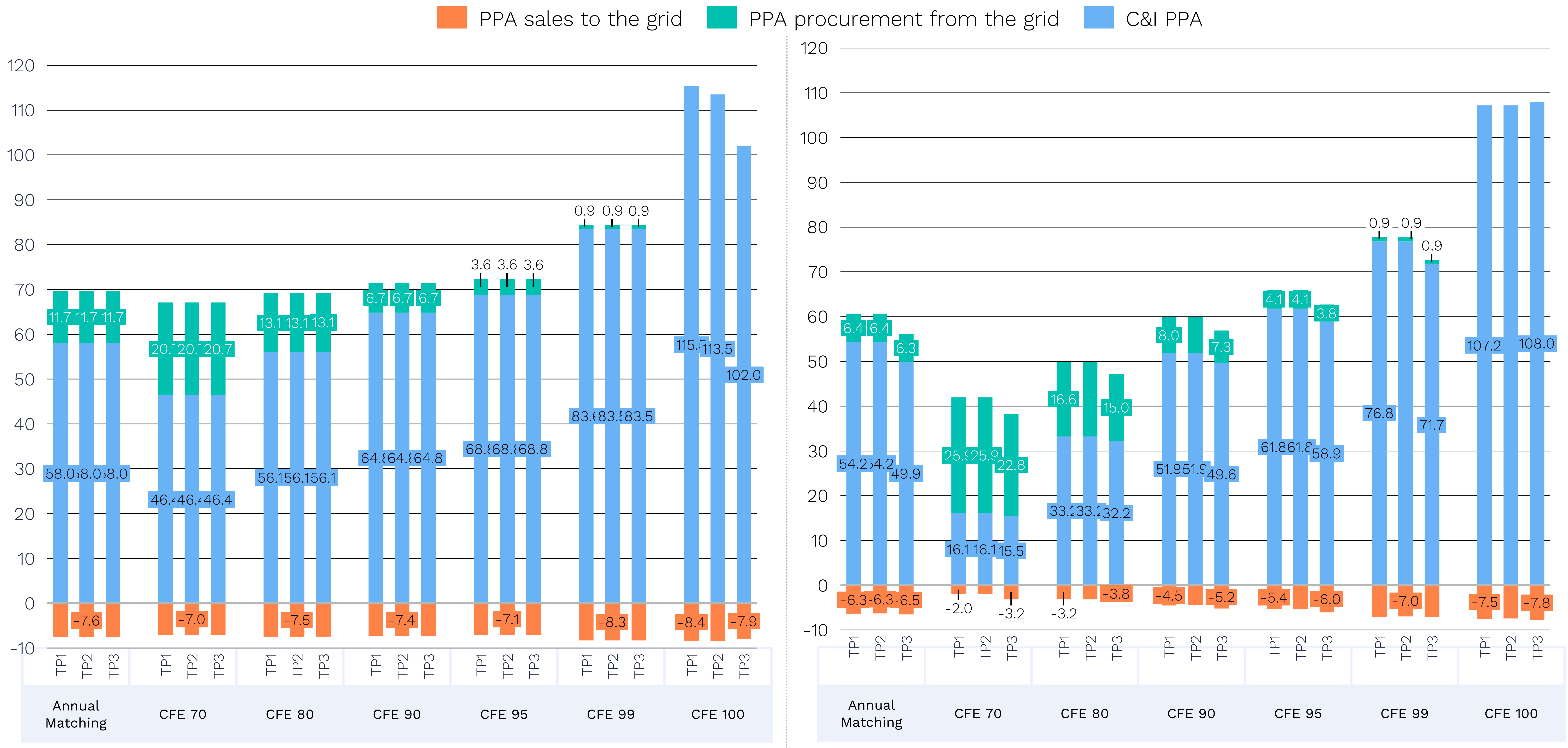
- Total procurement cost in **Peninsular Malaysia** under the annual matching scenario — covering both annualised capital and operational expenditure — is nearly equivalent to 80% CFE. While in **Sarawak**, costs under annual matching are similar to 90% CFE.
- The integration of LDES at high CFE targets raises total system costs by approximately US$1-9 million, primarily due to its high capital investment.
- Onshore wind, which supports 100% CFE by covering solar shortfalls for the last 1% of CFE hours in **Peninsular Malaysia**, nearly doubles total system costs compared to the annual matching baseline.
- When blending technologies are available in TP3, they replace the onshore wind (TP1 and TP2) built to meet 100% CFE in **Peninsular Malaysia**. This reduces overall costs by also reducing the need for overbuilding solar-plus-storage. In **Sarawak**, blending technologies in TP3 halve battery requirements at 100% CFE while still resulting in comparable system costs to solar and battery-only scenarios. Even so, this does not necessarily make blending the optimal path to full decarbonisation, as associated emissions require further assessment due to the risk of emissions leakage.

Costs to C&I consumers

Escalating PPA costs for C&I consumers at higher CFE levels

PPA costs in **Peninsular Malaysia** (US$/MWh)

PPA costs in **Sarawak** (US$/MWh)



Source: TZ modelling

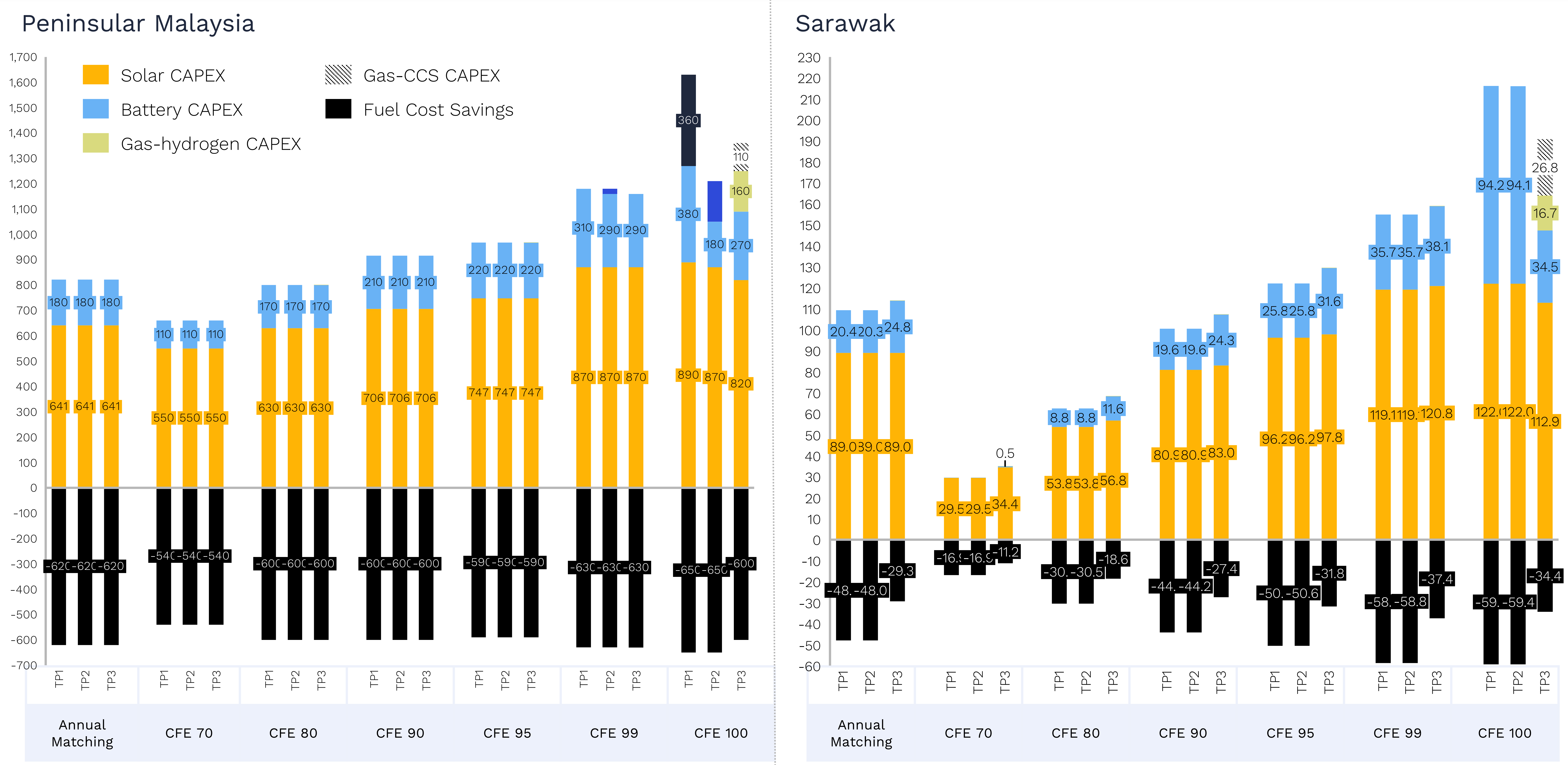
Notes

- PPA costs are the total investment and operating costs of the contracted clean portfolio over the full assumed life of the assets, giving a net cost that reflects what a corporate may pay for generation under a long-term clean energy contracts.
- The total PPA costs to C&I consumers doubles when increasing the clean energy target from 70% to 100% CFE, reflecting infrastructure needs for full CFE.
- The highest escalation in PPA costs occurs at 100% of CFE, ranging from 51-72% compared to annual matching, depending on the tech palette and nodes.
- If mechanisms for revenue earning from the sale of surplus power to the grid were available, this would offset some of the PPA cost for C&I consumers. This is particularly important at the most stringent hourly matching regimes, where the meeting the last 1% CFE sees an oversizing of capacity, resulting in the cost to C&I consumers to nearly double that of annual matching.
- 95% CFE appears to offer a cost-effective trade-off, with moderate increases in PPA costs compared with steep escalation beyond this threshold.

Benefits to the wider system

Annual cost savings from hourly matching range from US$540-650 million in Peninsular Malaysia and US$540-650 million in Sarawak

Costs vs. savings per grid system (million US$)



Notes

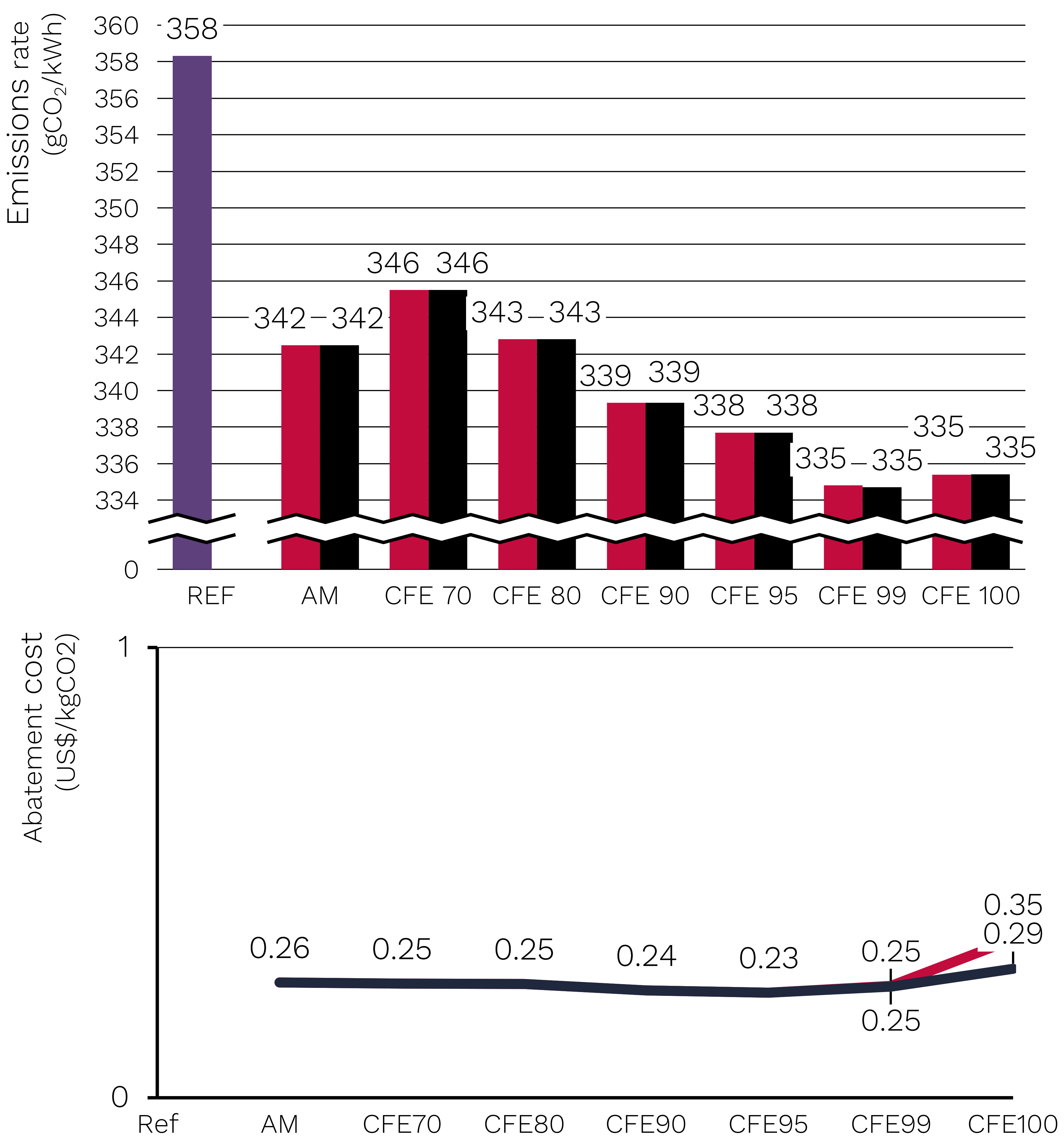
- CAPEX represents the upfront investment by C&I consumers to build or contract dedicated clean capacity for hourly matching — costs which are ideally not passed on to grid consumers. Conversely however, their clean supply sold back to the grid could displace gas-fired generation, lowering fuel and dispatch costs that would be borne by consumers on the grid.
- Hourly matching savings match that of annual matching at 90% CFE in Sarawak and 95% CFE in Peninsular Malaysia. Unlike annual matching however, the savings to the system can increase further
- For **Sarawak,** achieving CFE through hourly matching reduces total system costs by US$17-60 million. The availability of C&I PPAs in Peninsular Malaysia avoids even more with savings ranging from US$530-660 from avoided gas generation. These savings are sensitive to trade costs, which depend on policy and tariff design.
- While C&I consumers bear the upfront capital burden of hourly matching, operational savings — driven by reduced grid procurement — can be passed on to the grid operator and end-users through lower wholesale prices.
- Blending technologies, while decreasing total capex compared to TP1 and TP2, has higher operational expenditures and lower overall system savings due to their fuel requirements and partial carbon abatement, which may need to be paid by the main grid.

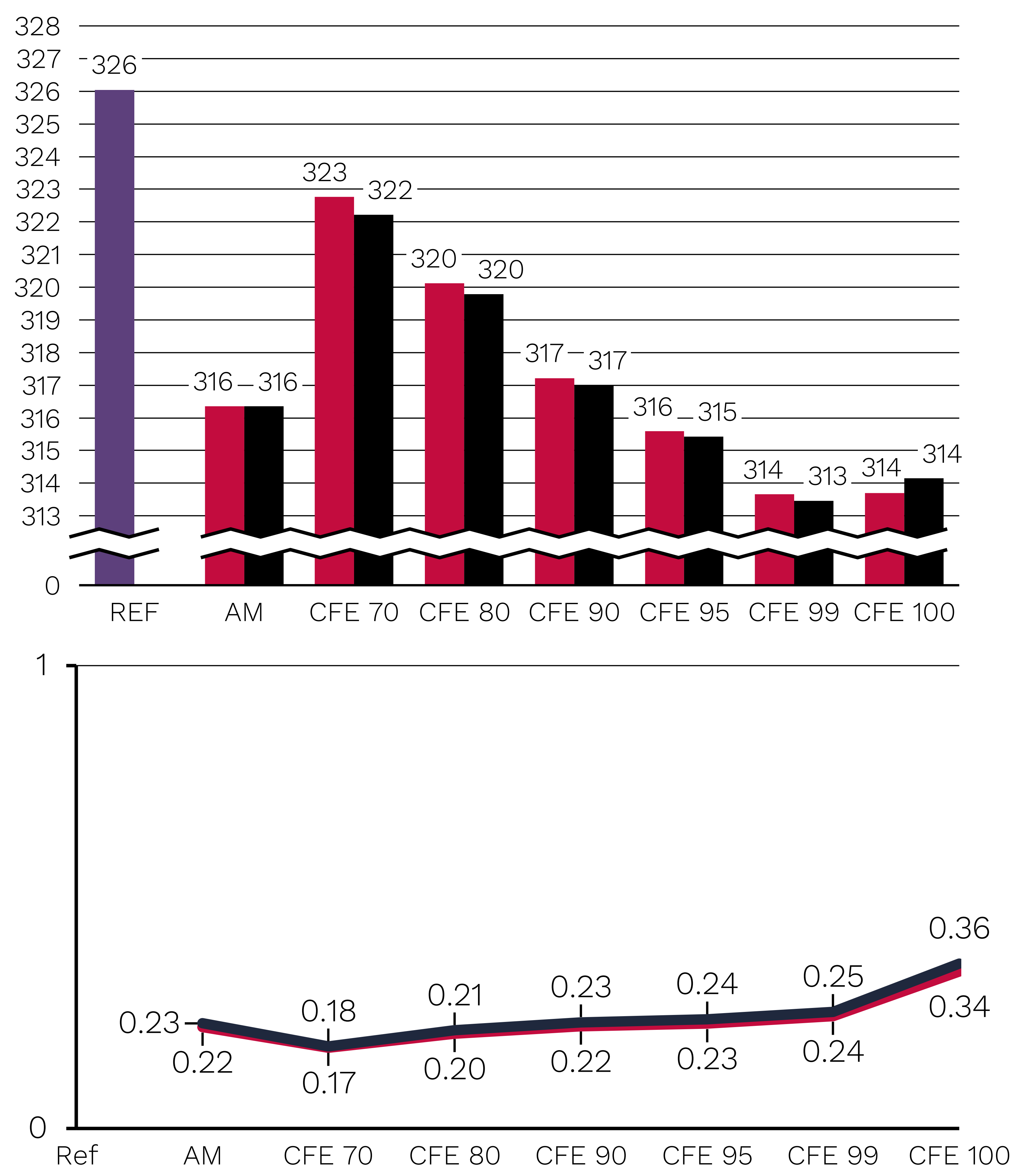
Source: TransitionZero modelling

What is the emission reduction potential?

Hydro advantages, blending trade-offs, and carbon price signals all shape emission outcomes

Peninsular Malaysia | Sarawak | TP1 | TP3





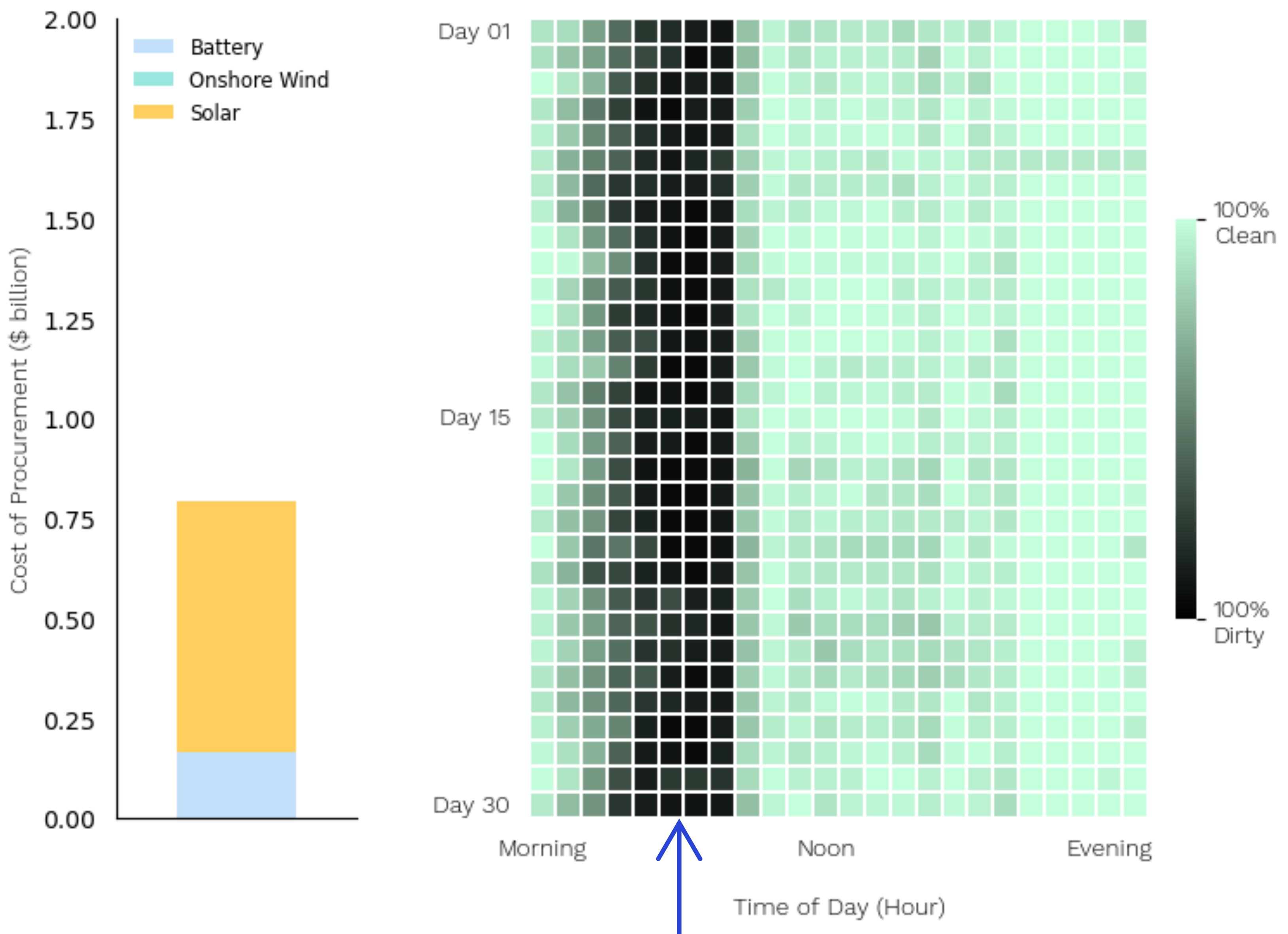
Notes

- All matching regimes reduce system-wide emissions compared to the reference scenario. In **Peninsular Malaysia**, 80% CFE achieves emissions reductions on par with annual matching. While in **Sarawak**, it aligns closely with the 90% CFE.
- Raising CFE targets lowers emissions intensity. In **Peninsular Malaysia**, emissions intensity from the reference is 29 gCO_2/kWh less at 100% CFE, with the most substantial reductions occurring at 99-100% CFE. **Sarawak's** emissions intensity falls by 12 gCO_2/kWh between 100% CFE and the reference.
- The system can achieve deeper decarbonisation per dollar spent when clean generation is aligned with hourly demand — demonstrating that tighter temporal matching can enhance both economic efficiency and emissions. In **Peninsular Malaysia**, it remains stable between annual matching and 95% CFE, rising only for the final 1–2 CFE percentages. **Sarawak** abatement costs are lower than annual matching until 90% CFE, indicating that hourly 24/7 matching delivers emissions reductions more cost-effectively than annual matching up to about 90% CFE.
- Blending technologies are not fully zero-emission. Their continued use contributes to residual system-wide emissions, meaning that full decarbonisation will incur additional mitigation costs.
- For both regions, scenarios relying solely on solar and battery achieve lower emissions and costs per kilowatt-hour than ones with innovative thermal solutions. This suggests that commercially-available technologies already offer an efficient and cost-effective pathway to high hourly matching requirements.

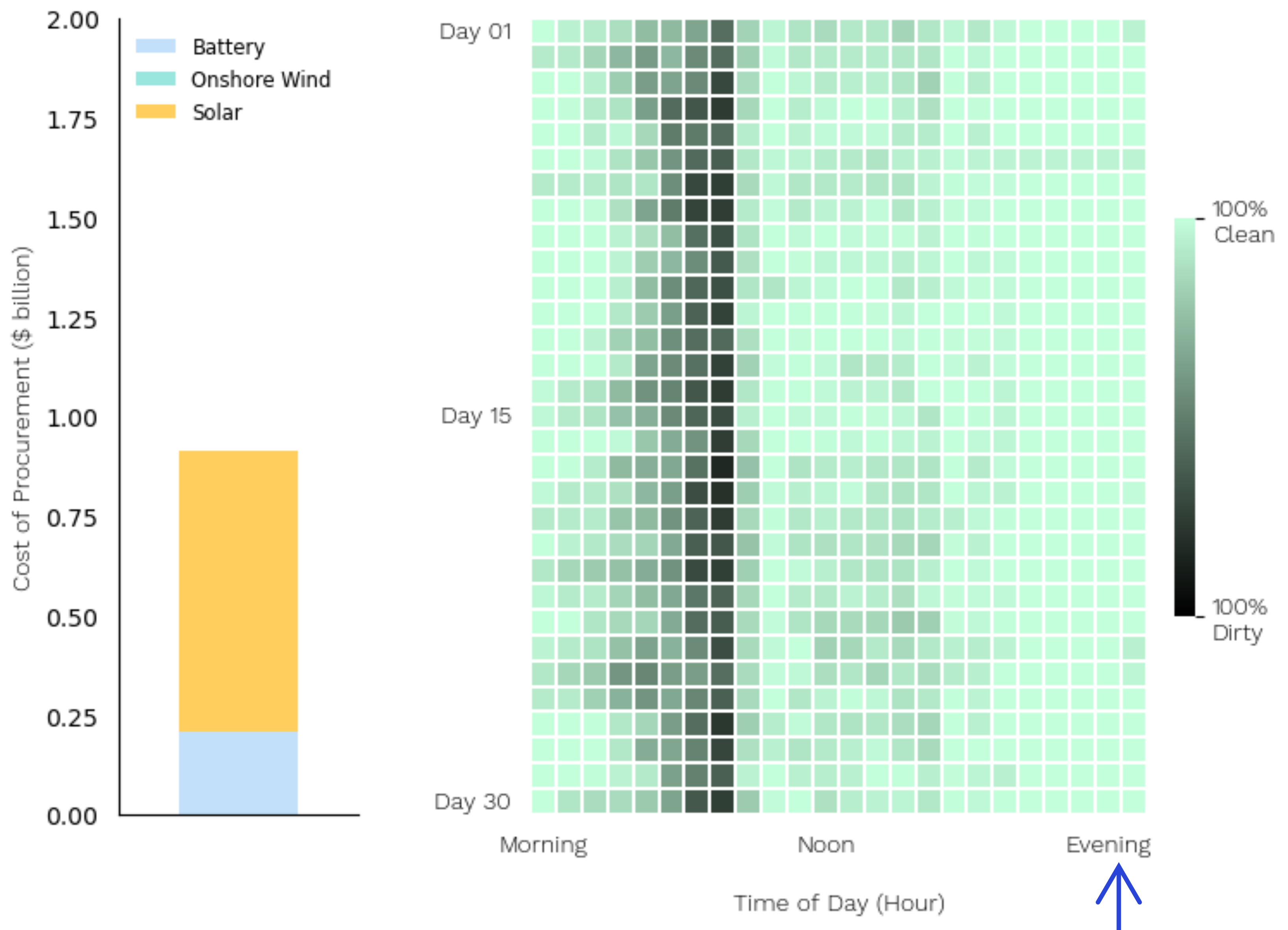
Cost and challenge of hourly decarbonisation

Costs and challenges of hourly decarbonisation increases with higher CFE targets in Peninsular Malaysia

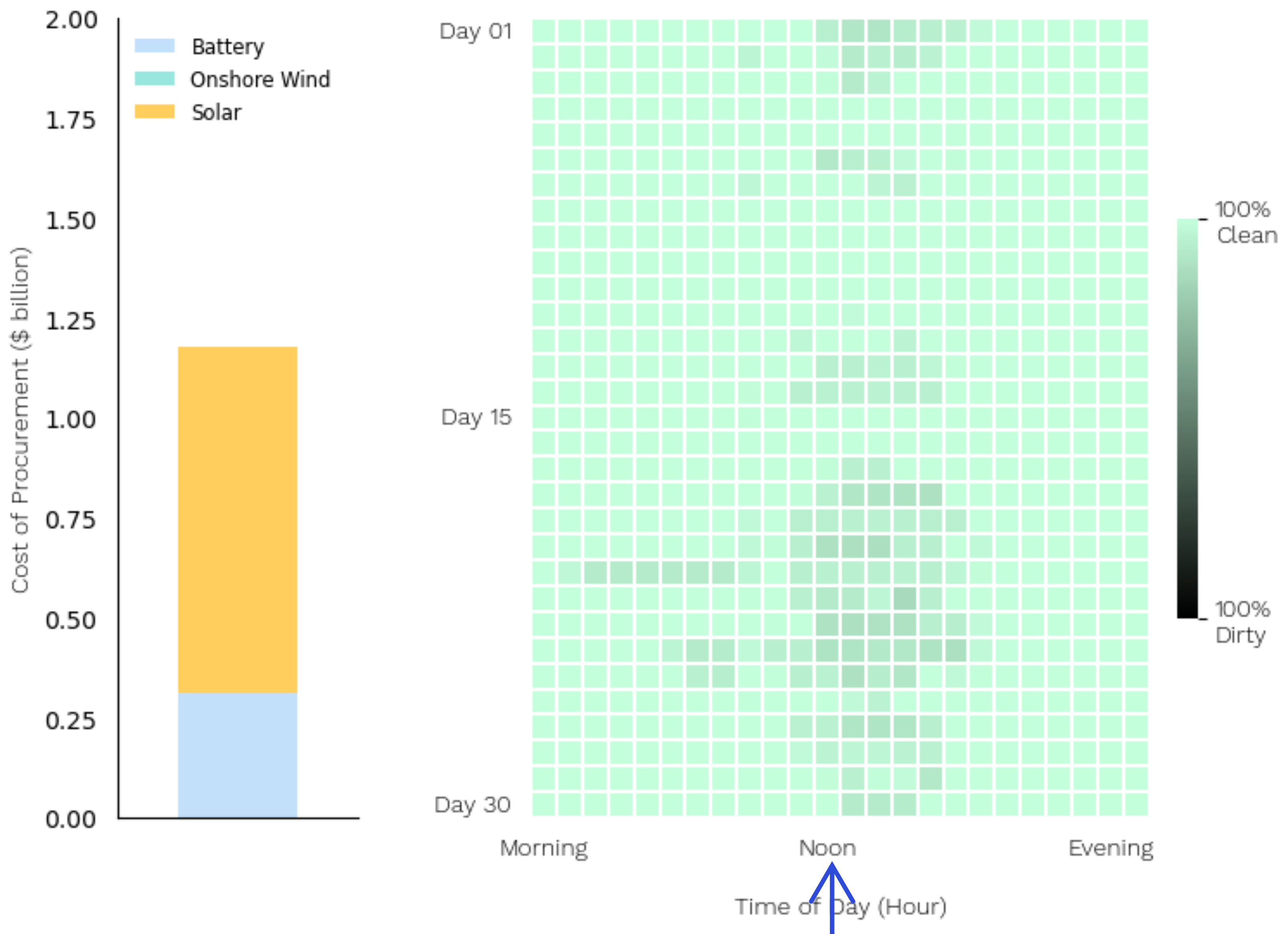
80% clean procurement: hour-by-hour



90% clean procurement: hour-by-hour



99% clean procurement: hour-by-hour



Decarbonising early morning hours are tricky when lower solar generation and the depletion of battery storage from overnight use. This is when imports from the main grid are highest.

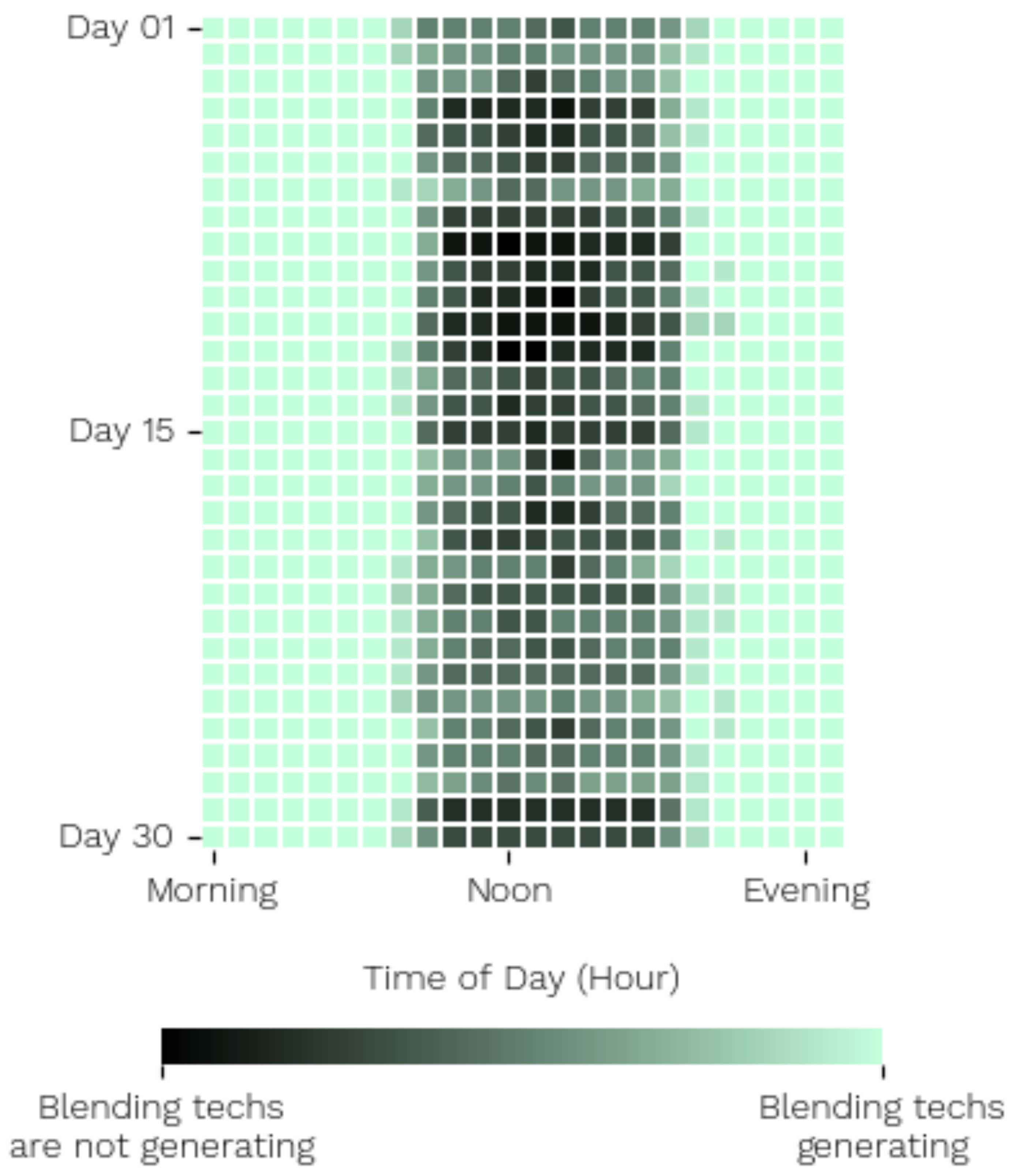
Evenings are easier to decarbonise, as batteries are typically freshly recharged with surplus CFE generation from earlier in the day

However, midday hours are the hardest to fully decarbonise. These periods are less cost-effective to cover with CFE, as adding more clean energy often serves existing clean demand on the main grid — rather than displacing costly fossil fuels.

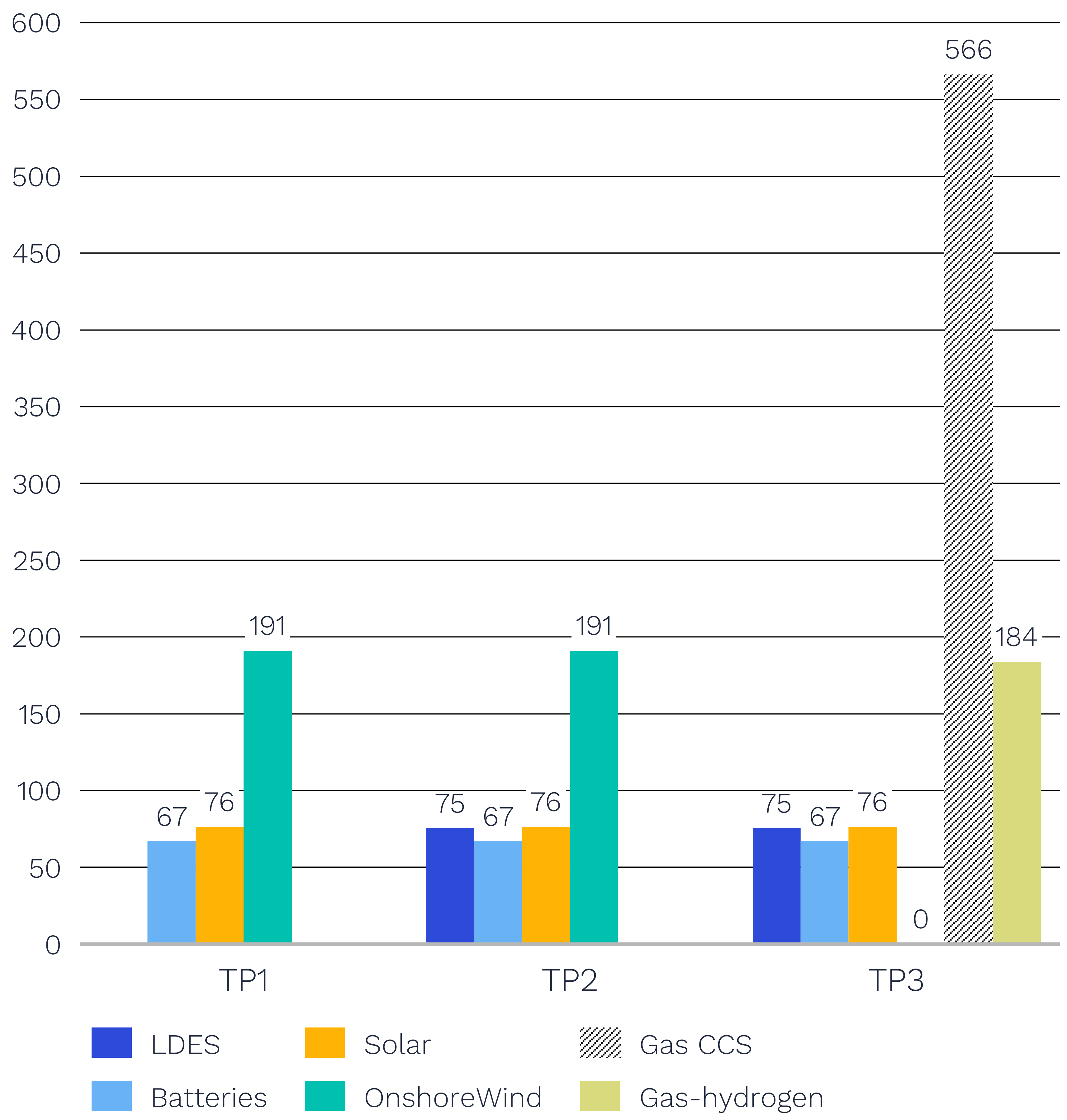
Technology risk of innovative thermal technologies

Blended technology, used sparingly due to high costs, comes in only at 100% CFE for the hardest-to-reach hours

Average month of generation in 100% CFE scenario



Total annual cost per unit capacity (US$/GW)



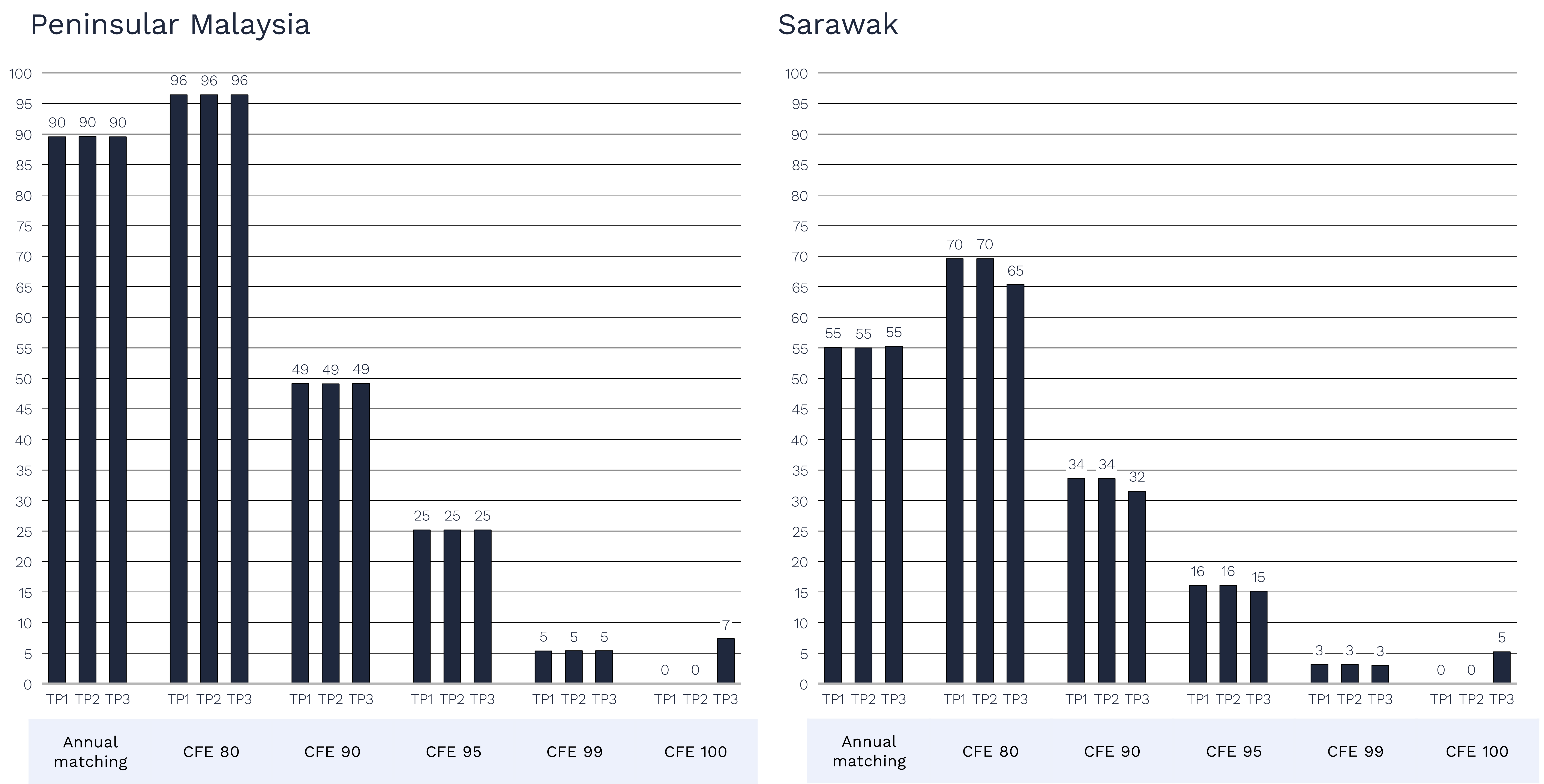
Notes

- While blending may reduce battery buildout to meet CFE, it raises the capital requirements for the overall system and introduces longer-term trade-offs that must be considered — including potential climate liabilities and regulatory risks related to fuel supply.
- TP3 technologies are only deployed to meet 99-100% CFE. Usage is concentrated in limited hours of the early mornings and evenings, when solar generation is minimal and battery reserves may be insufficient.
- CCS and Gas-hydrogen reduces battery installation in 100% CFE by 14% in Peninsular Malaysia and over 27% in Sarawak, compared to TP1 and TP2.
- However, these technologies appear at very low capacities because they remain expensive and geographically constrained. The total annual cost per unit of capacity is dramatically higher than all other technologies, at US$566/GW for Gas-CCS. This warrants inspection into whether deployment would be cost-effective for C&I consumers.
- CCS would require CO_2 transport and storage while gas-hydrogen would requirement fuel shipping, raising both infrastructure complexity and costs — making it a long-term, rather than near-term, investment option for meeting corporate decarbonisation needs.
- CCS deployment is highly sensitive to sequestration rates and transport costs. We assume a 70% CO_2 capture and storage rate, higher than what is currently commercially achieved and assuming a high domestic storage availability for Malaysia. The costs resulting in our modelling likely underestimate the likely real-world dynamics.

Limited need for innovative thermal technologies

Blending technology, used sparingly due to high costs, comes only at 100% CFE for the hardest to reach hours — but at the cost of higher emissions

Greenfield emission rate (gCO_2/kWh)



Notes

- Despite infrequent operation, TP3 increases the greenfield emission rate at 99-100%, suggesting that even the cleanest innovative thermal solutions still contribute to residual carbon intensity. The marginal abatement cost of CCS in Malaysia is estimated at USD 108 per tonne of CO_2.
- Under current assumptions, CCS is a 'leaky' solution — meaning the more it's used, the more the associated clean energy procurement (e.g., through a CFE PPA) becomes a net source of emissions rather than a sink.
- The additional emissions from TP3 necessitate compensatory investments in further decarbonisation or carbon offsetting, thereby increasing the marginal cost of CO_2 abatement when deployed to meet 99-100% CFE.
- Avoiding overbuild of storage and renewables through blending may offer short-term cost savings, but at the expense of long-term decarbonisation goals.

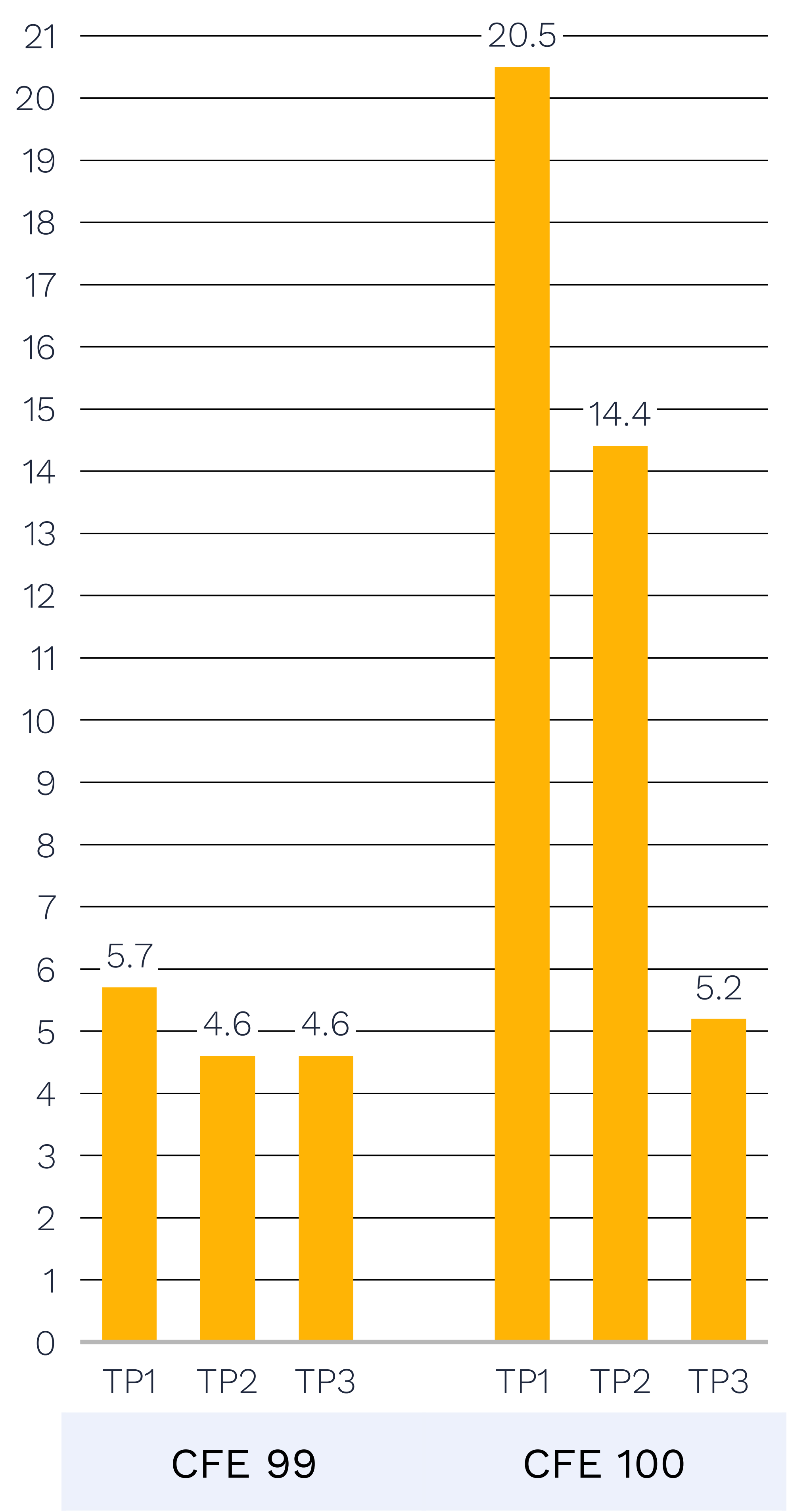
Source: TransitionZero modelling

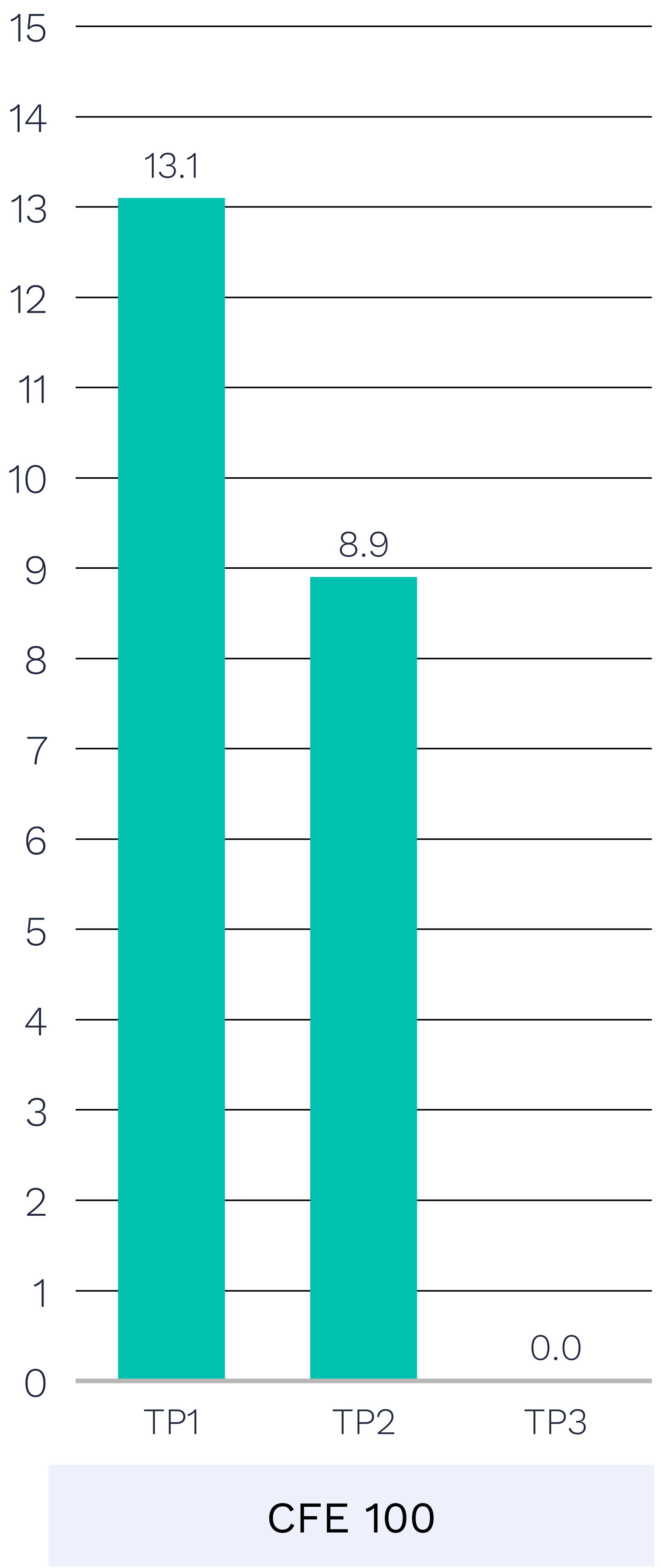
Solar vs. wind: efficiency and curtailment trade-offs

How export caps and grid policy influence renewable efficiency

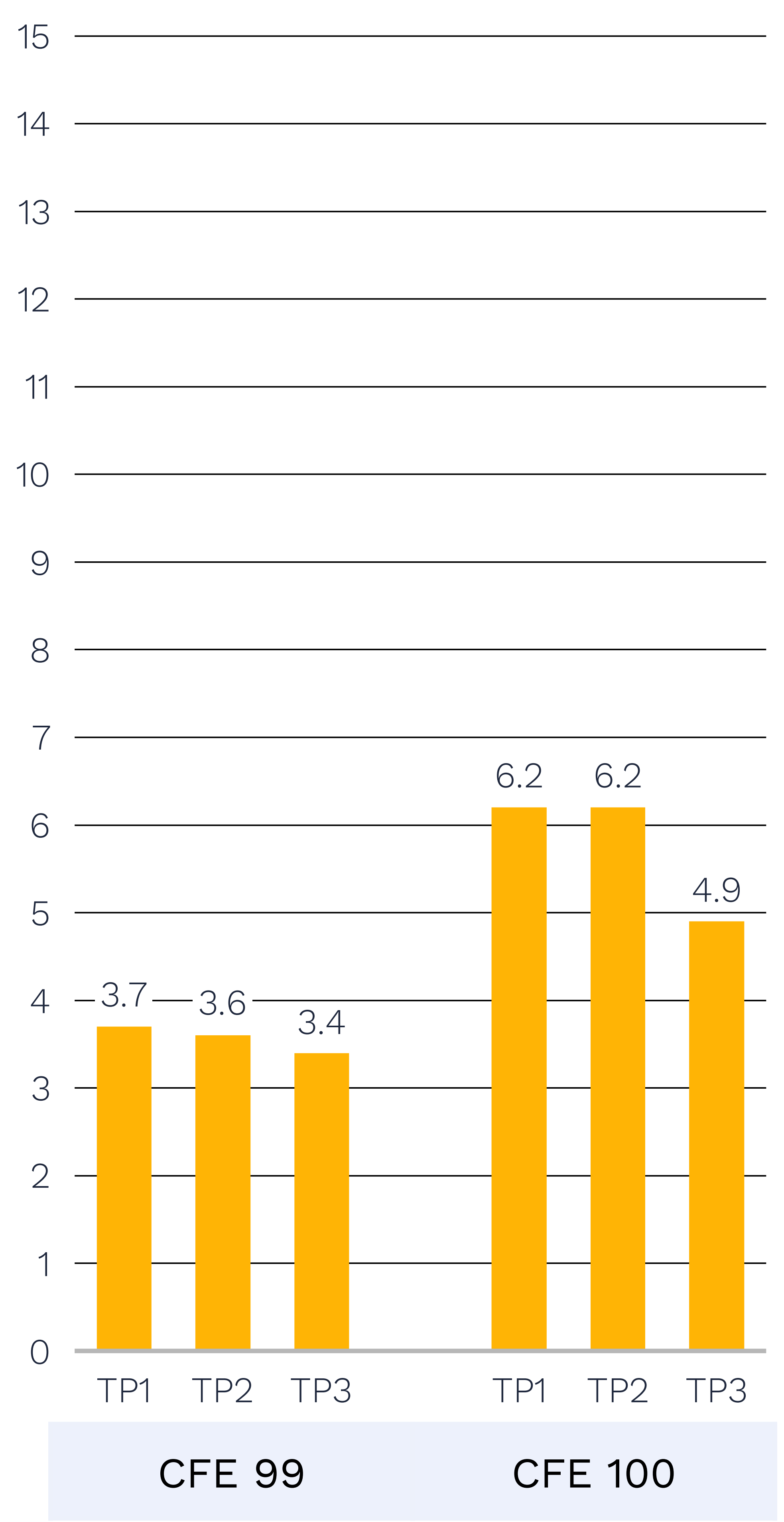
Renewable energy curtailment (%)

Peninsular Malaysia





Sarawak



Notes

- Solar curtailment remains minimal at low CFE scores, averaging 0.01-0.02% — equivalent to around 300 – 2,000 MWh over the whole year of 2030.
- Curtailment rises markedly at higher CFE levels owing to strict limits on exporting surplus clean electricity from the greenfield. Relaxing these restrictions could reduce curtailment but may shift additional operational and balancing costs to the system operator.
- In Peninsular Malaysia, TP1 has the highest solar curtailment when CFE score is at the highest when solar systems are oversized. Much of this occurs during solar peak outputs when battery storage is only able to absorb a finite amount. Adding LDES in TP2 helps reduce this, though some curtailment remains. Due to the reduction of solar capacity in TP3, solar curtailment in this palette is lower.
- Raising CFE targets encourages renewable deployment, but without adequate grid transmission or sell-back mechanisms, much of this clean energy — particularly solar — goes unused. Reforming sell-back caps or integrating more storage is crucial to maintaining system efficiency.
- Any move to ease export limits must weigh the cost implications for both C&I consumers and the main grid, both of which are shaped by national tariffs and regulatory policy.

Conclusion and Policy guidance

C&I clean energy can deliver system benefits — when designed right

Optimal targets, flexible sell-back, and 24/7 tracking unlock both corporate and national decarbonisation wins for Malaysia

01

80% CFE in Peninsular Malaysia and 90% CFE in Sarawak delivers the optimal balance between cost, feasibility, and emissions reduction.

Annual matching is often preferred by C&I consumers for its simplicity, but in practice, it offers similar benefits to achieving an 70% CFE score through hourly matching. Sarawak would see US$44.2 million savings at 90% CFE, while Peninsular Malaysia's fuel cost savings is estimated at US$600 million at 80% CFE.

When budget or operational constraints are present, targeting a lower CFE score may be more practical — though it comes with reduced clean energy utilisation and decarbonisation impact. However, the system savings and emissions benefits of CFE are seen even at lower CFE scores.

02

Solar, hydro and batteries are key for clean energy supply, and supportive policies can unlock their full potential

Solar remains a highly viable option for meeting C&I demand across matching regimes, especially when paired with battery storage. Its ease of deployment, scalability, and rapidly declining costs make the solar-plus-storage combination a leading pathway for achieving CFE compliance, provided that a supportive policy framework is in place.

In the near-term, expediting C&I consumers' access to solar-plus-storage via interconnections will be critical to ensuring a reliable, diversified pathway to 24/7 CFE, particularly as technologies such as LDES and advanced thermal remain uncompetitive in 2030.

03

Implementation of clean energy in C&I gives benefit to both system cost and emission.

Allowing and incentivising C&I consumers to export excess clean energy to the grid through a feed-in payment would help to reduce curtailment and support overall grid decarbonisation.

Enabling granular accounting and 24/7 clean energy procurement — combined with excess generation export rights — can lower overall system costs and achieve emissions reductions more efficiently.

Policy Guidance

Malaysia is a hotbed of opportunity for corporate decarbonisation

Accelerate solar-plus-battery deployment

- Raise near- and medium-term solar capacity targets by 2030 under the NETR, particularly in Peninsular Malaysia, to drive enabling policies for both generation expansion and grid infrastructure upgrades. This could include dedicated solar development zones that are permitted and grid-ready.
- Increase subscription quotas for programmes such as NEM (or successor schemes) and CGPP to support greater corporate participation.

Enable IPPs and corporate RE deployment and sell-back

- In Sarawak, issue regulations to allow independent power producers to participate in power generation, as well as frameworks on corporate PPA schemes supported by third-party grid access.
- In Peninsular Malaysia, ensure system access charges are transparently determined. This may include assessing the potential of sell-back provisions within CGPP and CRESS schemes, piloting initial ratios to evaluate their system-level decarbonisation impact.

Deepen regional connectivity and power exports

- Expand cross-border power trading relations with neighbouring countries to strengthen Malaysia's positioning as Southeast Asia's future renewable energy trading hub, while enhancing the economic viability of domestic solar assets.
- Advance regional cooperation through ASEAN power trading frameworks, including mutual recognition of green attributes associated with cross-border electricity flows.

TransitionZero

Annex

Further information, data and assumptions

Glossary (1/2)

Term	Definition
Brownfield generators	Total CFE and non-CFE capacity mix forming the basis of our Reference Scenario, required by 2030 to meet overall electricity demand, resulting from a mixture of present capacity and new-build to account for variations in demand, retirements of current plants, and restart of idled plants
Brownfield procurement	CFE procured by C&I consumers from brownfield generators from the same grid zone when contracted same-zone greenfield generators are insufficient to cover CFE demand
C&I	Commercial and Industry
CFE	Carbon-free electricity, including renewables, nuclear power, the emission-free part of innovative thermal plants, and electricity discharging from storage technologies [after being charged up from generation from the previous categories]
Consumer CFE score	Hourly share of CFE from a consumers' total electricity consumption, resulting from both greenfield and brownfield procurement
Grid CFE score	Hourly share of CFE from all carbon-free generation with a single grid zone or country (i.e. CFE on the main grid)
Grid zones	The three main regional grid zones of Malaysia, i.e. Peninsular Malaysia, Sarawak, and Sabah.

Glossary (2/2)

Term	Definition
Imports	Flows across interconnectors from adjoining grid zones to satisfy demand for electricity generally or CFE specifically
Innovative thermal	Thermal plants that are either equipped with carbon capture (capacity adjusted for leakage) or are co-firing fuels deemed to emit no CO_2 at the point of combustion (hydrogen, ammonia, biomass)
Interconnector	Transmission-level power cables connecting two countries or two grid zones within a country
Matching regime	Modelling constraint forcing C&I consumers to reach a specified CFE score, matched either against total annual consumption or across each hour of the year
Palette	Scenario-specific combination of technologies deemed eligible for CFE status

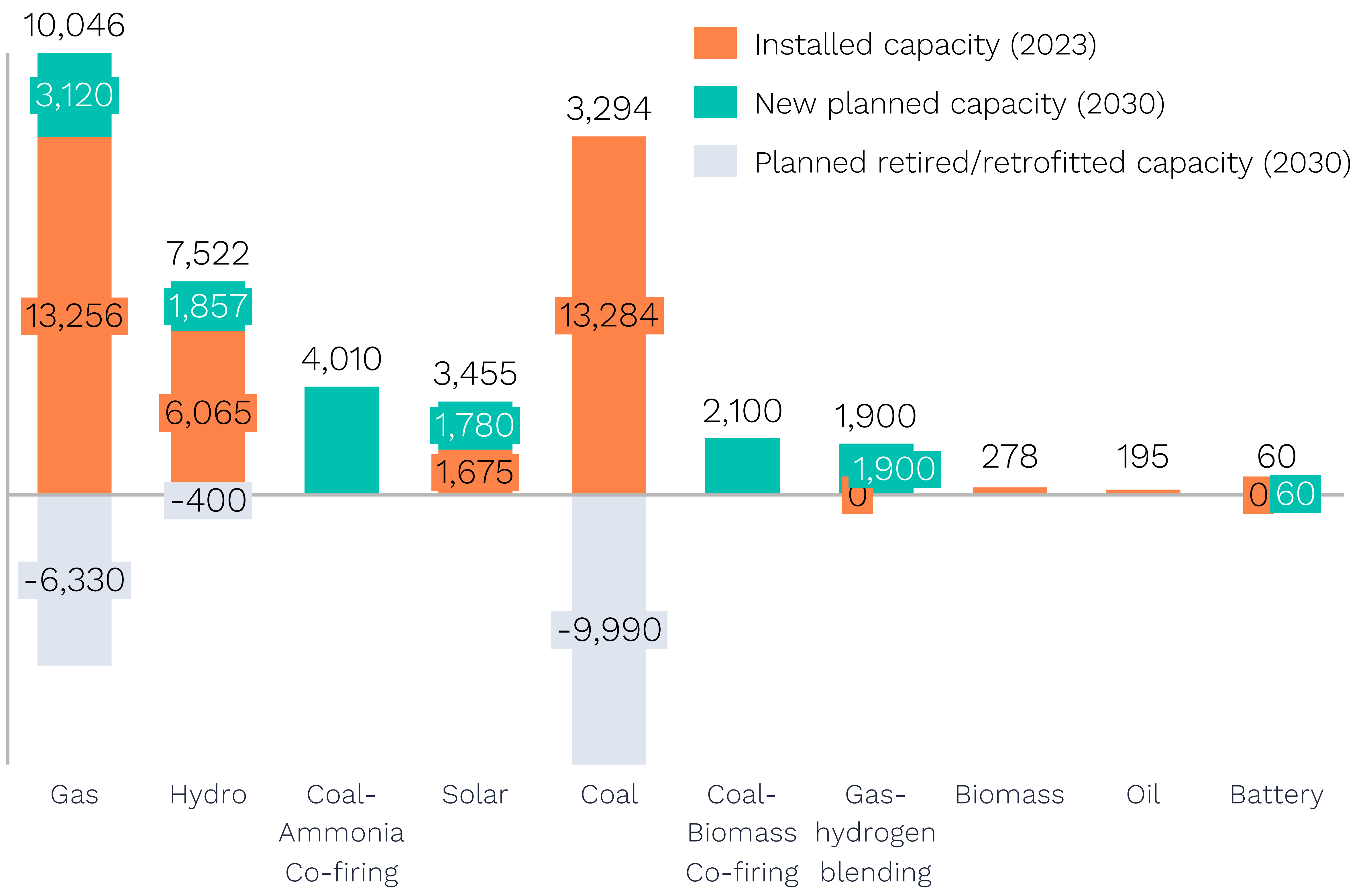
National targets and planned capacity

To guide system development into 2030, Malaysia's national targets are applied and required to be met by the model

Model constraints

Constraint type	Description
Solar penetration target	7,000MW of solar capacity by 2030
Fuel blending target	Gas-hydrogen blending at min 30% hydrogen
	Coal-biomass blending at min 15% biomass
	Coal-ammonia blending at min 20% ammonia

Existing and must-build brownfield capacity by technology (MW)



Source: Malaysia National Energy Transition Roadmap, Project announcements by companies

Notes

- We apply the government's planned 2030 capacity as a minimum build requirement in the model. Additional endogenous build is permitted for select technologies beyond this baseline.
- National decarbonisation targets for renewable energy, emissions, and fuel blending were also applied. Only targets related to the power sector and applicable for 2030 are included.
- The 2030 capacity pipeline includes: Over 3 GW of new gas capacity, 4 GW of gas retirements, and 1.9 GW of retrofitted gas units for gas-hydrogen blending.
- Additionally, nearly 4 GW of coal capacity will be retired, and around 6 GW of coal plants retrofitted for biomass and ammonia co-firing.

Tech build constraints

We seek to impose sensible limits on what type of capacity expansion we allow in the Reference Scenario

Tech name	Planned new-build	Modelled additional build
Coal	✗	✗
Oil	✓	✓
Gas	✓	✓
Biomass	✓	✓
Grid-scale Solar	✓	✓
Conventional Hydro	✓	✓
Pumped Hydro	✗	✓

Tech name	Planned new-build	Modelled additional build
Nuclear	✓	✗
Off-shore Wind	✓	✓
On-shore Wind	✓	✓
Co-firing Coal and Biomass / Ammonia[1]	✓	✗
Co-firing Gas and Hydrogen	✓	✗
Gas CCS	✗	✓
Batteries	✓	✓

[1] *For co-firing, we allow only blue hydrogen and blue ammonia, but endogenously the model can build both blue or green capacity*

Notes

- In the Reference scenario, the model endogenously builds new solar and wind capacity, in addition to planned capacity additions based on government targets (added exogenously).
- Renewable capacity additions are capped based on estimated resource potentials.
- Additional capacity for thermal co-firing and CCS is introduced exogenously, with the model allowed to build further capacity endogenously.
- To reflect long-term decarbonisation policies and siting constraints, no new coal-fired power capacity is permitted — neither exogenously nor endogenously.
- Conventional hydro is expanded exogenously to reflect already licensed small-scale hydro projects.

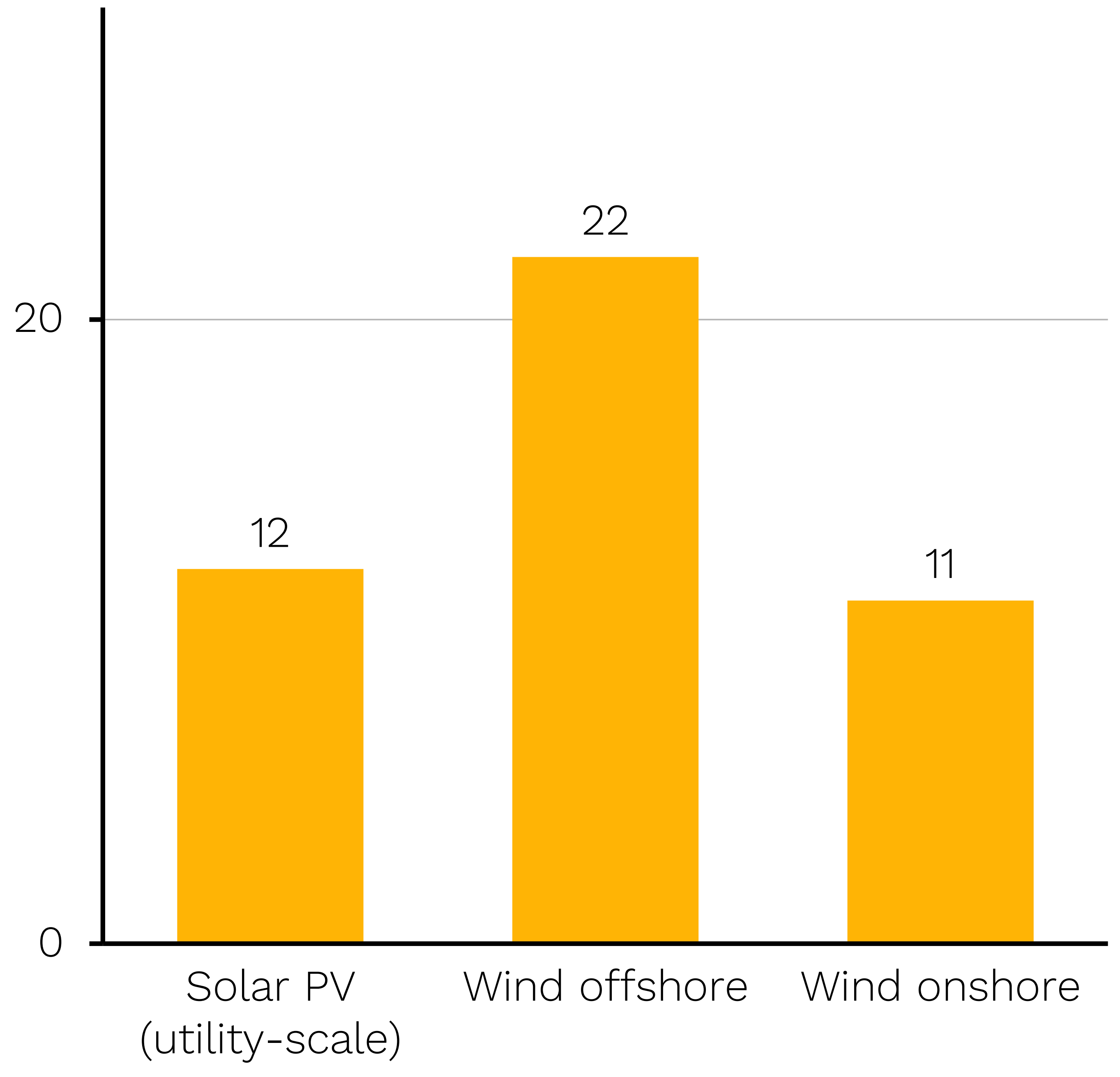
RE potentials and capacity factor assumptions

Technical capacity and generation potentials will constrain RE build-out and utilisation

RE Potentials

Technology	Peninsular	Sarawak	Sabah
Bioenergy	1,400	9,667	9,667
Hydro	14,230	5,390	380
Solar PV (Utility-scale)	17,335	21,768	4,645
Offshore wind	820,431	572,175	175,425
Onshore wind	12,455	5,528	1,506

Average capacity factor per technology (%)



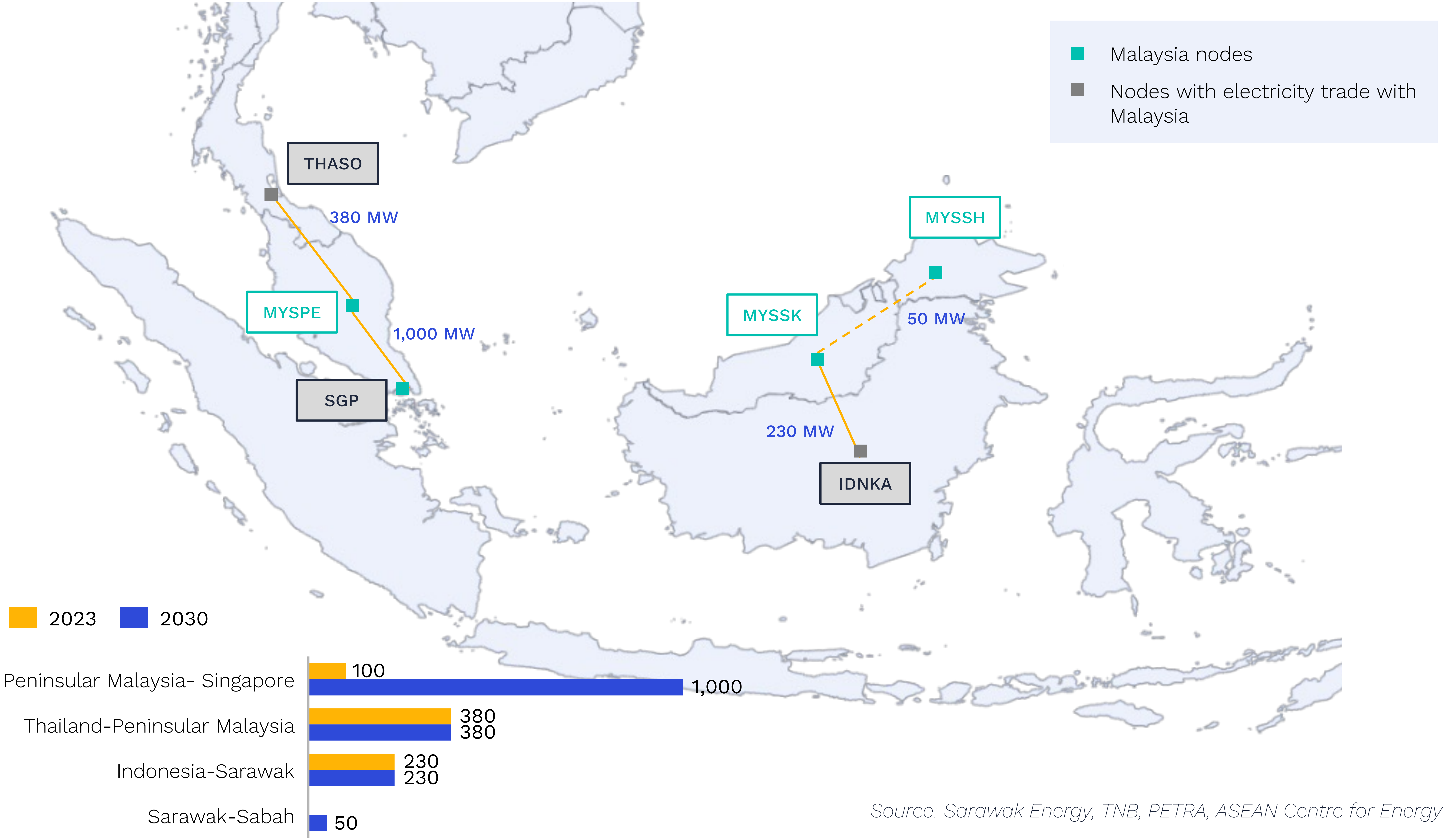
Source:
RE potential – TZ's in-house calculation
CF - TZ's in-house calculation scaled into renewables.ninja average values

Notes

- Our in-house renewable energy potential assessment indicates a diverse renewable energy resources across Malaysia. This is reflected in literature and government targets.
- RE potentials are spatially mapped to Malaysia's key grid zones, so the data can feed directly into scenario modelling for CFE deployment pathways
- Geographic resource availability is derived from high-resolution land-use and bathymetry datasets. This ensures technical potential reflects realistic land/sea use constraints.
- Long-term solar irradiation, wind speed profiles, and river flow data are processed into hourly time-series, calibrated with 2023 Malaysia-specific climate records to capture interannual variability and support temporal matching.
- Capacity factors and efficiencies are based on regionally relevant measurements and literature.

Interconnection constraints

We maintain a conservative view on transmission capacity expansion by 2030



Source: Sarawak Energy, TNB, PETRA, ASEAN Centre for Energy

Notes

- We divide Malaysia into three nodes in our model, namely Peninsular (MYSPE), Sarawak (MYSSK) and Sabah (MYSSH) to represent different power market, renewable potential and energy mix between them.
- Those have direct electricity trade with three countries, Thailand, Singapore and Indonesia with total capacity of 1.6GW. Domestically, Sabah and Sarawak also trade 50MW of electricity.
- For the base year of 2023, the transmission capacities between Malaysia and the neighbouring nodes are based on official statistics.
- Future expansions exogenously follow national and regional plans. They are not expanded endogenously and/or optimised by the model.
- The Singapore-Malaysia interconnector is 100MW in 2023, in line with bilateral agreements. In 2030, we allow the transmission capacity to reach 1,000 MW, with utilisation rate capped at 50%.

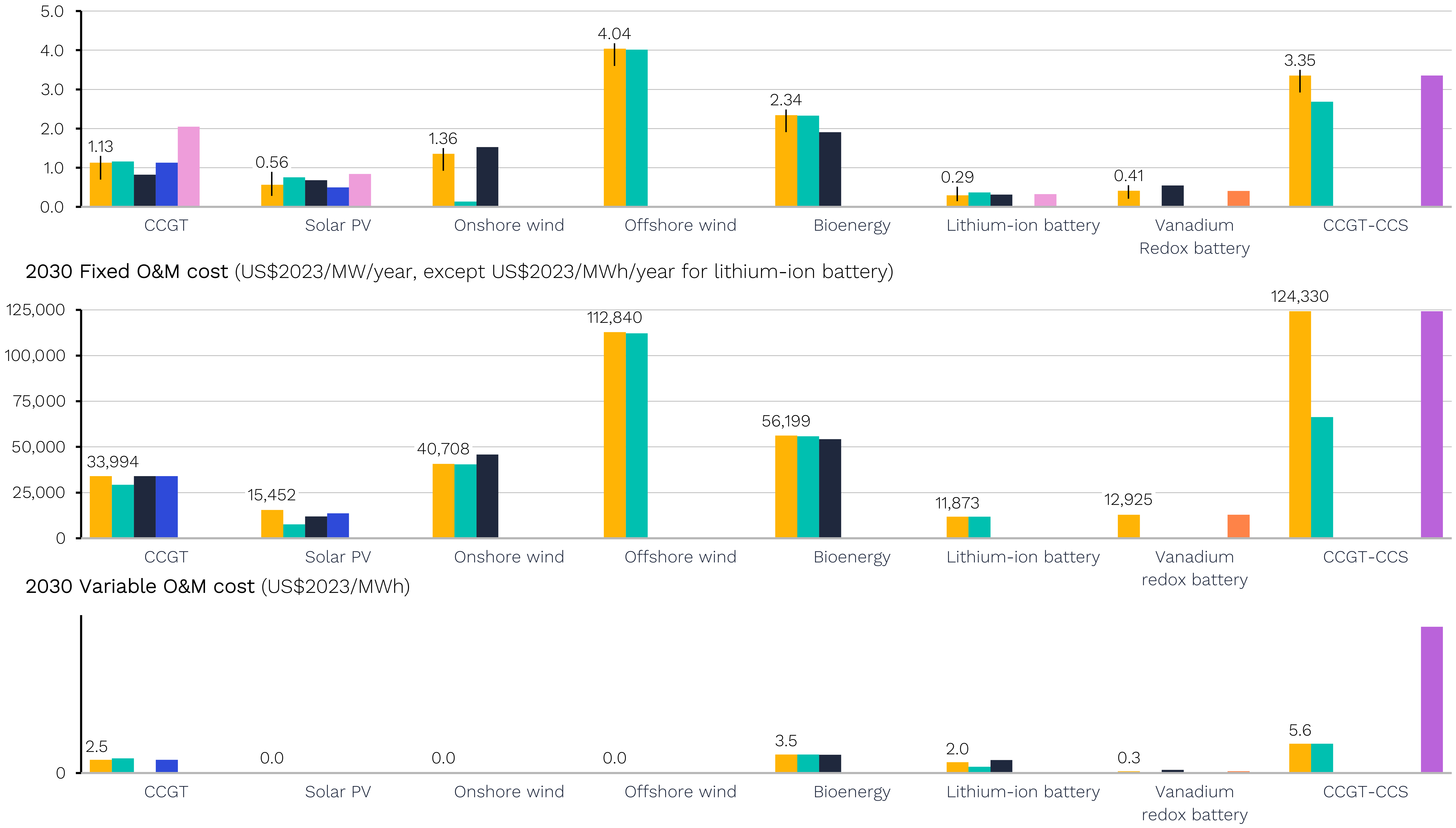
Technology costs

We consider various government and industry sources with ASEAN-specific data

2030 CAPEX of select technologies (US$2023/MW, except US$2023/MWh for lithium-ion battery)

2030 Fixed O&M cost (US$2023/MW/year, except US$2023/MWh/year for lithium-ion battery)

2030 Variable O&M cost (US$2023/MWh)



Notes

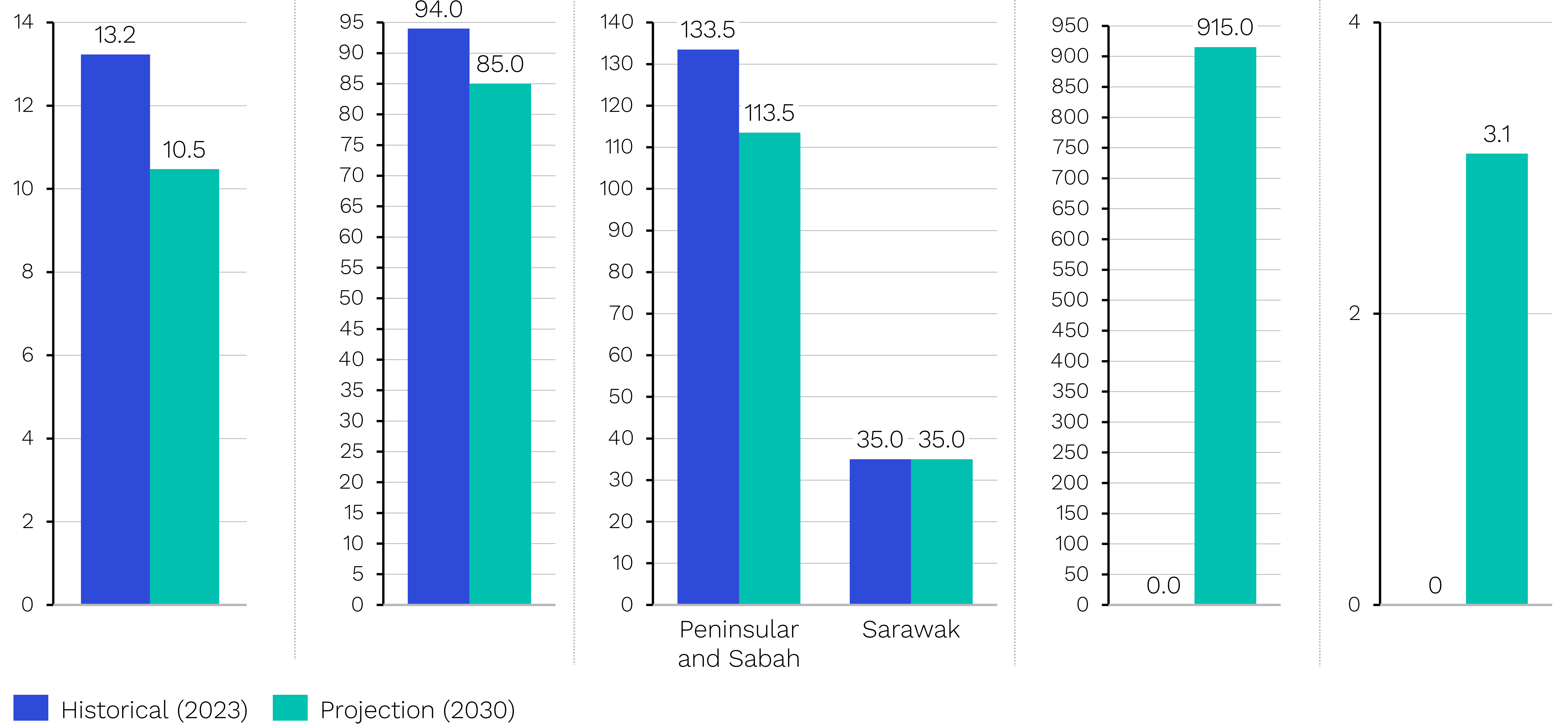
- Public country-level technology costs for Singapore were not available to use as inputs in our model.
- We reference technology costs that are specific to the region and released by trusted sources such as the Danish Energy Agency (with endorsement from local governments), ASEAN Centre for Energy, and Bloomberg New Energy Finance. Available data for the relevant technologies varied across these sources.
- We derived an average or the best-represented values for each technology, based on additional desk research and stakeholder consultations.
- Costs are expressed in USD 2023 values.

Projection used in the current model
Indonesia Technology Catalogue by Danish Energy Agency
Vietnam Technology Catalogue by Danish Energy Agency
BNEF's Malaysia tech costs
ASEAN Center for Energy's AOR8
US DOE
Japan

Fuel costs

Cost projections account for Malaysia's position as a net energy importer

Natural Gas – LNG (US$/mmBTU)	**Oil** (US$/barrel)	**Coal** (US$/tonne)	**Ammonia** (US$/tonne)	**Hydrogen** (US$/kg)



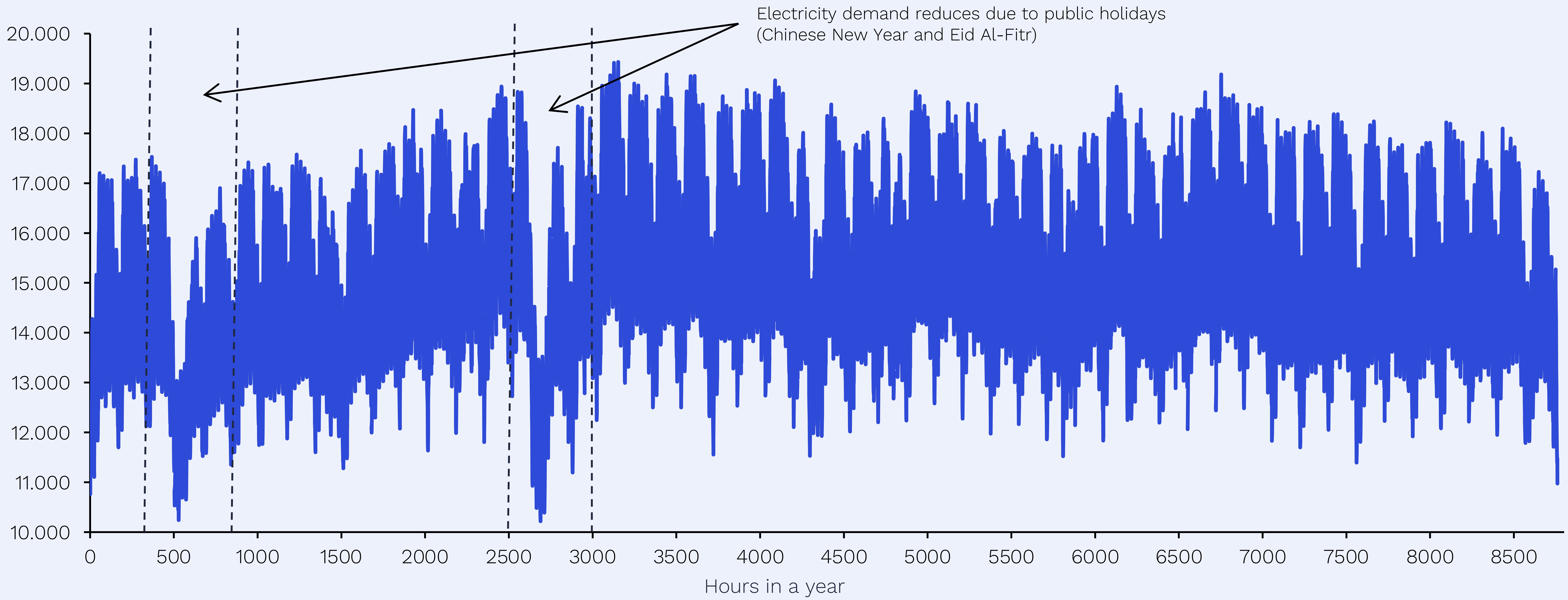
Notes

- The price of coal in Sarawak is cheaper than other Malaysian nodes because it is a domestic resource.
- Projected imported gas price is based on Japan's LNG import prices as a regional benchmark. Oil prices follow IEA crude oil price projections. We recognise both assumptions to be optimistic, given Singapore's reliance on imports for both fuels.
- Hydrogen costs are capped using IEA's STEPS supply cost curves for Asia.
- BNEF's ammonia cost estimates for Malaysia serves as the reference for ammonia pricing. Comparing with in-house TZ ammonia (renewable shipped) estimates and assumptions.

Sources:
Gas cost - S&P Global Commodity Insights for Japan
Diesel oil cost - IEA crude oil price projection
Hydrogen cost - IEA STEPS supply cost curve
Ammonia cost – BNEF projection for Malaysia

Hourly demand used follows recorded demand profile in 2023

This profile is applied to both brownfield and CFE demand across all the nodes



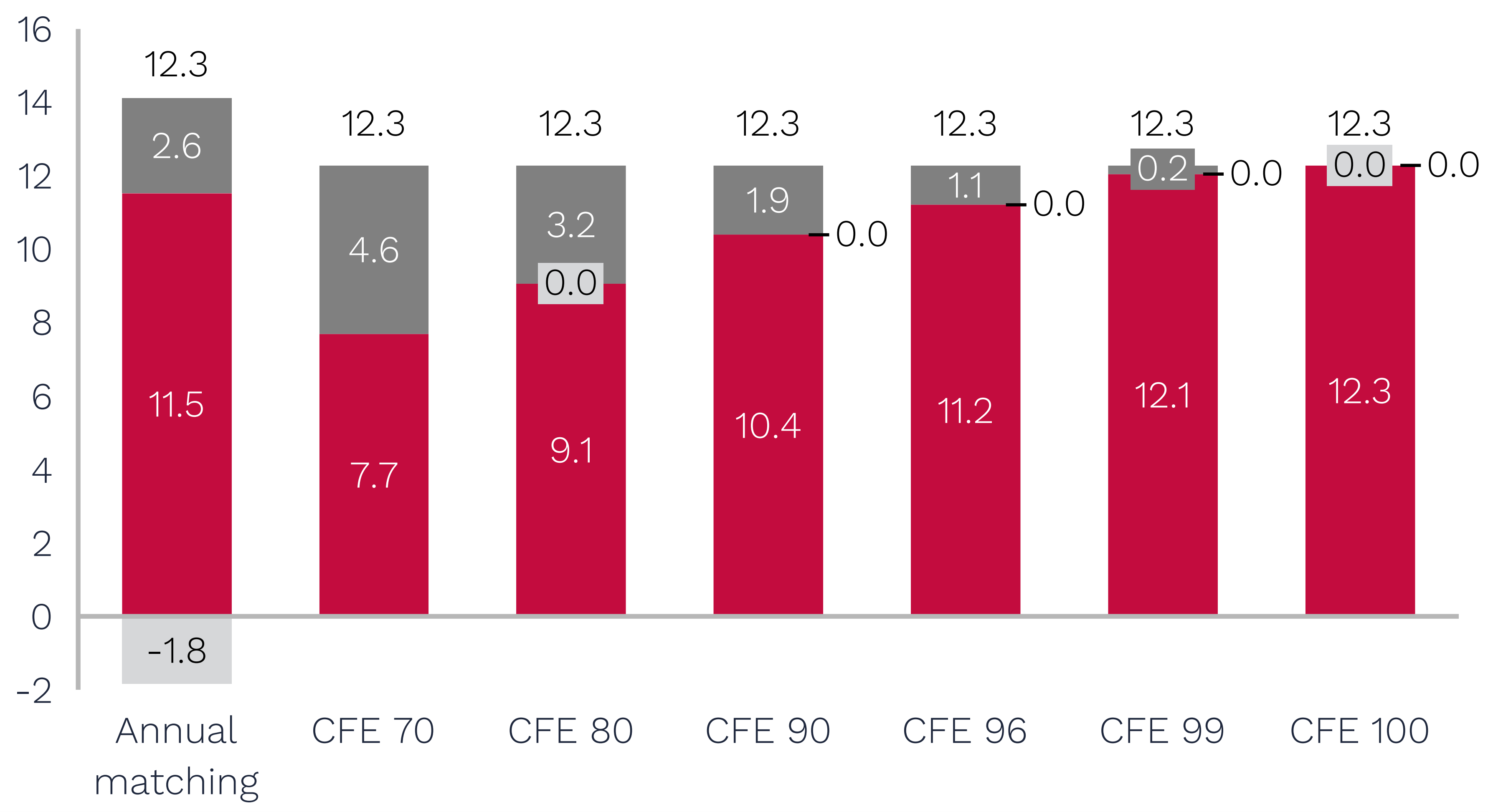
Source: Peninsular Malaysia GSO

Unlocking flexibility with sell-back policies

How export allowances shape clean energy procurement, curtailment, and system efficiency

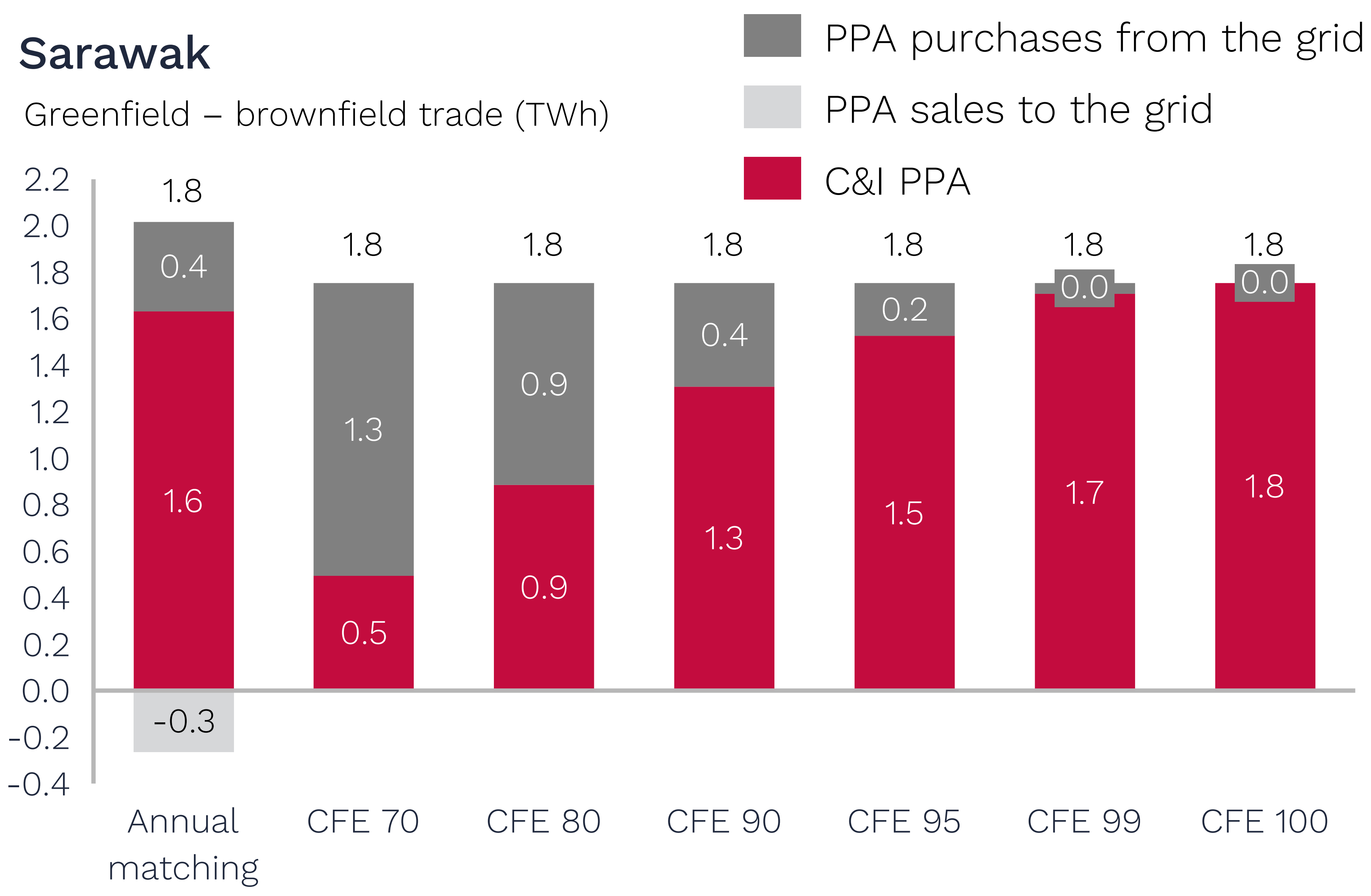
Peninsular Malaysia

Greenfield – brownfield trade (TWh)

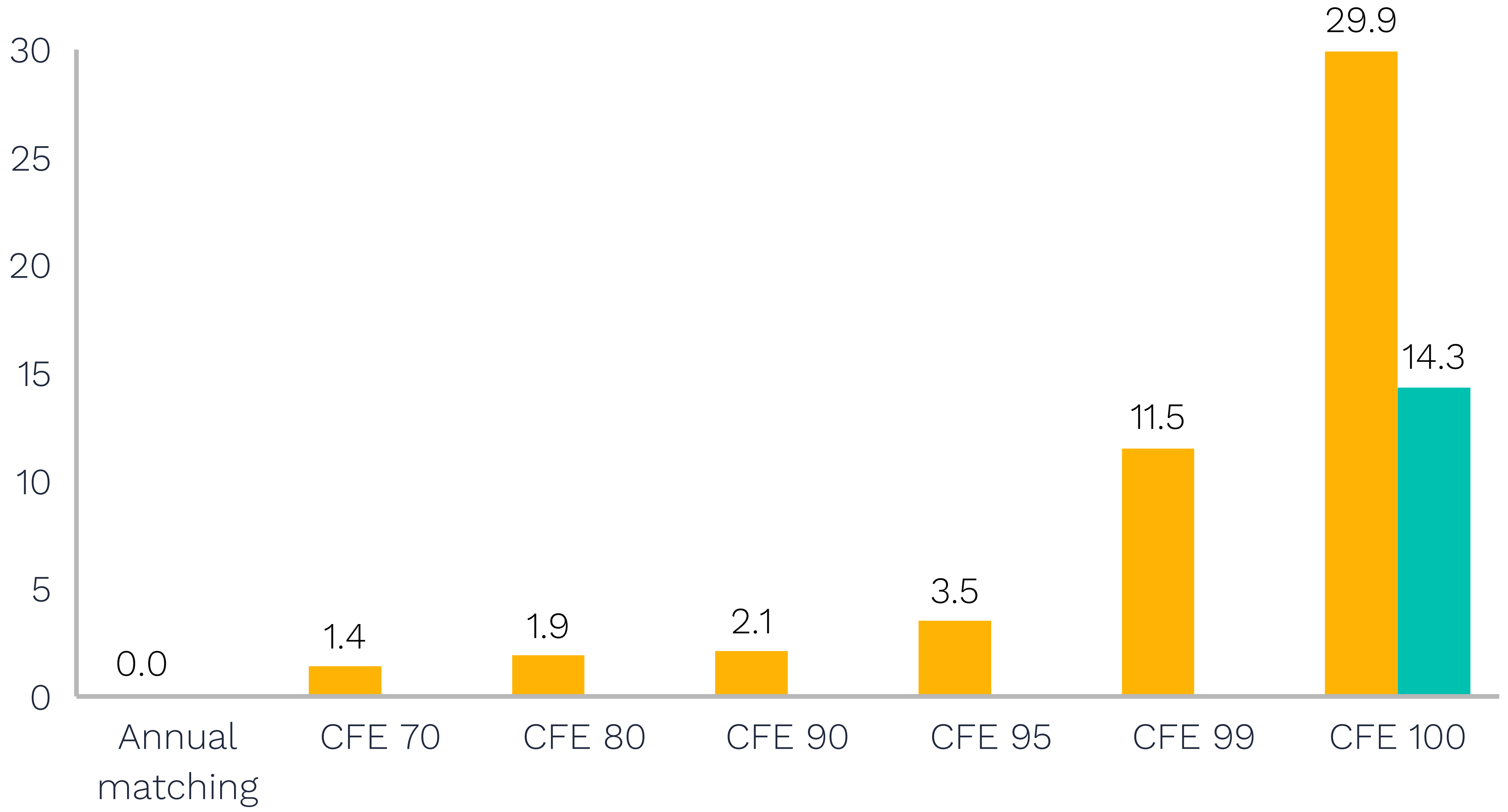


Sarawak

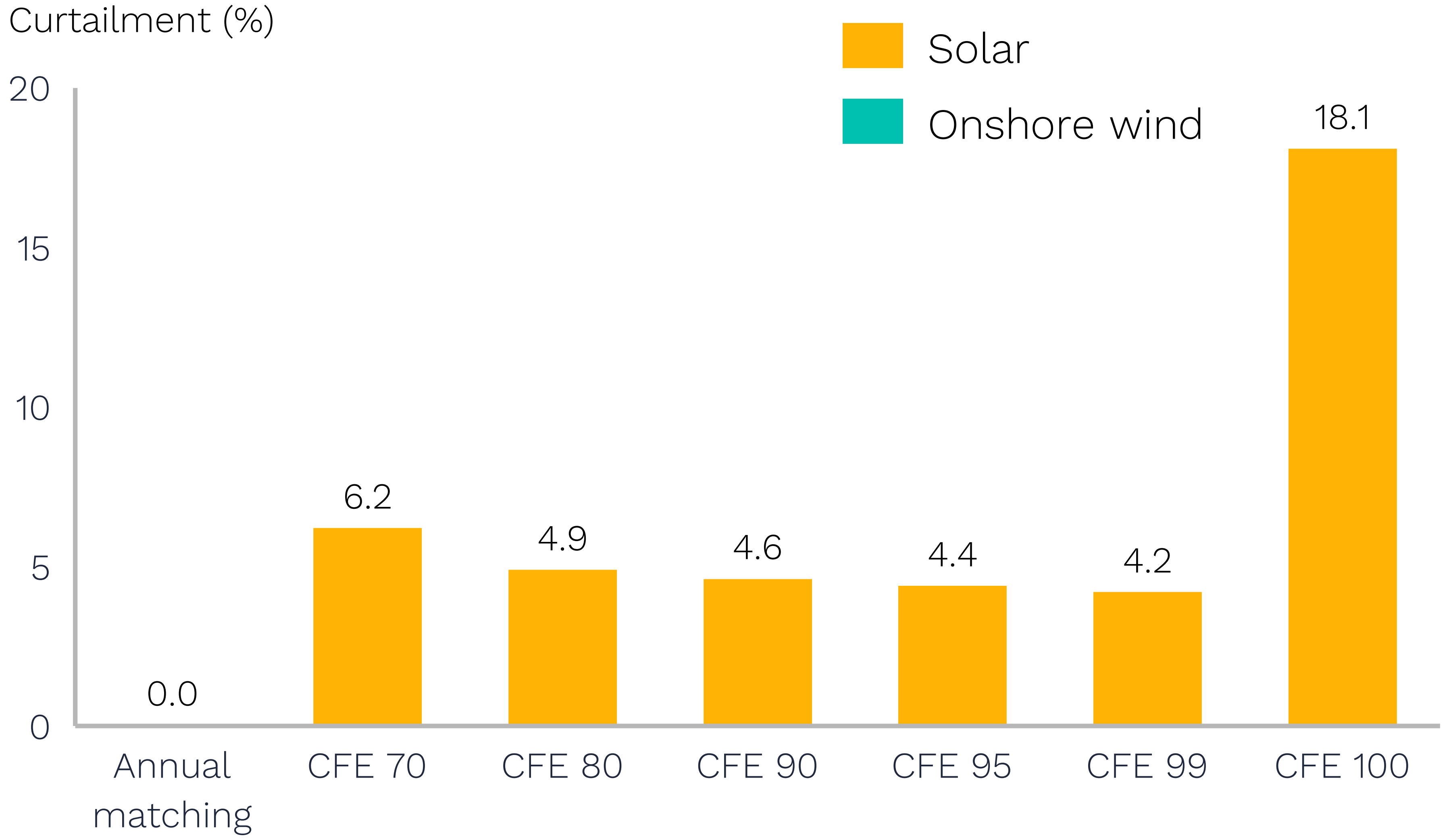
Greenfield – brownfield trade (TWh)



Curtailment (%)



Curtailment (%)



Notes

- Enabling excess electricity from C&I consumers to be sold to the grid not only boosts revenue streams but also plays a key role in reducing curtailment of clean energy. This flexibility also influences procurement decisions — typically leading to reduced investment in solar and battery capacity and rely more on the supply from brownfield.
- Curtailment increases significantly at higher CFE levels due to a strict limits for sell-back of excess electricity from C&I PPAs, capped at 15% sell-back. Easing these export limits could reduce curtailment but may shift additional balancing and operational costs to the system operator.
- Because the system prioritises meeting local demand first, the total amount of procured capacity and its associated costs remain largely unchanged, regardless of whether a 15% export limit is imposed.
- When excess generation cannot be exported under hourly matching, overall CFE generation decreases. Yet curtailment still occurs — especially at the 100% CFE target, leading to significant oversupply that the system cannot absorb.

TransitionZero

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