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Decarbonising Malaysia's electricity

Challenges to net-zero emissions and options to diversify energy mix

Policy paper

By
Dhana Raj Markandu

Foreword by
Datuk Prof Dr Mohd Faiz Abdullah

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Contributor

Dhana Raj Markandu was a senior analyst with the Climate, Environment and Energy programme when this study was conducted between 2024 and 2025. He has more than 20 years of technical and management experience in the electricity sector, encompassing a diverse mix of fossil fuels, renewables and nuclear energy. His research focused on data and policies related to energy and decarbonisation. He is a professional engineer with the Board of Engineers Malaysia, a Human Resources Development Fund-certified trainer and a TEDx speaker.

** The analysis and opinions expressed in this document are solely those of the author and do not represent the positions of any organisations with which he is affiliated.*

Foreword

The transition to a low-carbon energy system is one of the most critical strategic imperatives facing Malaysia today. Driven by our commitments to climate action and environmental stewardship, the pursuit of net-zero greenhouse gas emissions by 2050 is a journey that will also reshape our nation's economic resilience and global competitiveness, while building a more inclusive and sustainable future for all Malaysians. Realising this bold vision requires innovative solutions, ambitious policies and collective effort across all levels of government, industry and society.

Malaysia is not short of roadmaps and strategies that articulate the path forward to meet its decarbonisation aspirations. The National Energy Transition Roadmap (NETR), which spearheaded the Madani government's transformational approach for the energy sector in 2023, has been complemented by the 2025 Long-Term Low Emissions Development Strategy (LT-LEDS), which presents an economy-wide perspective to support Malaysia's 2050 goals. While these frameworks provide a solid foundation for our efforts, we must also recognise that plans developed during these uncertain times should not be set in stone. Navigating a rapidly changing technological, economic and geopolitical landscape demands agility and a readiness to adapt.

This research explores scenarios to diversify the technology options for Malaysia's energy mix – with particular focus on electricity production in Peninsular Malaysia. It builds upon the robust and thought-provoking discourse on this topic during PRAXIS – ISIS Malaysia's flagship public policy conference – in 2024, advancing the conversation with data-driven analysis and unconventional insights. Indeed, the report stands out by critically revisiting NETR's power sector projections by drawing upon and combining updated information from both Malaysia's First Biennial Transparency Report (BTR1), published in December 2024, and LT-LEDS, released in May 2025.

The challenges of the energy trilemma – sustainability, security and equity – are well recognised globally. Adding to this is Malaysia's own electricity trilemma, as the country balances growing demand from economic development, while reducing dependence on fossil fuels, as well as safeguarding societal wellbeing and prosperity. I am confident that this policy paper will provide a strong foundation to inform and augment future decarbonisation policies, while serving as a valuable catalyst to elevate discussions on Malaysia's energy transition beyond platitudes and echo chambers.

Datuk Prof Dr Mohd Faiz Abdullah
Executive Chairman
Institute of Strategic & International Studies (ISIS) Malaysia

Abbreviations

BAU	business-as-usual
BTR1	First Biennial Transparency Report
BUR4	Fourth Biennial Update Report
CCUS	carbon capture, utilisation and storage
CF	capacity factor
CO_2	carbon dioxide
DOSM	Department of Statistics Malaysia
EE	energy efficiency
GDP	gross domestic product
GHG	greenhouse gas
GW	gigawatt
GWh	gigawatt-hour
IPCC	Intergovernmental Panel on Climate Change
IPPU	industrial processes and product use
IRENA	International Renewable Energy Agency
LT-LEDS	Long-Term Low Emissions Development Strategy
LULUCF	land use, land use change and forestry
$MtCO_2e$	million tonnes of carbon dioxide equivalent
NETR	National Energy Transition Roadmap
NRECC	Ministry of Natural Resources, Environment and Climate Change
NRES	Ministry of Natural Resources and Environmental Sustainability
PETRA	Kementerian Peralihan Tenaga dan Transformasi Air (Ministry of Energy Transition and Water Transformation)
RE	renewable energy
ST	Suruhanjaya Tenaga (Energy Commission)
TWh	terawatt-hour
tCO_2e	tonnes of carbon dioxide equivalent
UNFCCC	United Nations Framework Convention on Climate Change
WAM	with additional measures (LT-LEDS scenario)

Executive summary

- Malaysia's energy transition, centred on the 2023 National Energy Transition Roadmap (NETR), builds on a pragmatic foundation of familiar technologies and leverages on existing national capabilities. Phasing out coal, ramping up solar and expanding regional interconnections, while maintaining a stable base of gas and hydro, provide a positive trajectory for power sector decarbonisation. However, as highlighted by the 2025 Long-Term Low Emissions Development Strategy, current measures will not be sufficient to achieve net-zero greenhouse gas emissions by 2050 and must be augmented further.
- Published data on greenhouse gas inventories are imprecise estimates that are subject to measurement uncertainties, data gaps and evolving methodologies. Malaysia's 2019 Fourth Biennial Update Report indicates an uncertainty margin of 15% for fossil fuel emissions and 20% for removals by natural carbon sinks. While the reported net-zero gap for 2019 was 115 $MtCO_2e$, accounting for the uncertainty factors suggests a variability of up to 80% and an upper bound of 208 $MtCO_2e$ for emissions neutrality. Therefore, net-zero targets should be a directional aspiration rather than an absolute endpoint, with policy efforts focusing on measurable, verifiable emissions cuts rather than relying on offsets and carbon accounting.
- Installed capacity values, which are typically used to describe the proportions of electricity sources, do not automatically translate to the actual amount of firm, dispatchable generation. Once intermittency and baseload capabilities are taken into account, NETR's 2050 installed capacity projection of 58% solar is expected to generate only 30% of electricity, while 29% gas could supply 50% to the grid. While installed capacity is a key metric for power system planning, it does not provide the complete picture necessary to illustrate the adequacy of energy supply and resulting decarbonisation impacts.
- Analysis of NETR's power sector pathway for 2050 suggests that supply may be insufficient to meet projected demand growth, with estimated shortfalls between 27% to 53%. While the median scenario does reduce absolute emissions by 29% and emissions intensity of electricity by 62%, weather dependency of the system increases to 50%. In addition, 80% of generation sources would consist of those without readily available on-site energy inputs. Therefore, while decarbonisation metrics may improve, this would compromise energy security and supply adequacy.
- Diversifying electricity generation sources beyond solar, hydro and gas is essential for Malaysia to ensure the right balance between reliability, equity and sustainability. Mapping energy technologies against a non-exhaustive set of key parameters – operational emissions, independence from weather and climate, on-site primary inputs, ability to provide gigawatt-scale, baseload and dispatchable supply, as well as global technology readiness – underscores the reality that no single solution can meet all the demands of the energy transition. Malaysia should consider all feasible options across multiple deployment horizons, with energy policies strategically focused on decarbonisation, economic development and national prosperity, while remaining tactically flexible and adaptive to evolving sectoral developments.

1 Introduction

Malaysia aims to achieve net-zero greenhouse gas (GHG) emissions by 2050, with the National Energy Transition Roadmap (NETR) spearheading energy sector decarbonisation efforts.[1] Launched in August 2023, NETR outlines 69 key initiatives and flagship projects, designates nearly 30 implementation champions and estimates that up to RM1.3 trillion in cumulative investment will be required to finance the shift to a low-carbon economy. Despite these ambitions, NETR projects that fossil fuels will still account for 77% of Malaysia's primary energy and 29% of installed electricity capacity in 2050.

For the electricity sector, NETR envisions that gas, solar and hydro will be the primary sources of supply moving forward. Coal is expected to be fully phased out by 2044.[2] This approach leverages on power generation technologies that are already familiar to Malaysia, providing a pragmatic foundation for developing emissions reduction pathways. However, there are opportunities to augment NETR's portfolio with an expanded suite of technologies that could further displace fossil fuels, mitigate over-dependence on intermittent or weather-dependent sources and enable deeper, more resilient decarbonisation.

This perspective is reinforced by Malaysia's Long-Term Low Emissions Development Strategy (LT-LEDS), which describes decarbonisation efforts across the broader economy until mid-century.[3] Published in May 2025, LT-LEDS suggests that the country's overall decarbonisation trajectory – shaped by policies introduced from 2023 to 2024 – may be insufficient to meet the 2050 net-zero target. Under current measures, net emissions are projected to decline by 25% from 2019 to 2050, leaving 86 million tonnes of carbon dioxide equivalent ($MtCO_2e$) still to be mitigated. Furthermore, Malaysia's aspirations will continue to rely heavily on natural carbon sinks to absorb more than 200 $MtCO_2e$ annually – about 70% of total emissions – in the coming decades.

The objective of this policy paper is to assess a selection of underexplored challenges for the electricity sector – guided by the projections of NETR and LT-LEDS – and consider the potential of supplementary technology options to diversify Malaysia's power generation mix. This research aims to complement the valuable work of other institutions that have examined a wide range of dimensions within Malaysia's evolving energy landscape, such as energy economics, financing and a human-centric transition. It seeks to broaden perspectives and enrich policy considerations to address the energy trilemma of sustainability, security and equitability.

2 Energy sector decarbonisation policies

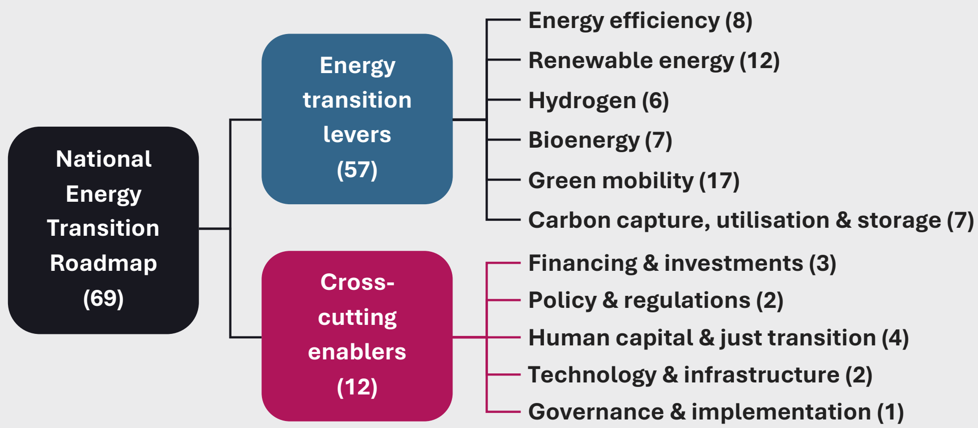
Malaysia has introduced a series of policy initiatives since 2020 to accelerate its clean energy transition, reduce emissions and drive low-carbon development. At the federal level, these include the Malaysia Renewable Energy Roadmap, National Energy Policy, Hydrogen Economy and Technology Roadmap, National Industrial Master Plan and NETR, among others. Regional plans – such as the Sarawak Post-Covid-19 Development Strategy and Sabah Energy Roadmap – have also been launched to address localised priorities. LT-LEDS seeks to harmonise these efforts into a consolidated pathway towards achieving net-zero emissions by 2050. This chapter explores the salient points of NETR and LT-LEDS as the overarching frameworks guiding decarbonisation in the energy sector and across the broader economy, respectively.

2.1 NETR overview

Unveiled in August 2023, NETR outlines 69 key initiatives and flagship projects across six energy transition levers and five cross-cutting enablers to accelerate decarbonisation of Malaysia's energy sector (Fig. 1). Its 2050 targets include reducing energy sector emissions by 32% (compared with 2019), increasing renewable energy (RE) capacity share to 70% and achieving 20% energy efficiency (EE) savings.

Fig. 1. NETR spans a broad range of technologies and supporting measures

NETR levers and enablers

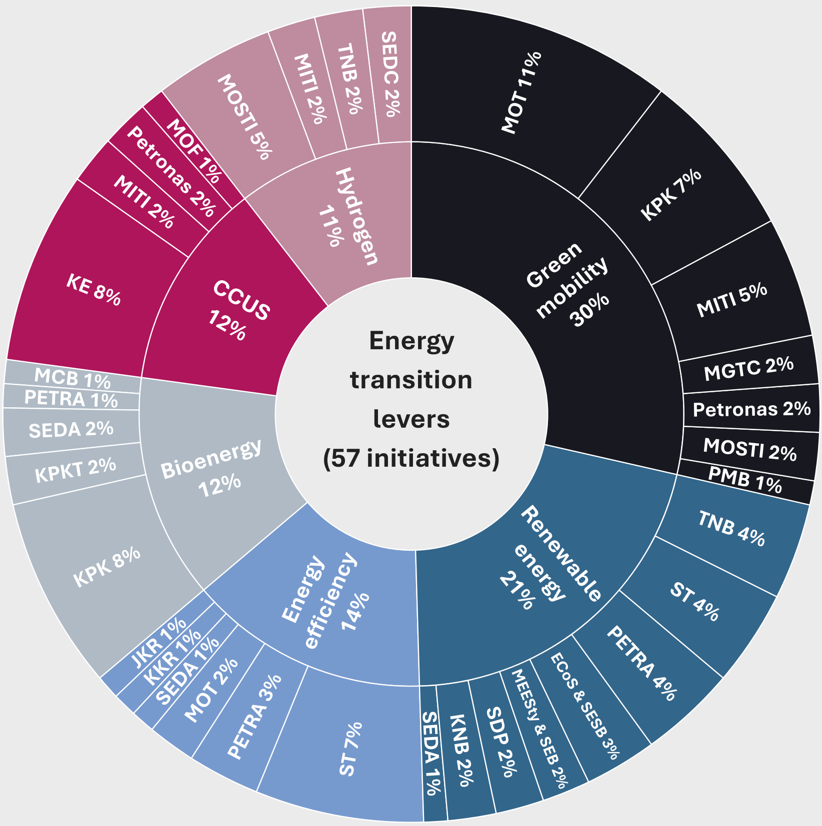


Notes:
1. Number of initiatives shown in brackets
Source: visualisation by author from NETR data

NETR identifies nearly 30 champions from ministries, government agencies, regulators, government-linked corporations, financial institutions and the private sector (Fig. 2 and 3). Champions with responsibilities across several levers and enablers include the Ministry of Economy, Ministry of Energy Transition and Water Transformation[a] (PETRA) and Ministry of Investment, Trade and Industry. Others with critical roles in their focus areas include the Ministry of Transport for green mobility, Tenaga Nasional Berhad and the Energy Commission for RE and EE, the Ministry of Plantations and Commodities for bioenergy and the Ministry of Science, Technology and Innovation for hydrogen.

Fig. 2. Technology-centric initiatives have 24 named champions

Distribution of NETR champions across energy transition levers



ECoS: Energy Commission of Sabah
JKR: Public Works Department
KE: Ministry of Economy
KKR: Ministry of Works
KNB: Khazanah Nasional Berhad
KPK: Ministry of Plantations & Commodities
KPKT: Ministry of Housing & Local Government
MCB: Malakoff Corporation Berhad
MEESty: Ministry of Energy & Environmental Sustainability Sarawak
MGTC: Malaysia Green Technology & Climate Change Corporation
MITI: Ministry of Investment, Trade & Industry
MOF: Ministry of Finance
MOSTI: Ministry of Science, Technology & Innovation
MOT: Ministry of Transport
PETRA: Ministry of Energy Transition & Water Transformation
PETRONAS: Petroliam Nasional Berhad
PMB: Prasarana Malaysia Berhad
SDP: Sime Darby Properties
SEB: Sarawak Energy Berhad
SEDA: Sustainable Energy Development Authority
SEDC: Sarawak Economic Development Corp.
SESB: Sabah Electricity Sdn Bhd
ST: Energy Commission
TNB: Tenaga Nasional

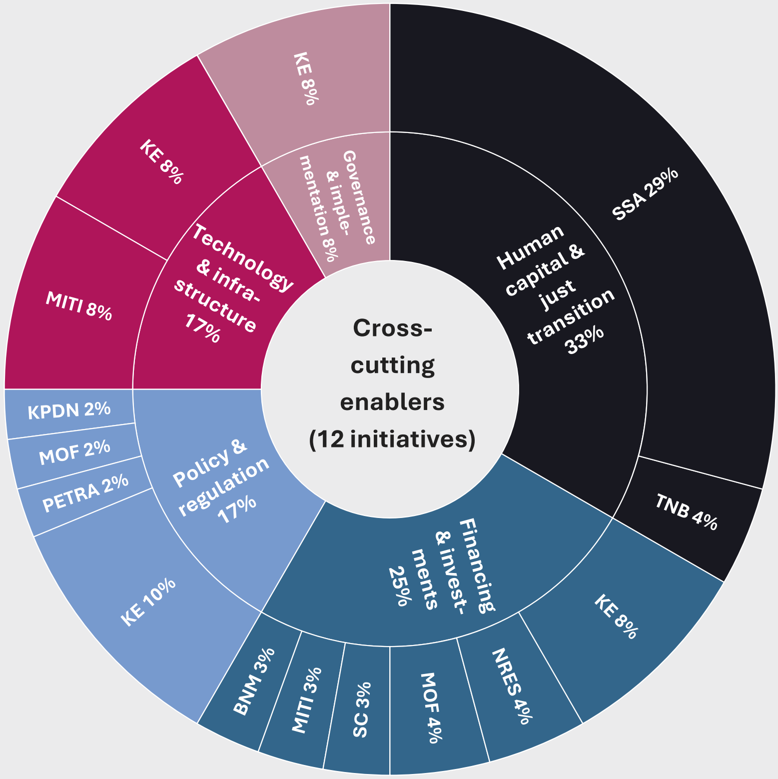
Notes:
1. Totals may differ from component sums due to rounding

Source: analysis & visualisation by author from NETR data

[a] At NETR's launch, energy came under the purview of the Ministry of Natural Resources, Environment and Climate Change (NRECC). In December 2023, NRECC was split into PETRA and Ministry of Natural Resources and Environmental Sustainability (NRES). As of May 2025, NETR has not been updated to reflect this but public sources indicate that PETRA leads all former NRECC initiatives except one related to carbon markets, which is under NRES.

Fig. 3. Supporting measures have nine named champions and more sector-specific agencies that were not explicitly identified

Distribution of NETR champions across cross-cutting enablers



BNM: Bank Negara Malaysia
KE: Ministry of Economy
KPDN: Ministry of Domestic Trade & Cost of Living
MITI: Ministry of Investment, Trade & Industry
MOF: Ministry of Finance
NRES: Ministry of Natural Resources & Environmental Sustainability
PETRA: Ministry of Energy Transition & Water Transformation
SC: Securities Commission
SSA: Sector-specific agencies
TNB: Tenaga Nasional Berhad

Notes:
1. Totals may differ from component sums due to rounding

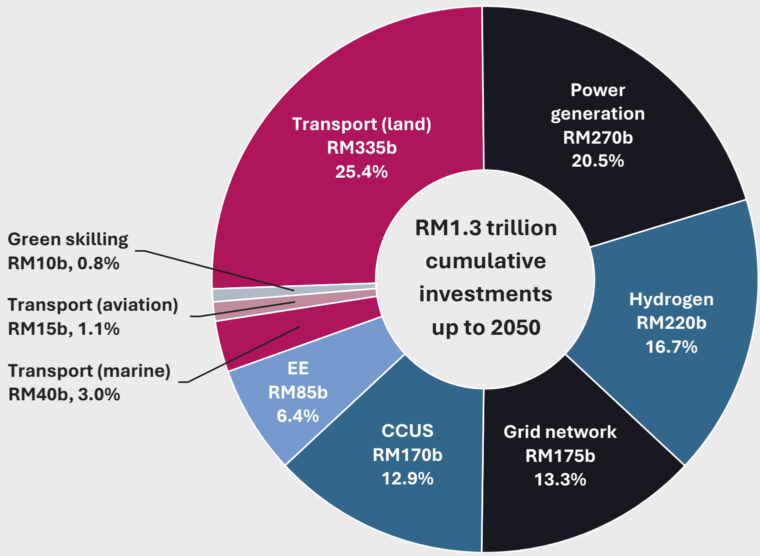
Source: analysis & visualisation by author from NETR data

At the federal level, governance of Malaysia's energy transition and coordination of implementing entities are undertaken by the National Energy Council, chaired by the prime minister, and by the National Committee on Energy Transition, chaired by the PETRA minister.

NETR estimates that up to RM1.3 trillion will be required between 2023 and 2050 to support energy sector decarbonisation, excluding business-as-usual (BAU) activities and projects already being financed (Fig. 4). Electricity supply and transport are each expected to account for about one-third of total projected investment, while the remaining share is largely directed towards emerging technologies, such as green hydrogen and carbon capture, utilisation and storage (CCUS).

Fig. 4. Land transportation, power generation and hydrogen are the top three investment segments with 60% share

Allocation of Malaysia's RM1.3 trillion energy transition financing needs



Notes:
1. Values show the maximum NETR range
2. Totals may differ from component sums due to rounding

Source: visualisation by author from NETR data

Progress is evident in the two years since NETR's launch, with some objectives already achieved. Notable developments include the enactment of laws for energy efficiency and CCUS, expansion of large-scale solar deployment and inclusion of floating solar options, issuance of guidelines for third-party grid access for renewable energy procurement and rooftop solar aggregation, establishment of an energy exchange to facilitate cross-border electricity trading and allocations in the annual budget for the National Energy Transition Facility, among others.

2.2 LT-LEDS overview

LT-LEDS is Malaysia's most recent low-carbon development framework as of June 2025, targeting 45% reduction in GHG intensity against gross domestic product (GDP) by 2030 (relative to 2005 levels) and achieving net-zero emissions by 2050.[4] It adopts a broader scope than NETR, which was intentionally focused on the energy sector. Four emissions scenarios are outlined by LT-LEDS, but only two are pertinent to this research. The first, "with additional measures" (WAM), models the projected GHG trajectory based on policies announced from 2023 to 2024 and finds that Malaysia will not achieve net-zero by 2050. The second scenario, "transformational shift", describes further initiatives required to close this gap and meet the desired target.[b]

[b] *Two excluded scenarios are "without measures" (WOM) and "with existing measures" (WEM). WOM is a hypothetical pathway without any decarbonisation policies since 2005, while WEM includes only those implemented prior to 2023.*

The emissions reduction pathways in LT-LEDS are classified based on Malaysia's GHG inventory reporting sectors: energy; industrial processes and product use (IPPU); agriculture; waste; and land use, land use change and forestry (LULUCF). Energy is further disaggregated into four sub-sectors: power, transport, oil and gas, and industry fuel use. A total of 15 sectoral and three cross-cutting strategies have been identified along with seven key enablers (Table 1).

Table 1. LT-LEDS outlines measures for economy-wide emissions reduction

LT-LEDS strategies and enablers

Category	Sector		Strategies & enablers
Sectoral strategies	Energy	Power	1. Renewables & storage at scale 2. New green fuels & clean technology 3. Interconnected grid of the future
		Transport	4. Electrified mobility 5. Sustainable fuels 6. Public transport
		Oil & gas	7. CCUS at scale 8. Green electrification 9. Methane reduction
		Industry fuel use	10. Low carbon materials & fuel alternatives
	Industrial processes & product use		
	Agriculture		11. Protection & restoration at scale 12. Sustainable agriculture
	Forestry & land use		
	Waste		13. Separation at source 14. Recycling at scale 15. Waste-to-wealth
Cross-cutting strategies			1. Energy efficiency 2. Hydrogen 3. Carbon capture, utilisation & storage
Key enablers			1. Measurement, reporting, verification & governance 2. Carbon pricing 3. Green financing 4. SME & MSME empowerment 5. Awareness & behavioural change 6. Talent & capabilities development 7. Technology transfers & partnerships

Source: LT-LEDS

In addition to these measures, LT-LEDS highlights several inflection points that could accelerate national decarbonisation if they become both technologically and economically viable for Malaysia. These include carbon capture for gas power plants and industrial facilities, emerging options, such as hydrogen, small modular reactors and long-duration storage, as well as nature-based solutions. Increased availability of green financing is also viewed as a key catalyst.

3 Net-zero ambiguities

Since 2020, Malaysia has submitted two GHG inventory reports under the United Nations Framework Convention on Climate Change (UNFCCC) – the Fourth Biennial Update Report (BUR4),[5] published in 2022 with data up to 2019, and the First Biennial Transparency Report (BTR1),[6] published in 2024 with data up to 2021. These stocktakes and their future iterations enable the benchmarking of recent decarbonisation initiatives, tracking of progress towards the net-zero aspiration and implementation of course-correction measures where needed.

The Intergovernmental Panel on Climate Change (IPCC) defines "net zero" as "a condition in which anthropogenic GHG emissions are balanced by anthropogenic GHG removals over a specified period".[7] However, precisely quantifying emissions and removals remains challenging due to data limitations, measurement uncertainties and evolving methodologies driven by advances in scientific knowledge. This chapter outlines Malaysia's emissions projections and examines several vectors of data ambiguity to underscore the view that net-zero targets should be interpreted as indicative ranges rather than exact figures.

3.1 Emissions projections for 2050

LT-LEDS presents a holistic outlook on Malaysia's emissions trajectory from 2019 to 2050 (Fig. 5), covering all primary GHG inventory reporting categories – energy, IPPU, agriculture, waste for emissions and LULUCF for removals – and superseding the previous energy-focused net-zero projection outlined by NETR.[c]

In the 2019 baseline derived from BUR4, national emissions totalled 330 $MtCO_2e$, with the energy sector accounting for 78%. Natural carbon sinks were estimated to offset 65% of GHGs, leaving net emissions at 115 $MtCO_2e$. Framed differently, this reflects a 35% gap that must be closed to reach net zero.

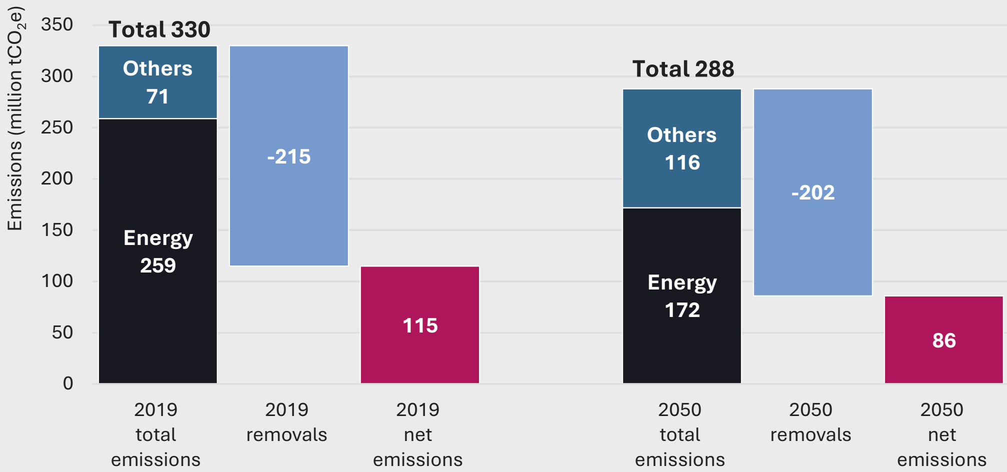
According to LT-LEDS's WAM scenario, total emissions in 2050 will decrease by 13%, reaching 288 $MtCO_2e$. While emissions from the energy sector may decline by 34%, those from non-energy sources are set to rise by 63%. Compounded by a small contraction in removals, net emissions may only be reduced by 26% compared to 2019. Crucially, despite existing measures and anticipated investments – such as those outlined in NETR – Malaysia is still projected to fall short of its net-zero target by 30%, or 86 $MtCO_2e$.

As described in Section 2.2, the transformational shift scenario seeks to close this gap by proposing additional decarbonisation measures across all sectors to augment current efforts, as well as by identifying techno-economic inflection points that could boost progress if and when they become viable for Malaysia.

[c] *NETR's projections focused solely on energy sector emissions, estimating a 32% reduction between 2019 and 2050. To simplify the analysis, non-energy emissions and removals were held constant at 2019 levels, with the caveat that these would be revisited in LT-LEDS. Final estimates from LT-LEDS suggest that these values would change unfavourably by 2050, resulting in higher overall emissions and a more challenging path to net-zero than NETR anticipated.*

Fig. 5. Malaysia will not achieve net zero by 2050 under its current trajectory

LT-LEDS emissions baseline (2019) and WAM scenario (2050)



Notes:
1. "Others" are the sum of IPPU, agriculture and waste emissions
2. "Removals" refers to LULUCF

Source: visualisation by author from BUR4 and LT-LEDS data

3.2 Revisions to baseline data

Both NETR and LT-LEDS derived their projections from BUR4's 2019 GHG inventory, which was the most recent dataset available for Malaysia at the time of their development. However, emissions data may not be static and could change over time as methodologies improve, models are refined and measurements become more accurate. This is clearly demonstrated in BTR1, which not only provides an updated GHG inventory for 2021, but also uses revised emissions factors[d] and other adjusted parameters to recalculate the 2019 values previously reported in BUR4 (Table 2). Notably, although released several months after BTR1, LT-LEDS continues to report the older BUR4 figures, which have since been superseded.

In the revised BTR1 values for 2019, total emissions were lower than reported in BUR4, but net emissions were higher due to reduced removals. Updated emissions factors led to downward adjustments across all sectors except energy and LULUCF. A comparison of the changes between 2019 and 2021, as reported by BTR1, shows a drop in all GHG categories except IPPU. Total emissions were nominally higher but net emissions were lower.

[d] Emissions factors are applied to convert the impact of non-CO2 GHGs, such as methane and nitrous oxide, to CO2 equivalents based on their relative global warming potential. This allows multiple GHGs to be expressed as a single emissions value. BUR4 applies emissions factors from the IPCC's 2007 Fourth Assessment Report, while BTR1 uses values from the 2014 Fifth Assessment Report. Even more recent emissions factors are provided in the 2021 Sixth Assessment Report, but these have yet to be utilised for Malaysia's GHG reporting.

In this instance, data revisions and updates did not affect materially the underlying assumptions for NETR and LT-LEDS, as differences between the BUR4 baseline and BTR1 revisions were marginal. However, this demonstrates the inherent variability of GHG data used to develop long-term strategies and does not preclude the possibility of more substantial deviations in the future as methodologies evolve and shed new light on past estimates.

Table 2. Revised BTR1 data indicate that total emissions were 0.9% less, while net emissions were 2.1% more than original values reported in BUR4

Comparison between BUR4 and BTR1 (million tCO_2e)

Category	2019 (original, BUR4)	2019 (revised, BTR1)	2021 (BTR1)
Energy	259.3	261.4 *(+2.1)*	259.7 *(-1.7)*
Industrial processes & product use (IPPU)	32.9	32.5 *(-0.3)*	37.0 *(+4.5)*
Agriculture	9.9	7.8 *(-2.1)*	7.3 *(-0.5)*
Waste	28.3	25.6 *(-2.6)*	23.7 *(-2.0)*
Total emissions	**330.4**	**327.4 *(-3.0)***	**327.7 *(+0.3)***
Land use, land use change & forestry (LULUCF)	-214.7	-209.3 *(+5.4)*	-212.3 *(-3.0)*
Net emissions	**115.6**	**118.1 *(+2.4)***	**115.4 *(-2.7)***

Notes:
1. Totals may differ from component sums due to rounding
2. Difference with preceding column in brackets

Source: compiled by author from BUR4 and BTR1

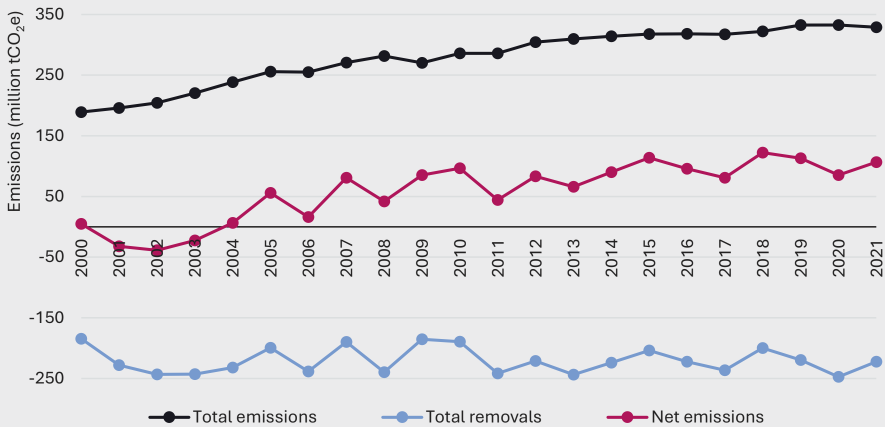
3.3 Variability of carbon sink values

Malaysia ranks among the top 20 countries for total emissions and among the top 30 per capita and per GDP, reflecting a highly carbon-intensive economy.[8] Natural carbon sinks play a key role in moderating the national GHG inventory by offsetting about 65% currently, rising to a projected 70% by 2050. LT-LEDS recognises the importance of forests and other nature-based removals to Malaysia's climate goals and outlines measures to reduce deforestation, promote sustainable forest management, as well as conserve and enhance the carbon stock. These efforts support a broader commitment to maintain at least 51% forest cover up to 2050, compared with 54.6% in 2020.

While these positive signals are encouraging, it is important to note that the data on emissions removals for Malaysia have shown high variability. From 2000 to 2001, annual removal values fluctuated between 184 $MtCO_2e$ and 247 $MtCO_2e$, with substantial year-on-year changes and no clear trend (Fig. 6). This volatility – averaging 13% and peaking at 27% – suggests that methodologies for estimating the impact of natural carbon sinks are still evolving, raising questions about the robustness of these figures in long-term projections. In contrast, total emissions have followed a steadily rising trend over the same period, growing at an average annual rate of 3%, reflecting Malaysia's increased fossil fuel use driven by industrialisation, urbanisation and energy demand.

Fig. 6. Malaysia's emissions have a consistently increasing trend, while removals exhibit high year-on-year variability

Malaysia's GHG emissions and removals (2000 – 2021)



Source: compiled from Malaysia's Common Reporting Tables to the UNFCCC (2000 to 2021)

Separately, the veracity of Malaysia's GHG reporting in BUR3 – especially regarding carbon removals – has been questioned by the international media in 2021. While the country officially disputed these claims by citing an adherence to UNFCCC methodologies, they nonetheless highlight the need for greater rigour in accounting for the impact of carbon sinks on overall emissions.[9,10]

3.4 Impacts of data uncertainty

Values for emissions and removals are not precise and have associated uncertainties. Potential sources of error identified by the UNFCCC in GHG inventory reporting by developing countries include incomplete data, modelling assumptions, sampling limitations, measurement inaccuracies and misreporting.[11] According to the IPCC, the global uncertainty margin for CO_2 emissions from fossil fuel combustion and industrial processes is ±8%, whereas that for CO_2 removals from LULUCF is significantly higher at ±70%.[12] This substantial discrepancy highlights the importance of prioritising deeper levels of tangible decarbonisation in sectors where the data is more accurate, rather than being overly dependent on estimated removals to achieve net zero.

Malaysia's national GHG reporting addresses uncertainties using methodologies recommended in IPCC's 2006 Guidelines for National Greenhouse Gas Inventories.[13] The margin of error in BUR4 – which was used by NETR and LT-LEDS as the basis for their long-term projections – was ±15% for total inventory excluding LULUCF, representing total emissions. This increased by almost four times to ±57% when LULUCF was included. Although not explicitly stated, the error just for LULUCF – representing removals – was calculated to be ±20%.[e]

Applying these uncertainty factors to the reported 2019 values shows that total emissions ranged from 281 to 380 $MtCO_2e$, while total removals were between 172 and 258 $MtCO_2e$ (Table 3). The variability in both parameters, and the wide net-zero band that results, should be considered when developing strategies to decarbonise the economy.

Table 3. Malaysia's reported GHG values could vary by up to 20% due to inherent margins of error

Malaysia's GHG emissions and removals with uncertainty ranges (2019)

GHG category	Reported value ($MtCO_2e$)	Uncertainty (%)	Uncertainty range ($MtCO_2e$)	Low end of range ($MtCO_2e$)	High end of range ($MtCO_2e$)
Total emissions	330	±15%	±49.5	281	380
Total removals	215	±20%	±43.0	172	258

Source: analysis by author from BUR4 data

Framing Malaysia's GHG emissions and removals as a range rather than absolute values offers a more nuanced perspective on the trajectory towards net zero (Table 4 and Fig. 7). In the "lower-bound scenario", where emissions are at the lowest and removals at the highest, the gap to net zero narrows to 23 $MtCO_2e$. Conversely, the "upper-bound scenario", with the highest emissions and lowest removals, results in the widest gap at 208 $MtCO_2e$. These boundaries suggest that Malaysia's net-zero target could vary by up to 80% around BUR4's baseline value of 115 $MtCO_2e$.

While Malaysia's net-zero gap could theoretically span from 23 to 208 $MtCO_2e$, the lower end of this spectrum may not be an accurate representation of national circumstances. Given the country's dependence on fossil fuels and the greater uncertainty surrounding natural removals data, adopting a pragmatic bias towards the higher end of the net-zero range would be a more prudent policy approach to bolster the low-carbon transition.

[e] *The uncertainty for "total inventory excluding LULUCF" was calculated by omitting IPCC category "3B: Land". This category was incorporated when quantifying the value for "total inventory including LULUCF". For removals only, the uncertainty was determined by the author using only category "3B: Land" guided by the methods prescribed by the IPCC 2006 Guidelines for National Greenhouse Gas Inventories.*

This perspective is supported by limitations in the national GHG accounting process and potential areas for improvement identified by NRECC in BUR4 and noted by UNFCCC in its technical analysis of the report.[14] Examples include developing country-specific emissions factors to replace generic defaults, reducing the number of non-estimated inventory categories and refining underlying assumptions. Despite these challenges, UNFCCC concluded that the information in BUR4 is mostly transparent.

As many of the proposed enhancements aim to tighten methodologies, improve accuracy and reduce variability, they are likely to result in upward adjustments of BUR4's net emissions baseline of 115 $MtCO_2e$, as evidenced by the marginal increment in BTR1's revised value for 2019. This reinforces the view that the upper end of the scale may offer a more credible representation of actual conditions.

Table 4. Data uncertainties create a range of net-zero scenarios

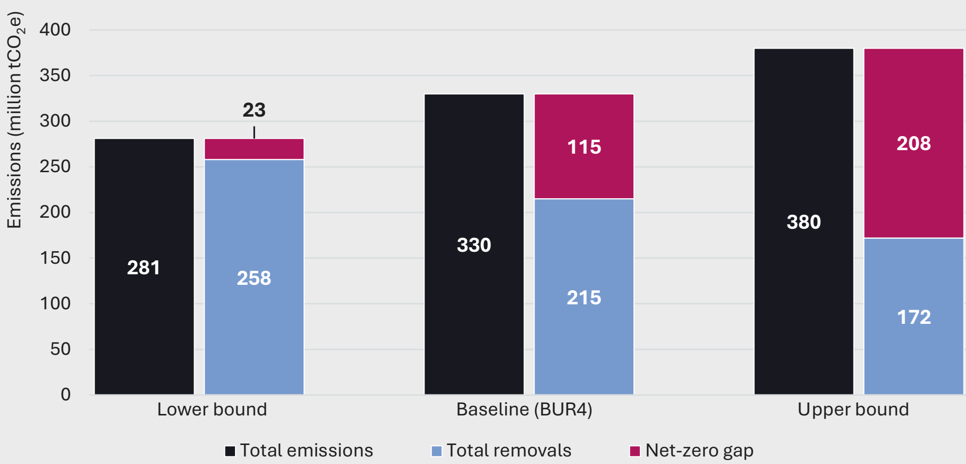
Lower and upper boundaries of Malaysia's net-zero aspirations

Net-zero scenario	Emissions ($MtCO_2e$)	Removals ($MtCO_2e$)	Net-zero target ($MtCO_2e$)
Lower bound	281 (least emissions)	258 (most removals)	23 (minimum net-zero gap)
2019 baseline (BUR4)	330	215	115
Upper bound	380 (most emissions)	172 (least removals)	208 (maximum net zero gap)

Source: analysis by author from BUR4 data

Fig. 7. Malaysia's net-zero target could vary by up to 80% from baseline

Lower and upper boundaries of Malaysia's net-zero aspirations



Source: analysis and visualisation by author from BUR4 data

4 Electricity decarbonisation challenges

Electricity generation is the dominant source of Malaysia's emissions, accounting for about one-third of the national total, as reported in BUR4 and BTR1. National policies have outlined commitments to stop building new coal power plants, fully phase out coal from the energy mix by 2044 and scale up RE capacity to 70% by 2050. These targets represent key energy sector pillars within NETR and LT-LEDS for delivering substantial emissions reductions and advancing Malaysia's net-zero aspirations.

However, the challenge of replacing the large volume of stable and dispatchable energy currently provided by coal, while also meeting the rising energy demands of a growing economy, should not be underestimated. This chapter outlines some of the fundamental technical considerations underlying Malaysia's electricity generation mix and analyses the implications of current pathways for decarbonising it, focusing on perspectives that have been largely underexplored in the mainstream energy transition discourse.

4.1 Installed capacity and generated electricity

In 2022, Malaysia's combined installed capacity for all RE sources – hydro, solar, biomass and biogas – was 23% of the total share, with hydro comprising the majority.[15] NETR outlines strategies to triple this value to 70% by 2050, led primarily by a significant scaling-up of solar – from 6% share of capacity in 2022 to 58% in 2050. While installed capacity is a key parameter in planning and managing power systems, it is important to recognise that this value does not automatically correspond to the actual electricity that is produced. In other words, 70% RE installed capacity does not mean that 70% of total electricity will be generated from renewables.

"Installed capacity" is typically defined as the "maximum energy that a power plant could theoretically produce under ideal conditions", while "generated electricity" reflects the "actual energy that is produced over a period of time, accounting for operational constraints".[16,17,f] Understanding the distinction between the two is crucial to recognising that different energy sources are not automatically interchangeable and appreciating the pragmatic challenges of decarbonising electricity supply. Notably, operational emissions are produced from the actual utilisation and output of power plants, which is represented by generation and not capacity.

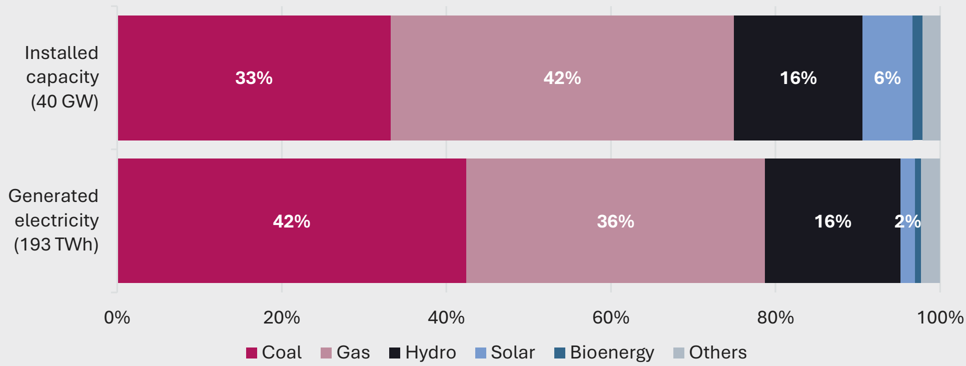
Fig. 8 illustrates these concepts using national data from 2022.[15] Coal power plants accounted for 33% of Malaysia's installed capacity and generated 42% of electricity (Fig. 8). In contrast, gas held a higher capacity share of 42% yet contributed a smaller proportion of electricity at 36%. Factors such as plant availability, fuel prices and grid considerations likely influenced the utilisation of these two sources, which

[f] *The units of measurement for installed capacity and generated electricity are unique to each parameter and not interchangeable. In this report, installed capacity is expressed as megawatts (MW) or gigawatts (GW), while generated electricity is stated as gigawatt-hours (GWh) or terawatt-hours (TWh).*

collectively made up over three-quarters of Malaysia's power infrastructure and supply. Hydro, Malaysia's largest source of renewable energy, had 16% share of both metrics. However, 6% solar capacity only provided 2% of electricity, while bioenergy contributed a nominal 1% to each.

Fig. 8. Installed capacity shares do not equate to actual generated electricity

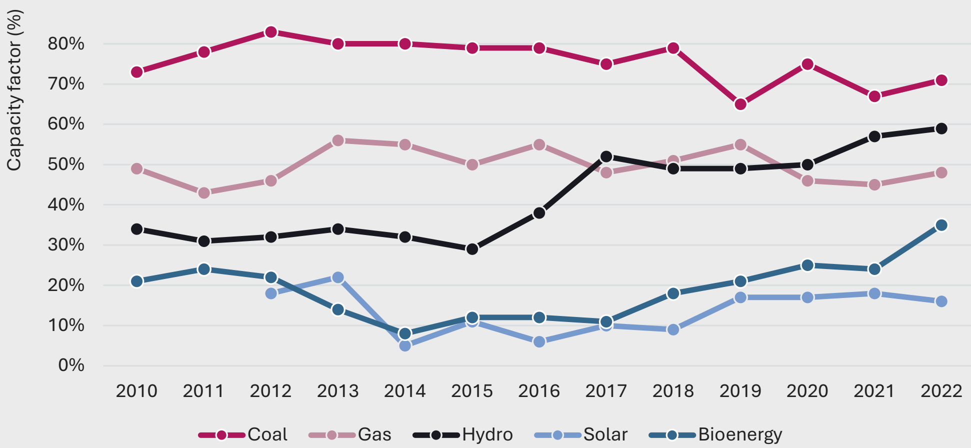
Malaysia's installed capacity and generated electricity (2022)



Source: visualisation by author from ST data

Fig. 9. Coal has consistently seen higher utilisation than gas; productivity of hydro and bioenergy is increasing but solar has plateaued

Malaysia's capacity factor trends (2010 – 2022)



Source: visualisation by author from ST data

The relationship between generated electricity and installed capacity is represented by the capacity factor (CF), which reflects the percentage of actual output from a power source relative to its theoretical maximum over a given period, indicating how productively it is utilised. From 2010 to 2022, the CF for coal in Malaysia mostly ranged between 70% and 80%, with a slight downward trend post-2018, while gas fluctuated around a mean of 50% (Fig. 9). This highlights the more consistent and intensive utilisation of coal power plants compared with their gas counterparts. Since coal is Malaysia's largest source of carbon emissions and a key factor to economic development – explored further in Section 4.2 – its planned phase out by 2044 presents significant challenges that will require careful planning.

As Malaysia accelerates the deployment of RE to meet NETR's targets, CF trends for low-carbon sources offer valuable insights. Hydro, in particular, has shown a marked improvement – rising from a steady 30% between 2010 and 2015 to around 50% after 2017, with an ongoing upward trajectory. A hydroelectric dam essentially functions as a fast-response, large-scale energy storage system – converting the potential energy of stored water to electricity on demand – with spare capacity typically reserved for backup generation or grid support. However, the substantial untapped capacity of up to 50% suggest that opportunities still exist to further optimise the use of current hydro assets to displace fossil fuels.

Bioenergy has also shown a positive trend since 2017, reflecting improved productivity of biomass and biogas facilities. While this is an encouraging development, these sources contribute only around 1% of total electricity generation, limiting the impact of their increased CFs on the overall electricity mix. Their greater potential may lie in localised applications – such as fossil fuel substitutes for off-grid power – or in non-electricity uses, such as industrial heating or transport fuels.

Solar, positioned as a key pillar of NETR's electricity decarbonisation strategy, has CFs that fluctuated significantly between 2012[g] and 2019, before plateauing at around 17%. This figure is in line with other estimates for Malaysia and suggests that any future improvements to the productivity of solar generation are likely to be marginal.[18] Consequently, more physical solar infrastructure – either utility-scale or rooftop – will be required to increase its share of generation.

Fig. 10 illustrates the evolution of Malaysia's installed capacity and generated electricity from 2010 to 2022 (shown in three-year intervals), growing by 48% and 54%, respectively. Coal's generation share has remained relatively stable around 42%, consistently exceeding its capacity share, with both parameters showing increasing trends as power demand grows. In contrast, gas experienced gradual declines in both metrics, signalling a shift to coal as the preferred fuel source during this period. Meanwhile, the share of hydro increased in the latter half of the decade. Although it remained a distant third behind coal and gas, hydro fulfilled a critical auxiliary role as a fast-response, standby source, as previously discussed.

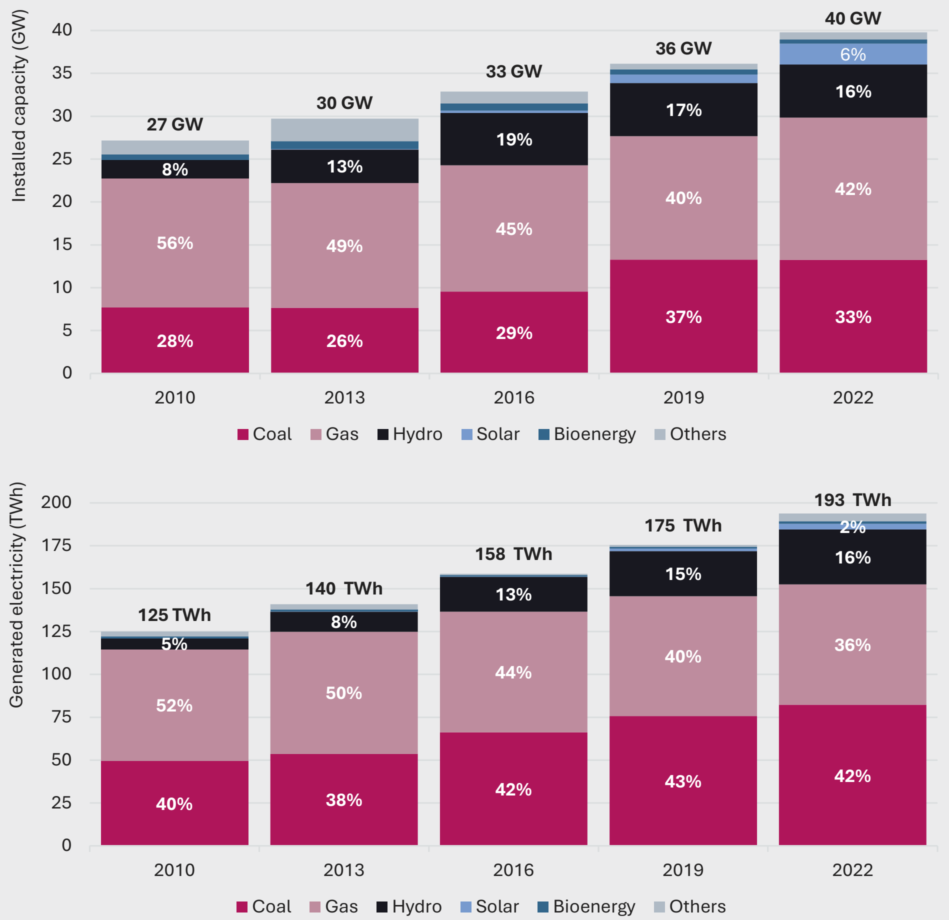
These three sources are considered "dispatchable" – meaning that their output can be adjusted to match electricity supply with real-time demand by ramping generation

[g] *Data from ST's MYenergySTats portal indicate that the installed capacity and generated electricity for solar prior to 2012 were zero.*

up or down, or by switching the plant on or off as needed. Their ability to deliver consistent, large-scale and controllable output underpins their role as Malaysia's "baseload" power sources, which are required to operate continuously to meet the country's minimum daily electricity demand.

Fig. 10. Coal has gained preference over gas; share of non-hydro RE is nominal

Malaysia's installed capacity and generated electricity (2010 – 2022)



Notes:
1. Numerical labels omitted for clarity: solar (before 2022), bioenergy and others
Source: visualisation by author from ST data

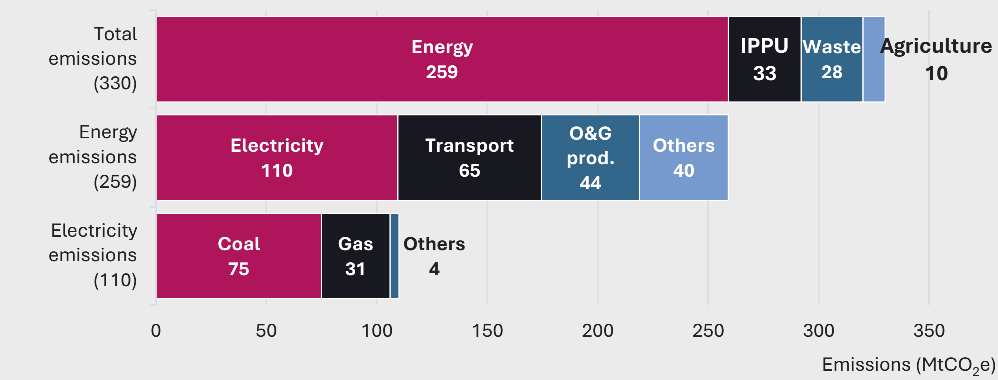
The growth of solar capacity post-2016, driven by national initiatives, such as ground-mounted large-scale solar projects and Net Energy Meeting schemes for rooftops, is an encouraging development. However, solar power remains inherently intermittent and non-dispatchable, as its output depends on weather conditions and daylight availability. This is reflected in its low and plateauing CF, as highlighted previously, and its nominal 2% generation share in 2022. While solar capacity can be significantly scaled up through aggressive deployment, its potential to displace stable baseload generation sources must be assessed pragmatically alongside system stability implications and land-use constraints.

4.2 Significance of coal

Coal combustion for electricity production is the single largest source of Malaysia's emissions, contributing 23% of the total share in 2019 (Fig. 11). This was marginally higher than the combined emissions from all non-energy sectors – industry, waste and agriculture. For the same amount of electricity generated, coal emits over twice the CO_2 of gas (Table 4). Given its higher emissions intensity, displacing coal offers the most significant opportunity to realise deep decarbonisation within the energy sector. This aligns with Malaysia's policy commitments to stop building new coal power plants and phase out existing ones by 2044.

Fig. 11. Electricity generation using coal is the largest source of Malaysia's emissions and presents the highest potential for decarbonisation

Malaysia's GHG emissions breakdown (2019)



Notes:
1. IPPU: industrial processes and product use
Source: visualisation by author from LT-LEDS data

Table 4. Producing electricity from coal emits twice the CO_2 of gas

Malaysia's emission intensities of primary electricity generation sources (2016 – 2021)

Source	Emissions intensity (tCO_2e/GWh)	
	Average	Range
Coal	1,050	999 – 1,113
Gas	475	441 – 522

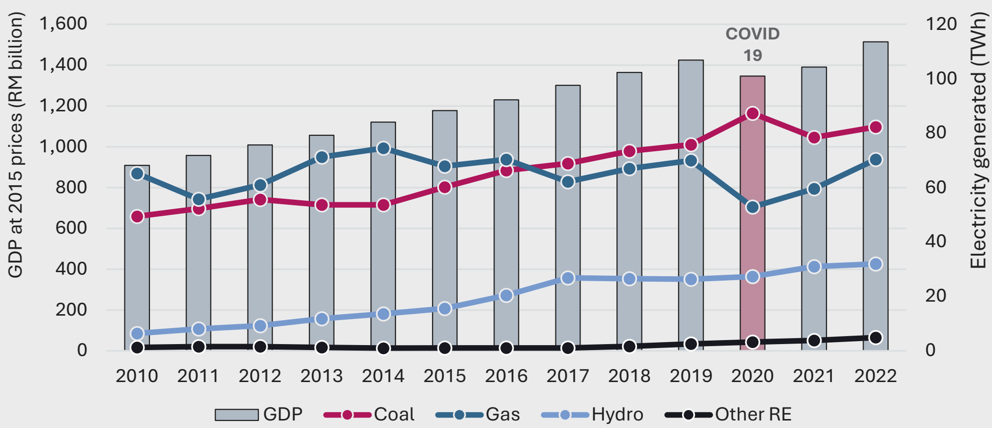
Source: analysis by author from ST data

However, Malaysia's GDP growth, particularly between 2010 and 2019, coincided with an increasing reliance on coal-based electricity generation, while the use of gas largely fluctuated by comparison (Fig. 12).[15,19] Although the shares of hydro and other RE sources have been growing, they remain relatively small. While the specific links between economic growth and fossil fuel consumption are complex and warrant deeper investigation, preliminary observations suggest a strong, positive correlation between GDP growth and increasing coal use, signalling potential challenges in decoupling them.

The impact of Covid-19 reveals notable insights. While total electricity generation declined by 6% year-on-year in 2020 due to reduced demand, the contribution of coal rose by 16%, while gas dropped significantly by 24%. This indicates that coal was not only the primary fuel during economic growth but also during periods of economic disruption. In the post-pandemic recovery period, coal use appears to have reverted to its pre-Covid trajectory, while gas has experienced a faster rate of increase to meet rising demand.

Fig. 12. Malaysia's use of coal-based electricity has paralleled GDP growth

Malaysia's GDP and generated electricity (2010 – 2022)



Source: visualisation by author from ST and DOSM data

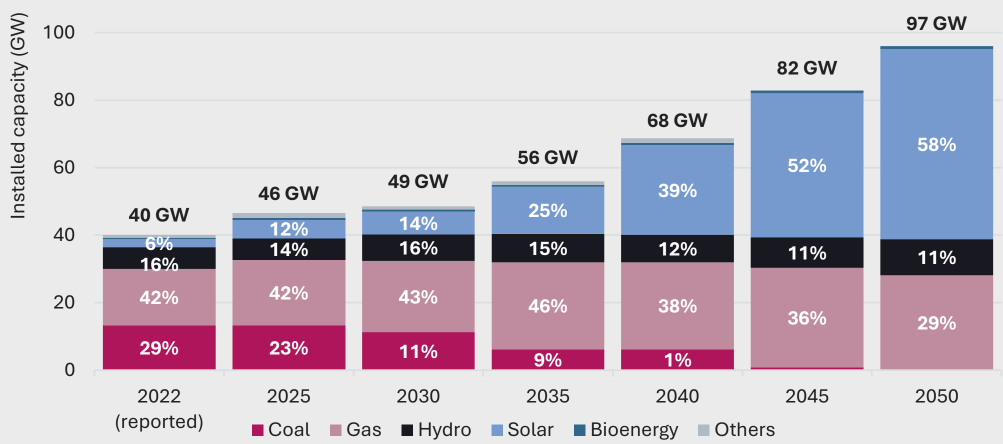
4.3 Generation projections for 2050

4.3.1 Electricity supply scenarios

NETR outlines a pathway in which Malaysia's long-term installed capacity will consist predominantly of solar, accompanied by gas and hydro (Fig. 13). However, as highlighted previously, installed capacity alone offers an incomplete picture of the electricity supply landscape. For a more holistic perspective, NETR's 2050 target should also be examined through the lens of the projected electricity generated and its adequacy in meeting future demand.

Fig. 13. Solar capacity is expected to surge, while coal will be phased out

Malaysia's electricity installed capacity projections (2025 – 2050)



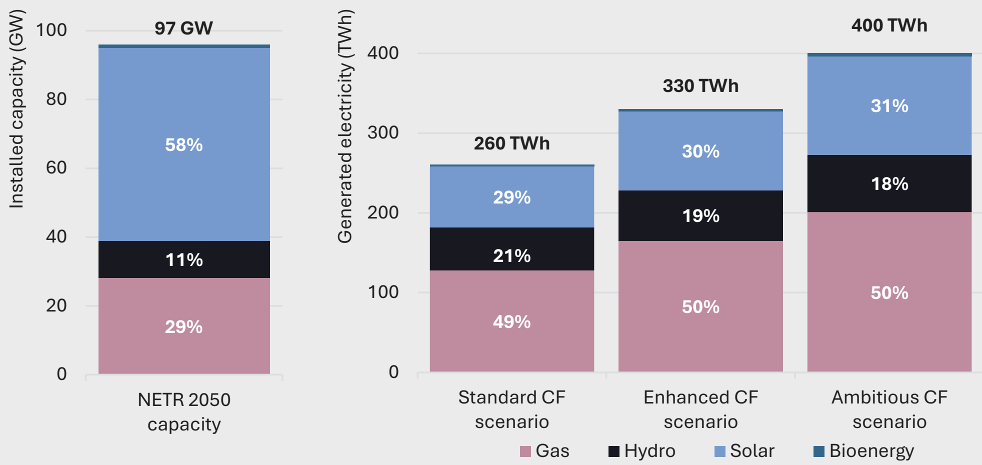
Notes:
1. Values below 5% are not labelled
2. 2022 historical data as reported by ST, 2025 – 2050 as projected by NETR
Source: ST and NETR

For this research, three electricity generation scenarios were modelled by applying differing sets of capacity factors to NETR's 2050 installed capacity projection (Fig. 14). The "Standard" scenario reflects Malaysia's current CFs for gas, hydro, solar and bioenergy – based on a five-year average from 2018 to 2022. "Enhanced" simulates increased electricity output from pragmatic improvements in technologies and efficiencies, optimised utilisation or greater resource consumption, while "Ambitious" represents aspirational stretch-goals, which would require significant technological advancements and investments.

The analysis yields a range of values estimating the electricity that could be produced by a mix consisting primarily of solar, hydro and gas, with a nominal share of bioenergy. The Standard scenario yields 260 TWh, the Enhanced scenario 330 TWh and the Ambitious scenario 400 TWh.

Fig. 14. Due to significant difference in CFs, 58% solar capacity will produce 30% generation, while 29% gas capacity will produce 50% generation

Malaysia's electricity supply scenarios (2050)



Source	Capacity factors		
	Standard scenario	Enhanced scenario	Ambitious scenario
Gas	50%	65%	80%
Hydro	55%	65%	75%
Solar	15%	20%	25%
Bioenergy	25%	35%	45%

Notes:
1. Bioenergy values are approximately 1%–2% and not labelled
2. All values rounded for clarity and illustrative purposes

Source: analysis and visualisation by author from NETR, ST, IRENA and other data sources

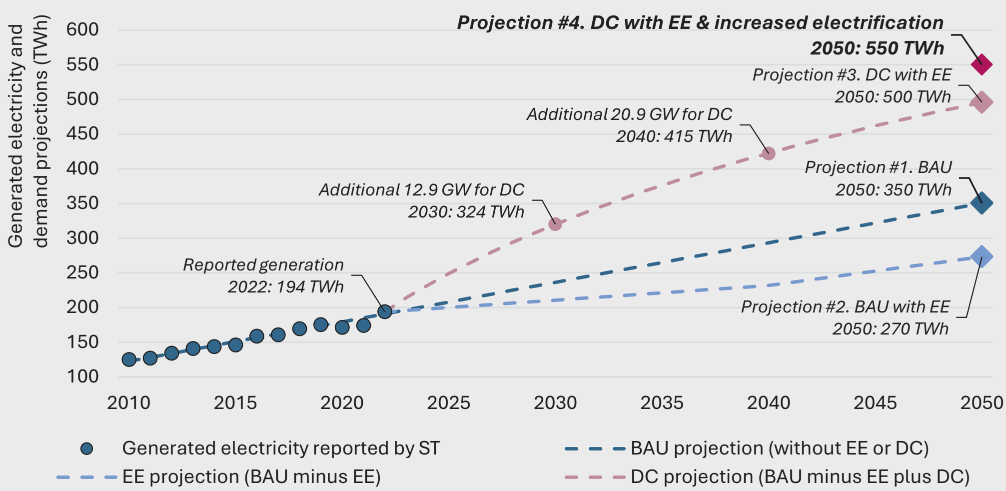
A key observation is that, despite accounting for 58% of installed capacity, solar is expected to deliver only around 30% of generation across all scenarios due to its inherently low CF. In contrast, gas, with just 29% installed capacity, will supply about half of the total electricity.

4.3.2 Electricity demand scenarios

From 2010 to 2019, Malaysia's electricity generation followed a linear growth trend, with a compounded annual growth rate of 3.84% (Fig. 15). Despite a slight dip in 2020 and 2021 due to the impacts of Covid-19, it recovered to its pre-pandemic trajectory in 2022. If this BAU trend continued, generation would reach 350 TWh by 2050 – an 80% increase from 2022 levels (Fig. 15, Projection #1).

Fig. 15. EE could reduce BAU demand projection by 23%, but data centre growth and increased electrification may cause 2× net generation increase

Malaysia's electricity demand scenarios (2050)



Notes:
1. BAU: business-as-usual; EE: energy efficiency; DC: data centres
2. Values rounded for clarity and illustrative purposes

Source: analysis and visualisation by author from ST, NETR and other data sources

EE is recognised as a key decarbonisation lever in NETR, which targets energy savings of 21% by 2040 and 22% by 2050. Applying these targets to the BAU projection of 350 TWh in 2050 suggests that total generation could potentially be reduced to 270 TWh because of EE initiatives (Fig. 15, Projection #2).[h]

The rapid growth of data centres is expected to become a major driver of Malaysia's future electricity demand, marking a significant shift from the BAU projection. Power requirements for data centres alone are estimated to reach 12.9 GW by 2030 and 20.9 GW in 2040 – on top of regular demand growth from economic development.[20] As data centres typically operate around the clock, they require a stable and constant

[h] NETR aims to broaden the scope of EE beyond just electricity to include other energy outputs. To streamline the analysis, the stated targets of 21% EE savings by 2040 and 22% by 2050 were applied entirely to electricity production.

supply of baseload electricity. Full utilisation of their power demand could translate to an additional 230 TWh of electricity by 2050 – or an 85% increase from the EE projection. Total generation in 2050, incorporating both EE savings and DC growth, could reach 500 TWh (Fig. 15, Projection #3).

Further deviation from the BAU trajectory can also be expected from the increasing electrification of transport and industry, the low-carbon energy required to produce hydrogen as an energy carrier – another NETR lever – and other ancillary applications. Modelling these demand projections accurately would require in-depth sectoral analysis, which is beyond the immediate scope of this research and could potentially be explored in future work. Hence, for the purpose of this report, this value is conservatively estimated to be 10% of Projection #3, or 50 TWh. This results in an upper limit for electricity demand at 550 TWh in 2050 (Fig. 15, Projection #4), which will be the value used for subsequent analysis in this report.

4.3.3 Electricity supply-demand gap

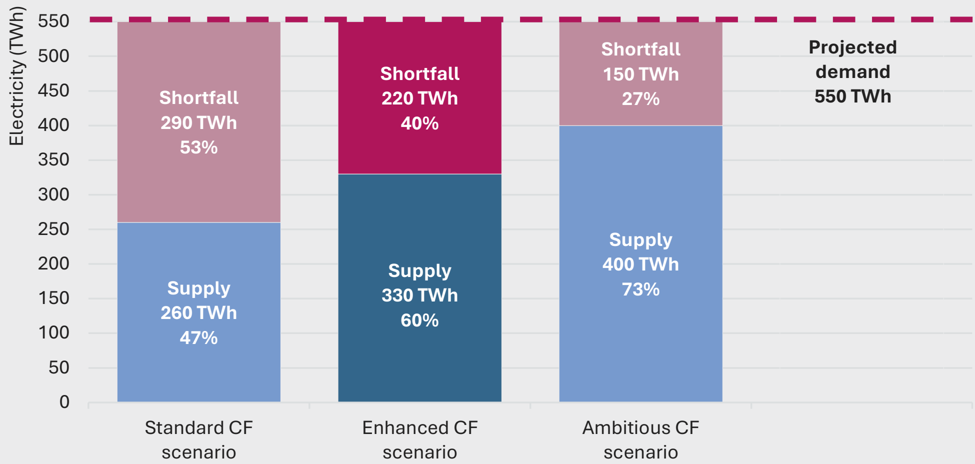
Integrating the analysis from Sections 4.3.1 and 4.3.2 demonstrates that none of the three generation supply scenarios would be sufficient to meet Malaysia's projected 2050 demand of 550 TWh (Fig. 16). The Standard scenario, applying current CFs to NETR's capacity mix, falls short by 53%, while even the Ambitious scenario leaves a 27% gap.

The mid-tier Enhanced scenario, which reflects feasible CFs, could potentially supply only about 60% of the required national electricity demand. This scenario will serve as the primary basis for the analysis in the next chapter of this report.

Eliminating coal and relying primarily on solar, hydro and gas marks a decisive step forward in Malaysia's transition to a low-carbon electricity system. However, the inability to meet future demand is a structural risk that poses significant challenges to energy security and access. If left unaddressed, this could constrain socio-economic progress, erode livelihoods and derail national development goals. To mitigate these risks, Malaysia must pursue a more diversified generation mix, giving due consideration to all viable low-carbon options.

Fig. 16. All generation supply scenarios of NETR's projected energy mix will be insufficient to meet Malaysia's projected 2050 demand

Malaysia's electricity supply-demand gap (2050)



Source: analysis and visualisation by author

5 Clean electricity options

NETR's projected 2050 capacity profile – 58% solar, 29% hydro and 11% gas – provides a strong foundation for advancing Malaysia's electricity sector decarbonisation by anchoring it in technologies that are already familiar and well-integrated within the domestic system. However, this combination – at the stated proportions – will be unable to satisfy fully the country's long-term energy demands. A broader portfolio of low-carbon technologies must therefore be explored to complement NETR's baseline projections, bridge the supply-demand gap and address the energy trilemma of sustainability, security and affordability.

Optimising a generation mix that can simultaneously satisfy a wide range of quantifiable parameters – such as net-zero targets, electricity demand, grid stability, economic considerations and technical feasibility – is a highly complex task routinely undertaken by power system planners using sophisticated modelling tools. The resulting outputs are then translated into actionable strategies with varying implementation horizons by policymakers. Accounting for broader environmental impacts and human-centric dimensions of the energy transition – which are not always easily measurable – further compounds this challenge.

Rather than emulating this process, this chapter applies insights from the preceding segments to a small selection of technical aspects that ground the energy transition in foundational considerations often underexplored in public discourse. The parameters analysed are non-exhaustive, and the intent is primarily to demonstrate some of the fundamental constraints in Malaysia's current power sector decarbonisation pathway, along with a sample of the trade-offs that should be considered moving forward. This approach also aims to complement and add new perspectives to the rich body of Malaysia-specific work that has already explored the topic through diverse lenses, ranging from techno-economics to human rights and beyond.[18,21]

5.1 Scenario implications

The following subsections unpack the implications of NETR's 2050 installed capacity mix – under the enhanced CF generation scenario – on three selected parameters: decarbonisation impacts, weather dependence and on-site storage of primary energy inputs.

Each parameter is examined through two framing questions:

1. How would the parameter change from 2019 to 2050 if the enhanced CF scenario – generating 330 TWh – was sufficient to meet Malaysia's electricity demand?
2. Given that the Enhanced CF scenario can only meet 60% of projected demand, what technology characteristics would be best suited to supply the energy shortfall in a way that either improves the parameter or avoids undermining any progress achieved?

The outcomes from the second question for each parameter are mapped against a spectrum of technologies in Section 5.2 to highlight trade-offs and illustrate the potential for greater diversification in Malaysia's generation mix. This also offers some insights on why closing the demand gap by simply expanding the shares of existing principal sources – solar, hydro and gas – may be a suboptimal approach.

5.1.1 Decarbonisation impacts

This parameter evaluates emissions produced by the power sector, which is the largest component of Malaysia's GHG inventory. By 2050, gas would be the only fossil fuel in use, with coal expected to be fully phased out by 2044. Although the combustion of biomass and biogas produces emissions, their combined share of the energy mix is minimal at just 1% and has been excluded from the analysis.

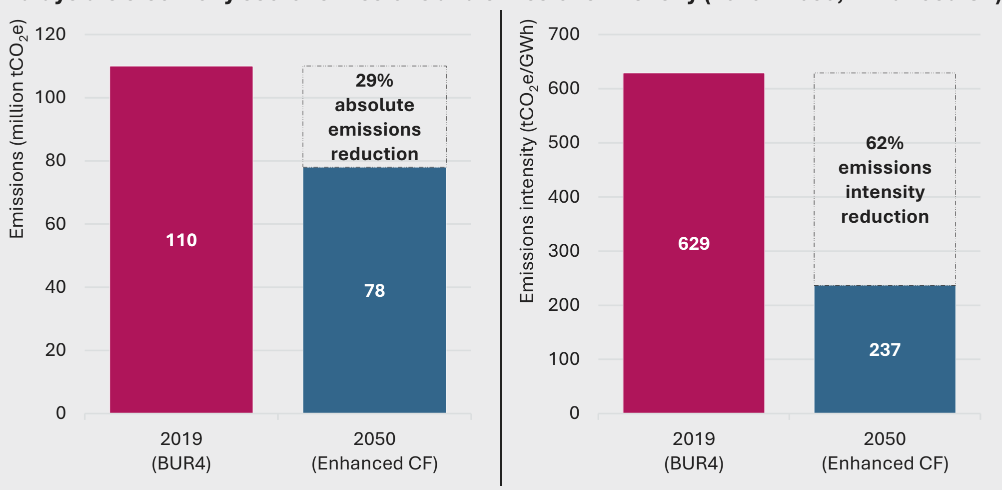
Parameter change from 2019 to 2050

In the Enhanced CF scenario, Malaysia's absolute emissions from electricity generation in 2050 could decline by 29% (Fig. 17). This aligns with NETR's projection of a 32% reduction for the entire energy sector, which includes transport, O&G production and others.

Although gas remains a key component of Malaysia's energy mix, the phase out of unabated coal would cause a substantial 62% drop in emissions intensity – measured as GHG emissions per unit of electricity. At 237 tCO_2e/GWh, Malaysia's projected emissions intensity in 2050 would match the European Union's in 2024 (237 tCO_2e/GWh from 45% RE, 23% nuclear, 17% gas and 12% coal) and outperform Germany's (334 tCO_2e/GWh from 57% RE, 17% gas and 22% coal).[8]

Fig. 17. Projections for 2050 indicate 29% absolute emissions reduction and 62% emissions intensity reduction

Malaysia's electricity sector emissions and emissions intensity (2019 v 2050, Enhanced CF)



Source: analysis by author

Supplying the 40% shortfall

To lock in the absolute GHG reductions and low emissions intensity achieved through fulfilling 60% of demand, the gap must be closed by deploying only domestic low-carbon sources or by increasing clean electricity imports. Given the inherent data uncertainties in GHG inventory measurements – as detailed in Chapter 3 – a prudent approach to meeting net-zero goals would be to aim beyond merely balancing emissions and removals, favouring deeper emissions cuts than the baseline requirement suggests.

5.1.2 Weather or climate dependence

This parameter assesses the reliance of the power sector on primary energy inputs that could be influenced by regular or subtle variations in the weather, as well as longer-term pattern shifts due to climate change. It reflects the underlying resilience of the electricity network to external conditions and the associated risks to energy security.

For this analysis, solar, hydro and bioenergy are categorised as being dependent on the weather or climate. Examples of disruptive conditions include reduced sunlight due to rain, cloud cover or haze for solar; shifting rainfall patterns or prolonged droughts for hydro; and uncertainties in the feedstock availability for bioenergy. Large-scale extreme events – such as major floods that could cause widespread infrastructure damages – are excluded from this parameter.

Parameter change from 2019 to 2050

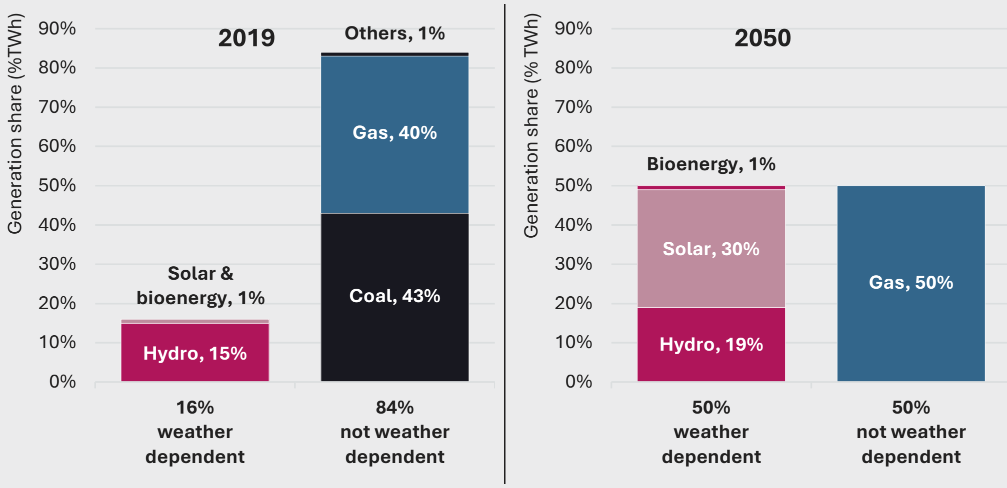
The Enhanced CF scenario could increase the weather or climate dependence of Malaysia's electricity generation mix from 16% in 2019 to 50% by 2050 (Fig. 18). The elimination of coal leaves gas as the only energy source that is largely decoupled from the influence of weather or climate. This reduces the available options for backup generation should disruptions occur to solar or hydro and places a significant burden on the gas supply network, as well as gas power plants, which would already be supplying half of the demand at elevated capacity factors.

Supplying the 40% shortfall

To mitigate structural risks faced by the power supply network arising from the growing exposure to weather and climate-linked variability, the remaining 40% demand gap must be served by deploying only robust sources that can operate normally regardless of external conditions. Although gas satisfies this requirement, increasing the already high reliance on this source may not be an optimal solution, even before economic considerations and fuel supply constraints are accounted for. Alternative measures should include large-scale deployment of long-duration energy storage, as well as multiple avenues for imports from neighbouring grids.

Fig. 18. Projections for 2050 indicate 50% weather-dependent electricity supply

Weather dependence of Malaysia's generation mix (2019 v 2050, Enhanced CF)



Source: analysis by author

5.1.3 On-site storage of primary energy inputs

This parameter assesses the availability or storage of primary energy inputs directly at the power generation facility. It reflects the facility's ability to maintain normal operations during short- to medium-term supply disruptions – an important factor in enhancing system reliability and mitigating energy security risks.

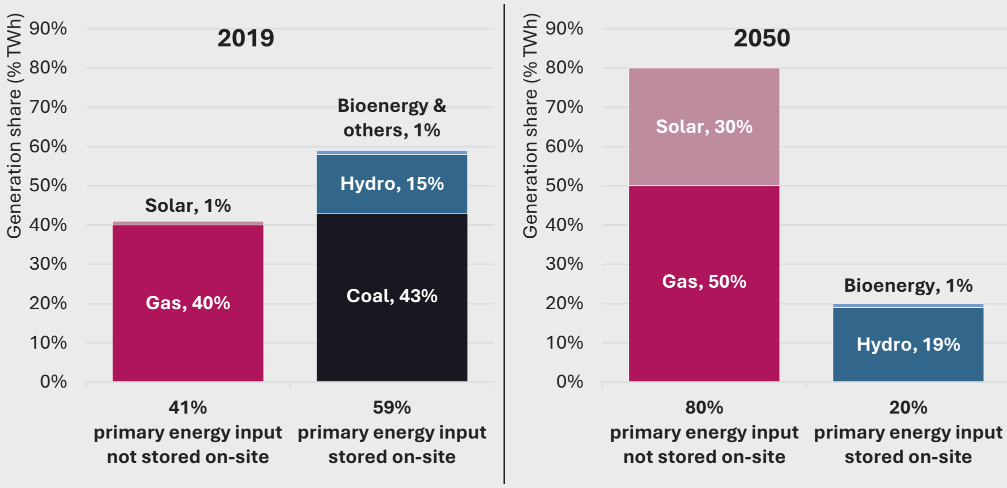
For this analysis, coal stockyards, hydro reservoirs and bioenergy feedstock stores are categorised as on-site energy inputs, as they are readily available for immediate use and can withstand external supply interruptions – a feature absent in gas and solar. Gas power plants in Malaysia depend on a continuous supply of piped gas from external networks and would be forced to curtail or cease operations if that is affected. Solar output, on the other hand, is entirely dependent on sunlight availability.

Parameter change from 2019 to 2050

Under the Enhanced CF scenario, Malaysia's reliance on electricity sources without on-site access to primary energy could rise from 41% in 2019 to 80% by 2050 (Fig. 19). With coal phased out, only hydro and bioenergy retain on-site storage capabilities. However, their relatively small shares compared with gas and solar limit their ability to compensate for supply disruptions.

Fig. 19. Projections for 2050 would result in 80% of electricity being produced by facilities that do not store their primary inputs on-site

On-site storage of energy inputs for Malaysia's generation mix (2019 v 2050, Enhanced CF)



Source: analysis by author

Supplying the 40% shortfall

To minimise the potential impacts of short- to medium-term disruptions, the 40% demand gap should be ideally fulfilled using sources with on-site storage of primary inputs or those that do not require real-time supply to sustain operations. Hydro satisfies this requirement but remains weather-dependent, and its further deployment may be constrained by the availability of suitable sites. Increasing the amount of electricity imports may also not be an optimal solution, as they constitute an external source for the grid as a whole and elevate energy security risks.

5.2 Technology matrix

Table 5 maps a broad selection of electricity supply options against the parameters from Section 5.1, along with additional factors to provide a broader context. The assessment is qualitative, with notes on the categories and technologies outlined in subsequent paragraphs, and not intended to be exhaustive. Rather, the technology matrix offers an overview that highlights key trade-offs, reinforces the case for diversification and enhances the energy transition discourse with more nuanced perspectives. It also serves as a foundation for more detailed studies in the future. The key takeaway remains that a narrow technology portfolio will not be sufficient to address all areas of concern related to the energy transition – economic development, sustainability, energy security, affordability, employment, land use, supply chains and more.

Table 5. An optimal generation mix should incorporate a diverse selection of technologies to balance trade-offs

Technology matrix for electricity supply options and characteristics (non-exhaustive)

Electricity technology	Low operational emissions	Independent from weather or climate	Primary inputs available on-site	Gigawatt-scale, baseload & dispatchable supply (Malaysian context)	Technology readiness level (global context)
Coal (unabated)	No	Yes	Yes	Yes	Mature
Coal (with carbon capture)	Potential	Yes	Yes	Yes	Emerging
Gas (unabated)	No	Yes	No	Yes	Mature
Gas (with carbon capture)	Potential	Yes	No	Yes	Emerging
Gas (with hydrogen co-firing)	Potential	Yes	No	Yes	Emerging
Solar (without battery storage)	Yes	No	No	No	Mature
Solar (with battery storage)	Yes	No	No	Potential	Scaling
Hydro (without pumped storage)	Yes	No	Yes	Yes	Mature
Hydro (with pumped storage)	Yes	No	Yes	Yes	Mature
Bioenergy	Situational	No	Situational	Situational	Mature
Wind (onshore and offshore)	Yes	No	No	No	Mature
Geothermal	Yes	Yes	Yes	No	Mature
Ocean thermal	Yes	No	Yes	No	Pilot
Nuclear (large reactors)	Yes	Yes	Yes	Yes	Mature
Nuclear (small modular reactors)	Yes	Yes	Yes	Yes	Emerging
Electricity interconnections	Situational	Situational	Situational	Situational	Mature

Source: analysis by author from multiple sources

Low operational emissions

This category, discussed in Section 5.1.1, refers to GHGs produced during electricity generation. Mature technologies, such as solar, wind, hydro and nuclear, do not directly emit CO_2 while operating and are favourable options to replace unabated coal and gas. Augmentations, such as advanced carbon capture and hydrogen co-firing, have the potential to reduce emissions from fossil fuel power plants. However, these are still emerging solutions and need to be commercially proven at scale. Lifecycle emissions from fuel extraction, manufacturing, decommissioning and other indirect or non-operational processes have been excluded from this analysis and could potentially be explored in future studies.

Independence from weather or climate

Described in Section 5.1.2, this criterion assesses whether a technology can produce electricity consistently despite short-term weather fluctuations or longer-term climate shifts. Output from solar, wind and hydro are variable and influenced by environmental conditions. In contrast, coal, gas, nuclear and geothermal are largely unaffected by weather and offer more reliable generation. As climate risks increase, weather-independent sources can provide greater predictability and system resilience.

Primary inputs available on-site

Section 5.1.3 evaluates whether the main input fuel or resource can be stored or is readily present at the generation site, which enhances energy security and continuity of supply. Hydro and coal power plants can typically meet these criteria, provided that sufficient water is available in reservoirs or coal in the stockyard, while nuclear facilities have the advantage of long-lasting uranium fuel that only needs to be replaced every 18 to 24 months. In contrast, gas plants in Malaysia rely on continuous piped supply, while solar and wind farms require real-time favourable conditions, such as adequate irradiance or wind speed – making them vulnerable to external disruptions.

Gigawatt-scale, baseload and dispatchable supply – Malaysian context

This category measures a technology's ability to deliver large quantities of consistent output power and adjust to changing demand. Coal, gas and hydro remain the mainstays for Malaysia, with nuclear technically suitable as a low-carbon replacement for fossil fuels. While solar deployment is accelerating, it is inherently intermittent and non-dispatchable without being supported by grid-scale storage – which would expand an already large land footprint and entail further investments. Malaysia has limited resources of geothermal and wind, which would not be sufficient to displace significant shares of fossil fuels.

Technology readiness level (TRL) – global context

The TRL indicates how commercially proven a particular technology is and signals its suitability to be considered for the electricity mix. “Mature” technologies have been widely operational for many decades, are well understood and can tap into a ready pool of human capital. “Scaling” technologies are gaining traction and may have regional maturity but are not yet widespread. “Emerging” or “pilot” options may not be ready for near-term deployment or are in early stages of research and development, and hence face higher uncertainty. The TRL helps policymakers assess risk, planning horizons and the need for institutional support.

Coal

Coal-fired power, currently the backbone of Peninsular Malaysia’s electricity mix, offers high reliability and on-site fuel storage, making it well suited for stable baseload generation. However, unabated coal has high operational emissions and is incompatible with long-term decarbonisation objectives. While carbon capture technologies can reduce emissions, their feasibility remains unproven. Current solutions are expensive, energy-intensive and largely confined to pilot or early commercial applications, especially in power sector contexts. Malaysia’s commitment to phase out coal by 2044 will significantly drive down power sector emissions, but replacing the lost generation remains a key challenge.

Gas

Gas is a pivotal part of Malaysia’s generation mix, offering dispatchability, weather independence and high technology maturity. However, it lacks on-site fuel storage and remains emissions intensive. Carbon capture for gas-fired plants, while emerging globally, is still at an early stage of deployment and carries uncertainties around cost and integration. Hydrogen co-firing adds another layer of complexity. Although theoretically viable, it depends heavily on future hydrogen production, transport and regulatory readiness. In Malaysia, these technologies may have some potential but are not yet scalable nor cost-effective in the short or medium term.

Solar

Solar photovoltaics are Malaysia’s most rapidly expanding renewable resource. However, they are wholly weather-dependent and generate electricity only when sunlight is available. Without storage, solar offers no dispatchability. With battery storage, the contribution of solar becomes more flexible, but its ability to serve baseload functions is still limited by scale, cost and the relatively short duration of current battery systems. The significant ramping up of solar will also necessitate grid upgrades to manage the challenges of increasing variable RE shares. Ground-mounted solar farms are also land-intensive due to the technology’s low energy density, and widespread deployment must also leverage rooftop, floating and agro-voltaic applications.

Hydro

Hydropower plays a foundational role in Malaysia's energy system. Both conventional and pumped storage systems offer low operational emissions, on-site energy inputs via reservoirs and dispatchable output. However, hydro is highly weather-dependent and sensitive to changing rainfall patterns, which could be exacerbated by climate change. Its scalability is also geographically constrained by topography and environmental impact considerations. Nevertheless, in areas where it is already deployed, hydro remains a robust, mature and dispatchable source of electricity.

Bioenergy

Bioenergy can be dispatched and has on-site input storage when properly designed, but its emissions profile, feedstock consistency and land-use impacts make it highly context-dependent. In Malaysia, opportunities exist in using palm oil waste and municipal solid waste, but their economic and environmental trade-offs vary widely. Bioenergy is therefore classified as "situational" across several parameters: technically mature but inconsistently scalable or sustainable depending on feedstock, policy design and lifecycle emissions accounting.

Wind

Wind power offers low emissions and mature global deployment but faces several challenges in Malaysia. Onshore wind is limited by low and inconsistent wind speeds, particularly in Peninsular Malaysia. Offshore wind shows better potential, especially in Sabah and Sarawak, but is constrained by higher costs, deeper waters and limited grid readiness. Both technologies remain non-dispatchable and weather-dependent and lack ready on-site input. Despite global technological maturity, the role of wind in Malaysia's mix is limited and highly location specific.

Geothermal

Geothermal provides continuous, emissions-free generation with on-site energy and full independence from weather patterns. Globally mature, it performs well across all parameters – except in terms of geographic suitability. While Malaysia possesses some geothermal resources, they are limited in scale and remain largely untapped. Development would require careful resource assessment, regulatory alignment and investment in specialised drilling expertise. Thus, while technically ideal, geothermal is unlikely to play a significant role in Malaysia based on site availability and current industry depth.

Ocean thermal

Ocean thermal energy conversion (OTEC) uses temperature differences between surface and deep-sea water to generate electricity. It offers low emissions and on-site energy inputs but remains in pilot-stage development globally. While Malaysia's equatorial waters are theoretically suitable, OTEC systems face high capital costs, limited commercial precedents and complex engineering challenges. This keeps them in the "pilot" category, with no large-scale near-term deployment expected.

Nuclear

Nuclear energy can generate large-scale, low-emissions, dispatchable electricity that is independent of weather or real-time input supply. Large conventional reactors are mature, evolutionary designs that currently operate in over 30 countries, while emerging small modular reactors – which may offer siting and financing flexibility – are still in the early stages of global commercial deployment. Both variants are viable options to diversify Malaysia's long-term energy mix, particularly for the post-2030 horizon, subject to financing capabilities and institutional readiness. However, major policy, regulatory and public engagement initiatives are still required before nuclear energy can be introduced domestically.

Electricity interconnections

Cross-border electricity trade via interconnections is technologically mature and already operational in ASEAN. Interconnections can complement domestic generation and displace fossil fuels if sourced from hydro, wind or solar. However, in addition to geopolitical considerations, they are still dependent on weather conditions and incorporate all the inherent challenges of the originating RE sources. In Malaysia, greater integration with the ASEAN Power Grid could enhance system resilience and contribute to power sector decarbonisation, but policy, regulatory alignment and physical infrastructure must be scaled to achieve these goals. Interconnections remain a key strategic enabler to unlocking ASEAN's significant RE potential but should not be considered a standalone solution for importing nations.

6 Conclusions and recommendations

Malaysia's energy transition trajectory is positive but can be enhanced

NETR commits to phasing out coal, the largest source of CO_2, and relies on technologies that are familiar to the national electricity mix – gas, hydro and solar – to meet future demand. This approach leverages existing capabilities and experience, while establishing a pragmatic foundation for power sector decarbonisation and growth. However, the analysis shows that this portfolio – at the projected proportions – will not be sufficient to meet long-term needs. **The current low-emissions pathway should be augmented to include new sources of domestic generation, a larger role for clean energy imports and storage, as well as enhanced carbon mitigation technologies.**

Emissions data are imprecise and net-zero targets not absolute

Malaysia has consistently reported its emissions inventory, as required by the IPCC, but it must be acknowledged that the figures are inexact estimates. BUR4 and BTR1 show that baseline data can shift due to changes in emission factors, methodologies and assumptions. While "net zero" is technically a balance between emissions and removals, the reality is more complex. In BUR4, fossil fuel emissions have an uncertainty margin of around 15%, while removals from forests and land use can vary by 20% or more. This puts Malaysia's 2019 net zero gap within a wide range of between 23 and 208 $MtCO_2e$, compared with the median value of 115 $MtCO_2e$ that underpinned NETR and LT-LEDS. **Inherent data uncertainties suggest that net zero targets should be treated as a trajectory indicator rather than a precise endpoint, with policy measures prioritising measurable and verifiable emissions reductions, rather than over-reliance on offsets and carbon accounting mechanisms.**

Installed capacity is not the same as generated electricity

Shares of installed capacity that are typically used to describe the power generation mix do not automatically translate to the amount of firm, dispatchable electricity produced. Analysis suggests that 58% solar capacity in 2050 is expected to contribute only about 30% of total generation, whereas gas, at 29% installed capacity, could potentially supply about 50% electricity. This mismatch indicates that, while installed capacity is a key metric for power system planning, it does not provide the complete picture necessary to illustrate the adequacy of energy supply and resulting decarbonisation outcomes. The actual contribution of various energy sources is more nuanced and should account for differing capacity factors that result from intermittency, availability of fuel and various other real-world factors. **As national energy literacy initiatives gain wider traction among the public, the related messaging should also evolve to more clearly reflect underlying complexities so that public understanding aligns with operational realities and the practical constraints shaping power sector decarbonisation.**

Current pathways predict potential long-term generation shortfalls

Applying a range of capacity factors to NETR's 2050 portfolio indicates that electricity generation may be insufficient to meet projected demand growth, with estimated shortfalls ranging between 27% and 53%. The median enhanced CF scenario, which assumes improved but achievable capacity factors, results in a 40% supply-demand gap. **An energy transition strategy centred on familiar technologies may struggle to simultaneously deliver the required emissions reductions and keep pace with growing electricity demand.**

Current pathways reduce emissions but increase power system risks

The enhanced CF scenario could potentially result in reductions of 29% in absolute emissions and 62% in power sector emissions intensity in 2050, driven by the complete removal of coal from the energy mix. However, relying primarily on gas, hydro and solar to achieve these decarbonisation levels also introduces new systemic risks that must be explicitly recognised and managed. Weather-dependent generation rises from 16% in 2019 to 50% in 2050, increasing exposure to sunlight intermittency, rainfall variability and long-term climate shifts. In parallel, sources without on-site energy inputs expand from 41% to 80%, shrinking operational buffers against short- to medium-term supply disruptions. **Lower emissions outcomes do not necessarily translate into greater system resilience, as increased exposure to weather variability and real-time resource availability introduces new operational vulnerabilities.**

Closing the supply-demand gap must utilise technologies that preserve gains

To lock in the emission reductions associated with the 60% demand fulfilment projected under the Enhanced CF scenario, the remaining 40% should be met with domestic low-carbon generation or clean electricity imports. Given the GHG inventory uncertainties outlined in this report, a prudent approach would be to aim beyond the mere balancing of emissions and removals, instead favouring deeper decarbonisation levels beyond net zero. **Additional generation sources deployed to fully satisfy demand should also mitigate weather exposure and strengthen on-site resilience, by prioritising technology options with stored inputs or strong decoupling from climate variability, ensuring that climate targets do not inadvertently erode system reliability.**

Diversification is essential for balanced electricity system

The technology matrix derived through this research signals that there is no single generation source that can meet all the demands of power sector decarbonisation. Each option advances some objectives while trading off others across the five sample parameters assessed – operational emissions, independence from weather and climate, on-site primary inputs, ability to provide gigawatt-scale, baseload and dispatchable supply in the Malaysian context, and global technology readiness. Broadening the analysis to encompass even more assessment criteria will emphasise this point even further.

This multi-parameter perspective underscores why a narrow generation portfolio will struggle to deliver on all electricity supply objectives simultaneously. Solar-plus-storage improves flexibility but remains duration-limited at the system scale and has land-use impacts. Hydro is firm where reservoirs are available yet remains weather-sensitive and faces siting constraints. Gas is dispatchable but still emits CO_2 unless paired with abatement and interconnections add system flexibility but shift some control beyond national borders and dilute energy security. Large nuclear reactors, which satisfy the limited and non-exhaustive assessment parameters, must still contend with other risk factors, such as institutional readiness, public trust, financing capabilities and geopolitics, among others. Small modular nuclear reactors, while promising in theory, are an emerging technology that will need to be commercially proven at scale.

Malaysia should diversify beyond the portfolio of solar, hydro and gas outlined by NETR and deploy a broader generation mix that balances reliability, equity and sustainability, accounts for emerging systemic risks and delivers a future-proof electricity system capable of supporting decarbonisation, economic development and national prosperity.

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INSTITUTE OF STRATEGIC &
INTERNATIONAL STUDIES
(ISIS) MALAYSIA

Address 1, Persiaran Sultan Salahuddin,
50480 Kuala Lumpur, Malaysia
Phone 603 2693 9366
E-mail info@isis.org.my

www.isis.org.my | ISIS_MY

ISISMalaysia | isis-malaysia

isis_malaysia