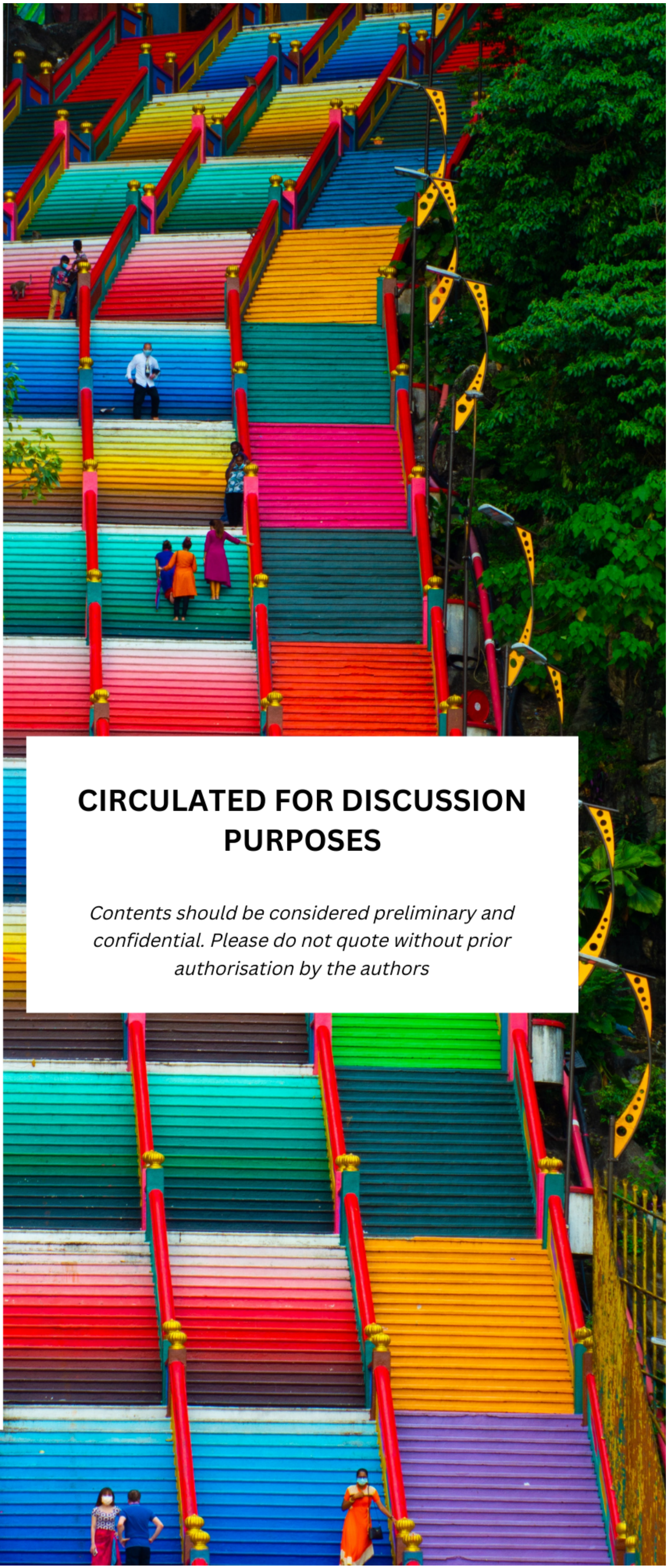
ASEAN GREEN FUTURE PROJECT PHASE II INTERIM REPORT

Net Zero Pathways for Malaysia



CIRCULATED FOR DISCUSSION PURPOSES

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NOVEMBER 2022

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Preface

ASEAN Green Future (AGF) is a multi-year project involving the Sustainable Development Solutions Network, ClimateWorks Centre and research groups in Southeast Asia. AGF started with an online meeting of seven country teams on 23 February 2021. Phase 1 of AGF was completed in in time for presentation COP26 held in November 2021. Phase 1 presented an overview of the current greenhouse gas emissions situation in each country and the climate actions undertaken; and identified the different pathways and technology options to achieve net zero emissions.

Several country teams share their research findings with policy makers and stakeholders, and the usual outcome has been the initiation of regular discussions between the country team and a key government agency. The Phase 1 reports have been put on various online knowledge platforms, and the large amount of feedback has helped shape the design of Phase 2 of the project.

Phase 2 of AGF has two components. The first component is the quantification of selected net zero pathways in each country. The second component is the analysis of several region-wide issues like an ASEAN-wide electricity grid, and an ASEAN high-speed train network. The number of country teams participating in Phase 2 has now grown to nine.

This interim report on Malaysia presents the main findings of the country team in 2022, after the completion of its Phase 1 report last year. The objective of releasing the interim report is to invite feedback and trigger discussion. The preparation of this report has benefited greatly from the outstanding technical support arranged by the UK Partnering for Accelerated Climate Transitions (UK PACT) and insightful comments of the participants at the meeting of the Asian Economic Panel held at the Bank of Finland in July 2022.

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Acknowledgements

We are grateful to the following people for their support, wisdom, insight, foresight and informed opinion: Syaqil Suhaimi, UK PACT; Hanna Chorbachi, UK PACT; Caitlin White, UK PACT; Khairun Zabidi, UK PACT; YB Dato' Sri Mustapa Bin Mohamed, Economic Planning Unit, Prime Minister’s Department; Ong Pang Yen, Sunway Berhad; Dato’ Dr. Ooi Kee Beng, Penang Institute; Dr. Chen Jit Ern, Sunway University; Huang Chi-Shou, Cosmic Sabre Paper Industries Sdn. Bhd.; Dr. Kam Yin Fah, NZ Bio Forestry; Lin Kai Hsuan, NZ Bio Forestry; Leon Lai, Solarvest Holdings Bhd; Prakash Sothivadivel, Petronas Power Sdn. Bhd.; Dr. Chen Wei-Nee, Bursa Malaysia; Nirinder Singh Johl, Asia CarbonX Change PLT; Vasu R. Vasuthewan, International Sustainability & Carbon Certification; Stephen Matthews, Digital Edge Technologies Sdn. Bhd.; Professor Toby Monsod, University of the Philippines; Professor Guy Liu, Peking University HSBC Business School; Teh Ah Kah; Ryan Hardin, Sarawak Energy Berhad; Terence Leong Shuh Onn, Sarawak Energy Berhad; Stephen Yee Han Min, Sarawak Energy Berhad; Professor Mohamed Kheireddine Aroua, Sunway University; Dr. Chong Kok Boon, Sunway University; Ku Kok Peng, Kuala Lumpur Kepong Berhad; Tony Foo, Sunway Marketing; Hugo Losada, Hume Cement; Serina Ho, Hume Cement; Grace Ong, Cement and Concrete Association of Malaysia; Elaine Chiew, Cement and Concrete Association of Malaysia; Ng Mor Kiang, Malaysian Iron & Steel Industry Federation; Rezuan Masran, Malaysian Iron & Steel Industry Federation; Yeoh Wee Jin, South East Asia Iron and Steel Institute; Yeoh Choon Kwee, Southern Steel; Chua Seok Cheng, Southern Steel; Professor Aldis Karklins, Latvia University of Agriculture; Chan Pek Wan, Fertilizer Industry Association of Malaysia; Tan Bee Chin, Fertilizer Industry Association of Malaysia. We would also like to thank the publication team: Danial Lissborg, Low Wai Sern and Justin Liew. Photo credit: Akhir Roslan (front) and Megan Thomas (back).

Disclaimer

1. Decarbonizing Technical Systems and Recarbonizing Ecosystems

Leong Yuen Yoong and Michael James Platts

In thinking about a green future for Southeast Asia, we propose two zones of analysis. One is technology development focused (Technology Road Mapping - TRM) and the other is ecosystem growth oriented (Ecosystem Growth Mapping – EGM). The latter is central to the whole nature of the Southeast Asian countries.

Technology Road Mapping

TRM develops a set of possible forward technology roadmaps and establishes key technical feasibility and costing issues, so that detailed clarifying explorations can be initiated within an overall plan. Everything can then be evidence based, both concerning technical possibilities (detailed products and infrastructural issues) and risks (giving a clear sight of not only what the risks are, but where we should focus work to explore and clarify the risks).

Carbon accounting (CA) which takes account of all carbon cost (CC) and carbon benefit (CB) is fundamental in TRM because it is what we are trying to achieve, i.e. decarbonization.

Calculating carbon benefits from a product is easier than calculating carbon costs. A complete accounting of carbon costs means the total carbon cost of developing, producing and operating it - from the establishing of the mines for the ores, transporting the ores and smelting the metals from the ores through to completing and installing the product and supplying the fuel for operating it.

Using energy and materials for human purposes without counting the cost, seems to be where mankind is heading. To suggest a carbon benefit from a product, without analyzing and setting out the total carbon cost is not 'accounting for it' at all. It is promulgating a wish.

Getting the basic data will be difficult. How do you get the underlying energy usage 'costs' of creating and operating a whole new mining operation, for instance? It requires the global mining companies to become collaborative and transparent. However, they will not disagree to the principle of doing so. Hence, it is an exercise in diplomacy to start those conversations and open them up. It is about developing trust. It is essential if the world is ever to achieve transparent understanding of the carbon emissions it creates in the process of 'going about its business'.

Ecosystem Growth Mapping

The second zone of analysis (EGM) considers soil, forest, mangroves, corals, seagrass etc. as ecosystems and are carbon sinks. EGM designs road maps on how to nourish ecosystems and encourage them to grow and expand. This will enhance their capacities to absorb CO_2.

Whilst technology needs decarbonizing, ecosystems – which absorb carbon to create life - have suffered from being decarbonized (e.g. deforestation and degradation result in ongoing carbon loss) and they need investment in recarbonization, not decarbonization. Growing ecosystems is in fact a process of re-carbonizing the natural ecosystem.

Most of the developed world is highly technically developed and thus naturally think in terms of technology road mapping into the future. As the majority of Southeast Asian countries are still heavily dominated by natural ecosystems, we need to develop a carbon strategy for Southeast Asia which puts the recarbonization of ecosystems at centre-stage.

Mainstream decarbonization research leans heavily in the TRM direction and does not really contain the EGM dimension, and there is no thought of mindset change. Even suggesting that a mindset change is needed will be something people will struggle with and not take on board easily.

Mindset | Vocabulary | Behavior | Actions

We need to develop the mindset, vocabulary, behavior and actions for carbon accounting and nourishing ecosystems. Besides developing analytical capabilities, we must also establish the language necessary for humanity to really evolve and deserve sustainability. The insights that come from humility in the EGM zone are key.

It is not simply about not losing - not destroying - the major global ecosystems within which the Southeast Asian countries live, it is about developing a more understanding relationship with them - recognising the enormous living value that they embody in their complexity and learning to enhance it and draw harvest from it.

Getting people to understand the coordinated complexity of life that a total ecosystem is and respect it as that totality is important. Humans are part of a community of beings within an ecosystem. Sustainability is not only about securing the wellbeing of future human generations, but also about ensuring the vibrancy of other living beings with which we share one planet. This is the way of nature – the *tao* or heaven's justice.

There is another mindset issue that needs to be understood and grasped in TRM. All the renewable (supposedly 'sustainable') energy technology currently installed, being designed and developed and due to be installed in the near future - wind and solar especially - has design lives of around 25 years, which means that none of it, anywhere in the world, will still be operational in 2050. All will be derelict, in need of being dismantled and replaced.

When civil engineers design infrastructure, it is usual to have design lives of 120 years in mind; much of the infrastructure around us is centuries old. Something designed to last 25 years is not infrastructure. We need to think about developing long lifetime technology.

ASEAN Green Future - Malaysia

Figure 1 shows the carbon intensive sectors in Malaysia. Decarbonization and recarbonization pathways are studied for seven sectors in Malaysia, as shown in **Figure 2Figure 2**[1].

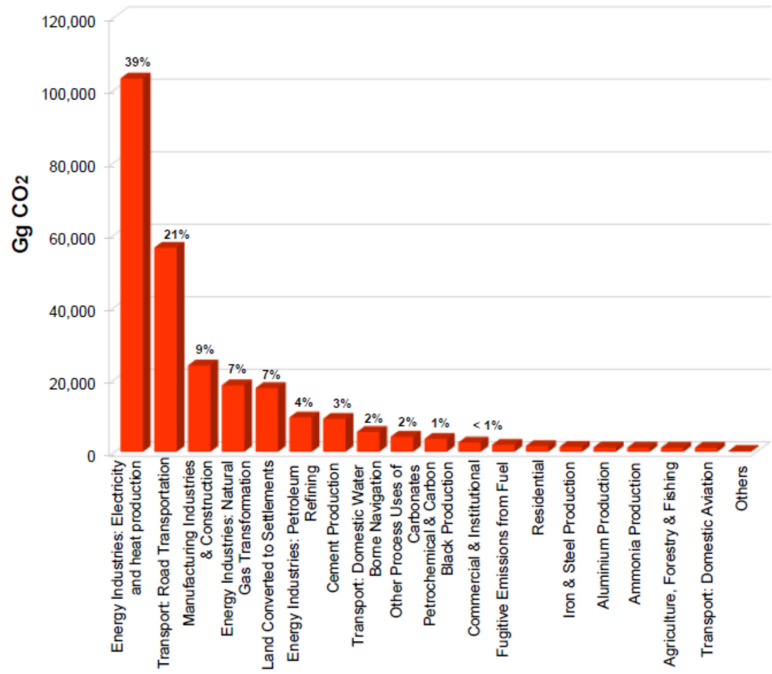


Figure 1: Major sources of carbon dioxide in Malaysia in 2016 *(Ministry of Environment and Water, 2020)*

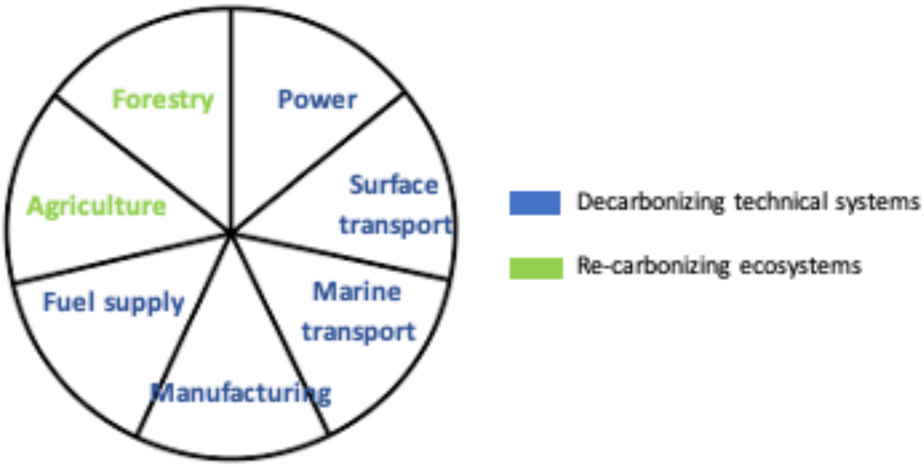


Figure 2: Sectors studied for Malaysia

[1] The size of the segments does not relate to the emissions impact, which is already shown in **Figure 1** (a snapshot of the past). All sectors are part of an ecosystem. A circular presentation symbolizes wholeness and vitality when the flow between sectors deepens in a circular economy.

2. Net Zero Pathways for Malaysia

Prime Minister Ismail Sabri Yaakob tabled the 12th Malaysia Plan (12MP) in parliament on 27 September 2022 with a pledge for Malaysia to "become a carbon neutral country by 2050 at the earliest", alongside other measures to accelerate green growth. Details on the 2050 net-zero emissions target may be released by the government this year **(Bernama, 2022)**. Details that are being discussed include:

- Exploring the introduction of a voluntary carbon market and carbon pricing mechanism such as carbon tax
- Expansion of green technology tax incentives
- Carbon trading

Notable developments that contribute to Malaysia's net zero target include:

- December 2021: Bank Negara Malaysia released the Exposure Draft on Climate Risk Management and Scenario Analysis, which sets out expectations to enhance financial sector resilience against climate-related risks
- December 2021: The Securities Commission Malaysia released a consultation paper on SRI Taxonomy for the local capital market to identify economic activities that are aligned with environmental, social and corporate governance objectives
- June 2011: Malaysia's Renewable Energy Act was passed to encourage the development of the renewable energy (RE) sector. The government has set a target of 30 per cent renewable energy installed capacity for the power sector by 2025;
- June 1992: The Malaysia government committed to keep 50 per cent of the nation's land area under forest cover at the 1992 Rio Earth Summit.

2.1 Electricity Generation

Leong Yuen Yoong

Abstract

This paper sets out a view of what a net zero compatible power system looks like in Malaysia and assess how this can most effectively be achieved both from a cost and carbon perspective. This is achieved by advancing answers to the following two questions as far as possible:

i. Figure out an optimum energy mix for Malaysia for 2030, 2040 and 2050, based on technical and financial feasibility, and economic and institutional considerations
ii. Consider the role of grid modernization to maximize new technology uptake and energy efficiency

Current and historical emissions in power

Carbon dioxide (CO_2) emissions from the electricity and heat production sector were 103 million MT in 2016, which is 39% of the Malaysia total (**Figure 1**). These emissions largely come from the burning of coal and gas for electricity, with a small proportion from fuel oil, diesel, biomass and biogas.

- Carbon intensity of electricity generation has been increasing in tandem with coal share increase since the 2000s (**Figure 3**)
- Natural gas plants contribute 28% of power emissions (**Figure 4**) and provide 43% of total electricity generation (**Figure 5**)
- Coal accounts for 70% of emissions (**Figure 4**), and 44% of generation (**Figure 5**)
- The remaining 2% of emissions come from fuel oil, diesel, biomass and biogas
- The specific CO_2 emissions (g/kWh) from fuel oil and diesel are much higher than coal and natural gas (**Figure 6**)
- Crude oil has a far higher specific cost of resource for 1 TJ of energy input (MYR/TJ) than coal and natural gas (**Figure 7**)

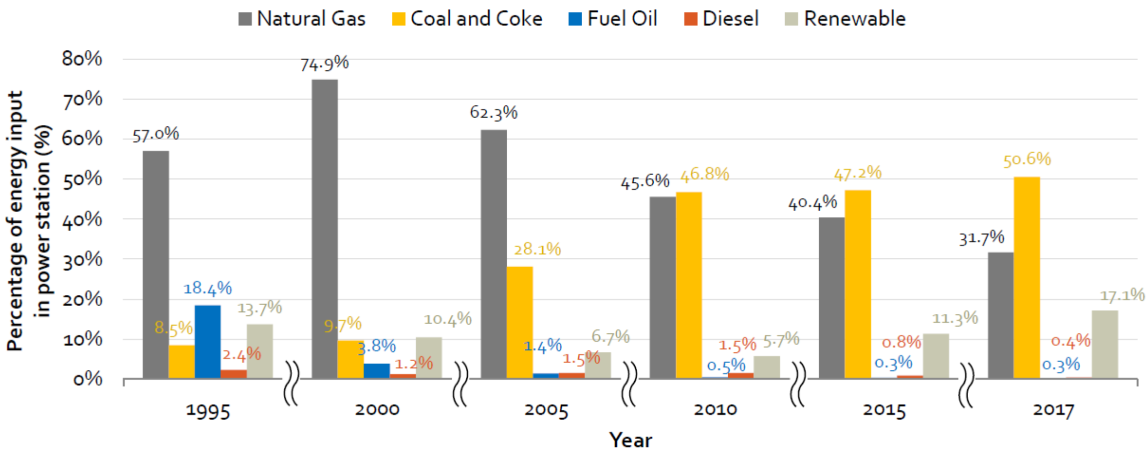


Figure 3: Energy input in power station (1995-2017) *(Siti, Chiong, Rajoo, Takada, & Chun, 2021)*

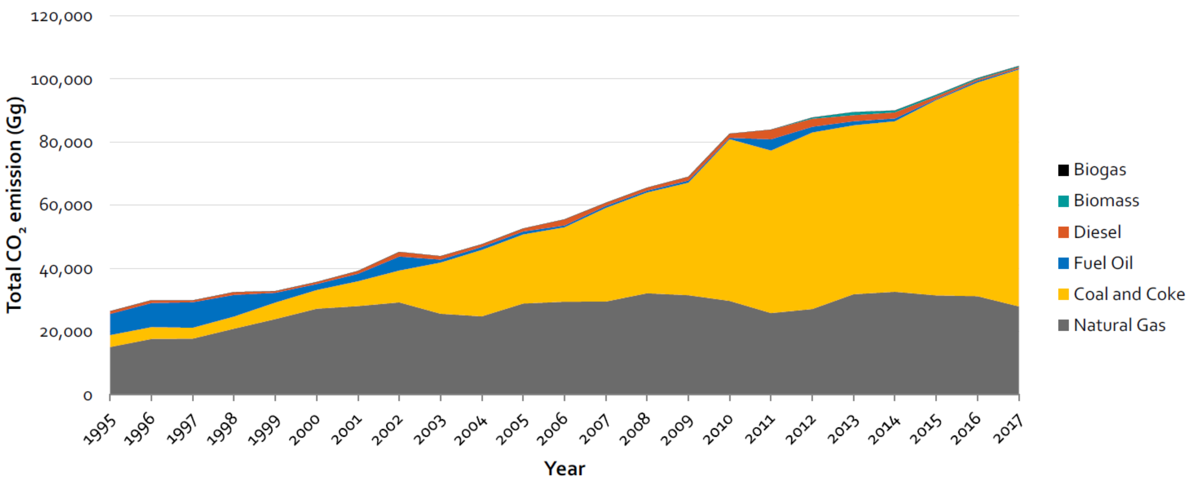
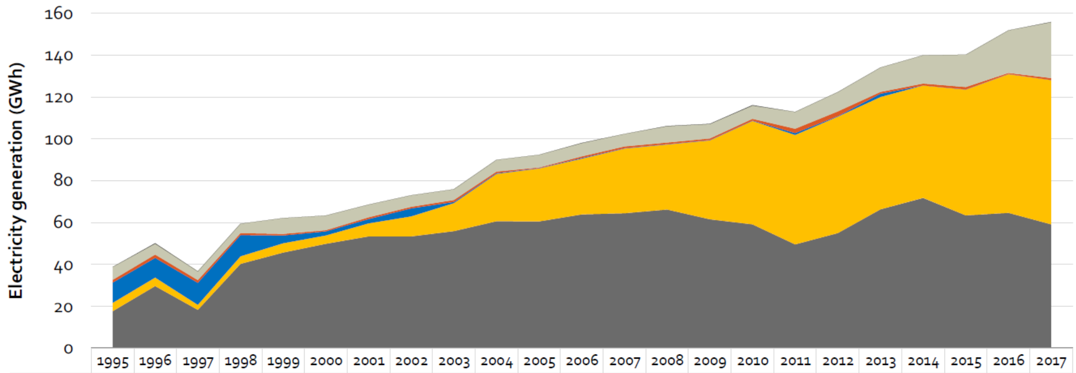


Figure 4: Total annual CO_2 emissions from Malaysia electricity generation sector (1995-2017) (Siti, Chiong, Rajoo, Takada, & Chun, 2021)



	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Others	0	0.189	0	0	0	0	0	0	0	0	0	0.05	0.063	0.066	0.132	0.17	0	0	0.002	0	0	0.018	1×10^{-4}
Hydro-power	6.2	5.2	4.1	4.5	7.6	7.0	6.1	5.4	5.1	5.6	6.0	6.3	6.0	7.8	6.9	6.4	8.0	9.2	11.7	13.4	15.5	20.3	26.8
Diesel & distillate	1.2	1.6	1.3	1.0	0.7	0.6	0.8	0.7	1.0	0.7	0.3	0.8	0.8	0.7	0.7	0.8	2.1	2.3	0.8	0.9	1.2	0.6	0.9
Oil	9.7	9.3	10.4	10.1	3.7	1.9	2.0	3.9	0.5	0.4	0.2	0.3	0.2	0.2	0.2	0.2	0.9	0.2	1.6	0.0	0.0	0.0	0.0
Coal	4.0	4.2	2.5	3.7	4.5	4.0	6.2	9.6	13.4	22.6	25.2	26.6	30.9	31.0	37.6	49.4	52.3	55.6	53.7	53.7	60.1	66.2	68.9
Natural gas	17.7	29.6	18.4	40.3	45.7	49.9	53.4	53.4	55.9	60.6	60.6	63.9	64.5	66.3	61.6	59.1	49.6	55.0	66.3	71.8	63.4	64.7	59.2

Figure 5: Electricity generation (1995-2017) *(Siti, Chiong, Rajoo, Takada, & Chun, 2021)*

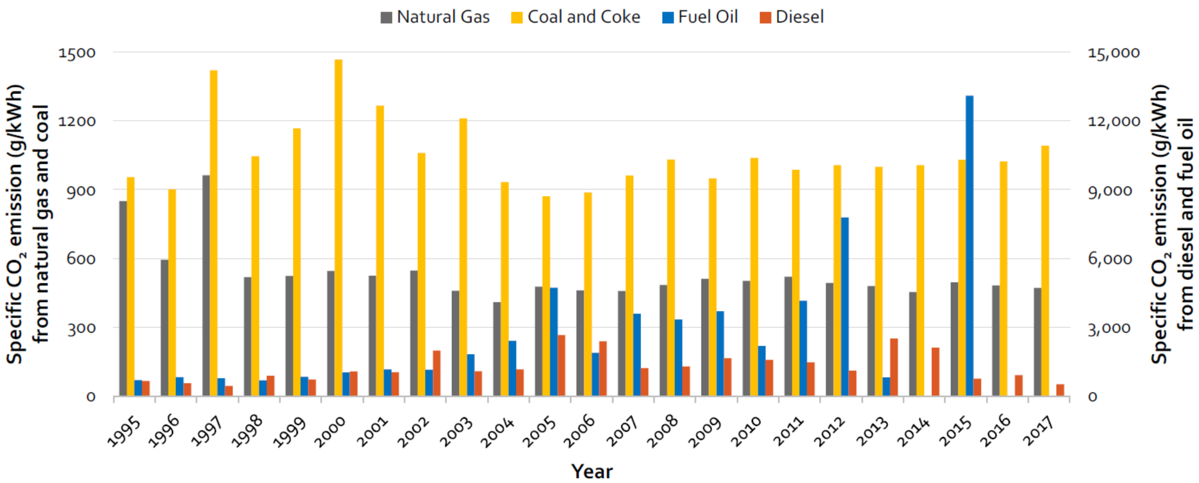


Figure 6: Specific CO_2 emissions from Malaysia electricity generation sector (1995-2017) *(Siti, Chiong, Rajoo, Takada, & Chun, 2021)*

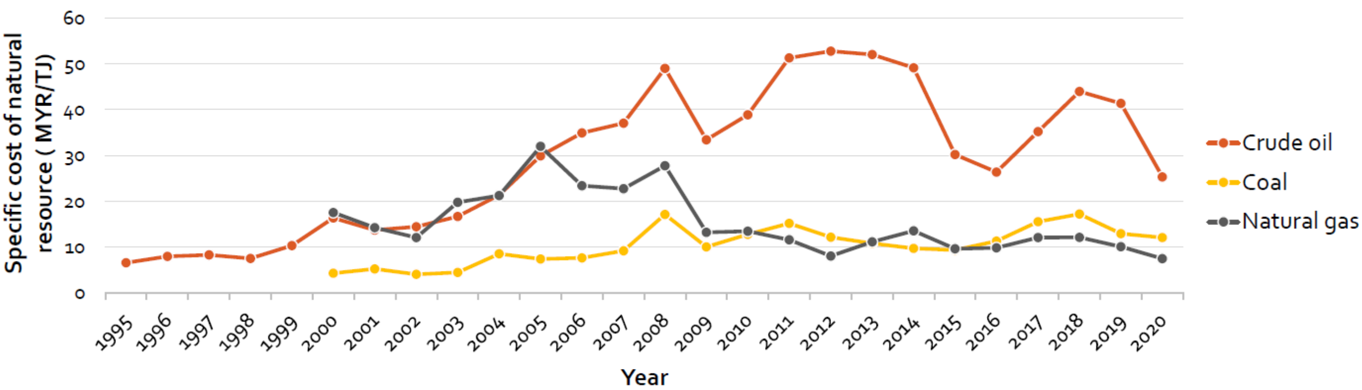


Figure 7: Specific cost of resource for 1 TJ of energy input (MYR/TJ) *(Siti, Chiong, Rajoo, Takada, & Chun, 2021)*

Malaysia’s decarbonization commitment

Malaysia’s absolute carbon emission will increase even when its NDC target is achieved

Malaysia’s revised nationally determined contribution (NDC) submitted in July 2021 sets an unconditional target to cut carbon intensity against GDP by 45% by 2030 compared to 2005 levels. Absolute carbon emission will still increase, even when the NDC target is achieved.

Four sources of renewable energy in Malaysia

Solar, hydro, biomass and biogas are the four sources of RE supported by policies in Malaysia. Their potential is abundant (**Table 1**) and different geographical locations are endowed by nature differently (**Figure 8**).

Malaysia targets 31% RE in its installed power generation capacity in 2025 and 40% in 2035. As of June 2021, the installed capacity for RE in Malaysia is 7,995MW. By 2035, the RE installed capacity is projected to more than double to 18,000 MW. The different RE components of these targets are shown in **Figure 9**. RE in Malaysia is driven by solar and hydro.

Table 1: Renewable energy resource potential identified in Malaysia

RE Type	Breakdown	Total
Solar PV	Ground-mounted: 210 GW Rooftop: 42 GW Floating: 17 GW	269 GW
Large hydro (>100 MW)	Peninsular Malaysia: 3.1 GW Sarawak: 10 GW Sabah: 0.5 GW	13.6 GW
Bioenergy	Biomass: 2.3 GW Biogas: 736 MW Municipal solid waste: 516 MW	3.6 GW
Small hydro (up to 100 MW)		2.5 GW
Geothermal		228 MW

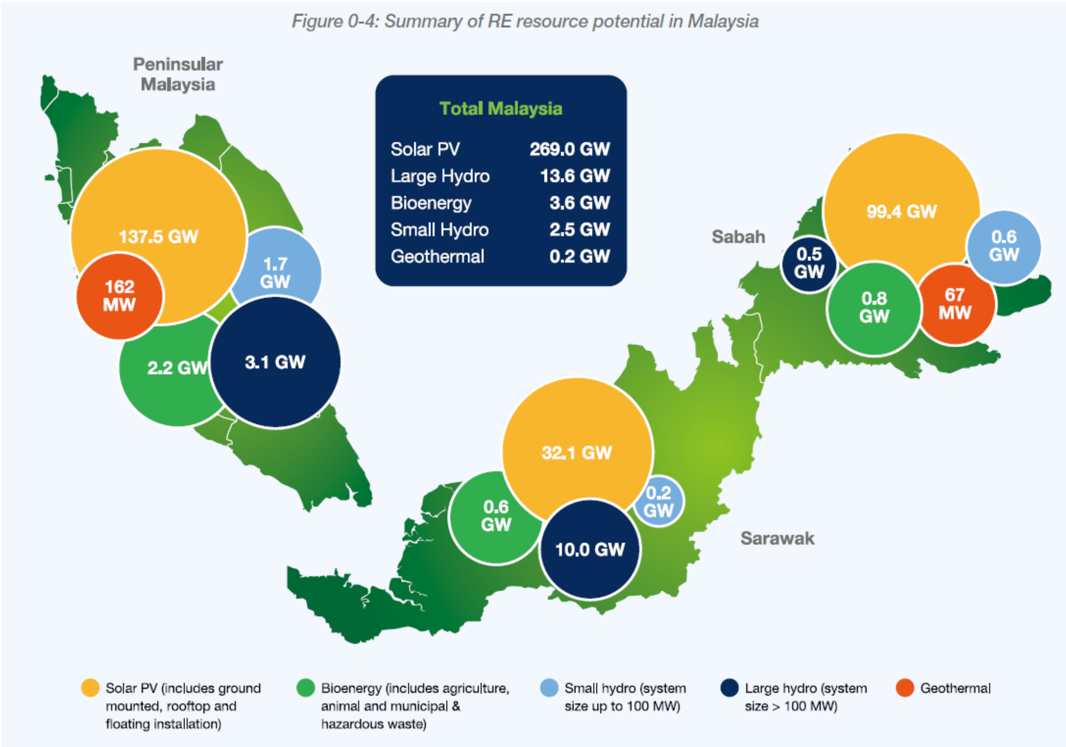


Figure 8: Geographical distribution of renewable potential in Malaysia *(SEDA Malaysia, 2021)*

Malaysia's commitment to No New Coal is uncertain

The Low Carbon Nation Aspiration 2040 (National Energy Policy 2022-2040) released in September 2022 *"**endeavours** to no new coal power plant amid increasing renewables share"*. However, from now till 2039, the retirement of coal-fired power plants in Peninsular Malaysia with a total capacity of 7,044 MW is projected to be replaced by 2,800 MW of new coal capacity in 2031 (2 x 700 MW), 2034 (700 MW) and 2037 (700 MW) (Energy Commission, 2021). The other retired coal-fired capacity will be mostly replaced by gas and RE.

What needs to be clearer is the percentage of overall electricity demand that is planned to be serviced by coal over time, the associated emissions, what this means for Malaysia's net zero target, and how it would be delivered.

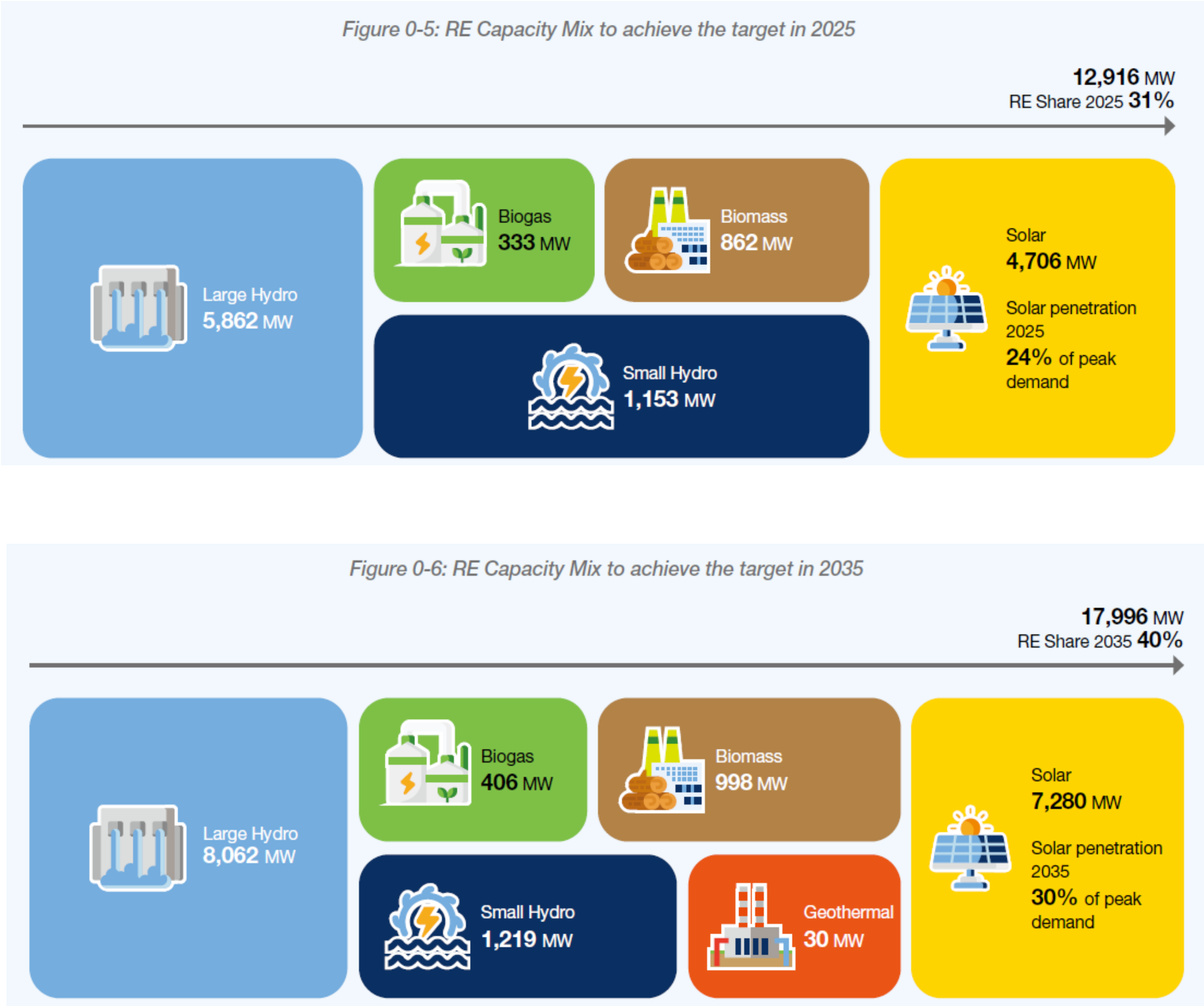


Figure 9: Targeted renewable energy capacity mix in Malaysia by 2025 and 2035 *(SEDA Malaysia, 2021)*

Sabah's power generation profile is shown in **Table 2.** Natural gas is the dominant fuel, followed by diesel. RE such as hydro, biomass / biogas and solar contributes to about 10% of the power generation capacity, and power generation in 2019. Coal is not in Sabah's energy mix.

The Sabah state government has established the Sabah State Energy Unit under the Chief Minister's Department to carry out the task of planning and regulating the development of RE, if the process of handing over the power of electricity supply is carried out[2]. RE capacity has grown to 15% (218 MW) in 2022 and Sabah Electricity Sdn Bhd (SESB) aims to increase it to 40% three years from now. SESB plans to phase diesel out of Sabah's energy mix, increase RE generation and achieve net zero emissions by 2050. (Inus, 2022)

[2] Parliament passed the preparatory bill for the re-handover of Sabah's electricity autonomy on 3 October 2022.

Table 2: **Sabah's electricity supply** *(Energy Commission, 2019)*

	Power Generation Capacity (1,235 MW)	Power Generation (6,512 GWh)
Natural gas	78%	86%
Diesel	12%	4%
Hydro	7%	7%
Biomass / biogas	2%	2%
Solar	<1%	<1%

Sabah is at a critical juncture as the state decides how to phase out diesel in locations that do not yet have natural gas infrastructure. In November 2022, the state approved a proposal to utilize lignite reserves for high efficiency lower emission coal power generation in such a location, despite receiving an independent review that highlighted the disadvantages of the coal route. Sabah has a natural advantage for biomass power generation due to the wood and oil palm industries. Planning for biomass (wood pellet and palm kernel shell) as a feedstock right from the start can improve a power generation project's viability.

The regulation of energy and electricity in the state of Sarawak is under the purview of Sarawak's Ministry of Utilities, with Sarawak Energy Berhad (SEB) being the primary supply authority. SEB has decarbonized the state's power system by 70% within a decade (2010-2020) through investment in hydropower. SEB owns three coal-fired power plants in Sarawak and two gas-fired power plants. The 210 MW Sejingkat coal-fired power station[3] will be decommissioned in stages from now until 2026. The other coal-fired power plants in Mukah (270 MW) and Balingian (624 MW) in central Sarawak were commissioned in 2009 and 2020, respectively. No more new coal power plants will be built in Sarawak. SEB's direction to continue greening Sarawak's power generation to an even higher degree is clear.

Options to reduce emissions and ensure security of supply

The grid in Malaysia has been developed for centralized generation for a long time

A map of Malaysia's electricity generation universe is shown in **Figure 10**. All the power plants (red font) are already present in Malaysia, except for a nuclear power plant (blue font). Electricity generation systems within the dash line box generate power from fossil fuel resources under the ground, in a centralized manner, which is the classic model for the very big power plants connected to the power system.

The power plants outside the box harness energy resources above the ground (e.g. sun and water) and from organic residue, thus building circularity into agriculture and forestry. This can be done in either a centralized or distributed manner. Distributed generation consists of small-medium power plants (300-700 MWe).

Distributed generation

When electricity is generated near the point of use, it is called distributed generation. It is

[3] The Sejingkat power station was built in two phases in 1998 and 2004.

an alternative to centralized generation at large power plants. It has less to do with generation technology, but more to do with where the generated electricity will be used.

The Renewable Energy Act 2011 was put in place to enable distributed generation and to decarbonize the grid by establishing a system of feed-in tariffs (FiT) for renewables such as solar, biomass, biogas, and small hydro power. Payments to Feed-in Approval Holders are guaranteed from the RE Fund (funded via a 1.6% levy on electricity bills of all consumers, except for Sarawak) for a period of 21 years for solar photovoltaic (PV) and small hydropower and 16 years for biogas and biomass.

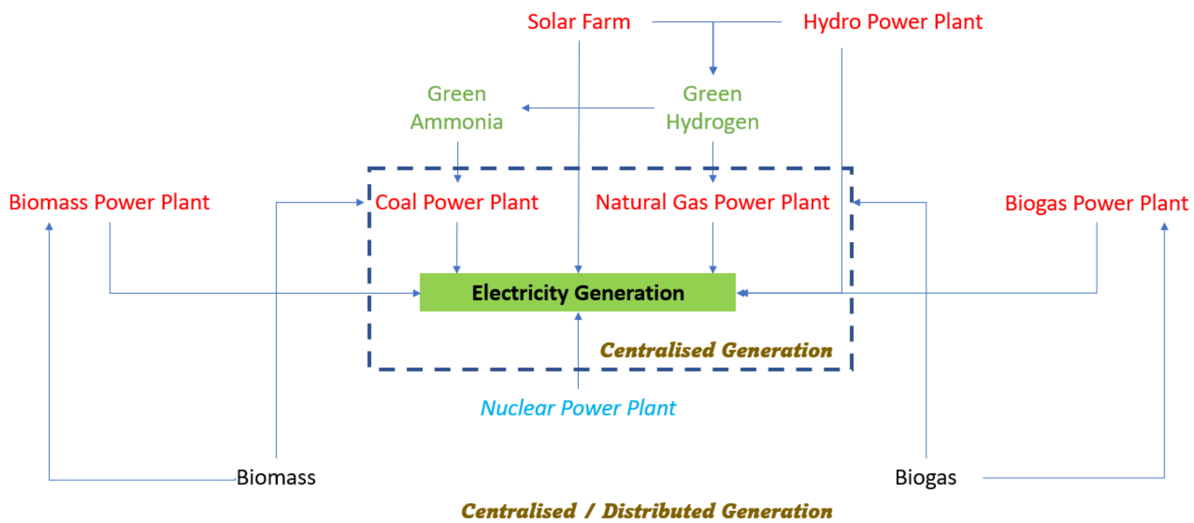


Figure 10: Malaysia's electricity generation universe

Distribution network connection cost distribution needs to be redesigned to facilitate investment in distributed RE generation

An obstacle to palm oil mills capturing biogas, generating electricity and feeding it into the grid is the high upfront cost of connection to the distribution network.

In Europe, natural gas system operators must accept biogas into their natural gas systems, if a biogas producer complies with all technical, quality and other requirements in the law[4]. 40% of the connection cost is covered by the natural gas system operator and 60% is borne by the biogas producer. (Tallat-Kelpšaitė, 2017)

Domestic and small-scale storage is a nascent sector with growth potential

Tenaga Nasional Berhad (TNB) is working together with property developers to install solar energy panels on the roof of new property premises, provide electric vehicle (EV) chargers at property developers' housing and a combination of solar energy and batteries to the property developers' and TNB's customers. (Bernama, 2022)

To unleash rooftop solar generation systems' full potential, battery technology needs to be applied. Concepts like Virtual Power Plants, which optimizes the resources of a

[44] Art. 31 of the Law on Energy from Renewable Sources (Chapter VI Art. 32 Law on Energy from Renewable Sources)

network of distributed energy resources (DER) to trade power at scale on the electricity market, could transform wholesale distribution. Small solar DER owners could be interested in further investment and innovation in the space, if incentives are clear. (Hutt, 2021)

Flexible generation

With flexible generation (e.g. gas-fired peaking power stations, pumped hydro, and grid-scale batteries), power output can be ramped up or down, or even switched on and off, easily and relatively quickly in response to changing demand.

This contrasts with baseload power, which is the minimum threshold of power generation (supply) required from a power system to ensure that a power grid runs smoothly and without outages.

Concept of baseload is increasingly less helpful

Baseload power plants are often powered by coal, hydro and nuclear are designed to provide constant power outputs, thus unable to quickly ramp power output up or down. Baseload makes up more than 50% of peak electricity demand in typical power systems.

This no longer needs to be the only approach for managing a stable grid because other more cost-effective ways are emerging, e.g. reducing baseload demand through energy efficiency improvement, putting in place RE sources that can supply baseload power and increasing the proportion of flexible peak load plant in the generating mix.

Enhancing system flexibility is a key priority

Due to the rapid decline in technology cost of solar PV, wind turbines and power storage, renewables are already amongst the cheapest options for new generation in many power markets (IEA 2019). To prepare for a future with high shares of low cost RE, Malaysia will need to focus on enhancing system flexibility.

Electrification of vehicles, heavy machinery and equipment will also bring wider changes in energy demand and usage patterns. Deeper integration between EVs and the electricity system will happen through vehicle-to-grid technologies.

Flexible generation has been described as a *"necessary precondition for operating and reaping the benefits of an efficient power system in the future"* because it reduces the frequency of curtailments and negative market prices. This will improve plant revenue planning, and the investment climate for RE generation and consumer prices. (Vemuri, Bohn, & Schrade, 2018).

Flexibility can be increased by: (Vemuri, Bohn, & Schrade, 2018)

i. Physical alterations to the system, such as retrofitting conventional power plants, strengthening grid connections and introducing large-scale energy storage;
ii. Institutional changes, such as the amendment of grid codes to encourage new RE generators to provide a variety of grid services, better RE forecasting and

sub-hourly scheduling of load or dispatch.

Demand side response (DSR) is an important flexibility measure to reduce generation and network capacity needed to address additional electricity demand due to electrification of transport and industrial processes

DSR is about consumers shifting demand to times of day when electricity is cheaper and more abundant. This is enabled by smart meters, energy smart appliances, tariffs and services that incentivize change in consumption pattern.

From 2020 to 2035, RM36 billion has been allocated to modernize TNB's distribution and grid network. The smart meter roll out across Peninsular Malaysia is essential for a two-way grid[5] because it improves electricity demand prediction. Smart grid technologies will enhance grid reliability[6] and efficiency[7], demand-side management, and customer participation in the system. (Farezza, 2021)

Flexibility markets and cost reflective price signals will motivate system participants (individual domestic and business consumers, network companies and generators) to behave in a way that optimizes their impact on the system (BEIS and Ofgem, 2021)

In the UK, a flexible energy system without demand side flexibility could cost around £5bn more per annum in 2050 (Carbon Trust and Imperial College London, 2021)

Connect international grids for increased distribution flexibility

Flexible international grid connections bring three key advantages:

- Greater supply stability
- Support deployment and reduce curtailment of renewables (**Figure 11**)
- Lower electricity cost

Enhanced interconnection between ASEAN Member States (**Figure 12**), a well-functioning and integrated ASEAN energy market, continuous investment in renewable technology and energy efficiency improvements and will result in lower prices for all consumers.

Research flexibility in the 21st century power system

As flexibility is a new feature in Malaysia's energy planning, industry and policy makers will benefit from research that shapes the role of flexibility for a cost-effective net zero energy transition, supports the deployment of flexibility technologies in a cost-effective way, and develops business models for flexibility and identifies conditions that will improve deliverability and viability (Carbon Trust).

[5] Electricity travelling from power plants to the point of consumption and consumers who can produce their own electricity (prosumers), thus creating a two-way grid.
[6] Digital technology is used to swiftly identify and pinpoint the source of a fault (e.g. lightning strike, or a tree falling on a line), thus enabling problem solving at root cause level.
[7] Transmission efficiency allows us to benefit more from the electricity generated.

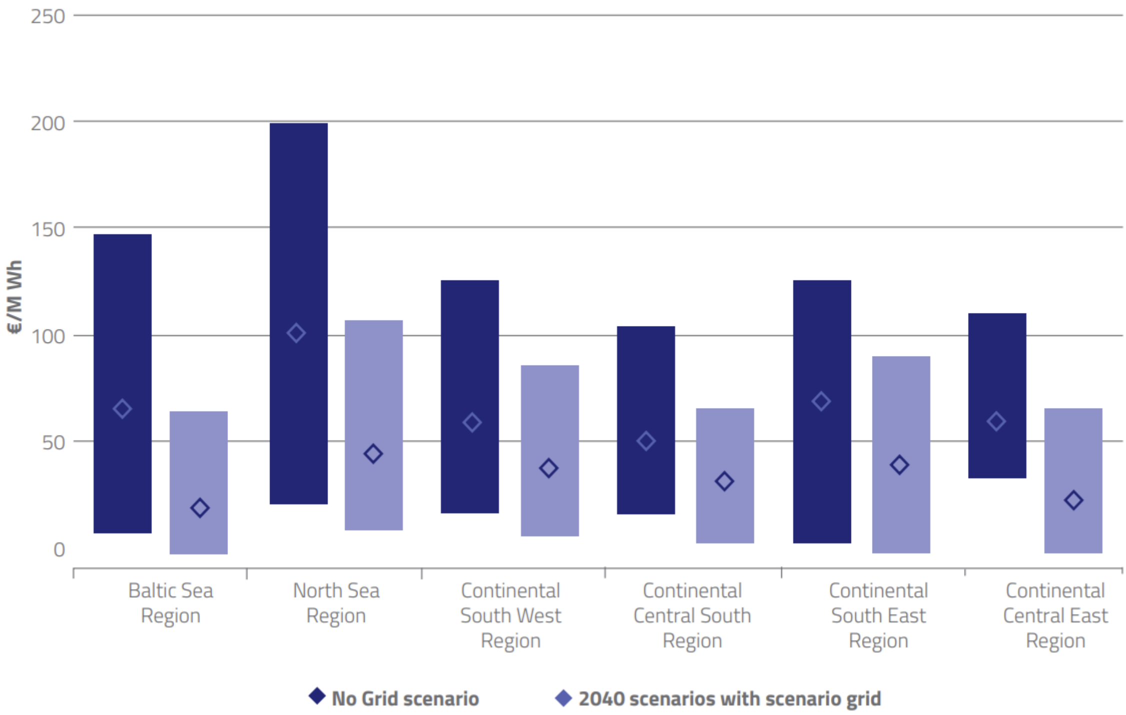


Figure 11: European curtailed renewable energy range with and without cross-border grid *(ENTSO-E, 2019)*

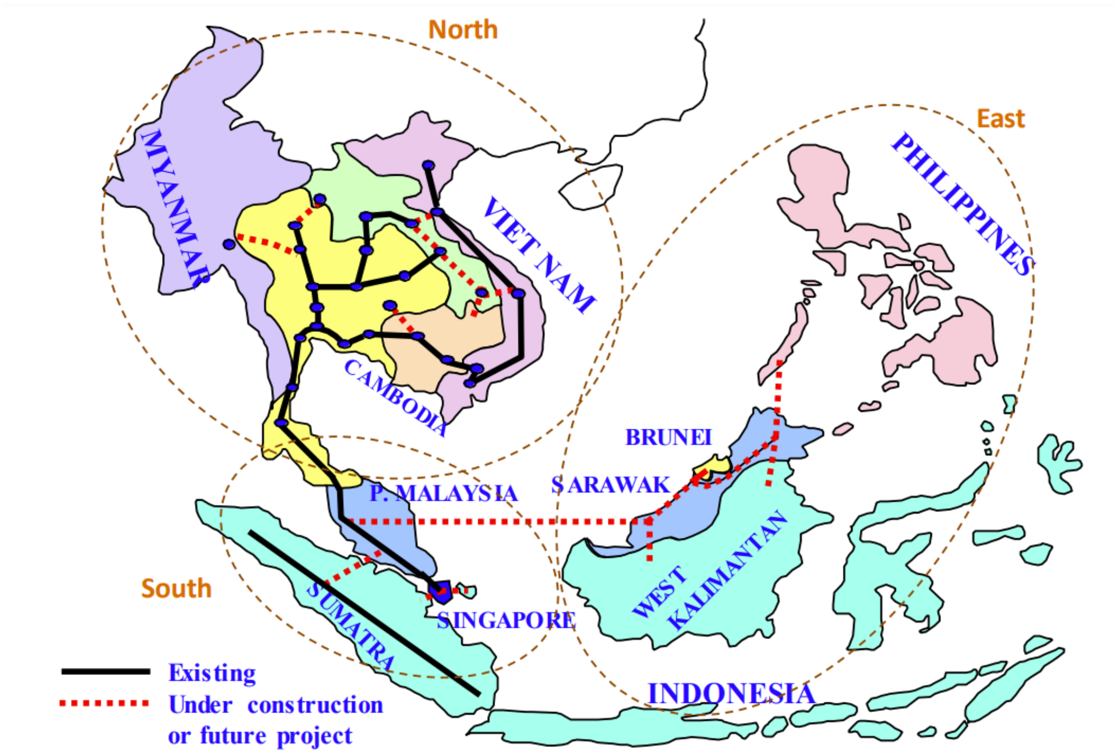


Figure 12: ASEAN power grid interconnection master plan *(ASEAN Centre for Energy (2015)*

Power generation technologies

Power generation capacity design criteria: carbon emission intensity, cost and contribution to net carbon emission reduction

Different power generation technologies have different carbon emission intensity (**Figure 13**), cost (**Figure 14**) and potential contribution to net carbon emission reduction (**Figure 15**). These three charts are used in this paper to inform a view of those technologies which should play a dominant role in the energy transition. There are also considerations beyond the cost and carbon emission aspects. Solar, hydro, bioenergy, nuclear, natural gas and coal are discussed in this paper.

Wind, being the lowest in emission and also one of the cheapest forms of generation, will be investigated in future work. Malaysia's mean annual wind speed is less than 2ms^{-1} (typically measured 2 meters above ground), whilst most wind turbines need a minimum speed of 4 ms^{-1} for electricity generation. Nevertheless, Terengganu and northern Sabah show wind energy potential. Technology advances in low-speed turbine can make a difference in other locations. Post 2025, Malaysia's Sustainable Energy Development Authority plans to conduct a feasibility study and economics assessment on implementation of onshore and offshore wind (SEDA Malaysia, 2021). This could pave the way for wind energy to be approved as a source of RE in Malaysia.

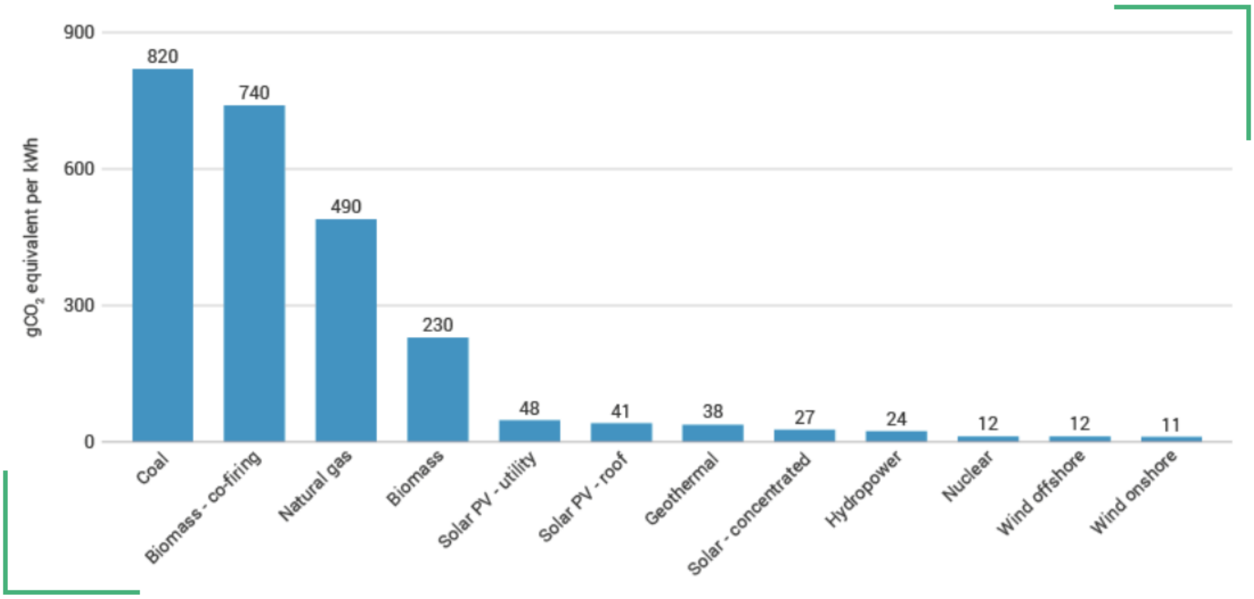


Figure 13: Average life cycle CO_2 eq emissions *(IPCC)*

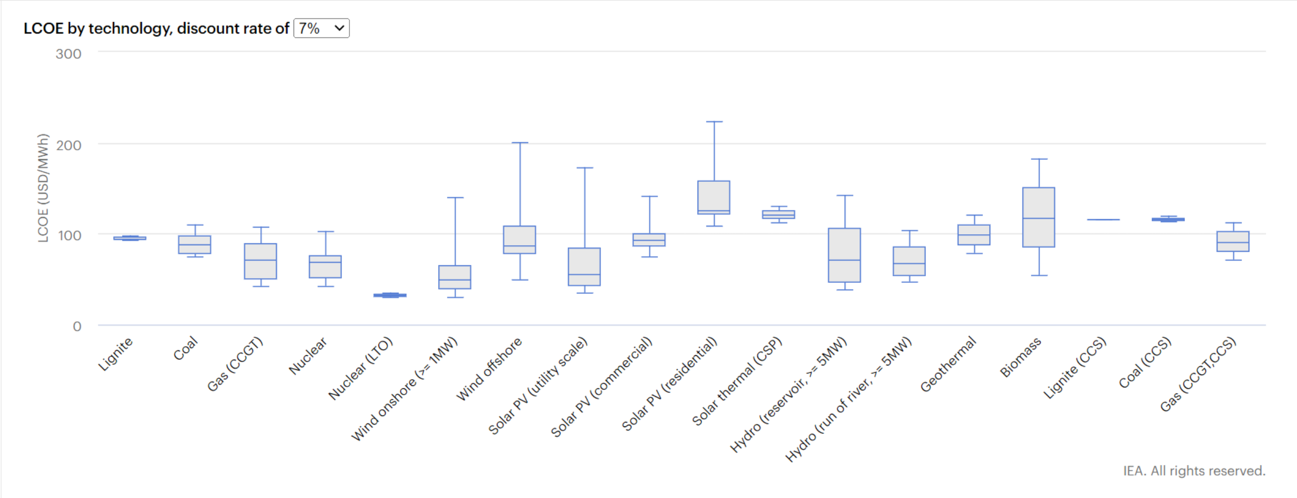


Figure 14: LCOE by technology *(IEA; NEA; OECD, 2020)*

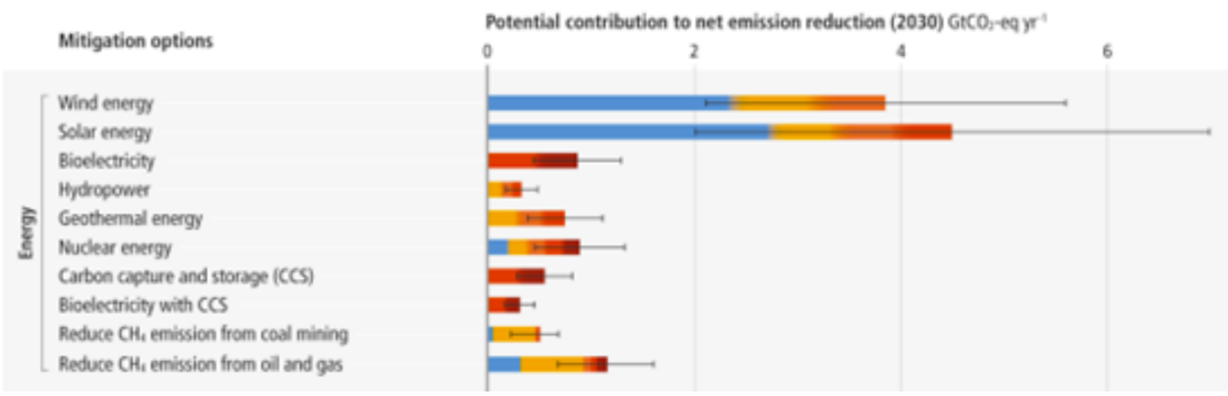


Figure 15: Renewable energy's potential contribution to net carbon emission reduction (2030) Gt CO_2-eq yr^{-1} *(IPCC, 2022)*

Solar

RE capacity can increase beyond the current targets with demand side response and interconnection

Peninsular Malaysia and Sabah's solar penetration limits are set at 24% and 20% respectively, based on a solar penetration limit assessment study done by DNV-GL in 2018 (**Table 3**). DNV-GL's cost-benefit analysis assumed that network and system remain as is, and did not analyze scenarios of network evolution and management tools like demand side response (DSR), energy export etc.

Table 3: Renewable energy penetration study for Peninsular Malaysia and Sabah *(DNV-GL, 2018)*

Solar Power Penetration Level (%)	System Stability Test Findings
20	Brings the most benefits
Up to 30	Based on the system stability test results, the system is technically capable to accommodate penetration up to 30%, which promotes further environment sustainability and reduces the affordability.
30-40	Stretches the system towards environment sustainability further at the cost of compromising affordability. Stability of the system under contingent events is compromised, but could be mitigated with more costly dispatch, thus further reducing the affordability.
>40	Results in scheduled solar curtailments. System under contingent condition shows both frequency and voltage stability issues due to low inertia and governor response from online conventional generators.

Similar early studies for the UK also suggested low levels of renewables would be possible on the UK grid, but the UK is now planning for up to 90% of RE penetration into the grid. A similar outcome might be plausible in Malaysia.

Figure 20 shows a big slow-down in renewables from 2030. Should deployment be increasing faster than this, at least at the rate in the 2020s, particularly given how cheap renewables are?

New interconnection between Peninsular Malaysia and Sumatra coming online in 2030

Peninsular Malaysia's interconnections:

i. Lao PDR-Thailand-Malaysia interconnection: currently stands at 300 MW; projected to contribute minimally at 1% (Energy Commission, 2021).
ii. Sumatra – Malaysia interconnection: commercial operation date scheduled for 2030; transmission capacity is 600 MW. This can improve the capability to connect new solar power to the grid in Peninsular Malaysia.

Borneo grid connections:

i. Peninsular Malaysia–Sarawak interconnection: awaiting economic justification beyond 2030 due to a giant gas reserve in East Natuna, which Indonesia plans to develop in the future (Atmo, Otsuki, & Nurcahyanto, 2022)
ii. Sarawak-West Kalimantan interconnection: nominated capacity of 110 MW (peak) and 80 MW (off peak).
iii. Sabah-Sarawak enclave connection: feasible for up to 300 MW, but has a nominated capacity of 30-50 W.
iv. Sarawak-Brunei interconnection: feasible to supply up to 50 MW

The capacity of the electricity grid to absorb variable RE should not limit Malaysia's ambition to develop its solar power potential. There is a large difference between the targets and the potential for solar power – 7 GW (**Table 1**) and 269 GW (**Figure 8**). Besides DSR and energy export, green hydrogen/ammonia and storage could support further growth in solar energy provision.

Green hydrogen and green ammonia

Malaysia can export solar energy through a carrier like ammonia

Theoretically, large scale solar can be built in states with high solar irradiance and unused land[8] and the electricity generated is channelled into water electrolysis plants to produce green hydrogen, which is then fed into a traditional Haber Bosch plant to produce green ammonia. This presents an opportunity for Malaysia to diversify and transition not only the domestic economy towards solar, but also export solar energy through a suitable energy carrier like ammonia. Due to a century of ammonia use in agriculture, ammonia infrastructure is mature globally. 180 million MT of ammonia is produced annually, and 120 ports are equipped with ammonia terminals (Tullo, 2021).

The absence of solar to green hydrogen / ammonia projects in Malaysia suggests that this technology pathway has yet to reach commercial viability here. The largest single cost component for on-site production of green hydrogen is the cost of the renewable electricity powering the electrolyser unit. Electrolyser is the second largest cost component of green hydrogen production. 85% of green hydrogen production costs can be reduced, in the long term, by a combination of cheaper electricity and electrolyser capex investment, alongside increased efficiency and optimized operation of the electrolyser (**Figure 16**)

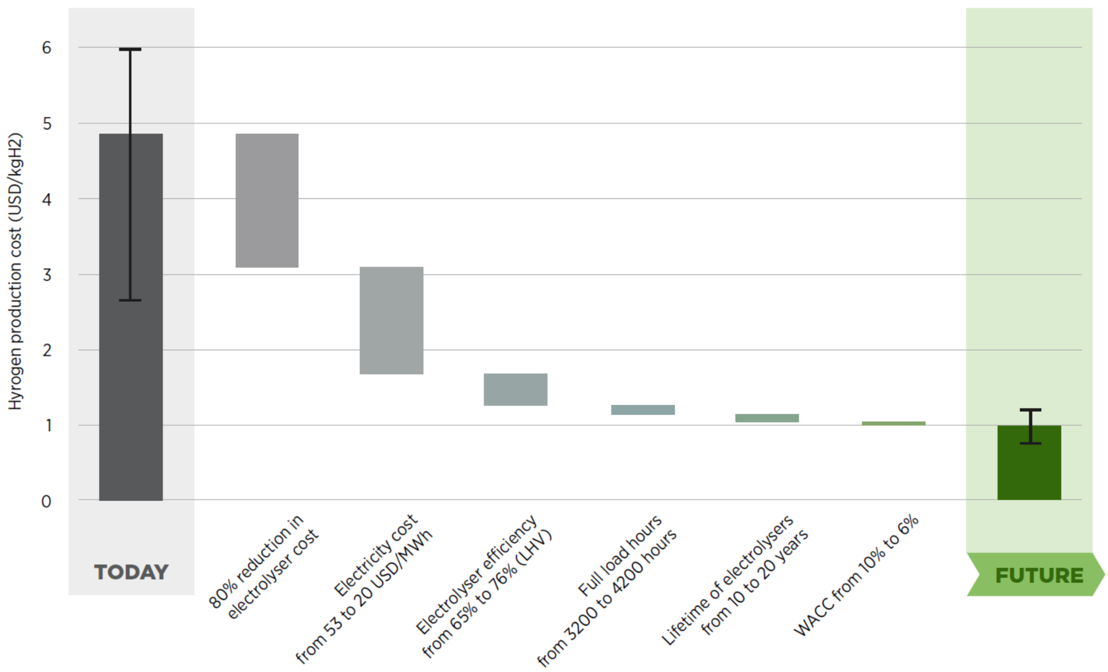


Figure 16: Cost reduction levers for green hydrogen production *(IRENA, 2020)*

Grow new industries and decarbonize industries through green hydrogen / ammonia

- **Table 4** shows the targets and policies of countries that are actively building their hydrogen economies, which Malaysia can learn from.
- New industries like electrolyzer manufacturing can be nurtured. The global electrolyzer market is projected to grow from $416.8 million in 2022 to $619.6 million by 2029, at a CAGR of 5.8% (Fortune Business Insight, 2022).

[8] Unused land refers to gas pipeline right of way and land around landfills. Malaysia has little unused land (industry inputs).

- Policy instruments can be used to incentivize production and drive demand for green hydrogen/ammonia in the cement, steel, chemicals and fertilizer industries.

Table 4: International moves on green hydrogen and green ammonia *(Varadhan, 2022; Lee, 2021; Standaert, 2022)*

	Green Hydrogen & Green Ammonia Production / Import Targets	Policy Support
China	100,000–200,000 metric tonnes / year of green hydrogen by 2025 *China is currently the top producer of hydrogen in the world at 33 million MT per year – 80% of which comes from fossil fuel. With only ~27,000MT of green hydrogen currently produced in China, the 2025 target is conservative compared to the potential production in the future.*	• 50,000 hydrogen-fueled vehicles by 2025 Manufacturing capacity for electrolyzers to supply domestic and overseas market: 1.5–2.5 GW in 2022
EU	Domestic production: 10 million tonnes / year of green hydrogen by 2030; 80GW of electrolysis Import: 10 million tonnes / year	Dedicated strategy on hydrogen in the EU was adopted in 2020: create a European hydrogen ecosystem that includes research, innovation, scale up production, infrastructure and international dimensions
India	Domestic production: 5 million tonnes / year of green hydrogen per by 2030 *To meet climate targets and become a production and export hub for the fuel*	• National Hydrogen Mission 2021 • Set up separate manufacturing zones, waive inter-state power transmission charges for 25 years and provide priority connectivity to electric grids to green hydrogen and ammonia producers to incentivize production. • Green hydrogen manufacturers would be allowed to transmit unused electricity to the grid Planning to provide federal financial support to set up electrolyzers, as policymakers consider legislating a minimum quota of green hydrogen to be used in the industrial processes of oil refineries and fertilizer plants
Japan	*Lacks the natural resources needed to deploy sufficient levels of wind or solar to generate clean hydrogen at scale, thus is developing long-term supply agreements to import hydrogen from overseas (Australia, Brunei, Indonesia, Malaysia, Singapore, Saudi Arabia, Russia, the United Arab Emirates, and US). Sourcing is done for grey/blue/green hydrogen and ammonia.*	• Basic Hydrogen Strategy 2017 • Adopting the fuel across all sectors Expanding its hydrogen market from 2 million tons per year in 2021 to 3 million tons per year by 2030 and 20 million tons per year by 2050
South Korea	Like Japan, South Korea has limited space for large scale domestic hydrogen production. Thus, the country is planning 40 foreign hydrogen bases.	• 2019 Hydrogen Roadmap • Hydrogen to satisfy 10% of the energy needs of its cities, counties and towns by 2030; 30% by 2040; largest single energy carrier in the country by 2050

		Government will introduce policies that drive hydrogen demand, e.g. encourage steel and chemical firms to shift to hydrogen-based processes, promote hydrogen-based transport technologies and encourage fossil power generators to blend hydrogen into their fuel mix.

Carbon footprint of global blue/green ammonia supply chains needs to be calculated

The other sourcing strategy is to invest overseas to produce blue/green ammonia and ship it back home, like what Japan and Korea are doing in Australia, Canada, Chile, Middle East and Malaysia. Peninsular Malaysia's coal-fired power plants in Lumut, Jamananjung, Kapar, Port Dickson and Tanjung Bin are close to ports. However, the carbon footprint of global supply chains needs to be calculated to check if the emissions reduction potential in the country of use exceeds the emissions associated with the ammonia production in the country of origin (Stocks, Fazeli, Hughes, & Beck, 2021).

Storage

The 100MW batteries that will be installed annually into the Malaysian power system from 2030–2034 are for grid stability, not energy storage

- Grids run in terms of gigawatt days. One cannot isolate 30,000 houses and supply only them. The grid supplies everything within a designated area.
- There are four technological approaches to energy storage systems (**Table 5**):

Table 5: Technological approaches to energy storage systems

Energy Storage	Description
Batteries	Electrochemical storage solutions such as advanced chemistry batteries, flow batteries and capacitors
Thermal	Captures heat and cold to create energy on demand or offset energy needs
Mechanical	Harnesses kinetic or gravitational energy to store electricity; dominated by pumped hydropower[9]
Hydrogen	Converts excess electricity generated into hydrogen via electrolysis and stored

Batteries have evolved from nickel cadmium to lithium-ion to vanadium flow, but still not cheap enough for widespread utility scale use. Innovation and economies of scale brought lithium-ion batteries' cost down drastically between 2010 and 2021, which enabled the biggest advance in grid-scale electric storage in recent times. This has allowed more megawatts of capacity to be added to grids around the world in the form of batteries instead of natural gas combined cycle turbines. However, utility-scale lithium-

[9] The sole pumped hydro storage scheme on the UK grid – Dinorwic in Wales – can deliver 10GW for half an hour. It was built decades ago when the grid was significantly smaller. Even Dinorwic is only used for grid stability.

ion batteries are still rare. 99% of grid storage today is pumped hydro, a solution that has geographical and environmental constraints. (Conca, 2019)

Vanadium flow battery is water-based, thus non-flammable and non-explosive, which lithium batteries are. Vanadium is also more abundantly available in the earth crust than lithium, which is already much sought after for EV batteries. The high cost of vanadium extraction is a hurdle to commercialization. Researchers are working on how to lower the cost of vanadium extraction, store more electricity through improved chemistry, and improved cell and stack designs. (Conca, 2019).

Hydro

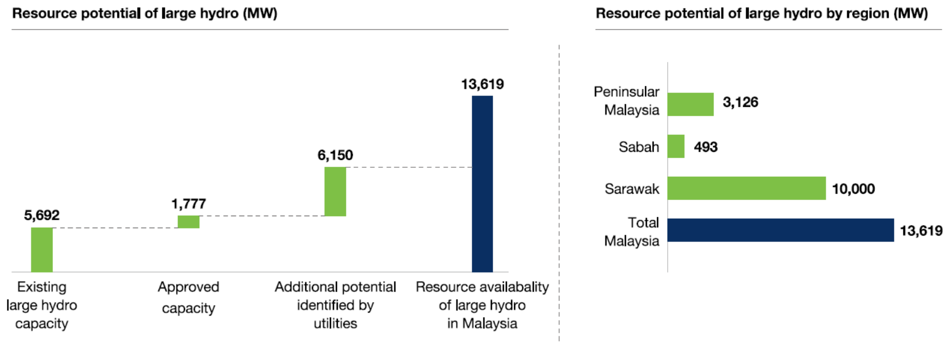
Malaysia has storage and run-of-river hydropower

Storage hydropower uses a dam to store water in a reservoir with enough capacity to operate independently of the hydrological inflow for many weeks or months. Electricity is produced by releasing water from the reservoir through a turbine, which activates a generator. It provides base load and can be shut down and started up at short notice according to the peak load demands of the system.

Run-of-river hydropower channels flowing water from a river through a canal or penstock to spin a turbine. A typical run-of-river system has little or no storage facility, thus little to no ability to control when water is released. It provides a continuous supply of electricity (base load), with some flexibility of operation for daily fluctuations in demand through water flow that is regulated by the facility.

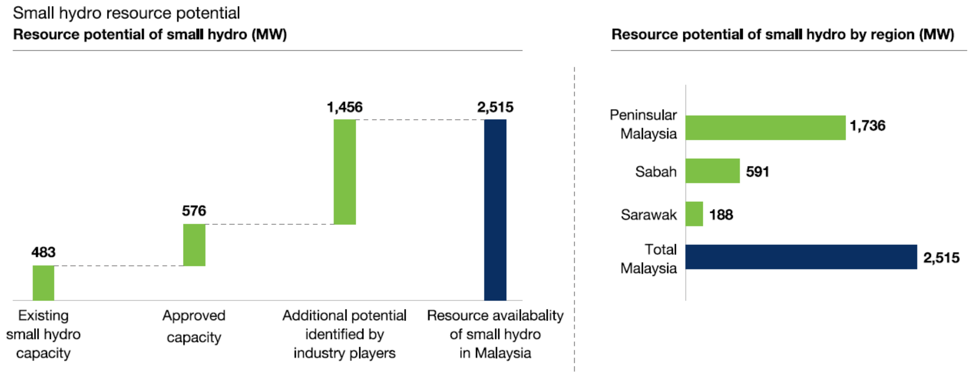
Malaysia's existing large hydro capacity is 5.692 GW and small hydro capacity is 483 MW (**Figure 17**). Two new dams – Baleh (1.285 GW) in Sarawak and Nenggiri (300MW) in Kelantan - are expected to be commissioned in 2026 and 2027 respectively.

Figure 4-8: Large hydro resource potential



Source: SEDA; TNB; SESB; SEB

Figure 4-7: Small hydro resource potential



Source: SEDA; TNB; SESB; SEB; Industry players

Figure 17: Hydro resource in Malaysia

Malaysia does not have pumped storage hydropower

Pumped storage hydropower provides peak-load supply, thus has good potential if there is peak demand. Water is cycled between a lower and upper reservoir by pumps powered by surplus energy from the system at times of low demand. When electricity demand is high, water is released back to the lower reservoir through turbines to produce electricity. However, the head difference normally needs to be high (100-300m), which results in high cost in the water transfer tunnel

A 1000 MW pumped storage hydroelectric project was under planning and construction at Cameron Highlands but was temporarily shelved due to escalating cost.

Construction of dams brings large scale ecosystem destruction and displaces communities

Hydro power is often considered a RE because it is zero emission in generation. Once the dam and turbines are built, the only costs associated with them are largely operational and maintenance. However, the construction of dams is far from carbon free. Lush green forests surrounding rivers disappear when dams are built.

Although 22.5% of electricity production in Finland comes from hydropower, the country has now designed the Wild River Act to prohibit the building of new hydropower plants so that the natural environment could be protected. Rehabilitation and uprating of existing hydropower installations have come into focus (Andritz, 2022).

There is a misconception that small dams damage the environment less than the large ones. Small hydropower is often incentivized in policies (including Malaysia), triggering investment that leads to many small dams with an insignificant contribution to the national grid collectively, whilst causing substantial cumulative environmental impacts. There are more than ten times the number of small hydropower dams (at least 83,000) around the world than large dams, and tens of thousands more in the planning pipeline. Although small hydropower projects do not flood whole valleys like large dams do, they change river flows and alter fish communities.

A holistic approach to dams

For water regulation purposes, dams and hydropower constructions can be used to adjust water levels and flows.

The Lancang-Mekong Cooperation promotes an integrated planning approach for regulating water, which includes multiple objectives such as hydropower production, flood protection, drought relief, water abstraction, fisheries, recreational use and trade connectivity. This seems to be a good example of regional decision-making where the aim is to reconcile various interests, taking account of conflicting views.

Sarawak's abundant hydropower is insufficient to support Malaysia's green transition

There is a hopeful perception that Sarawak has abundant hydropower, thus can produce all the green hydrogen and green ammonia needed for Malaysia's energy transition. However, the electricity produced in Sarawak has already largely been allocated to various customers. International industry heavy weights that are conducting feasibility studies in Sarawak to produce green hydrogen, green ammonia and green methanol at a commercial scale are exploring production capacities that would require an electricity amount exceeding the expected electricity generation from the upcoming 1.285 GW Baleh dam by several GW (Liew & Leong, 2022).

Allocation of electricity is influenced by factors such as number of jobs created per MW capacity and bidders' willingness to pay. Feeding the electricity directly into industries generates 200 jobs per MW capacity whilst converting that electricity into green hydrogen generates 1 job per MW capacity (industry input). In general, job opportunities increase from upstream to midstream to downstream. Industry comes under downstream and hydrogen production comes under upstream.

Bioenergy

Biomass

Biomass is the largest bioenergy resource with 2.3 GW potential in Malaysia, which comes from 1.3 GW in Peninsular Malaysia, 561 MW in Sabah and 448 MW in Sarawak

On average, Malaysia's 450 palm oil mills process 95.5 million tons of fresh fruit bunch (FFB) each year. Palm biomass waste in Malaysia is vast at over 2 million tonnes per week[10]. How these wastes are handled is summarized in Table 6.

[10] Estimated palm biomass waste in Malaysia in 2020: 129 million tonnes per annum

Table 6: Handling of oil palm residues in Malaysia *(SEDA Malaysia, 2021; MIGHT, 2020)*

Oil Palm Residues	Estimated Quantity (million MT / year)	Handling
Empty fruit bunch (EFB)	22.43	Millers typically send half for mulching, and dispose or incinerate the other half
Mesocarp fiber (MF)	13.76	Disposed, incinerated or used for electricity (self-consumption)
Palm kernel shell (PKS)	5.61	Majority is exported to Japan, South Korea and Taiwan for biomass power generation under subsidized schemes

PKS is the dominant oil palm residue used for biomass power generation, but the supply is seasonal due to harvesting and monsoon seasons. A biomass power generation plant would require 100,000-200,000 MT / month of PKS. Unstable PKS supply leads to sub-optimal biomass power generation plant size and capacity factors.

Sustainable harvesting of trees allows for ongoing carbon sequestration in forest

Wood pellet is a more reliable fuel supply for biomass power generation plants because trees can be harvested throughout the year. This enables larger power plant capacity - which reduces equipment and interconnection costs per MW - and higher plant utilization.

Once trees reach their full growth potential, they also reach a limit of their ability to absorb carbon from the atmosphere. Thus, sustainable harvesting of trees for wood products and using the wood residue to produce wood pellet for power generation promotes a sustainable cycle (CCC, 2018).

Developing biomass supply chains has international business prospects

Malaysia can develop sustainable low carbon biomass supply chains due to its oil palm and wood industries. Beyond local biomass power generation, the international demand for sustainably harvested biomass is big and growing because it can help countries meet long-term climate targets. Japan, Taiwan and the UK have been sourcing PKS and wood pellet overseas to support their renewable energy policies.

Biomass feedstock innovation projects can support rural economies, provide jobs and encourage investments. Malaysia can learn how to make sure sustainability is guaranteed and overseen by strong governance processes.

Biogas

Biogas can be used for electricity, heat and transport - a renewable fuel that is available and scalable today, and makes cost-competitive use of existing gas infrastructure

Biogas comes from the decomposition of organic material in an anaerobic (oxygen free) environment, which results in a saturated gaseous mixture of 60%–70% methane and CO_2 with trace amounts of hydrogen sulphide, nitrogen and oxygen. Anaerobic digestors are usually connected to gas-fired engines for heat and power generation; electrical capacity ranges from tens of kWe up to a few MWe.

Raw biogas needs to be purified[11] and upgraded to natural gas quality (biomethane) before it can be injected into a natural gas grid or used in transport vehicles.

Most biogas projects registered in Thailand, Malaysia and Indonesia utilize wastewater residues of agroindustry and farming activities. Thailand is currently the lead biogas player in the region. (Hoo, Lee, & Low, 2020).

The feasibility for biogas capture cannot be built solely on carbon credit price

Despite the Kyoto Protocol Clean Development Mechanism (CDM) stimulus for biogas (2008-2012), biogas utilization from the agroindustry remains low in Southeast Asia, despite about half of the CDM biogas projects registered globally being in this region. The reason being the oversupply of carbon credits caused carbon market prices to collapse in 2012, which caused carbon revenue dependent biogas projects here to cease operations. (Hoo, Lee, & Low, 2020).

EU is the global leader in biogas production. Combined biogas and biomethane production in Europe exceeded 200 TWh in 2021, up from 191 TWh in 2020. Europe now has 20,000 biogas and biomethane production plants in operation. 1023 of them are biomethane plants, 87% of which are connected to the gas grid. Supported by RE policies, in addition to economic, environmental and climate benefits, the EU has set a target for 1,000 TWh biogas production by 2050. (European Biogas Association, 2021)

FiT and distribution network connection cost distribution need to be redesigned to facilitate investment in biogas capture

The total biogas resource in Malaysia is 736 MW, including landfill gasification. This comes from 453 MW in Peninsular Malaysia, 158 MW in Sabah and 125 MW in Sarawak (SEDA Malaysia, 2021).

An average of 68 million m^3 of palm oil mill effluent (POME) is generated in Malaysia each year, which could generate ~500 MW of biogas power (Jain, 2019). Using biogas to generate electricity and feed into the main grid is being implemented with tariff payment to the mills in Peninsular Malaysia.

Only 90 (mostly in Peninsular Malaysia) out of 480 palm oil mills in Malaysia are connected to the grid because the FiT is too low for biogas at around RM0.28 per kWh. The current base tariff is RM0.3945 per kWh. Other inter-related reasons for the low adoption of biogas capture include:

- Palm oil mills need to pay for their own grid connection
- Maintaining a grid is a new task for palm oil mills, which requires a new department

The income generated from the FiT is too low to be worth investing in for mills that are located more than 5km away from an existing grid.

Capturing biogas from POME has more obstacles in Sarawak and Sabah due to insufficient gridlines, especially in the rural areas, and lack of infrastructure for feed-in capability. Some of the palm oil mills set out to capture biogas and utilize it for their own

[11] Methane content is first enriched through the removal of CO_2, followed by desulphurization, and water removal. All other interfering substances are removed through low-level gas combustion.

boilers. (Borneo Post, 2014; Kamar, 2010)

Nuclear

China and Russia have been actively investing in new nuclear power plants whilst the US and Germany pulled back after the 2011 Fukushima disaster

Nuclear power reactors generate 10 per cent of the world's electricity supply. These come from around 440 commercial reactors operated by 32 countries, with the US having the highest number (93), followed by France (56) and China (53). The US gets 20% and France gets nearly 70% of their electricity from nuclear today.

The Chinese government will double the country's nuclear power capacity this decade with six new reactors and overtake the US as the top nuclear electricity generator.

Time for Malaysia to reconsider nuclear for generating carbon-free electricity

Nuclear energy was mentioned in Malaysia's 2009 National Budget. A Nuclear Power Development Steering Committee was set up and TNB had planned for the first nuclear power plant to be up and running by 2021. By 2017, the International Atomic Energy Agency (IAEA) had deemed Malaysia to be almost ready for nuclear power in terms of judgment and know-how. Construction of a nuclear plant could have started after putting in place relevant regulations and approval from the cabinet. However, due to strong public opposition towards nuclear energy and the lack of urgency to adopt nuclear power, Malaysia's nuclear plant deadline was pushed back to 2030.

The time has come for Malaysia to reconsider nuclear for the following reasons:

- Climate change and impetus for energy decarbonization
- Advances in nuclear technology and safety in recent years
- Volatility of fossil fuel prices, which shakes energy affordability
- Finite oil and gas reserves in Malaysia
- Increase Malaysia's energy independence and ability to export energy regionally

A country's nuclear power planning process includes considering its electric grids' capacity and future growth because the grid influences the size and type of reactor that can be deployed. Historical stability and reliability, and the potential for local and regional interconnections, are the other factors to consider. Plans for grid improvement and nuclear power should be developed hand-in-hand.

Technology evolution

Generation IV (molten-salt) gigawatt-scale reactors

Existing Generation I reactors to modern Generation III+ reactors are gigawatt-scale light water reactors (LWRs) associated with high initial cost, high risk (explosion and waste) and long construction time. Most of the reactors in operation around the world today are Generation II reactors (Wikipedia, 2022). Generation IV reactors (e.g. molten-salt) offer better safety, cleanliness, sustainability, efficiency, cost and proliferation-resistance than earlier reactors.

Small modular reactors (SMR)

SMR sidesteps many disadvantages associated with traditional gigawatt-scale reactors. SMRs are nuclear fission reactors like the traditional reactors, but are smaller in size, land footprint, electrical power output (<300 MW_e, i.e. one-third of the generating capacity of traditional nuclear power reactors). They can be mass produced in a factory and delivered to site, which removes the high up-front onsite construction cost and long onsite construction time. They are often delivered already fuelled and can operate for many years on the initial load of fuel, which implies fuel security. Passive cooling[12] is a feature of many SMR designs, meaning that a power outage would not cause a nuclear meltdown and explosion. SMR is resilient because it can start up from a completely de-energized state without receiving power from the grid. As SMR can operate connected to the grid or independently, it is expected to be useful for industrial applications or in remote areas with limited grid capacity.

- More than 80 SMR designs are under development in 19 countries and the first SMR units are already in operation in China and Russia (Watson & Donovan, 2022)
- The prospect of installing SMR in the boilers of existing coal power plants exists. SMR's generation capacity (200-400 MW_e) is similar to that of a typical coal-fired plant, therefore suited to existing grid connections. Romania and the US are the frontrunners in repurposing coal power plants for SMR. (Watson & Morelova, 2022)

Nuclear cost and risk reduction drivers

New nuclear power will be among the cheapest dispatchable, low-carbon power producing technology by 2025 while extending the life of existing nuclear plants is the most cost-effective source of low carbon electricity (IEA, 2020)

Figure 14 shows that nuclear power is in a similar LCOE range as utility scale solar PV and long-term operation (LTO) of nuclear gives the lowest LCOE amongst all the power generation technologies. LTO involves extending the lifetime of existing nuclear power plants, which has limited project risks and a LCOE of $30-50MWh.

Malaysia needs to think about nuclear power generation in terms of multiple projects and developing local nuclear expertise

Regulatory control and approvals, supply chain readiness and availability of local nuclear expertise affects the cost of nuclear power on the ground. A country that is doing it for the first time should expect its cost to be higher than a country that has been building and managing a fleet of nuclear power plants.

Nuclear new build, first-of-a-kind (FOAK) projects or building a new nuclear power plant after a long hiatus are often late on schedule and over budget. However, countries that build new nuclear power plants regularly like China and Korea have developed supply

[12] No electrical supplies or pumps are required to cool the reactor following an incident, as this is achieved by natural convection and gravity coolant feed. This feature ensures the reactor will remain safe under severe accident conditions. Passive safety systems reduce the capital and maintenance costs compared to large power reactors and fundamentally changes the economic equation in favour of SMR nuclear power generation. (SMR Nuclear Technology, 2017)

chains and accumulated experience and lessons learned from previous projects, which enable schedules to be kept and costs to drop (Day, 2021).

Figure 18 shows factors that keep construction costs down - design maturity, effective project management with a robust implementation strategy, the predictability of regulation and stability and multi-unit and series effects where a sufficient level of design maturity has been achieved and subsequent models replicates the first. Once these drivers and conditions are in place, the cost could be further reduced via design optimization, technology and process innovation, revisiting regulatory activities and the harmonization of licensing codes and standards (Nuclear Energy Agency, 2020).

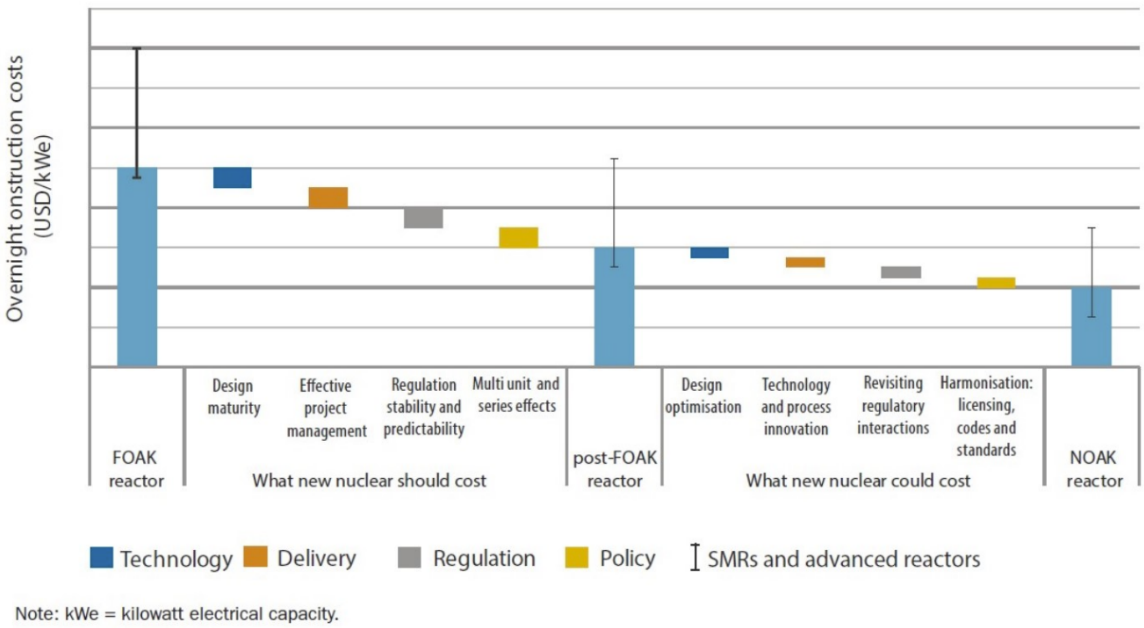


Figure 18: Nuclear cost and risk reduction drivers *(NEA)*

Waste management

Nuclear power generates a relatively small amount of waste compared to other thermal electricity generation technologies

A 1 GW nuclear power station produces 3m^3 of vitrified[13] high-level waste per year, if the used fuel is recycled. In contrast, a 1 GW coal-fired power station produces approximately 300,000 tonnes of ash and more than 6 million tonnes of CO_2 every year. (World Nuclear Association, n.d.)

Spent nuclear fuel can be recycled or disposed as waste. Safe methods for the final disposal of high-level radioactive waste are technically proven. Geological disposal is considered the best option internationally. (World Nuclear Association, 2021)

[13] Vitrification is a process for stabilising and encapsulating high-level radioactive waste with a substance that will crystallise when heated (e.g., sugar, sand) and then calcined

Natural Gas

The combustion of natural gas results in 40% carbon emissions savings relative to coal for each unit of energy output, and 20% compared to oil (IEA, 2019)

The latest high efficiency combined cycle power generation system has a gross thermal efficiency of approximately 63% (GE, 2018). Replacing old and inefficient power generation units with new and more efficient facilities will cut CO_2 emissions.

Peninsular Malaysia plans to grow its gas power generation capacity from today's 12 GW (44%) to 17 GW (47%) in 2039 (**Figure 19**). Minimizing methane emissions along the gas value chain from production to consumption should be a priority to reap the most benefits of switching from coal to gas.

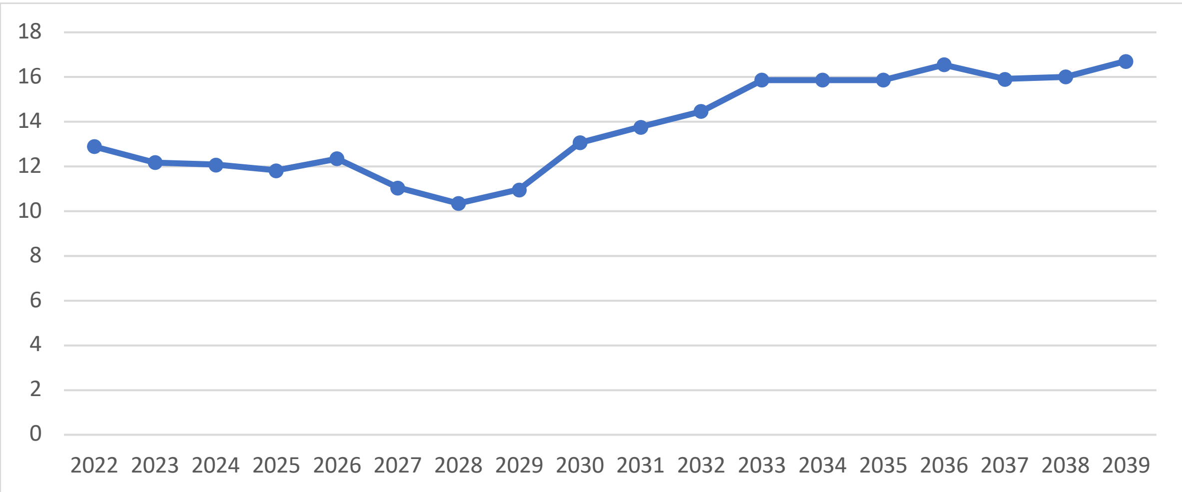


Figure 19: Natural gas power generation capacity in Peninsular Malaysia (GW) *(Energy Commission, 2021)*

Sabah's natural gas resource is controlled by Petronas Gas. Sabah Gas only has a very small quantity, which needs to be supplied for industrial needs. Thus, building new natural gas plants is not a major decarbonization pathway for Sabah's electricity generation. The price of natural gas, which is regulated by the Energy Commission, will impact existing gas power plants' viability. The Sabah state government has requested for the price of gas at the existing independent power plants (IPP) be maintained at the minimum of RM6.40 per Metric Million British Thermal Unit (MMBtu) until their concessions expire to avoid a sharp increase in operating cost, which will directly impact Sabah's electricity tariff (Miwil, 2022).

Role of natural gas as a transitional fuel or a fuel of last resort to fill gaps?

The difference in natural gas's positioning in the energy transition journey will impact new power generation investments, public policies and spending.

Whilst pushing measures such as energy efficiency, renewables, storage, DSR, energy system digitalization, market integration, cross-border grid connectivity, and long-distance HVDC cables as far as possible, natural gas with carbon capture can fill the gap caused by intermittent renewables generation. (Popov, 2021)

From natural gas to biomethane and low carbon hydrogen

Substituting natural gas with biomethane or low carbon hydrogen has inter-linkages with biogas and solar and should be actively worked on. Biomethane is purified biogas. Sky high natural gas prices is conducive for increasing biomethane deployment and scaling up the production of sustainable biomethane in Malaysia. When natural gas prices were low, Gas Malaysia was not interested in the biomethane that palm oil mills could produce. Whilst green hydrogen need time to scale up and is 2-4 times more expensive than natural gas, biomethane is available, cheaper and scalable now.

Mitsubishi Heavy Industries Ltd (MHI) Group succeeded in a co-firing test of 30 vol% of hydrogen, which reduced CO_2 emission during power generation by ~10% compared to conventional natural gas thermal power generation (INOUE, et al., 2018).

A plan is underway to repower the Sultan Ismail Power Station (SIPS) 1,400 MW gas-powered plant in Paka, Terengganu by making it hydrogen-ready by 2029. SIPS was Southeast Asia’s first combined-cycle power station, which was decommissioned on 31 December 2019, after 33 years of operation. (Azreen, 2022)

Natural gas supply chain

Natural gas supply in Malaysia has been tight due to declining domestic production and increasing demand

Natural gas demand from Peninsular Malaysia’s power sector is expected to rise from 643 million standard cubic feet per day (mmscfd) in 2021 to ~1600 mmscfd in 2039.

There is no gas pipeline connection between the gas producing regions of Borneo Island and the gas consuming regions in Peninsular Malaysia. Earlier modest gas demand in Peninsular Malaysia was supplied by offshore Terengganu’s (eastern Peninsular Malaysia) shallow water offshore gas fields. The country started importing LNG from neighbouring gas fields in 2012 via a Floating Regasification Unit in Peninsular Malaysia – Melaka LNG Terminal - whereas Borneo’s production was channelled to LNG exports governed by long term contracts. (Gomes, 2020)

Malaysia has 34 years of natural gas reserves (at current consumption levels and excluding unproven reserves) (Worldometers, n.d.). In 2020, Malaysia exported $7.3B of liquid natural gas (LNG), making it the 4th largest exporter of LNG in the world. The main destination of LNG exports from Malaysia are Japan ($3.48B), China ($1.57B), South Korea ($1.56B), Thailand ($317M), and Taiwan ($263M). (OEC, n.d.)

In 2020, Malaysia imported $1.06B of LNG, making it the 14th largest importer of LNG globally. Imports of LNG came mainly from Australia ($756M), Brunei ($267M), Nigeria ($19.1M), and Singapore ($13.8M). LNG import is expected to grow as domestic demand increases and production from Malaysian gas fields continues to decline.

The other possibility is to divert LNG from Bintulu to the internal market as and when the long-term LNG export sales contract expire. A similar strategy is adopted by Indonesia. This is important given the exposure of LNG to international volatility.

Natural gas pricing for the power sector needs reforming

The sale price of gas to the power sector in Malaysia is regulated by the Energy Commission and is priced lower than the global market. This has the following effects:

- Higher international LNG prices compared to domestic prices encourages exports, leading to tight supply in local markets
- The gas industry in Malaysia is unattractive to outsiders
- The heavily controlled gas price induced inefficient use of energy and constrained PETRONAS' capacity and motivation to invest in developing more expensive (deeper water) domestic gas production
- Unattractive prices for biomethane

Since 1 January 2022, gas prices to the industrial, commercial and residential sectors have been fully liberalized.

Third-party access (TPA) has been set up and fully implemented in January 2022 to allow third parties to use Petronas Gas Berhad's (PetGas) two regasification terminals (in Sungai Udang, Malacca and Pengerang, Johor) and gas transport pipeline, as well as Gas Malaysia's gas distribution pipeline (Malaysian Gas Association, 2022).

In 2021, there was only one client that was utilising PetGas's facilities under the TPA arrangement. Efforts to attract other gas players to participate under TPA was not fruitful due to controlled gas pricing for the power sector. High natural gas price globally does not help Malaysia's gas market liberalization. (Intan, 2021)

Production cost of green hydrogen

Production cost of green hydrogen will decrease rapidly within this decade

Table 4 shows the carbon intensity and production cost of hydrogen today. Grey hydrogen produced with cheap fracked natural gas costs US$2/kg in the US, and US$5-6/kg in Europe, Australia and Asia due to higher natural gas prices. (SG H2 Energy, n.d.)

By 2030, green hydrogen can cost less than $2/kg to produce in most geographies and even lower in locations (e.g. in parts of Europe, the Middle East and Africa) that can produce green electricity cheaply with renewables; production cost will be $0.7-$1.6/kg in most parts of the world before 2050. (Bloomberg NEF, 2020; Meza, 2022)

Infrastructure for transporting and storing hydrogen needs foresight planning and investment because cheap green hydrogen may arrive sooner than expected

Much focus has been on producing green hydrogen through electrolysis using RE, which is expensive (US$10-15 per kg). SGH2 Energy is now using a plasma-enhanced thermal catalytic conversion process optimized with oxygen-enriched gas to gasify waste and produce hydrogen at a cost of $2/kg.

The City of Lancaster in California is building the world's largest green renewable hydrogen facility using SGH2's technology. The plant will process 40,000 tons of waste annually, saving the City $50-75/MT annually in landfilling and landfill space costs.

Table 7: Carbon intensity and production cost of hydrogen today *(SG H2 Energy, n.d.)*

	Hydrogen Types	Carbon Intensity	Production Cost ($/kg)
Green hydrogen	Gasification of waste using plasma-enhanced thermal catalytic conversion process optimized with oxygen-enriched gas	-188g CO_2 eq/MJ (avoiding 29kg of CO_2 per kg of H_2)	2
	Electrolysis using RE	0 g CO_2 eq/MJ	10-13
Hydrogen from fossil fuels	Grey hydrogen from natural gas	+12kg of CO_2 per kg of H_2	2-6 (cost of natural gas)
	Brown hydrogen from coal gasification	+20kg of CO_2 per kg of H_2	2-3
Blue hydrogen with carbon capture and sequestration	Grey hydrogen	+12kg of CO_2 per kg of H_2 with CCS	6-10
	Brown hydrogen	+20kg of CO_2 per kg of H_2 with CCS	6-7

Coal

Coal will be in Malaysia's power generation mix in 2050 under business-as-usual

Figure 20 shows that Peninsular Malaysia's coal power plants contribute to 37% (13 GW) of the country's power generation capacity mix by fuel today. By 2039, this will fall to 22% (8.756 GW) and by 2044, 3.746 GW of capacity will remain (**Figure 21**).

In parallel to increasing the RE generation capacity, Malaysia is moving towards high efficiency lower emission coal-fired power generation through:

i. Ultra-supercritical (USC) coal-fired generation and tight emissions regulations
ii. Co-firing coal and ammonia
iii. Carbon capture and storage

USC coal plant emits 26% less CO2 per MW than the average coal plant

Malaysia started installing USC coal-fired generation plants in 2015. Manjung 4 (1 GW) in Lumut was the first USC coal-fired power plant in Southeast Asia. Currently, one-third out of the 12 GW coal-fired generation capacity in Peninsular Malaysia come from USC coal-fired generation plants (**Table 2**). Emissions regulations in Malaysia also require coal power plants to install flue gas desulphurization technology.

Table 8: Ultra-supercritical coal-fired generation plants in Malaysia

Name	Location	Capacity (GW)	Year Commissioned
Manjung 4	Lumut	1	2015
Manjung 5	Lumut	1	2017
Jimah East (Tuanku Muhriz)	Port Dickson	1 x 2	2019

Conventional (sub-critical) coal-fired power plants, have an efficiency of about 38% whilst USC power plants have higher efficiencies of 44-47%. Due to less coal required per megawatt-hour (MWh), each percentage point improvement in efficiency reduces CO_2 emissions from coal power plants by over 2 percentage points. Advanced USC is on the horizon, which drives efficiency towards 50%. Whilst it is good to improve efficiency, it is even better to build non-coal capacity.

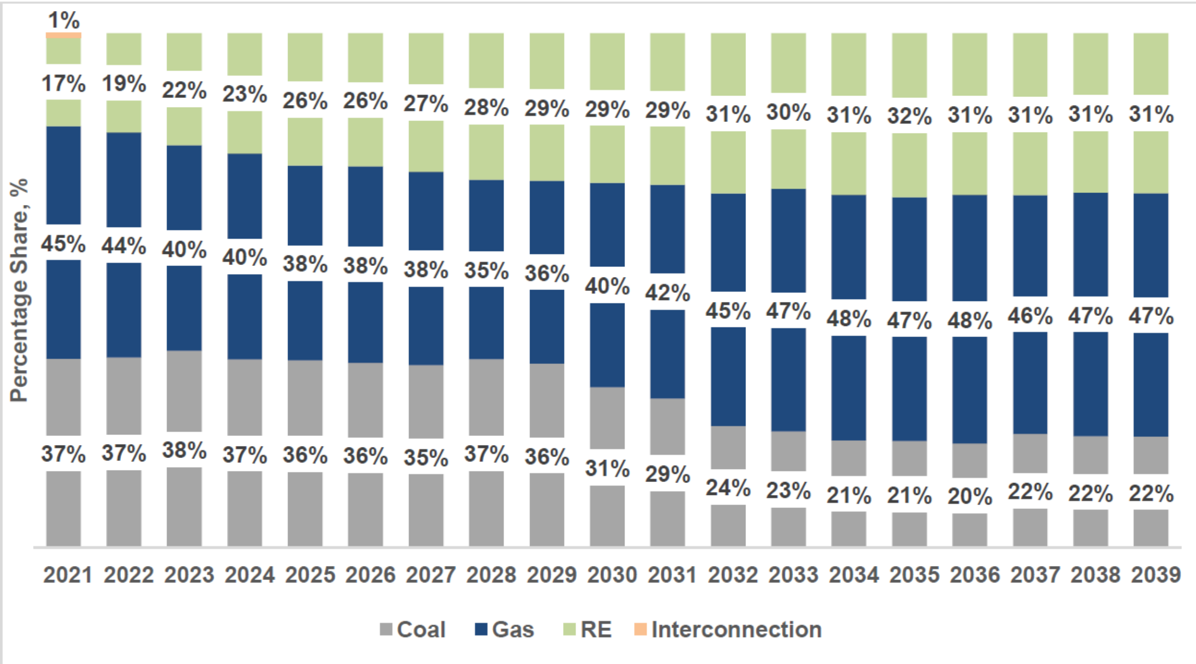


Figure 20: Peninsular Malaysia's power generation capacity mix by fuel (%), 2021-2039 *(Energy Commission, 2021)*

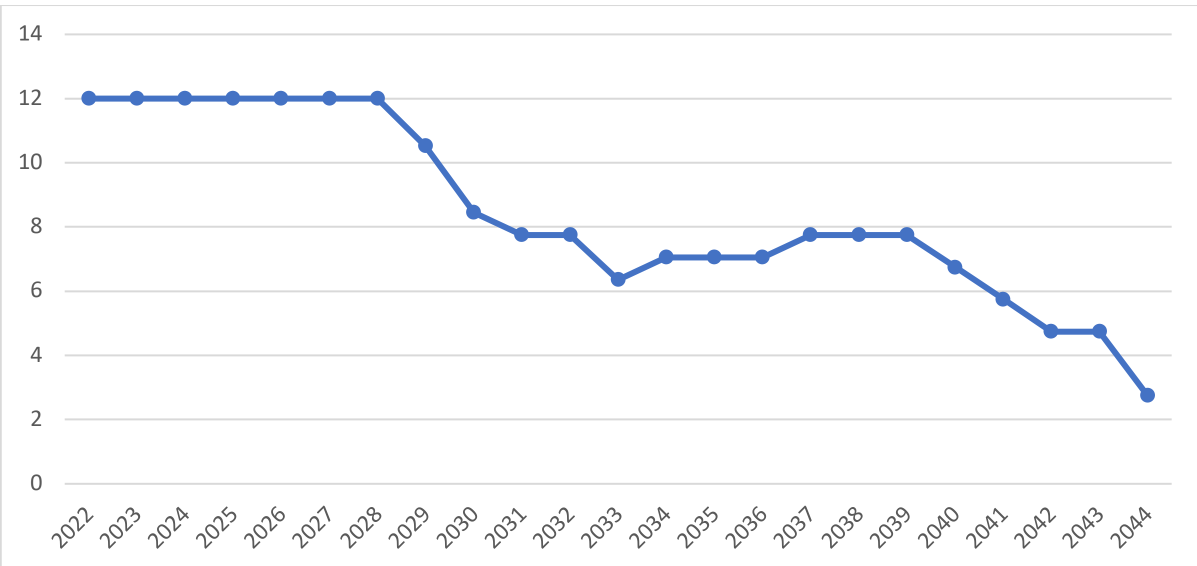


Figure 21: Coal-fired power generation capacity in Peninsular Malaysia (GW) *(Energy Commission, 2021; Teh, 2021)*

At a 20% ammonia co-firing ratio, CO_2 emissions decrease up to 26% compared to pure coal firing (Cardoso, et al. 2022)

If 20% ammonia co-firing is implemented in all coal power plants in Peninsular Malaysia in 2030[14], it could lead to 16 million MT of CO_2 savings that year, conditional on the source of ammonia and whether it is low carbon.

The technology and supply chain for co-firing coal and ammonia are actively being developed by Japan and Korea. Replacing a given amount of coal with the equivalent heat fraction of ammonia reduces the CO_2 emissions by the same fraction and does not result in increase in NOx emissions (Tamura, Gotou, Ishii, & Riechelmann,, 2020).

In October 2021, TNB Power Generation Sdn Bhd (TNB Genco), IHI Corporation and Petroliam Nasional Bhd[15] (PETRONAS) Gas + New Energy launched a feasibility study in low carbon hydrogen, low carbon ammonia supply chain in Malaysia, and on ammonia co-combustion in coal-fired power generation systems[16].

The ammonia and coal co-combustion test carried out at TNB Research's test rig facility in Kajang, Selangor was successful with CO_2 and sulfur dioxide emissions being reduced in proportion to the co-firing rate (Li, 2022). Post study, TNB is serious about procuring green ammonia and has requested for PETRONAS to identify possible locations to produce green ammonia and transport it to a coal power plant. The Manjung 4 coal-fired power plant (1 GW) in Lumut, Perak has been selected as a study site, but it is not clear if Manjung would try the expensive machines that allow the adding of ammonia in full scale. A feasibility study on building a green hydrogen production facility powered by solar in Lumut is underway.

Blue and green ammonia supply chain

If Peninsular Malaysia adopts a 20% ammonia co-firing ratio across all the coal power plants in 2030, 4.7 million MT of green/blue ammonia[17]

A 1 GW coal-fired power plant would need about 500,000 MT/year of ammonia for 20% co-burning (Kumagai, 2021). Malaysia has an existing 2.04 million MT of ammonia production capacity (**Table 9**), which is based on natural gas steam methane reforming. The ammonia produced is largely used as feedstock for downstream granulated urea (fertilizer) production.

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[14] JERA - the largest power generation company in Japan that produces about 30% of Japan's electricity - pledges to commercialize its ammonia co-firing power generation technology by 2030

[15] Malaysia's national oil company that is integrated and generates substantial government revenue

[16] The study evaluates the technology and commercial viability across the entire ammonia supply chain, which includes green ammonia production from renewable electrolytic hydrogen and blue ammonia from natural gas with carbon capture.

[17] Green ammonia is made with hydrogen that comes from water electrolysis powered by alternative energy. Blue ammonia is a low-carbon approach to ammonia production which combines traditional ammonia synthesis using natural gas with carbon capture utilization and storage (CCUS).

Table 9: Ammonia production plants in Malaysia

Name	Location	Capacity (MT / annum)	Year Commissioned
Sabah Ammonia Urea (SAMUR) *Owned by Petronas Chemical*	Sipitang, Sabah	740,000	2016
Petronas Ammonia Sdn Bhd *(100% owned by Petronas)*	Kerteh, Terengganu	460,000	Nov. 2000
ASEAN Bintulu Fertilizer (ABF) *(partially owned by Petronas, and other ASEAN parties)*	Bintulu, Sarawak	450,000	Sept. 1985
Petronas Fertilizer Kedah Sdn Bhd *(100% owned by Petronas)*	Gurun, Kedah	390,000	May 1999

Malaysia needs to think how new coal assets built in the 2030s, even with ammonia co-firing, fit within the goal of reaching net zero around 2050. These assets and their supply chains will be locked-in and still in existence in 2050.

The cost of deploying coal now is higher than renewables. Besides this, new coal investment should consider the scenario of it becoming a stranded asset with a shorter lifetime because that will impact overall system cost.

Production cost of blue and green ammonia

Co-firing ammonia to reduce carbon emissions of coal power plants is an expensive option, and is likely be low down in the hierarchy of options

- A 300MW coal power plant consumes ~75,000MT of coal / month (industry estimate)
- A 1GW coal power plant consumes ~250,000MT of coal / month.
- A 20% substitution of coal thus leads to a reduction of 600,000 MT of coal / year for a 1 GW coal power plant
- A 1 GW coal-fired power plant needs about 500,000 MT / year of ammonia for 20% co-burning (Kumagai, 2021).
- Blue ammonia costs around $250-350 per tonne to produce, while green ammonia costs around $350-450 (Reed, 2021). Green ammonia pricing is driven by renewable electricity costs, while blue ammonia pricing is driven by gas (or whichever hydrocarbon is used) price.

			Breakeven price for coal (GCV 6500-6300 Kcal/kg)
Blue ammonia cost per year	$162500000	Low end	270.83
	$227500000	High end	379.17
Green ammonia cost per year	$227500000	Low end	379.17
	$292500000	High end	487.50

For coal power plants to readily substitute coal with blue/green ammonia from a feedstock cost perspective, the coal price is estimated ("breakeven price for coal") to range from $270.83 to $487.50. Recently, 6500-6300 Kcal/kg coal is priced at $209.70/MT CIF Peninsular Malaysia, which is already considered high and unsustainable. Besides this, at that level of coal price, most coal-fired power plants would be losing money.

Most new coal power plants will lose money even in business-as-usual scenario

In 2017, half of Europe's coal plants lost money due to air pollution and climate change policies (Carrington, 2017). A 2021 study by Carbon Tracker found that 92% of new coal power plants will lose money even in a business-as-usual scenario, costing the public $150 billion in the form of subsidy, or propped up with favourable market design, power purchase agreements or other forms of policy support (Carbon Tracker, 2021).

Given this and the emissions impacts, the need to transition away from coal to cheaper and cleaner forms of power generation is clear.

Carbon capture and storage is low in the IPCC hierarchy of mitigation options that contribute to net carbon emission reduction (Figure 15)

In August 2022, TNB and PETRONAS signed a memorandum of understanding (MoU) to pursue a joint feasibility study on the application of carbon capture and storage (CCS) solutions at TNB power generation plants.

A balanced net zero pathway for electricity generation | Timeline to end state

A future aim is to present net zero pathways after large cross sectoral modelling exercises. The analytical context will make clear the drivers of technology choices and how the proposed pathways can be made compatible with a net zero objective.

2.2 Surface Transport

Lee Chean Chung

Abstract

In 2021, Malaysia government has commissioned a Low Carbon Mobility Blueprint (LCMB) to assess the best options in energy and greenhouse gas (GHG) mitigation planning in transport sector. As the transport sector is one of the largest emitters, the blueprint aims to respond to Malaysia's nationally determined contributions (NDC) intending to reduce 45% GHG emissions intensity by 2030 relative to the intensity in base year 2005.

LCMB has outlined 3 scenarios and its respective policy targets: Business as usual (BAU), existing policies (EP) and LCMB scenarios. However, due to rapidly changing environment, especially the unprecedented black-swan event – COVID19, the assumptions made earlier have been rendered inaccurate. The paper conducted a review on the latest policy change and delayed implementation, and revised two out of three scenarios outlined previously so that it can serve as better inputs for modelling or projection purpose.

Four observations made are:

1. Better data collection and quantification of energy efficient vehicles (EEVs) are needed as its energy and carbon reduction contribution were not counted in Malaysia Third Biennial Update Report to the UNFCCC 2020 (3BUR).
2. LCMB's EV promotion is less ambitious and possibly would not achieve the needed impacts to fulfill NDC targets.
3. Eco-driving program yields much benefits but often overlooked by policymakers. It is important to prioritize the program to ensure the decarbonization efforts are on track.
4. Targeting heavy freight sector that possesses characteristics of long-distance travelling and laggard in embracing fuel-economy program, Bio-diesel program is well-suited as a transition option before going fully-electric.

INTRODUCTION AND BASELINE DATA PREPARATION

Road Transportation Background

The population in Malaysia grew from 28.6 million in 2010 to 32.5 million in 2020, and expected to reach 41.5 million in 2040 (DOSM 2022). While population growth rate is slowing down, from 1.8% in 2010 to 0.8% towards 2040, the increasing affluence and mobility needs suggest that road transportation sector will continue to grow in tandem with demographic change.

Road transport in the country consists of cars, motorcycles, buses, road freight vehicles (freight), and others (taxi, hire and drive cars, and etc). Malaysia experienced one of the fastest growth of registered vehicles in the region, thereby increasing the car ownership ratio substantially. Total registered vehicles in 2021 is about 33.3 million, experiencing a compound annual growth rate (CAGR) of 3.6% compared to 29.96 million in 2018.

The assumptions in each area are derived based on a detailed review of available or closest data that is relevant and representative. They are then combined to compute the baseline energy consumption and carbon emission for year 2018.

Vehicle Kilometer Travelled

The growth of total registered vehicles are supported by increasing on-the-road vehicles even the country was struck by COVID-19 pandemic and restricted by Movement Control Order (MCO). About one million new vehicles entered the road transport system during the pandemic, with total industry volume (TIV) (i.e., sales of new motor vehicles) reaching 529,514 and 508,911 units in 2020 and 2021 respectively.

It should be highlighted that the number of total registered vehicles is not a suitable parameter for energy consumption and carbon emission computation for several reasons. First, the figure is an accumulation of all registered vehicle with Road Transport Department (JPJ) since the inception of Registrar and Inspector of Motor Vehicle (RIMV) in April 1, 1946. Second, it includes heavy machinery and vehicles used in construction, agriculture, plantation, airports and other areas that are not present on the public roads on daily basis. Third, there is no yet end-of-life vehicle policy, and clear guidelines for a registered vehicle to be categorized as inactive or inoperative (FMT 2022).

To overcome this, the “active vehicles” officially announced by JPJ is used for the computation of vehicle kilometre travelled (VKT), and subsequently energy consumption and carbon emission. In 2021, total active vehicles recorded is 21,709,492 units.

To calculate VKT of passenger vehicle, data are first drawn from Malaysia Institute of Road Safety Research (MIROS). Shabadin et al. (2014)’s finding using manufacturers’ odometer reading data shown that the average VKT for car is 24,129 km in 2013. A subsequent study in 2017 validated that the VKT of 28,184 km for cars and 21,495 km for motorcycles (Shabadin et al. 2017).

For goods vehicle, studies using the data collected from Pusat Pemeriksaan Kenderaan Berkomputer or Malaysia National Automobile Inspection Center (PUSPAKOM) found that the average VKT for goods vehicles is approximately 70,000 km (Jamaluddin et al. 2020).

However, in Malaysia Stocktaking Report on Sustainable Transport and Climate Change, Briggs and Kian (2016, 16) argue that if VKT above are used, it would result in a huge discrepancy compared to the estimates from Energy Commission:

> *The number recorded by PUSPAKOM are based largely on newer and public vehicles which undergo frequent inspections. These newer, safer, more reliable and efficient vehicles are generally driven more than older vehicles, thus accumulating higher mileage in their first few years, while the 10+ year old vehicles, (which comprise around 50% of the fleet) are generally driven much less.*

Consistent with the findings, 15,000 km of annual average VKT for cars, and 5,000 km for motorcycle will be used for computation. For freight vehicles and buses, due to lack of other available data, latest MIROS findings, that is annual average VKT of 56,197.2 km (commercial freight vehicles) and 57,922.5 km (buses) will be used (Sim et al. 2020, 30), as shown in **Table 10**.

Table 10: Estimation of VKT for Commercial Vehicles, Buses and Taxi *(Sim et al. 2020, p. 30.)*

Type of Vehicle	Frequency	Total Odometer Readings	Half Yearly VKT	Annual VKT
Commercial Vehicles	16350	459411958.4	280908.6	56197.2
Bus	1326	38401947.1	28960.7	57921.5
Taxi	3207	84415369.0	26322.2	52644.4

For simplification purpose and lack of detail breakdown of 'other vehicles' by JPJ, the energy usage and emission for taxi, hire and drive car, and other types of vehicles are assumed to have characteristics as car category.

Fuel Economy

In 2015, average fuel consumption for new light-duty vehicles in Malaysia is 6.6 LGe/100km (ASEAN Secretariat 2019, 24). Malaysia heavily promotes energy efficient vehicle (EEV) as an integral part of National Automotive Policy 2014. EEV, defined loosely as vehicles that meet a defined specifications in terms of carbon emission level (g/km) and fuel consumption (L/100 km), covered wide spectrum of technologies: energy-efficient, hybrid, compressed natural gas (NGV), electric vehicle (EV), or even hydrogen and fuel-cell (NAP 2014). Since the launch of NAP2014, total number of EEVs sold to the market has seen a continuous year-on-year increase.

Table 11: EEV Penetration Rate and Volume *(MARii & Paultan.org 2020)*

Year	% of EEV	Total Units of EEV
2014	14%	93,975
2015	33%	217,336
2016	43%	248,293
2017	52%	299,850
2018	62%	339,978
2019	87.6%	529,256

The study is constrained by the availability of type, age and fuel economy of existing active vehicles. Nevertheless, as more dominated share of EEVs enter the road each year, coupled with the European-like transport path that is believed to be emulated by Malaysia (ASEAN Secretariat 2019, 21), which is at the annual improvement rate of about 2.9% (67), the average fuel economy of 6.6 LGe/100km is chosen as the baseline number for cars.

For motorcycles, studies by Lee, Chong and Gitano (2010) shown that the fuel economy of small motorcycles is about 45km/L or 2.2 LGe/100km, which coincidently also the threshold to quantify for the EEV of two-wheeler 101-150cc category.

For freight vehicles, the baseline fuel consumption for median freight trucks (MFT, 3.5t < GVW < ~15t) and heavy freight trucks (HFT, GVW > 15t) in Malaysia are modelled based on the proxy figure of China, which are (21.2 L/100km) and (41.6 L/100km) respectively, due to closest GDP per capita and state of development (GFEI 2016, 29). Next, the ratio of MFT and HFT in Malaysia is derived from JPJ statistics in 2017. On the other hand, fuel economy for bus is extracted from the work done by Mahadin and Mustafa (2018), which is normally about 24 litre/100km, or 26.88 LGe/100km.

ENERGY CONSUMPTION OF LAND TRANSPORT

In 2018, Malaysia's total Final Energy Consumption (FEC) stood at 64,658 ktoe, 3.4% higher than the previous year (Malaysia Energy Statistics Handbook 2020). Among the sectors, transport is the largest contributor with a total FEC of 23,555 ktoe, or 36% of the country's total.

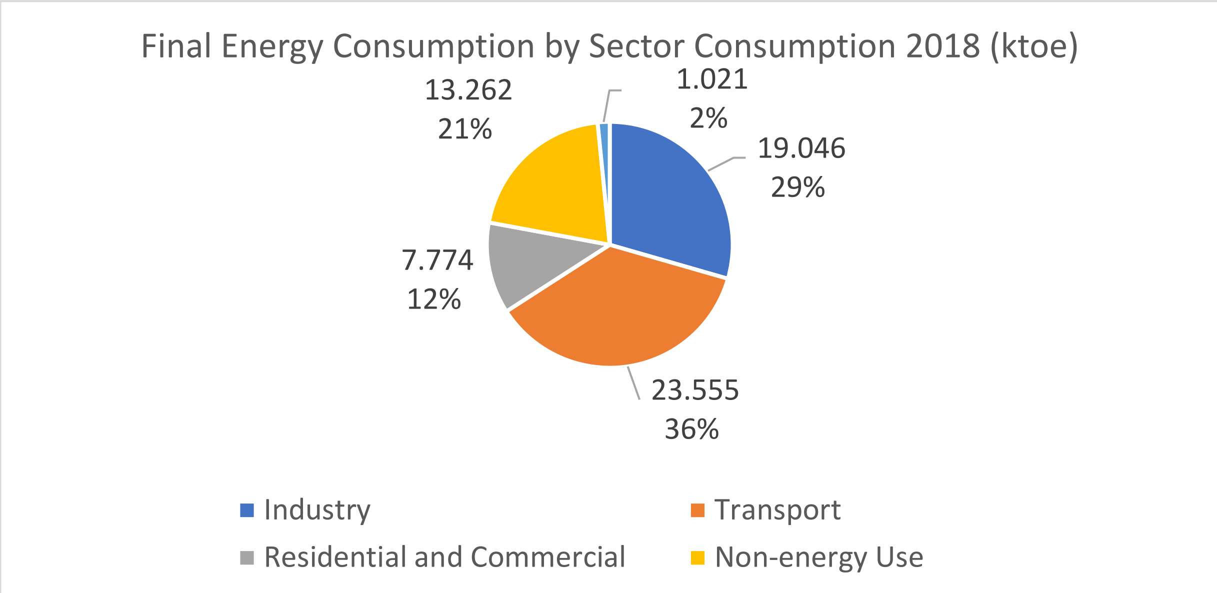


Figure 22: Final Energy Consumption by Sector Consumption (ktoe) *(Malaysia Energy Statistics Handbook 2020)*

Final energy consumption for Transport sector includes fuel consumption in the international civil aviation (Malaysia BUR 2020, p. 13), as well as diesel and gasoline sold directly to government and military (Malaysia Energy Statistics Handbook 2020, 79). LCMB report (2021) and estimated that road transport accounted for more than 90% of energy consumption in 2017 (14), which if extrapolated, is about 21,120 ktoe in 2018. To set the baseline for energy consumption, the fuel type of different vehicles need to be categorized. In 2020, more than 91% of the number of vehicles consist of petrol-fueled engine, as shown in **Figure 23**.

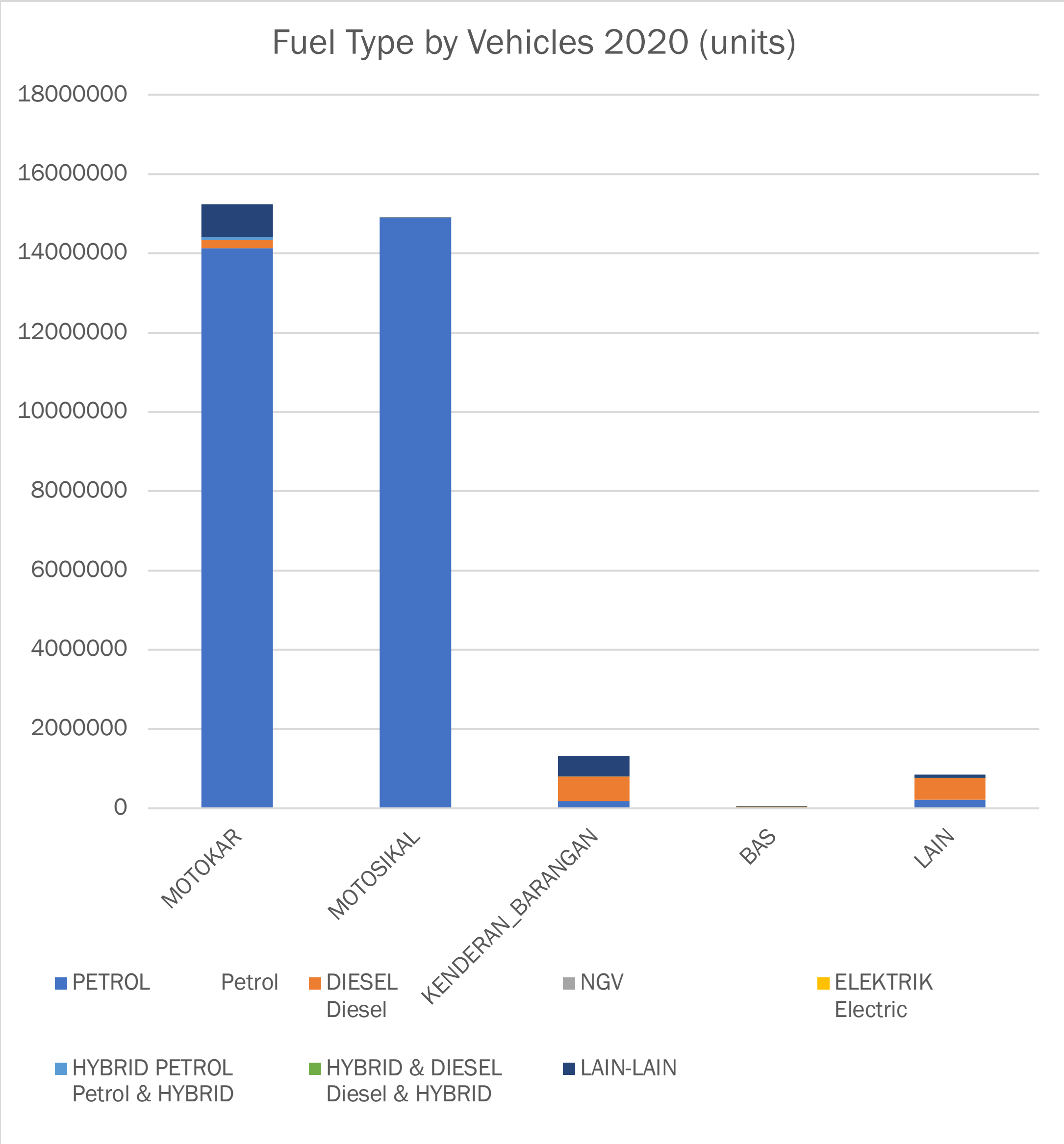


Figure 23: Fuel Type by Vehicles in 2020 *(Road Transport Department, data.gov.my and author's calculation)*

The conversion coefficient of petroleum products are taken from official figures from Energy Commission of Malaysia.

Table 12: Conversion Coefficients and Equivalence of Petroleum Products (Energy Statistics Handbook 2020, 81)

Petroleum Products (TJ/1000 tonnes)	Conversion coefficient
Motor gasoline	43.9614
Diesel oil	42.496
Liquified Petroleum gas (LPG)	45.544

1,000 Tonnes Oil Equivalent (toe) = 41.84 TJ

Carbon Emissions

In terms of CO_2 emissions, road transportation sector remained the second highest sector after electricity and heat production in 2016, accounted for 21% of total CO_2 emissions at 55,188 Gg CO_2 (Malaysia Third Biennial Update Report to the UNFCCC 2020, 32). The growth rate from 1990 to 2016 is 5.9% and have slowed down over the past few years (Malaysia Third Biennial Update Report to the UNFCCC 2020, 42).

Calculating CO_2 emission from vehicles of different fuel type requires fuel-specific emission factors. The conversion table provided in ASEAN Fuel Economy Roadmap (91) is used.

Table 13: Fuel-specific CO_2 Emission Factors (*ASEAN Fuel Economy Roadmap, 91*)

Fuel	Base Unit	Multiplicator	Target Unit
Petrol	Lge/100km	23.20	gCO_2/km
Diesel	Lge/100km	24.80	gCO_2/km
CNG	Lge/100km	18.80	gCO_2/km
EV	Lge/100km	-	gCO_2/km

OPTIONS OF DECARBONIZATION PATHWAYS

LCMB (2021) has suggested four focus areas and ten strategies, namely:

1. Vehicle fuel economy and emission improvement
   a. Strategy 1: Encourage adoption of low emission vehicle
   b. Strategy 2: Strengthen eco-driving program
2. Electric vehicle adoption
   a. Strategy 3(i): Electric car adoption
   b. Strategy 3(ii): Electric bus adoption
   c. Strategy 3(iii): Electric motorcycle adoption
3. Alternative fuel adoption
   a. Strategy 4: Enhancing use of biodiesel in road transport
   b. Strategy 5: Creating an eco-system for growth of alternative fuel and energy industry
4. Mode shift
   a. Strategy 6: Shifting private transport to public transport
   b. Strategy 7: Promoting public transport through land-use development
   c. Strategy 8: Improving traffic flow
   d. Strategy 9: Shifting freight mode from road to rail
   e. Strategy 10: Promoting active and micro mobility

Some of the strategies above have proven to be effective based on previous emission reduction records in 2016 as estimated in 3BUR:

Table 14: Strategies for CO_2 Emission Reduction (*3BUR, LCMB, Author's analysis*)

Strategies/Mitigation Actions	LCMB Strategies	Emission Reduction Gg CO_2 eq (in 2016)
Urban rail-based public transport	6	212.93
Energy Efficient Vehicles (EEVs)	3(i)	90.65
Palm-oil based fatty acid methyl ester (Biodiesel)	4	1,127.34
Natural gas vehicle	5	114.77
Total		1,545.69

It is important to note that the under 3BUR, quantification of GHG emission reduction by EEVs is only limited to hybrid and electric vehicles, as the report has stated that "quantification of fuel-efficient ICE vehicles could not be carried out due to insufficient activity data" (Malaysia 3BUR, 53). In 2018, 62% of total industry volume in Malaysia were EEVs. Therefore, if proper data structures are made and quantified, emission reduction in the sector driven by fuel-efficient technology is actually sizable.

To assess the best options in energy and GHG mitigation planning in the transport sector, in particular land transport, LCMB has outlined 3 scenarios:

1. Business as usual (BAU) – modelled based on historical data and trends regarding population and GDP growth assuming there will be no new energy and GHG emission policy initiative.
2. Existing policies (EP) – subsumes the BAU scenario and further incorporates effects of new policy initiative that have already been announced by the Government of Malaysia but has yet to be implemented.
3. LCMB – incorporates additional policies proposed by this study and those already considered in Scenario.

The strategies/policies have the following targets:

Table 15: Three Scenarios and The Policy Targets (*LCMB 2021-2030, 83.*)

Business as Usual (BAU) Scenario
Implemented Policy Targets: a. 7% biodiesel content (B7) – 2015-2018 b. 10% biodiesel content (B10) – 2019-2020 c. 2% (by 2019) and 20% (by 2025) RE mix in electricity generation
Existing Policies (EP) Scenario
Announced Policy Targets: a. 20% biodiesel content (B20) in 2021 b. Assumed 1% passenger shift from road to rail by 2030 from the following announced targets: I. Operation of MRT 2 beginning 2021 II. Operation of LRT 3 beginning 2024 III. Operation of ECRL beginning 2027 c. Assumed 1% road freight to rail by 2030 from the following announced targets: I. Operation of ECRL beginning 2027 d. 100% of total industry volume (cars) being EEV beginning 2020 – NAP2014
LCMB Scenario
Proposed Policy Targets (by 2030): a. Increase share of energy-efficient car travels: ICE 10%, Diesel 6%, ICE-EEV 73.9%, HEV 5%, EV 5%, NGV 0.1% b. Reduce car travels by 10% to bus, 5% to rail, and 1% to motorcycle c. Shift use of conventional motorbikes to e-bike (85% : 15%) d. Adopt cleaner energy for bus: E-bus 20%, and B100 for 30% of big bus e. Adopt cleaner energy for taxi: diesel 0%, petrol 0%, NGV 0%, EV 20%, and ICE-EEV 80% f. Shift from CNG and LNG to biogas (2%) g. Promote eco-driving: 10% reduction in energy use for freight vehicles and buses and 1% for other road vehicles h. Improve traffic management: 2% reduction in energy use for all classes of road vehicles i. Shift of 5% from road-based freight to rail

Apparently, the report targets have been caught off-guard by the unexpected COVID-19 pandemic. For instance, Euro 5 B10/B20 has only replaced Euro 2M diesel as late as April 1 2021 in light of the pandemic and constraints faced by various industries. Correspondingly, the biodiesel targets under Scenario 1 have also been shifted. The 20% biodiesel (B20) has not been implemented as of now, although the ministry's secretary general said this was more likely to happen by the end of 2022 (Reuters 2022).

At the same time, due to a minor setback during trial operations, the commencement of MRT2 has also been delayed. Originally slated to begin operation in November 2021, now only phase one of the line has opened on Jun 16 2022, and phase two by January 2023 (The Edge 2022).

Regarding the energy efficient vehicle (EEV), obviously the original target set by National Automotive Policy (NAP 2014) of 100% EEV by 2020 is not achieved. The National Automotive Policy (NAP 2020) is launched on 21 February 2020 with the emphasis of developing Next Generation Vehicle (NxGV). However, industries lamented for the lack of specific details on the scopes offered, and even the self-impose target of developing NxGV standards by 2021 cannot be met (National Automotive Policy 2020, 42).

Indeed, using the overarching EEV regime to pursue decarbonization is itself a controversial strategy. First, Daud et al. (2021) observes that the definition of EEVs itself is cross-cutting between ministries, and there is no one policy-feed for all EEVs in Malaysia.

Second, EEV's broad regime allows fuel-efficient vehicles, hybrids, 100% battery-powered electric vehicles (EVs), and alternative-fueled vehicles to fall under the same category, thereby getting across-the-board accreditation and incentives. As there is no targeted policy, and subsequent value incentives accorded to EV, the adoption is believed to fall short against other countries that have EV-specific policies. The one-size-fit-all strategy provides near zero incentive for existing local manufacturers to pursue hybrid technology, let alone EVs.

Third, it is also important to note that while both National Automotive Policy 2014 (NAP2014) and NAP2020 define EEV that meet a set of criteria in terms of carbon emission level (g/km) and fuel consumption (l/100km), the specifications to qualify for EEV specifies ONLY the fuel consumption requirements based on curb weight. While we know that the carbon emission level and fuel consumption are often in linear dependence (Valentinas and Alvydas 2007), NAP2014 has clearly stated that "carbon emission will be used once the EURO 4M fuel quality standard is introduced" (National Automotive Policy 2014, 9), which the government finally did on December 31 2019, however, the standards to measure carbon emissions have yet to be implemented. The latest Malaysian Standard "Energy efficient vehicle (EEV) – Requirements" (MS 2722:2021) is still developed based on a single parameter - fuel consumption.

Fortunately, not all targets are revised downward. In 2021, the renewable energy mix target has been reviewed to 31% (by 2025), instead of the 25% target previously (MIDA 2021).

Moving forward to 2022, in view of recent developments discussed above, coupled with the black-swan COVID19 event, have rendered the previous BAU and EP projections by LCMB inaccurate. The scenario assumptions and targets are thus revised and listed below next to the original targets:

Table 16: Existing and Revised Scenarios with Their Policy Targets (*Author's estimation*)

Existing BAU Scenario	Revised BAU Scenario
Implemented Policy Targets: a. 7% biodiesel content (B7) – 2015-2018 b. 10% biodiesel content (B10) – 2019-2020 c. 2% (by 2019) and 20% (by 2025) RE mix in electricity generation	Implemented Policy Targets: a. 7% biodiesel content (B7) – 2015-2018 b. 10% biodiesel content (B10) – 2021 c. 2% (by 2019) and 31% (by 2025) RE mix in electricity generation
Existing Policies (EP) Scenario	**Existing Policies (EP) Scenario**
Announced Policy Targets: d. 20% biodiesel content (B20) in 2021 e. Assumed 1% passenger shift from road to rail by 2030 from the following announced targets: I. Operation of MRT 2 beginning 2021 II. Operation of LRT 3 beginning 2024 III. Operation of ECRL beginning 2027 f. Assumed 1% road freight to rail by 2030 from the following announced targets: I. Operation of ECRL beginning 2027 g. 100% of total industry volume (cars) being EEV beginning 2020 – NAP2014	Announced Policy Targets: d. 20% biodiesel content (B20) in 2022 e. 30% biodiesel content (B30) in 2025 f. Assumed 1% passenger shift from road to rail by 2030 from the following announced targets: I. Operation of MRT 2 beginning 2022-2023 II. Operation of LRT 3 beginning 2024 III. Operation of ECRL beginning 2027 g. Assumed 1% road freight to rail by 2030 from the following announced targets: I. Operation of ECRL beginning 2027 h. 87.6% of total industry volume (cars) being EEV beginning 2020 – NAP2020 i. Improve fuel economy level in Malaysia to 5.3 Lge/100km by 2025
LCMB Scenario	**LCMB**
Proposed Policy Targets (by 2030): h. Increase share of energy-efficient car travels: ICE 10%, Diesel 6%, ICE-EEV 73.9%, HEV 5%, EV 5%, NGV 0.1% i. Reduce car travels by 10% to bus, 5% to rail, and 1% to motorcycle j. Shift use of conventional motorbikes to e-bike (85% : 15%) k. Adopt cleaner energy for bus: E-bus 20%, and B100 for 30% of big bus l. Adopt cleaner energy for taxi: diesel 0%, petrol 0%, NGV 0%, EV 20%, and ICE-EEV 80% m. Shift from CNG and LNG to biogas (2%) n. Promote eco-driving: 10% reduction in energy use for freight vehicles and buses and 1% for other road vehicles o. Improve traffic management: 2% reduction in energy use for all classes of road vehicles p. Shift of 5% from road-based freight to rail	Proposed Policy Targets (by 2030): a. Increase share of energy-efficient car travels: ICE 10%, Diesel 6%, ICE-EEV 73.9%, HEV 5%, EV 5%, NGV 0.1% b. Reduce car travels by 10% to bus, 5% to rail, and 1% to motorcycle c. Shift use of conventional motorbikes to e-bike (85% : 15%) d. Adopt cleaner energy for bus: E-bus 20%, and B100 for 30% of big bus e. Adopt cleaner energy for taxi: diesel 0%, petrol 0%, NGV 0%, EV 20%, and ICE-EEV 80% f. Shift from CNG and LNG to biogas (2%) g. Promote eco-driving: 10% reduction in energy use for freight vehicles and buses and 1% for other road vehicles h. Improve traffic management: 2% reduction in energy use for all classes of road vehicles i. Shift of 5% from road-based freight to rail

METHODOLOGY

The action plans and strategies on energy consumption, CO_2 emissions and expenditure on fuels are translated into modelling tool. Sensitivity and cost-benefit analysis will be conducted to determine which policy targets will achieve the most reduction in energy consumption and CO_2 emissions.

DATA PREPARATION

The data preparation method is illustrated below:

1. Establish Baseline Scenario: Unconstrained growth in car demand, no modal shift, any efficiency improvements lost to bigger cars and more driving.
2. Use the baseline scenario to deduce EP and LCMB scenarios.

Data needed for energy consumption are:

1. Active vehicles on the road: Total numbers of vehicles (unit)
2. Vehicles by type: Car, Motorcycle, Bus, Freight and others (unit)
3. Fuel type: Petrol, diesel, fully electric, NGV, petrol hybrid, diesel hybrid, and others (unit)
4. Average vehicle-kilometre travelled (VKT): (billion-vehicle-km/year)
5. Fuel economy: The measurement unit used for vehicle fuel efficiency is in terms of litres of gasoline equivalent consumed per 100 kilometres (LGe/100km)
6. Energy demand by fuel: petrol, diesel, NGV, EV, petrol hybrid, diesel hybrid and others.

Data needed for GHG emissions are:

1. Fuel characteristics
2. Emission factors of various transportation modes
3. Biodiesel emissions
4. Electricity generation mix

ASSUMPTIONS

1. Compound Annual Growth Rate (CAGR) of total registered vehicles between 2018-2021 is 3.6%. The same growth rate will be used for 2022-2030 projection.
2. The active vehicles of 2021 is 65.2% of total registered vehicles. The same percentage will be used for 2022-2030 projection.
3. The average vehicle type split between 2018-2020 is car (47.2%), motorcycle (45.9%), bus (0.2%), freight (4.2%) and others (2.6%), respectively. The same percentage will be used for 2022-2030 BAU projection.
4. The Average vehicle-kilometre Travelled (VKT) for car is 15,000 km while for motorcycle is 5,000km (Briggs and Kian, 2016).
5. Annual average VKT of 56,197.2 km (commercial freight vehicle) and 57,922.5 km (bus) will be used (Sim et al. 2020, p. 30).
6. Taxi, hire and drive car, and other types of vehicles are categorized as car in terms of usage patterns and emissions.

7. the baseline fuel consumption for median freight trucks (MFT, 3.5t < GVW < ~15t) and heavy freight trucks (HFT, GVW > 15t) in Malaysia are modelled based on the proxy figure of China, which are (21.2 L/100km) and (41.6 L/100km) respectively, due to close GDP per capita and state of development (GFEI 2016, p.29).
8. The percentage split of MFT and HFT is approximated based on 2017 JPJ data.
9. In terms of fuel usage, "Petrol & NGV", "Petrol & LPG" is categorized as "Petrol & HYBRID", whereas "Diesel & NGV" is categorized as "Diesel & HYBRID" (Road Transport Department, 2018).
10. Since the stated fuel economy for car is the average figure across conventional ICE cars and hybridized cars, the same fuel economy will also be used for hybrid cars.

DISCUSSIONS

The impact assessment section of LCMB has singled out few strategies that will exert greater impacts in reducing energy use and carbon emission. Top three strategies are highlighted in green below:

Table 17: Reduction in GHG Emission and Energy Use by Strategy: LCMB Scenario (2030) (*LCMB, 86*)

Strategy	Energy Use Reduction (ktoe)	Emission Reduction (Million tonnes)
Strategy 1: Encourage adoption of low emission vehicle	2,928.29	9.25
Strategy 2: Strengthen eco-driving program	1,200.93	3.30
Strategy 3: Adopting Electric Mobility in Strategic Applications	2,000.58	2.83
Strategy 4: Enhancing use of biodiesel in road transport	128.37	4.35
Strategy 5: Creating an eco-system for growth of alternative fuel and energy industry	1.35	0.06
Strategy 6: Shifting private transport to public transport	846.16	2.41
Strategy 7: Promoting public transport through land-use development	391.88	1.10
Strategy 8: Improving traffic flow	678.36	1.98
Strategy 9: Shifting freight mode from road to rail	513.50	1.40
Strategy 10: Promoting active and micro mobility	81.08	0.22
Total	8,770.50	26.90

It is intriguing that encouraging adoption of low emission vehicle is expected to bring the greatest reduction benefits both in energy consumption and carbon emission (2,928 ktoe and 9.25 mtCO_2), but was never submitted in 3BUR, as discussed before. Collection and quantifying the benefits of fuel-efficient vehicle activity data is obviously an immediate task.

Adopting electric mobility in strategic applications would bring about 2,000 ktoe of energy reduction, ranked second in terms of energy consumption but only ranked third in GHG emissions. As many countries are heavily opting a sector-wide transition that produce zero tailpipe emission, LCMB has set a less ambitious target for Malaysia, which is to achieve just 5% of EV on the road by 2030. That is amounted to about 700,000 units of EVs in the span of 8 years. Given China has sold more than 3.33 million EVs in 2021 alone, whereas Romania has reached 15.5% of EV market share in 2021, LCMB's target looks pale if compared to countries with more ambitious drive.

The availability of charging infrastructure remains one of the main hurdles in EVs' uptake by consumers. As of 2021, there are only about 500 AC charging stations in the country, and only 9 public DC fast-charging facilities (Green Fiscal Policy, 2021). Studies by Adnan, Nordin and Rahman (2017) and stakeholder interview have confirmed that having public charging facility in place is paramount in promoting EVs among consumers[18]. Overlooking the ecosystem and infrastructure supporting EV is likely to hamper EVs' growth potentials.

On the other hand, there is a counter-argument against EV adoption in the context of Malaysia. Joshi (2018) argues that EVs merely shift the source of vehicular emissions from tailpipe to smokestack, and "if electricity is predominantly generated from carbon-intensive sources such as coal, the environmental effects of vehicle fleet electrification may indeed be negative". His analysis deserves more scrutiny, but probably explains why the emission reduction is much less at only 2.83 mtCO_2 reduction. It is also important to note that the government has revised upward the RE mix from 25% to 31% by 2025, thus contributing positively in reducing carbon emission by EV adoption.

Unexpectedly, strengthening eco-driving program yields much benefits, but is never discussed seriously by the government until 2011, when it was revealed in 12th Malaysia Plan that energy-efficient driving program will be made mandatory for all driving license classes in the country. Nevertheless, no specific details are given until today.

Enhancing use of biodiesel in road transport could reduce GHG emission by 4.35 MTCO_2, 54% more than adopting electric mobility. As diesel-based heavy goods vehicles continue to drive long distance and slow in improving fuel-economy, biofuel blending serves as a good transition option towards fully-electric.

[18] Interview was conducted on 6 July 2022 with Powered by RISE at its headquater.

2.3 Marine Transport

Vijeya Seelen

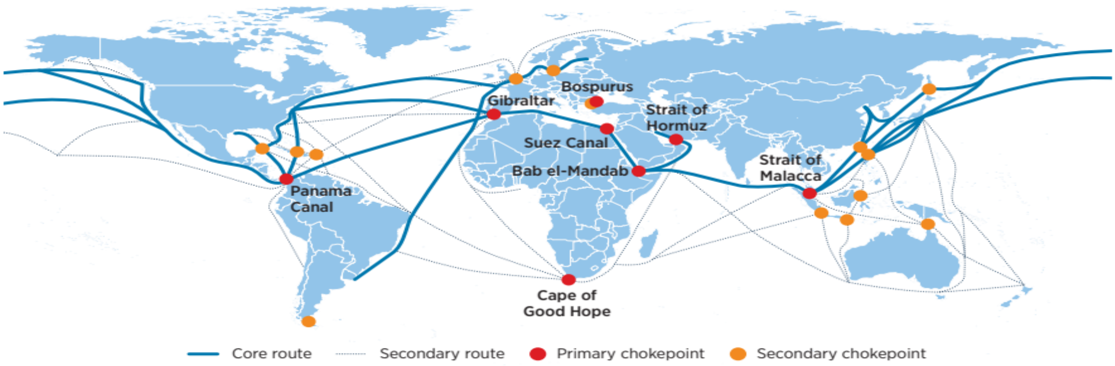
Abstract

Maritime emissions on oceans are substantial and around 85% of emissions come from containerships and tankers. Containerships have short port stays, but high emissions during these stays. Most of CO2 emissions in ports from shipping are in Asia and Europe (58%), but this share is low compared to their share of port calls (70%). The ports with the largest absolute emission levels due to shipping are Singapore, Hong Kong (China), Tianjin (China) and Port Klang (Malaysia). The distribution of shipping emissions in ports is skewed: the ten ports with largest emissions represent 19% of total CO2 emissions in ports and 22% of SOx emissions. Approximately 230 million people are directly exposed to the emissions in the top 100 world ports in terms of shipping emissions. Most shipping emissions in ports (CH4, CO, CO2, and NOx) will grow fourfold up to 2050. This would bring CO2-emissions from ships in ports to approximately 70 million tonnes in 2050 and NOx-emissions up to 1.3 million tonnes. Asia and Africa will see the sharpest increases in emissions, due to strong port traffic growth and limited mitigation measures. To reduce these projected emissions, strong policy responses will be needed. This could take the form of global regulation such as more stringent rules on sulphur content of ship fuel, or more emission control areas than the four that are currently in place (Baltic Sea, North Sea, North American ECA and United States Caribbean Sea ECA). In addition, shipping could be included in global emissions trading schemes and climate finance schemes. A lot could also be gained by policy initiatives of ports themselves. Various ports have developed infrastructure, regulation and incentives that mitigate shipping emissions in ports. These instruments would need wider application for ship emissions in ports to be significantly reduced.

This analysis begins with an introduction of Global Marine Decarbonization evolution. It then narrates the effect of decarbonization of International Marine Transport particularly Containers, Breakbulk, and Carriers Liners on Malaysian Waters. Next, explained Global Marine Transport emissions by 2035 baseline scenario including Malaysian Waters, then brief factual about Malaysian Marine Transportation infrastructure and current data, then Malaysia's commitment in the marine transportation and Net Zero Pathway and finally brief recommendation on ways moving forward.

Introduction and Marine Transport Emissions Evolution

Marine Transportation is the backbone of the global economy. It is by far the most efficient mode of freight transport and transports approximately 80% of the world's trade volume, according to the United Nations Conference on Trade and Development (UNCTAD). However, as the industry's development continues, it generates increasing carbon emissions from the ships.



Source: Rodrigue (2020)

Figure 24: Main Maritime Transport Traffic Routes

Maritime Transportation is a major contributor to global air pollution and anthropogenic climate change. About 60,000 people die prematurely each year due to exposure to shipping air pollution, and global shipping emits about 1 gigatonne (Gt) of greenhouse gases (GHGs) each year. Heavy fuel oil (HFO), a viscous, residual fuel that remains after higher-value fuels are distilled off crude oil, continues to be burned in marine engines. A related fuel, very low sulphur fuel oil (VLSFO), is also gaining favour to comply with international marine fuel standards that took effect in 2020.

The main compounds of concern emitted by voyages and port operations are sulphur dioxide (SO2), carbon dioxide (CO2), black carbon (BC), carbon monoxide (CO), nitrogen oxides (NOx), and various kinds of particulate organic matter (OECD 2011). Generally, a distinction is made between greenhouse gas emissions (GHG) and other emissions (non-GHG). GHG emissions are at the origin of climate change and affect the stratospheric ozone layer, so have global impacts, whereas non-GHG emissions generally have more local impacts. Maritime transport is at the origin of a large share of global non-GHG emissions, among which SO2 emissions.

Marine Transport greenhouse gas (GHG) emissions and the associated climate impact are currently subject to intense debate within the International Maritime Organization (IMO). Its member countries decided in 2016 to develop an Initial IMO Greenhouse Gas Strategy by 2018 and a Revised Strategy in 2023. This Strategy is supposed to define an ambition for GHG mitigation in maritime transport, which includes targets, guiding principles and candidate measures to reach these targets. Although global regulation on mandatory energy efficiency standards in shipping was introduced in 2013, various studies project shipping's GHG emissions to grow if additional measures are not taken. For example, the official IMO GHG study foresees an increase of shipping's GHG emissions of 50-250% by 2050 (Smith et al. 2014).

The 2015 Paris Climate Agreement formulated clear ambitions for mitigating GHG emissions. This included a long-term goal of keeping the increase in global average temperature to well below 2°C above pre-industrial levels; to aim to limit the increase to 1.5°C; and for global emissions to peak as soon as possible. Although Marine Transport is not explicitly excluded from the Paris Climate Agreement, one could argue on the extent to which it is covered by it. The Agreement does not mention international shipping and – considering that international shipping is a global activity – countries have not included the sector in their Nationally Determined Contributions (NDCs) that form the backbone of the Paris Agreement.

The International Maritime Organization (IMO) has set an ambition to reduce the carbon intensity of emissions from marine transportation by at least 40% by 2030, and 70% by 2050, compared with 2008 levels. To achieve this, the shipping industry needs to unite in taking urgent action. The Paris Agreement, ratified by 175 countries, calls for limiting global mean temperature rise to below 2°C, and, ideally, below 1.5°C (UNFCCC, 2015). To meet the 2° goal, the Intergovernmental Panel on Climate Change (IPCC) argues that global annual Greenhouse Gas (GHG) emissions must be reduced 42–57% by 2050 (relative to 2010 levels) and 73–107% by 2100 (IPCC, 2015). This monumental task will require extensive decarbonization of economic growth.

According to the International Energy Association (IEA), for international marine transport to contribute equally to the Paris Agreement goal of limiting anthropogenic warming to well below 2 °C, marine transport must emit no more than 17 Gt CO2 in total from 2015 onward. The IMO targets allow a total of between 28 and 43 Gt CO2 to be emitted by international marine transport through 2100. Thus, IMO's initial GHG strategy suggests an emissions trajectory that overshoots a 1.75 °C pathway by between 65% and 150%. In this case, international marine transport would consume between 3.8% and 5.8% of the world's remaining Paris-compatible carbon budget, compared to 2.3% of anthropogenic CO2 emissions today.

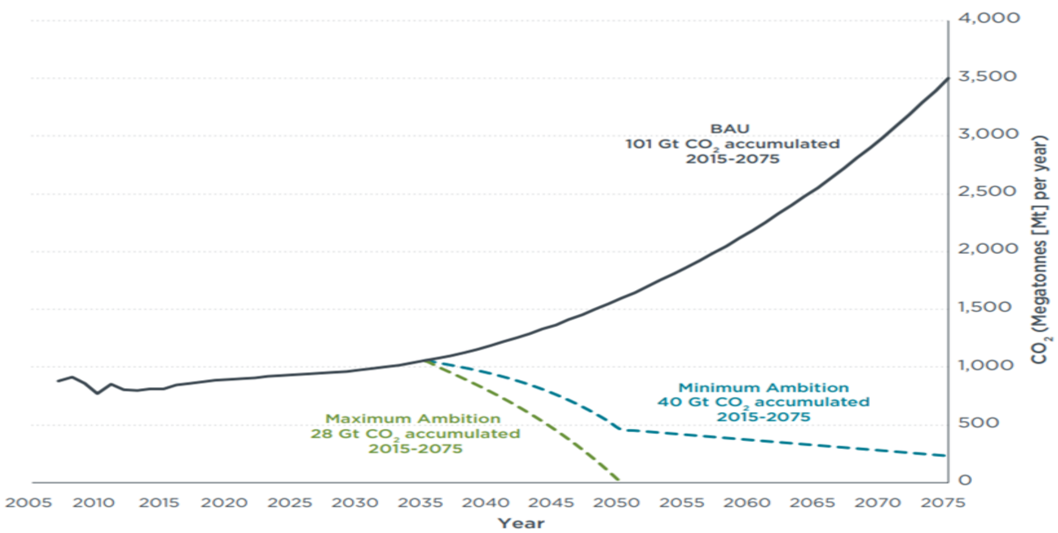


Figure 25: CO2 emissions from international marine transportation under IMO's initial GHG strategy (blue and green) vs. BAU (black), with cumulative emissions 2015 through 2075 (*Dan Rutherford, Bryan Comer April 2018, ICCT.*)

Marine Transportation Decarbonization on Malaysia Waters

Burning HFO in marine engines emits fine particulate matter (PM2.5), sulphur oxides (SOx), and nitrogen oxides (NOx) that drive premature mortality and morbidity in coastal communities. Earlier work found that most early deaths occur in Asia, particularly Singapore as the world's largest seller of marine bunker fuel, suffers the world's highest per-capita premature death rate from shipping emissions. Malaysia ranked 7th in the world.

A group of researchers from the ICCT, The George Washington University Milken Institute School of Public Health, and the University of Colorado Boulder released a new study assessing premature mortality associated with air pollution from transportation. The study found that fine particulate matter (PM2.5) and ozone from on-road vehicles, non-road engines, and oceangoing vessels was linked to an estimated 385,000 premature deaths in 2015 worldwide. About half of these deaths were attributed to air pollution from diesel cars, trucks, and buses. But a surprisingly large fraction of the early mortality approximately 15%, or 60,000 deaths were due to air pollution from the 70,000 international ships that ply the world's oceans. That equates to about 160 billion dollars of health damages annually. The study highlights the uneven distribution of premature mortality due to air pollution from international shipping. It provides the raw data, which allows anyone to run their own secondary analysis and found some interesting results, namely that many of these deaths occur in places one might not expect.

Table 18. Premature mortality linked to shipping air pollution, 2015 (Rutherford & Miller, 2019)

TOP 20 COUNTRIES BY EARLY DEATHS FROM SHIPPING EMISSIONS, 2015

Rank	Country	2015 shipping deaths	Share of shipping deaths
1	China	22,400	37%
2	Japan	4,100	7%
3	India	3,400	6%
4	United Kingdom	3,200	5%
5	Indonesia	1,900	3%
6	Germany	1,900	3%
7	Brazil	1,400	2%
8	Vietnam	1,400	2%
9	Italy	1,300	2%
10	United States	1,200	2%
11	France	1,100	2%
12	Egypt	1,100	2%
13	Malaysia	1,000	2%
14	Netherlands	880	1%
15	Spain	880	1%
16	Philippines	730	1%
17	Turkey	730	1%
18	South Korea	690	1%
19	Russian Federation	600	1%
20	Morocco	590	1%
	Top 20	**50,500**	**84%**
	Other	**9,200**	**16%**
	Total	**59,700**	**100%**

Source: Anenberg et al. 2019. https://www.theicct.org/publications/health-impacts-transport-emissions-2010-2015

TOP 20 COUNTRIES BY EARLY DEATHS FROM SHIPPING EMISSIONS PER 100,000 POPULATION, 2015

Rank	Country	Shipping deaths per 100,000 population[1]
1	Singapore	7.9
2	Denmark	5.5
3	Netherlands	5.3
4	United Kingdom	5.1
5	Belgium	4.7
6	Ireland	4.0
7	Malaysia	3.6
8	Japan	3.4
9	Mauritius	3.2
10	Portugal	2.4
11	Germany	2.4
12	Italy	2.3
13	Spain	1.9
14	Cuba	1.9
15	Morocco	1.8
16	France	1.8
17	China	1.6
18	Sri Lanka	1.6
19	Sweden	1.6
20	Vietnam	1.5
	Top 20	**2.0**
	Other	**0.4**
	Total	**0.8**

[1] Not age adjusted; excludes countries with fewer than 10 total deaths attributable to shipping

The table above summarizes two metrics: total early deaths attributable to marine vessels air pollution in 2015, and early deaths per 100,000 population. It's not too much of a surprise that China, which hosts seven of the ten busiest ports by throughput and has many millions living near impacted shores, accounts for more than one third (37%) of the estimated 60,000 odd premature deaths. Likewise, Japan (4,100), India (3,400), the UK (3,200), and Indonesia (1,900) each ranked within the top 5 by total early deaths due to their large populations and exposure to air pollution from major marine vessels lanes.

What is perhaps more surprising is that the per-capita early death rate, as expressed in deaths per 100,000 population, shows a very different set of countries. On this metric, Singapore is the country most impacted by air pollution from ships. Moreover, six of the 10 most impacted countries are in Europe. Only Japan and the UK appear in the top 10 most impacted countries on both metrics. Why are these two lists so different? Obviously, countries with larger populations, like China, India, Brazil, and the United States, will have many deaths even if the per-capita damages are relatively low. Per-capita early mortality is a bit different because it's a function of the magnitude and exposure to emissions, and the sensitivity of the local population (the elderly, for example, have a higher incidence of both baseline disease and incremental impacts). Singapore and European countries with relatively "clean" air and a higher fraction of elderly citizens end up with more per-capita mortality when it's all tallied up. Malaysia ranked 13th and 7th respectively and possible ranking change along the years if business as usual (BAU).

Global shipping emissions by 2035 baseline scenario including Malaysian Waters.

In a baseline scenario without additional policy measures, carbon emissions from global marine vessels are projected to reach approximately 1 090 million tonnes by 2035. This would represent a 23% growth of emissions by 2035 compared to 2015. The baseline scenario incorporates the impact of existing international regulations, including the energy efficiency of ships. A geographical representation of marine vessels emissions and their evolution shows that a large share of carbon emissions in the baseline scenario is generated along main East-West trade lanes (**Figure 26**)

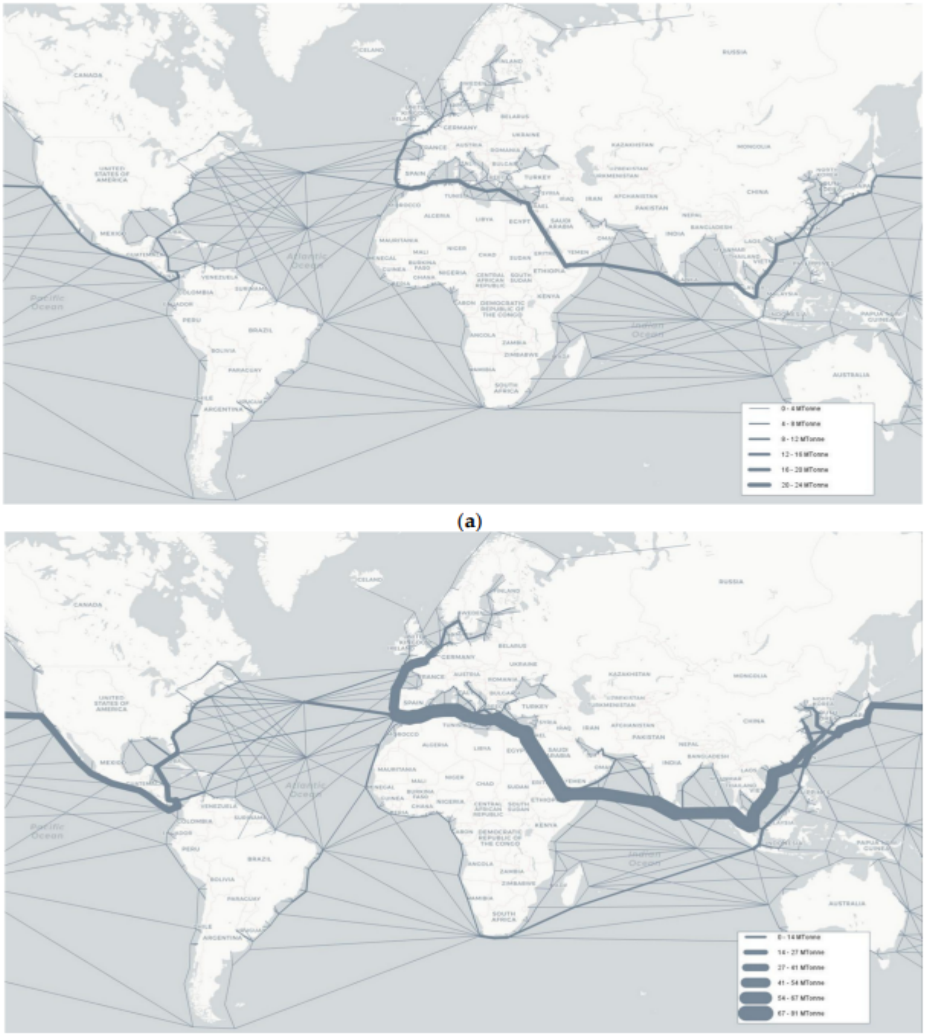


Figure 26: Visualization of CO2 emission across global shipping routes in 2015 (a), 2035 (b)

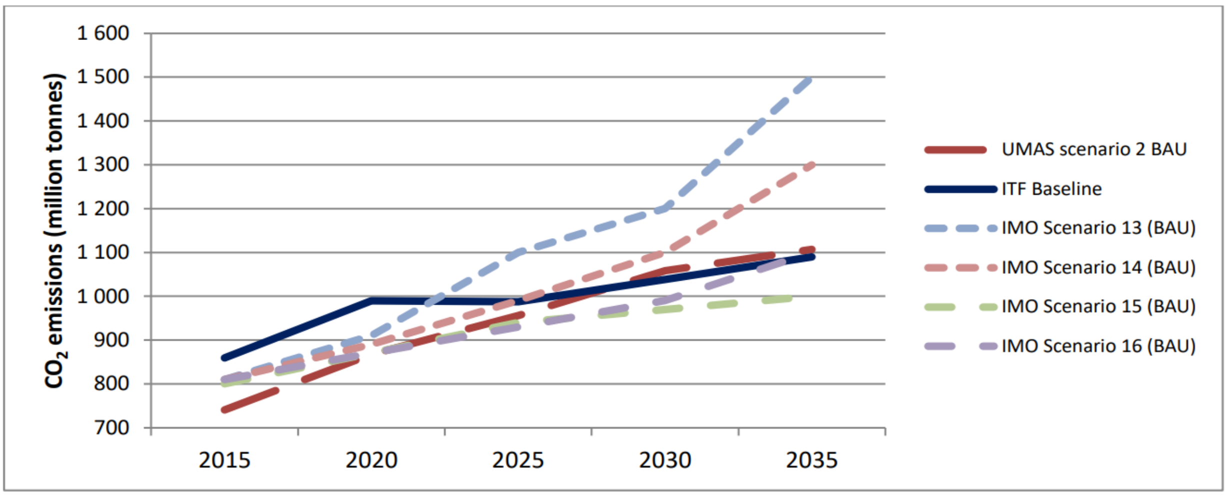


Figure 27: Different projections for shipping's CO2 emissions to 2035 (*MDPI [Ronald A. Halim, Lucie Kirstein, Olaf Merk and Luis M. Martinez]*)

The projections are based of carbon emissions from global marine vessels on the International Trade Forum (ITF) international freight model, designed to estimate freight transport flows for 19 commodities in all transport modes, using actual routes and related real distances, converting trade in value into freight volumes in tonne-kilometres. The model uses trade projections from the OECD ENV-Linkages model (Chateau et al. 2014), a Spatial Computable General Equilibrium Model, which accounts for the dynamic evolution of international trade, both in terms of spatial patterns and commodity composition. The carbon emission projections are the result of a comparison of these freight flow data with energy and carbon intensity data per different ship types, as published by UMAS (Smith et al., 2016).

The main driver for the growth of global marine vessels emissions is the rise of international trade, projected to almost double by 2035 and growing at a rate of approximately 3% per year until 2050 (ITF, 2017). The projection reflects an outlook for international trade with a relatively lower growth rate compared to the historical values between 1950 and 2009. The GDP growth of emerging and developing economies is projected to outpace those of OECD countries, resulting in a shift of global economic weight to non-OECD countries. This would lead to a restructuring of global trade patterns.

Malaysia Maritime Landscape, Infrastructure and Data.

The rapid growth and development of the Malaysian economy over the past decades cannot be seen apart from the country's location alongside world's most important trade routes. The Straits of Malacca have been a strategic waterway in global trade for centuries. Today that is no different. Malaysia is a real maritime nation and home to some of the world's largest ports.

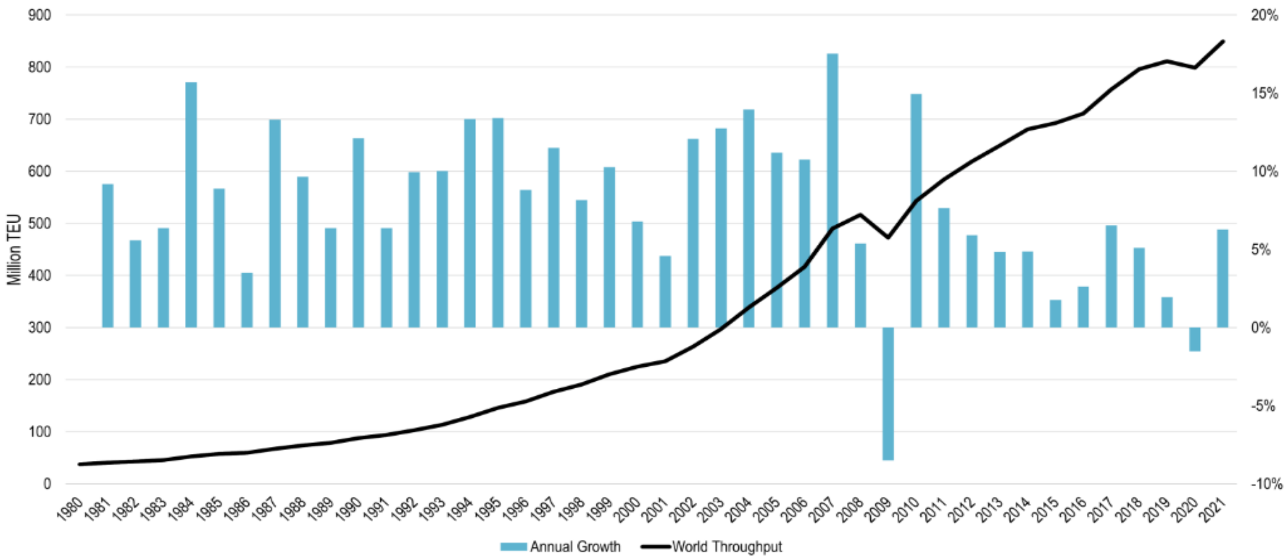


Figure 28: World Container Throughput, 1980-2021 (*Jean-Paul Rodrigue and Dr. Theo Notteboom, The Geography of Transport System*)

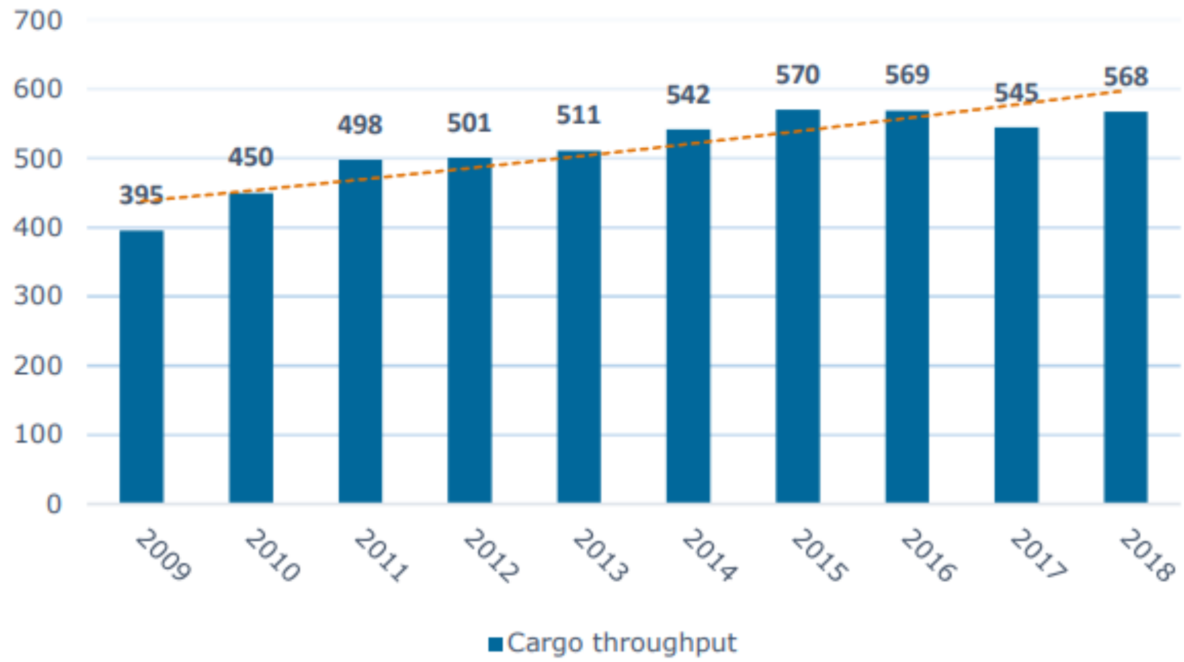


Figure 29: Trend in Cargo Throughput by Malaysian Ports (million tonnes) (*UNCTAD Review Maritime Transport 2018*)

According to UNCTAD, Malaysia is the world's fifth best connected country in terms of shipping line connectivity, ahead of the Netherlands and the United States. Malaysia is a container transhipment hub in the region and a market leader in handling and exporting oil and gas products. Over the last ten years Malaysian ports have recorded an average growth of 3% in compound cargo throughput. Following a drop in 2017 due to a change in the marine transportation market and overall lows in global seaborne trade, cargo throughput recovered in 2018 totalling at 568 million tonnes. About 70% of the cargo is containerized. With a total throughput of 24.9 million twenty-foot equivalent units (TEUs) in 2018, Malaysian ports handled almost as many containers as the Ports of Rotterdam and Antwerp combined. Port Klang and Port Tanjung Pelepas registered 13.64 million TEUs and 11.2 million TEUs respectively in 2021, and they are among the top 15 of the world's busiest container ports. In 2020, 6 of the 10 most connected economies are in Asia (China; Singapore; the Republic of Korea; Malaysia; Hong Kong, China; and Japan, 3 are in Europe (Spain, the Netherlands, and the United Kingdom), and 1 in North America (the United States). The most connected country – China – improved its liner shipping connectivity index by 56 per cent since the baseline year 2006, while the global average liner shipping connectivity index went up by 50 per cent during the same period.

Table 19: Maritime Best-Connected Countries (*UNCTAD, Trade and Development Report 2021.*)

UNCTAD MARITIME CONNECTIVITY INDEX

Best connected countries and/or territories	1. China
	2. Singapore
	3. Korea, Rep.
	4. Hong Kong (China)
	5. Malaysia
	6. Netherlands
	7. Germany
	8. United States
	9. United Kingdom
	10. Belgium

A shorter time in port is a positive indicator of a port's efficiency and trade competitiveness. Based on the criteria explained above, container ships spent an average time of 23.2 hours (0.97 days) in port per call in 2019. **Table 20** lists the world's leading 25 economies in terms of total container ship port calls and provides their average in-port time, weighted by call size. The average port-call time across these 25 economies in 2019 was 21.7 hours (0.91 days), slightly less than the global average. Malaysia ranked 8th most efficient in term of Port Performance.

Table 20: The Top 25 Countries for Container Port Calls Efficiency (*UNCTAD calculations, based on data provided by Marine Traffic*)

Table 3.6 Weighted average port call hours in top 25 economies, 2019

Country	Number of weighted average port hours
United Arab Emirates	14.1
China	15.5
Singapore	17.4
Republic of Korea	17.8
India	18.2
Thailand	20.0
Netherlands	20.3
Malaysia	20.5
Belgium	20.7
Hong Kong, China	22.5
Germany	23.0
Viet Nam	23.0
United States	24.7
Taiwan Province of China	25.8
United Kingdom	26.5
Spain	26.8
Indonesia	27.2
Japan	28.2
Philippines	31.7
Panama	32.3
Turkey	32.5
Brazil	33.6
Australia	34.6
Italy	36.5
France	41.8
Top 25 economies	**21.7**

Greece, Japan, and China remain the top three ship owning countries in terms of cargo-carrying capacity (**Table 21**), representing 40.3 per cent of the world's tonnage and 30 per cent of the value of the global fleet. The list of the top 35 ship-owning countries in terms of cargo-carrying capacity has remained stable since 2016. In the 12 months prior to 1 January 2020, countries recording the highest increases in carrying capacity compared with the previous year included Nigeria (up 17.2 per cent), the United Arab Emirates (up 5 per cent) and the United Kingdom (up 11.9 per cent). By contrast, Germany, Saudi Arabia, and Malaysia lost ground (minus 6.2 per cent, 3.6 per cent and 3.4 per cent, respectively.

Table 21: Top 25 ship-owning economies, as of 1 January 2020 (Million dollars)
(*UNCTAD Calculations, based on data from Clarksons Research*)

	Country or territory	Bulk carriers	Oil tankers	Offshore vessels	Ferries and passenger ships	Container ships	Gas carriers	General cargo ships	Chemical tankers	Other /not available	Total
1	Greece	34 426	37 873	187	2 404	7 936	12 238	189	1 064	468	96 785
2	Japan	34 027	9 981	4 713	3 030	11 805	15 173	3 482	4 937	9 150	96 298
3	China	30 108	13 278	10 189	5 089	17 243	4 267	5 244	3 126	3 008	91 553
4	United States	3 352	6 308	20 392	52 130	1 190	1 458	1 122	1 971	732	88 655
5	Norway	4 213	6 217	23 156	3 088	1 852	7 847	950	2 423	3 002	52 748
6	Singapore	12 860	13 975	5 189	25	6 845	4 428	1 043	4 695	566	49 626
7	Germany	5 857	2 121	630	9 630	17 211	1 966	3 429	791	360	41 996
8	United Kingdom	3 760	4 106	13 226	4 575	4 592	5 318	920	1 457	2 581	40 535
9	Hong Kong, China	10 209	7 239	601	2 723	10 082	1 173	898	282	1 027	34 234
10	Bermuda	4 826	5 895	5 779		2 079	8 431		375	62	27 447
11	Republic of Korea	7 319	5 999	264	366	2 400	4 914	710	1 595	2 816	26 383
12	Denmark	1 412	4 008	2 373	999	10 642	2 014	752	971	111	23 282
13	Switzerland	813	821	3 244	10 243	7 337	225	236	213	9	23 142
14	Netherlands	747	535	13 457	619	386	753	3 411	1 228	1 938	23 076
15	Italy	1 162	2 319	2 655	8 944	4	305	2 068	553	504	18 515
16	Brazil	145	1 029	15 345	69	298	131	35	84	1	17 138
17	Monaco	3 292	7 232		32	997	3 712		32	30	15 327
18	Taiwan Province of China	7 057	1 668	37	79	4 088	396	632	156	105	14 219
19	France	374	130	5 393	1 813	4 174	521	179	141	224	12 949
20	Turkey	3 208	1 433	691	346	1 290	145	1 892	1 121	42	10 168
21	Russian Federation	246	3 966	1 456	74	72	1 489	1 227	633	849	10 014
22	Malaysia	166	239	6 409	14	73	1 897	138	142	166	9 245
23	Belgium	1 515	4 070	88		262	1 221	811	167	529	8 663
24	Indonesia	838	2 091	849	1 942	790	517	1 105	348	47	8 528
25	United Arab Emirates	1 530	2 300	3 051	59	216	473	75	584	72	8 359
	Other	13 157	19 676	23 857	12 120	3 135	15 552	8 345	4 169	3 317	103 328
	World total	**186 622**	**164 511**	**163 232**	**120 413**	**116 998**	**96 568**	**38 894**	**33 258**	**31 718**	**952 213**

Source: UNCTAD calculations, based on data from Clarksons Research, as at 1 January 2020 (estimated current value).
Note: Value is estimated for all commercial ships of 1,000 gross tons and above.

Marine Transportation Co2 Emissions - Malaysia

In 2021 international maritime transportation accounted for 2% of global energy-related CO_2 emissions. The emissions from the international maritime transportation sector grew by 5%, rebounding from the sharp decline in 2020 to reach 2015 levels. To get on track with the Net Zero Scenario, total emissions will need to remain steady to about 2025, despite an expected increase in activity, and then begin decreasing by about 3% per year to 2030 (resulting in a total decrease of over 15% from 2025 to 2030).

In Malaysia sources of air pollution and GHG emissions from the maritime sector are from ships transiting the Strait of Malacca, east peninsular coastline, Borneo coastlines, ships calling at Malaysian ports, and domestic ships trading within Malaysian waters. Total emissions attributed to international and domestic water-borne navigation is estimated based on bunker fuel total emissions. **Table 22** summarizes the share of marine vessels emissions within the Exclusive Economic Zones (EEZs) of select countries from ships burning residual fuel bunkered in Singapore. Emissions are ranked in order of absolute tonnes of PM2.5; data for the regional share of NOx and scrubber washwater emissions are also presented. Countries where fuel bunkered in Singapore is responsible for more than 30% of PM2.5 within their EEZ are highlighted in dark blue; countries with between 20 and 29% are highlighted in light blue. Singapore ranks low in terms of absolute emissions, owing to the small size of its EEZ, but high in terms of relative contribution of PM2.5 (35%) and NOx (29%) from ships burning residual fuel bunkered in Singapore. Other neighbouring countries, including Malaysia (37% of shipping PM2.5), Vietnam (30%), Sri Lanka (25%), Indonesia (23%), and India (22%), are also heavily impacted by Singapore marine fuel sales.

Table 22: Share of marine vessels emissions in Exclusive Economic Zones of select countries from ships burning residual fuel bunkered in Singapore (*ICTT July 2022*)

Exclusive Economic Zone	$PM_{2.5}$		NO_x		Scrubber washwater	
	Thousand tonnes (kt)	Share of shipping total	Thousand tonnes (kt)	Share of shipping total	Million tonnes (Mt)	Share of shipping total
Indonesia	9.13	23%	215	19%	187	37%
China	8.24	14%	195	13%	181	40%
Malaysia	4.42	37%	100	31%	33.6	43%
Vietnam	4.37	30%	104	25%	98.1	45%
India	4.05	22%	94.8	20%	132	41%
Australia	2.42	18%	54.1	14%	50.2	29%
Japan	2.32	7%	52.4	5%	59.0	19%
Sri Lanka	2.05	25%	49.6	23%	56.1	42%
Taiwan	1.85	18%	43.9	14%	52.9	32%
Philippines	1.78	11%	40.9	8%	43.8	22%
Singapore	0.752	35%	12.6	29%	4.68	44%

Table 23 below summarizes the distribution of PM2.5 and NOx pollution by port. Singapore itself is the most heavily impacted port from its own fuel sales, with more than 650 tonnes of PM2.5 and more than 10,000 tonnes of NOx emitted at home. The second most impacted port, Jakarta in Indonesia, received less than a tenth as much PM2.5 and NOx as Singapore on a mass basis. Still, relative shares could still be quite high, 35% of PM2.5 and 28% of NOx at Port Klang in Malaysia comes from fuels sold in Singapore.

Table 23: Top 10 ports by PM2.5 and NOx emissions from residual fuel sold in Singapore (*ICTT July 2022*)

Country	Port	$PM_{2.5}$		NO_x	
		Tonnes	Share of total	Tonnes	Share of total
Singapore	Singapore	655	41%	10,233	34%
Indonesia	Jakarta	45	17%	713	13%
China	Qingdao Gang	41	14%	834	13%
Malaysia	Port Klang	30	35%	475	28%
China	Hong Kong	28	27%	607	21%
South Africa	Durban	25	17%	437	17%
United Arab Emirates	Mina Jabal Ali	24	14%	424	14%
China	Tianjin	22	13%	448	13%
Australia	Melbourne	18	23%	262	21%
Egypt	Port Said	17	15%	330	14%

Singapore is the world's largest seller of marine bunker fuel and sells 35 million tonnes (Mt) of marine residual fuels to large cargo ships each year. The consequence is significant air and water pollution. While Singapore's marine fuel sales exert a global environmental footprint, much of the pollution is concentrated in seas and coastal areas neighbouring the country particularly Malaysia and Indonesia. **Figure 30** shows the distribution of PM2.5 pollution from marine fuels sold in Singapore. In the seas surrounding Southeast Asia, marine residual fuel sold in Singapore accounts for more than 42% of all shipping PM2.5, as shown in the darkest blue colour.

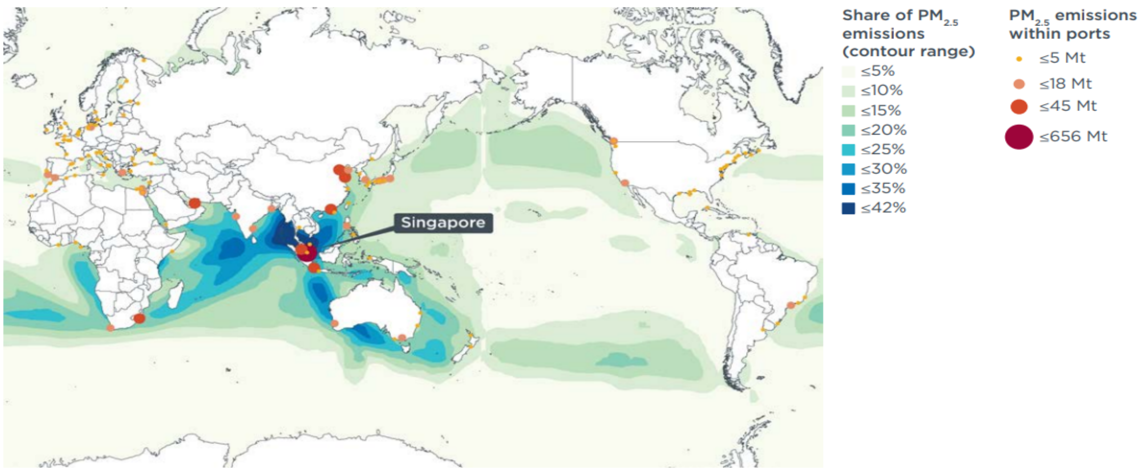


Figure 30: Share and mass of marine vessels PM2.5 emitted by ships burning residual fuel sold in Singapore to neighbouring countries (*ICCT July 2022*)

Malaysia decarbonization commitment for Marine Transportation and Zero Net Pathway

In maritime transport sector, most countries traditionally have referred to IMO's Green House Gas Emission Goals. Malaysia has implemented strategic measures under the ASEAN Blueprint 2025 to move towards sustainable climate by strengthening the efforts of government, private sector, and community in reducing GHG from marine activities. The decarbonization measures in the areas of power, heating, and land transportation that generate a lot of carbon dioxide are mainly implemented at the individual national level, whereas marine transportation, which is conducted at a global level, is based on the conventions, standards and goals set by the international maritime community centered on IMO. Most of the decarbonization policies in the marine transport sector have been established as national policies. The initial IMO GHG strategy will be revised in 2023 and reviewed again every 5 years thereafter. The IMO is following a two-tier approach to implementing decarbonization measures, focusing first on a limited set of short-term measures, before embarking on more comprehensive medium- and long-term measures.

- Short term measures (Phase 0 to Phase 2) undertaken by IMO, existing measures addressing GHG emissions include six mandatory requirements:
    - i. the Energy Efficiency Design Index (EEDI) for new builds mandating up to 30 percent improvements in design performance depending on ship type and size
    - ii. the Ship Energy Efficiency Management Plan (SEEMP) for all ships above 400 GT in operation, although it contains no explicit and mandatory performance requirements
    - iii. the Fuel Oil Consumption Data Collection System (DCS) mandating annual reporting of carbon emissions and other activity data and ship particulars for all ships above 5,000 GT
    - iv. the Energy Efficiency Design Index for Existing Ships (EEXI) imposing a requirement equivalent to the modified EEDI to all existing ships regarding of year of build and intended as a one-off certification
    - v. the Mandatory Carbon Intensity Indicator (CII) rating annual carbon intensity released from all cargo and cruise ships above 5,000 GT and requiring corrective action plan to developed as part of SEEMP and approved
    - vi. Enhanced SEEMP to strengthening and improving the mandatory content of original SEEMP such as implementation plan on how to achieve CII targets and making it subject to approval. The implementation of enhanced SEEMP will also be subject to audit.
- Phase 3 aimed at gradual improvement in energy efficient ship design and building. This measure already into force on 1 April 2022, and new build ships must apply the reduction factors for each ship type. For example, it varies by ship type, but most of the new ships should aim for 30% energy efficiency, but container ships with 200,000DWT or more should achieve 50%.

- Phase 4 aimed to make the large-scale development and deployment of carbon neutral fuels a core part of IMO long-term strategy and considered implementing some measures including GHG and carbon factors for fuels, methane emission regulation, and energy efficiency design index (EEDI). This is driven by the understanding that not only are these fuels essential for achieving the 2050 reduction goals, but they are also the only practical way for marine transportation to achieve the ultimate vision of full decarbonization before 2100.

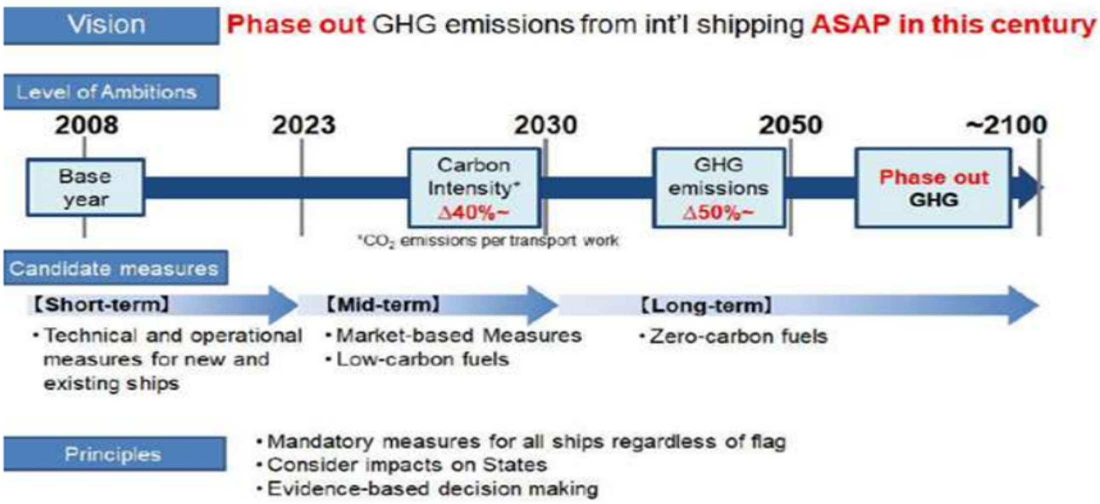


Figure 31: IMO's initial GHG reduction strategy (*Roadmap to Zero Emission from International Shipping, JSTRA & MLIT, March 2020*)

Moving Forward

First, because port and coastal communities in Asia are exposed to substantial air and water pollution from fuels purchased, country like Malaysia could win twice by producing and selling renewable marine fuels at it ports: first by reducing local air and water pollution and second by capturing the economic benefits of new renewable marine fuel markets. Countries and ports that develop policies to support such fuels will reduce pollution, improve public health, and contribute to IMO's GHG reduction targets for international shipping.

Malaysia could participate in regional and international efforts to advance green shipping corridors. Relevant corridors may be along northward along coastal China and then extending to East Asia; westward to India, the Middle East, and then Europe; and throughout the ASEAN region to Australia (IAP, 2021). International agreements like the 2021 Clydebank Declaration could help structure that involvement. Coordinated investments will be needed at the route level. Previous ICCT studies (Georgeff et al., 2020; Mao et al., 2020) evaluated the feasibility of a transpacific container shipping corridor supported by hydrogen bunkering infrastructure and found that a distributed refueling network will be needed, and that small and mid-sized ports with hydrogen infrastructure may attract new refueling calls and therefore trade opportunities.

Whether by Malaysia or a new entrant, a comprehensive package of public investments, infrastructure development, and supportive policies will be needed to start producing, transporting, and distributing new fuels like hydrogen, ammonia, and methanol.

Governments will also need to implement fuel certification schemes that are supported by proper well-to-wake accounting practices to ensure that renewable fuels reduce emissions on a life-cycle basis, including direct and indirect land use change. Policies that mandate the use of renewable marine fuels, reduce the price gap between fossil and renewable marine fuels, or both will be needed. Targeted policies to promote the use of clean fuels at port, such as the zero emissions “at berth” mandate in the European Union’s Fit-for-55 legislative package for shipping, could help scale up supply chains. Finally, proactive investments in renewable energy (wind, solar, and geothermal) and local bunkering infrastructure are needed to support renewable marine fuels.

2.4 Manufacturing

Andrew Fan

Abstract

The second largest emitter of greenhouse gases (GHG) in Malaysia is the industrial process and product use (IPPU) sector. Our observations for the IPPU sector are:

1. Malaysia is adding a significant amount of blast furnace iron production capacity that would increase the emissions of the iron and steel sector to around 30 million tonnes of CO_2 equivalent ($MtCO_2e$) as soon as 2024 from a 2016 base year of around 1.4 $MtCO_2e$, a growth rate that is substantially higher than past growth rates. As far as we know, there is only one country-wide study on decarbonization in Malaysia and it had assumed a linear projection of GHG emissions, thereby underestimating the GHG challenge that Malaysia is facing. We recommend an immediate end to issuance of new blast furnace licenses. For near term mitigation, the sector could use Electric Arc Furnaces to recycle scrap steel and reduce demand by improving material usage efficiency. However, for the long run, the adoption of new, near-zero emission technologies (e.g. Hydrogen Breakthrough Ironmaking Technology, HYBRIT) – is unavoidable.
2. For the cement industry to reduce GHG emissions, it could substitute clinker with fly ash in the short run. For the long run, it would have to adopt new production processes like Low Emissions Intensity Lime & Cement (LEILAC).

Further, we highlight three recommendations to accelerate adoption of new, near-zero emission technologies for the IPPU sector in Malaysia:

1. Given the higher decarbonization challenge for Malaysia than usually projected new green production technologies have to be adopted. As Malaysia is a technology adopter not a technology innovator, it requires technology transfer from developed countries. Malaysia must therefore specify its technology needs in its “nationally determined contributions” (NDC) report to press the developed countries to transfer technology to enable Malaysia’s timely transition to green production processes.
2. The Technology Mechanism under the Paris Agreement must proactively promote and facilitate the development and transfer of advanced near-zero emission technologies (e.g. HYBRIT and LEILAC) for high carbon emitting and hard to abate industries like the iron and steel and cement sectors, so that it can achieve its mandate under the Paris Agreement.
3. Because near zero emission technologies cost more than carbon intensive technologies (e.g. HYBRIT steel is expected to cost 20%-30% more than blast furnace steel), developing countries like Malaysia will need the concessionary finance promised in the Paris Agreement to fund installation of the new green technologies at scale.

Historical emissions in the IPPU sector

The energy sector is the largest emitting sector, largely driven by electricity power generation and internal combustion engine (ICE) vehicles. This is followed by industrial process and product use (IPPU) sector. An overview of Malaysia's GHG emissions by sectors is displayed in **Table 24.**

Table 24: Malaysia's GHG emissions and removals in 2016 (*Third Biennial Report, pp.g xvii, Ministry of Environment and Water, 2020*)

Sector	GHG emissions/removals ($MtCO_2e$)
Energy	251.695
IPPU	27.348
Agriculture, Forestry and Other Land Use (AFOLU) - Agriculture	10.627
AFOLU - Land use, land use change, and forestry (LULUCF) [Emissions][19]	17.801
AFOLU - LULUCF [Removals][20]	-259.146
Waste	27.161
Total emissions (With LULUCF emissions only)	334.634
Total emissions (With LULUCF emissions and removals)	75.488

Malaysia's decarbonization commitment

Currently, Malaysia does not have an official decarbonization commitment for the IPPU sector.

There is an increasing number of research reports and academic papers written on decarbonization in Malaysia. In November 2021, the Boston Consulting Group (BCG) and the World Wildlife Fund (WWF), released the most comprehensive report on Malaysia's Net Zero Pathways by 2050, which includes recommendations for the IPPU sector.

A summary of the key decarbonization levers identified for Malaysia to achieve net zero is presented in **Table 25.** This report was prepared with inputs from various stakeholders, including Tenaga Nasional, the country's monopoly electricity utility in Peninsular Malaysia[21], and Bursa Malaysia, the country's stock exchange.

[19] LULUCF emissions. Examples of causes are deforestation and forest clearing for agriculture and settlement.
[20] LULUCF removals. Examples of causes are reforestation and natural carbon sequestration by forest.
[21] Peninsular Malaysia accounts for 85% of the Malaysia's total GDP.

Table 25: Full range of decarbonization levers proposed by BCG-WWF for Malaysia to achieve net zero by 2050

Sector	Proposed decarbonization lever to achieve net zero by 2050
Energy	Power generation – Improve energy efficiency, zero coal power plants, 61% of capacity from renewable energy (solar, hydro, biomass), 39% from more efficient combine cycle gas turbine (CCGT) plants Transport – 100% electric vehicles, 60% public transport share, biofuel and hydrogen for heavy transport Oil and gas – reduce fugitive emission intensity
IPPU	Reduce clinker to cement ratio to 50%, increase share of Electric Arc Furnace to recycle steel to 80%, use blue or green hydrogen for existing direct reduced iron process, increase use of recycled material and inert anodes for aluminum production
AFOLU - Agriculture	Reduce fertilizer usage through increased precision and control, employ alternate wetting and drying techniques in rice plantations, improve feed to cattle to reduce enteric fermentation
AFOLU - LULUCF	Strengthen post-felling silviculture, zero deforestation for cropland expansion, reforestation of degraded forest, rehabilitation of drained organic soil
Waste	Increase biogas plants, increase recycling, reduce food waste, increase waste to energy plants

In reviewing the decarbonization levers proposed by BCG-WWF for the IPPU sector, we notice that there was a reliance on the use of existing technologies to build new capacity (e.g. Electric Arc Furnaces which are limited by the availability of scrap metal). This could be the result of its methodology of applying a least cost method to choose the decarbonization levers. As a result, only relatively low-cost and low-ambition decarbonization levers were proposed.

However the decarbonization challenge will be significantly higher than projected because a large increase in iron and steel production capacity is expected to be operational in the near term (to be elaborated in section 3). Therefore, this paper considers the implications of relatively low ambition strategies for the IPPU sector in Malaysia.

Emissions outlook and options to reduce emissions

Iron and steel

According to the 3BUR, the IPPU sector in Malaysia contributes around 8% of GHG emissions in 2016. BCG-WWF report had examined the sector and concluded that the mineral sub-sector and the metal sub-sector are the two most significant sub-sectors in the IPPU sector contributing 49.2% and 19.2% to GHG emissions respectively. For the mineral sub-sector in Malaysia, the cement segment contributed about 70%, while the carbonate, lime, and glass segment contributed approximately 30% of GHG emissions. This is consistent with global GHG emissions in 2014 where cement is the dominant segment for the mineral sub-sector (Rissman et al., 2020). For the metal sub-sector in Malaysia, the aluminum segment contributed around 70%, while the iron and steel segment contributed approximately 30% of GHG emissions. However, for the global GHG emissions in 2014, iron and steel GHG emissions was more than 3 times greater aluminium emissions (Rissman et al., 2020). Hence, we examined this inconsistency more deeply.

The data of the iron and steel industry in 3BUR recorded emissions in 2016 to be 1.385 million tonnes of CO_2 equivalent ($MtCO_2e$). When we used data from industry reports and stakeholder interviews, we estimated the emissions of the iron and steel industry in 2016 to be 1.221 $MtCO_2e$[22]. Therefore, our method of estimating emissions of the iron and steel industry in 2016 is aligned with the official figures in the 3BUR. However, our stakeholder interviews (verified by public media announcements) had informed us about significant new capacity of blast furnace that had been installed recently or are being installed after 2016. As a result, the total potential carbon emissions in 2024 could increase to 30.515 $MtCO_2e$ as presented in **Table 26**. Given that Malaysia's net GHG emissions is around 75.488 $MtCO_2e$, this represents a potential increase in net GHG emissions of around 38.6% by 2024.

[22] Our analysis of emissions only covered installations which reduced iron ore to iron, because this is the key process which emits GHG. Processes to recycle steel from scrap steel, and forming steel into long and flat products were not included as they have relatively negligible contribution to GHG emissions.

Table 26: Estimation of Malaysia's potential GHG emissions from the iron and steel sector in 2024 (1 of 2)

Installations (Firm, Location)	Technology	Status of additional capacity	Estimated annual production capacity ('000t)[23]	Actual utilization rate, 2016[24]
Existing capacity as of 2016				
Antara (Sold to Esteel in 2020), Labuan	Direct reduced iron	-	888	75%
Lion DRI (Sold to Lion Industries in 2021), Banting[25]	Direct reduced iron	-	1,540	0%
Perwaja DRI, Kemaman[26]	Direct reduced iron	-	1,500	0%
Ann Joo, Penang	Blast furnace	-	500	43%
Eastern, Kemaman	Blast furnace	-	700	43%
Authors' estimate of total emissions in 2016			**4,428**	
3BUR total emissions in 2016			-	
Change in capacity since 2016				
Alliance, Kuantan	Blast furnace	Announced by firm	Built 3,500 in 2018 Additional 6,500 but operational date not specified	-
Eastern, Kemaman	Blast furnace	Announced by firm	Additional 2,000 by 2021	-
Lion, Banting	Blast furnace	Announced by firm	2,500 by but operational date not specified	-
Wen An, Bintulu	Blast furnace	In construction	10,000 by 2024	-
Total additional emissions since 2016				
Total potential emissions				

[23] Malaysia Iron and Steel Industry Federation (MISIF) 2018/2019 Outlook report pg 90-92 and public media announcements of additional capacity.
[24] Malaysia Iron and Steel Industry Federation (MISIF) 2018/2019 Outlook report pg 111.
[25] Lion DRI, with annual production capacity of 1.54 mil t temporarily ceased operation in 2016 with no public announcement to date of resumption.
[26] Perwaja DRI, with annual production capacity of 1.5 mil t temporarily ceased operation in 2013 with no public announcement to date of resumption.

Table 26: Estimation of Malaysia's potential GHG emissions from the iron and steel sector in 2024 (2 of 2)

Installations (Firm, Location)	Long term utilization assumed in 2024[27]	Emission factor[28]	Estimated annual production capacity in 2016 ('000t)	Potential annual carbon emissions in 2024 ('000tCO_2e)
Existing capacity as of 2016				
Antara (Sold to Esteel in 2020), Labuan	80%	0.7	467	497
Lion DRI (Sold to Lion Industries in 2021), Banting[29]	0%	0.7	0	0
Perwaja DRI, Kemaman[30]	0%	0.7	0	0
Ann Joo, Penang	80%	1.46	439	818
Eastern, Kemaman	80%	1.46	314	584
Authors' estimate of total emissions in 2016			**1,221**	**1,899**
3BUR total emissions in 2016			**1,385**	-
Change in capacity since 2016				
Alliance, Kuantan	80%	1.46	-	11,680
Eastern, Kemaman	80%	1.46	-	2,336
Lion, Banting	80%	1.46	-	2,920
Wen An, Bintulu	80%	1.46	-	11,680
Total additional emissions since 2016				**28,616**
Total potential emissions				**30,515**

[27] Ibid.

[28] 3BUR, pg 89.

[29] Lion DRI, with annual production capacity of 1.54 mil t temporarily ceased operation in 2016 with no public announcement to date of resumption.

[30] Perwaja DRI, with annual production capacity of 1.5 mil t temporarily ceased operation in 2013 with no public announcement to date of resumption.

Our data shows that a significant portion of the new blast furnace capacity that has been or is being added since 2016 are by Chinese firms or joint ventures with Chinese firms. According to Tham and Yeoh (2020), China has identified Southeast Asia as a market with huge potential because of the region's high demand for infrastructure as well as rising manufacturing activity. In 2018, ASEAN-6[31] countries imported 37.2 million tonnes of steel which were mostly imported from China, Japan and South Korea. Therefore, the significant investment by Chinese interests in iron production facilities in Malaysia is explained by the significant and expected demand growth for iron and steel in ASEAN.

Our finding has significant implications on the realism of net zero pathways developed by stakeholders. For example, the BCG-WWF analysis took the 3BUR figure of 1.385 $MtCO_2e$ as the base case in 2020 for the iron and steel industry, then grew it annually by 2.2% per annum. This means an emission of 1.721 $MtCO_2e$ in 2030 and 2.660 $MtCO_2e$ in 2050, significantly lower than the potential emissions of 30.515 $MtCO_2e$ estimated using the expectations-based approach. This implies that the BCG-WWF's net zero policy recommendations for the iron and steel sector to reduce emissions by 1.5 $MtCO_2e$ in 2050, through increasing share of Electric Arc Finance to recycle steel and using hydrogen for existing direct reduction iron installations will not be sufficient for the IPPU sector to be consistent with BCG's net zero pathway for Malaysia.

A holistic and sequenced solution will be to, first stop the issuance of licenses for the construction of more blast furnace installations. This is to avoid being locked-in into old and polluting technologies as a blast furnace has a campaign life of 17 years (Vogl et al., 2021). Second, in the near term, reduce the use of steel through improving the yields of steel production, extending the useful life of existing buildings and employing lighter vehicle designs (IEA, 2019). Third, if capacity needs to be developed in the near term, build Electric Arc Furnaces to recycle scrap metal, despite the constraint that scrap metal is limited in availability, particularly in developing countries (Fan, 2021; Battle, 2014). For the longer-term Malaysian firms will have to adopt near zero emission iron producing technologies from iron ore as soon as they are commercially available. Two promising near zero emission iron producing technologies that could be commercially available by 2030 are Hydrogen Breakthrough Ironmaking Technology (HYBRIT) and Hisarna.

HYBRIT is a fossil-free steel producing process where iron ore is extracted from the mines using electrified machines, and green hydrogen is used to reduce iron ore into iron, thus no CO_2 is emitted. The iron is then melted and alloyed into steel in the EAF. The first HYBRIT demonstration plant is being constructed in Gällivare, Sweden by a consortium of SSAB, LKAB, and Vattenfall and is expected to be completed in 2025. SSAB plans to start offering fossil free products commercially by 2026 (SSAB, 2022). However, the steel produced will be 20% to 30% more expensive, and there may be a challenge to acquire adequate green hydrogen (Axelson et al., 2018).

If adequate green hydrogen is not available to enable HYBRIT, Hisarna could be a viable alternative. Hisarna is a highly efficient blast furnace process where the blast furnace process and the basic oxygen furnace process are integrated and the CO_2 released is concentrated to enable effective carbon capture. Hisarna has been piloted in Ijmuiden Netherlands by Tata Steel since 2011. A larger pilot plant is being considered to be established in India. The plan is to have an industrial scale plant producing commercial steel by 2030 (Tata Steel, 2020). It is expected to reduce emissions by 80%-90% relative

[31] Indonesia, Malaysia, Philippines, Singapore, Thailand, and Vietnam.

to standard blast furnace but will cost USD40-70 for each tonne of emissions avoided (IPCC, 2022).

Cement

3BUR reports that the cement industry in 2016 was 9.125 $MtCO_2e$. Our estimate based on industry reports, feedback from industry players, and review of public announcements for new installations estimated an emissions level in 2021 of 10.465 $MtCO_2e$[32] as calculated in **Table 27.** In the BCG-WWF report, similar to the iron and steel industry, it assumed that the amount of GHG emission by the cement industry in 2020 to be the same as the 3BUR's 2016 emissions. As the margin of difference between the BCG-WWF report emissions base case is within 15% of our 2021 emissions estimates, we conclude that their emissions estimate for the cement segment is reasonable.

Table 27: Estimation of Malaysia's potential GHG emissions from the cement sector 2021

Installations (Firm, Location)	Technology	Status of additional capacity	Estimated annual production capacity ('000t)	Long run expected utilization rates[33]	Emission factor[34]	Estimated annual carbon emissions ('000tCO_2e)
Existing capacity as at 2016						
YTL Cement, Rawang	Integrated plant	-	2,600	80%	0.515	1,071
YTL Cement, Kanthan	Integrated plant	-	4,200	80%	0.515	1,730
YTL Cement, Langkawi	Integrated plant	-	5,400	80%	0.515	2,225
YTL Cement, Padang Rengas	Integrated plant	-	3,500	80%	0.515	1,442
YTL Cement, Bukit Sagu	Integrated plant	-	1,500	80%	0.515	618
CIMA, Kangar	Integrated plant	-	1,700	80%	0.515	700
CIMA, Bahau	Integrated plant	-	1,300	80%	0.515	536
HUME Cement, Gopeng	Integrated plant	-	1,700	80%	0.515	700
Cahaya Mata	Integrated plant	-	1,000	80%	0.515	412

[32] Our analysis of emissions only covered integrated plants which produce clinker, because this is the key process which emits GHG. Grinding plants which do not produce clinker are not analyzed as they have relatively negligible contribution to GHG emissions
[33] HUME Cement 40th AGM Question and Answer 2020: HUME Cement utilization rate in 2020.
[34] 3BUR, pg 89.

Installations (Firm, Location)	Technology	Status of additional capacity	Estimated annual production capacity ('000t)	Long run expected utilization rates[33]	Emission factor[34]	Estimated annual carbon emissions ('000tCO_2e)
Sarawak, Mambong						
Tasek, Ipoh	Integrated plant	-	2,300	80%	0.515	948
Aalborg, Ipoh	Integrated plant	-	1,900	80%	0.515	783
Authors' estimate of total emissions in 2016			**24,500**			**10,094**
3BUR total emissions in 2016			-			**9,125**
Change in capacity since 2016						
YTL Cement, Rawang	Integrated plant	Shut down in 2020	-2,600	80%	0.515	-1,071
HUME Cement, Gopeng	Integrated plant	New line[35]	2,000	80%	1.46	824

[35] HUME Cement Annual Report 2021.

BCG-WWF's proposed decarbonization lever for the cement industry is to reduce clinker-to-cement ratio from 89% to 50% by 2050. We concur with this lever, because the key substitute for clinker in Malaysia is fly ash, which is a by-product of coal power plants. In the near term up to 2030, the government plans for up to 31% of Peninsular Malaysia's energy mix to be from coal power plants (JPPET, 2019). Therefore, cement producers can expect a stable supply of affordable fly ash in the near term.

Another effective near-term decarbonization strategy is to reduce the demand for cement by extending the useful life of existing buildings, reducing the cement concentration in concrete and designing buildings which require less concrete (IEA, 2019).

For the longer term, a promising near zero cement production technology is Low Emissions Intensity Lime & Cement (LEILAC) technology. This is a calcination process to decompose limestone ($CaCO_3$) into lime (CaO), where the calcination process and the heating process is separated. Therefore, the CO_2 produced by the calcination process is concentrated as it is not diluted by the air in the heating chamber. The concentrated flow of CO_2 allows for highly efficient carbon capture, thus enables the production of lime with minimal CO_2 escaping into the atmosphere. The near zero emission lime is then sintered with gypsum, iron, aluminum silicates to produce clinker. The clinker is then cooled and grinded to form cement.

A demonstration LEILAC installation is being built in Hanover, Germany by Heidelberg Cement and is expected to be operational in 2023. LEILAC technology has the potential to be retrofitted to existing cement plants. The technology is expected to be commercially available in developed markets by 2025 but will cost USD40 for each tonne of emissions avoided to produce clinker and will require access to cheap renewable energy to provide heating for the calcination process (IPCC, 2022).

Net zero pathway for the sector and timeline

Our research shows that the challenge to decarbonize the IPPU sector is much more significant than forecasted in the BCG-WWF report because it did not take ongoing and planned iron producing installations into account. For 2016, we estimated emissions to be around 1.2 $MtCO_2e$, largely the same with the 3BUR official figures of 1.4 $MtCO_2e$. When we considered new capacity that is under construction and has been announced by the firms, the estimated potential emissions by 2024 is around 30 $MtCO_2e$.

However, analysis of levers to decarbonize the IPPU sector suggest that Malaysia can achieve net zero by 2050 by deploying advanced technologies at scale (e.g. HYBRIT fossil free steel). This will need technology transfer from developed countries because Malaysia is a technology adopter not a technology innovator.[36] Therefore, Malaysia should have specified technology transfer requirements in its latest NDC report in 2021 to assist it to secure the more advanced technologies needed to raise its decarbonization ambition.

In addition, the Technology Mechanism, established under Article 10 of the Paris Agreement, to promote and facilitate enhanced action on technology development and transfer in order to support the implementation of the agreement needs to pay attention to high carbon emitting and hard to abate industries like the iron and steel and cement

[36] This is verified by interviews with industry players in the IPPU sector, who communicated that they are adopters not innovators of near zero emission technologies.

sectors. Our review of recent achievement reports by the Technology Mechanism, specifically “Technology and Nationally Determined Contributions: Stimulating the Update of Technologies in Support of Nationally Determined Contribution Implementation” (UNFCCC, 2021a) and “Joint Annual Report of the Technology Executive Committee and the Climate Technology Center and Network for 2021” (UNFCCC, 2021b) observed no evidence that the Technology Mechanism has implemented any interventions to promote abatement for the iron and steel and cement sectors. To deliver on its mandate, the Technology Mechanism must promote and facilitate the technology development and transfer of near zero technologies for high carbon emitting and hard to abate sectors.

Technology transfer of advanced green technologies is necessary but insufficient for most developing countries to decarbonize in a timely fashion because these technologies are more expensive than existing technologies, even when they are commercially available (e.g. HYBRIT steel is expected to be 20% - 30% more expensive than blast furnace technology). Therefore, concessionary financing (e.g. loans with subsidized interest) is required to enable adoption of the new green technologies at scale.

Article 9 of the Paris Agreement states that “Developed countries shall provide financial resources to assist developing country Parties with respect to both mitigation and adaptation” (UNFCCC, 2015). At COP 21, the Parties noted with regret that the commitment of developed countries to provide USD100 billion per annum of financial assistance to developing countries by 2020 was not achieved, and hence urged the developed countries to meet this commitment by 2025 (UNFCCC, 2021c).

Right now, concessionary financing is available for developing countries like Malaysia to access funding for climate mitigation projects through multiple channels. According to the OECD, in 2019, 36.2% of climate finance was channelled through public bilateral arrangements, 42.9% through public multilateral arrangement like the World Bank and the Green Climate Fund, and the remaining 20.9% export credits and private arrangements (OECD, 2021). As there is no centralized mechanism to coordinate the disbursement of climate funds, developing countries need to be diligent and proactive in matching potential projects which require concessionary financing with the terms and conditions of each of the multiple financing channels.

Further, the world should state the climate finance under the Paris Agreement to be accounted in terms of “grant-equivalent basis”. According to Oxfam (2020), the average annual climate finance on a “grant-equivalent basis” for the 2017-2018 period was USD25 billion, which is significantly lower than the average annual face value of USD59.5 billion. The “grant-equivalent basis” has been adopted to account for Official Development Assistance (ODA) since 2018, because it is the true measure of the amount of value provided by donor countries (e.g. 1 dollar of grant is more valuable than 1 dollar of loan).

2.5 Fuel Supply

Low Wai Sern

Abstract

Malaysia is the second largest oil and natural gas producer in Southeast Asia and is the fifth-largest exporter of LNG in the world, as of 2019 (EIA 2021). Fossil energy exports continue to make up a substantial bulk of revenue and economic growth despite the drop in oil prices during 2014-2016 as well as recent instabilities due to the pandemic of 2020.

Emissions from this sector largely come from methane emissions, either from the intentional venting or burning of gas or fugitive emissions. In Malaysia, nearly 1013Gg was released in 2016 from fugitive emissions which accounted for nearly half of total methane emissions, with most of the remaining attributed to the waste sector. This represents a significant volume of emissions as methane has a high global warming potential.

Malaysia has yet to introduce formal laws and/or policy measures for methane abatement. However, the nation has recently become a signatory of the Global Methane Pledge, joining over a hundred countries seeking to reduce methane emissions by 30 percent by 2030. PETRONAS, as the national oil and gas corporation has since begun efforts towards reducing methane emissions, pledging in turn to avoid routine flaring in new oil field developments and end routine flaring at existing oil production sites by 2030.

Based on estimates for the costs of abatement, a majority of methane abatement measures covering a large portion of emissions can be enacted at zero or less cost. Most are likely to even have a small return on investment. While net zero within the industry will be difficult, IEA estimates show that up to 73% abatement is possible. Many of these measures are technical measures and can be enacted within a short time frame.

Current and Historical Emissions

Table 28: Official estimates of carbon (and other GHG) emissions from the oil and gas sector are published as part of Malaysia's Biennial Update Report to the UNFCCC
(*Summary Table for GHG Inventory Year 2016, Malaysia Third Biennial Update Report to the UNFCCC (Ministry of Energy, Science, Technology, Environment, and Climate Change 2018)*)

		CO_2	CH_4	N_2O	NOx	CO	NMVOCs	SO_2
1A	**Fuel Combustion Activities**	222,510.5	24.5	4.4	1,010.1	4,820.4	897.8	693.9
1A1b	**Petroleum Refining**	9,498.1	0.4	0.1	8.2	5.1	0.3	0
1A1c	**Manufacture of Solid Fuels and Other Energy Industries**	18,378.8	0.3	0	29.2	12.8	0.9	0.1
1B	**Fugitive emissions from fuels**	1,942.2	1,013.1	NA	0.2	0.7	4.1	0

When it comes to the production of oil and gas, the largest contributor to global warming is methane emissions, either from the intentional venting or burning of gas or fugitive emissions; that is leaks from infrastructure (pipelines, storage, etc.). In Malaysia, nearly 1013Gg was released in 2016 (**Figure 32**) from fugitive emissions which accounted for nearly half of total methane emissions, with most of the remaining attributed to the waste sector. This represents a significant share of emissions as methane has a relatively high global warming potential of 86 over a 20-year horizon (Myhre et al. 2013), this is equivalent to 87Mt of CO^2eq; a little over a fifth of total emissions.

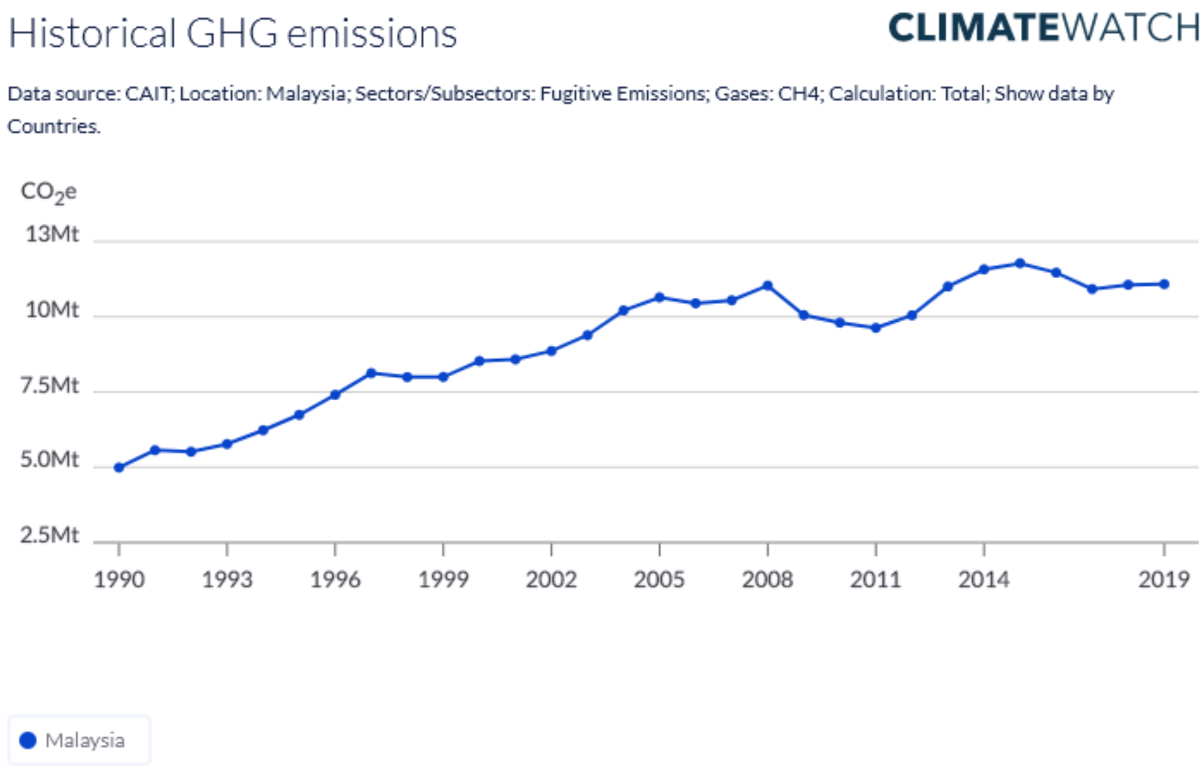


Figure 32 - Climate Watch Historical Country Greenhouse Gas Emissions Data (*World Resources Institute 2022*)

Historically, methane emissions have been steadily rising up to the recession in 2008 and have since plateaued. Within the oil and gas sector, emissions have risen slightly in the last few years, but the intensity of fugitive emissions compared to production volume have improved, indicating that measures to reduce these emissions have begun to show results.

Malaysia's Decarbonization Commitment

Data from the World Bank's Global Gas Flaring Tracker (World Bank 2022) estimates around 2 billion m^3 of gas was flared from Malaysian fields in 2021. That is between 1 to 2 percent of the annual production volume, estimated at around USD 230 million. Flaring has been a consistent issue since the mass production of oil began, historically due to it being logistically and economically challenging to collect, transport, and refine the inconsistent and often impure gas. The flaring intensity per barrel of oil produced in Malaysia is relatively high as well, especially compared to more advanced economies.

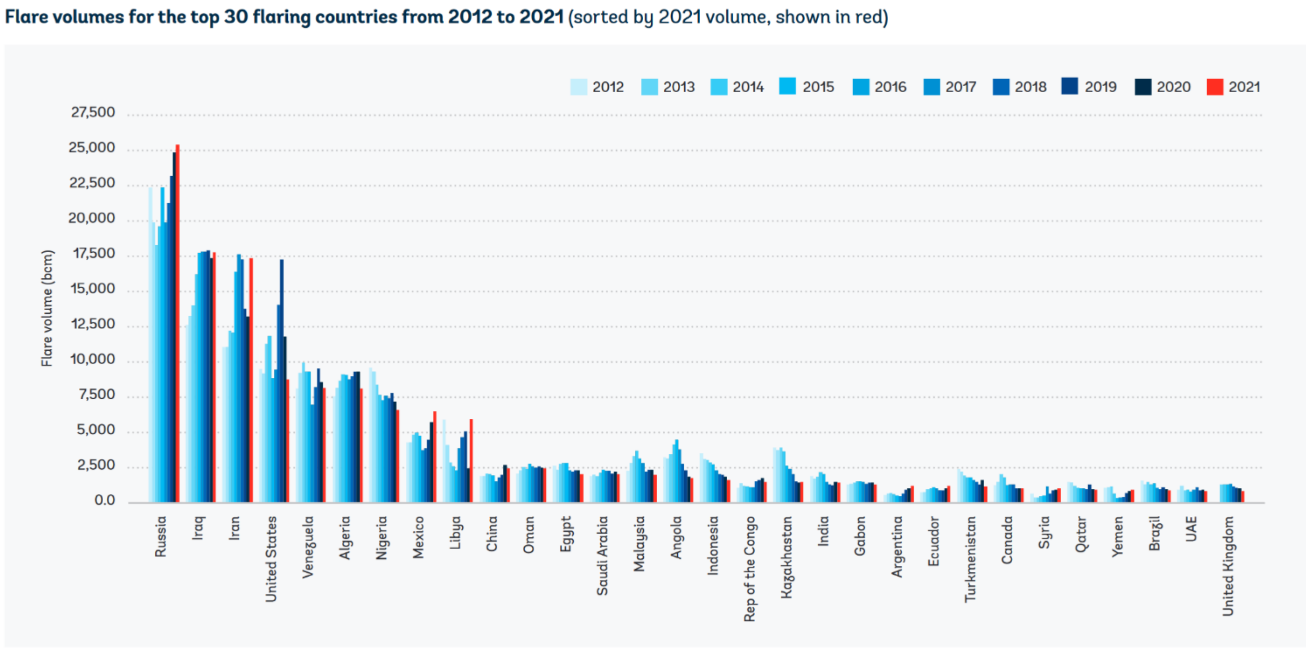


Figure 33 World Bank Global Gas Flaring Tracker

Concerns over methane emissions were brought to the forefront over COP26 just last year, with Malaysia being one of the signatories to the Global Methane Pledge, joining over a hundred countries seeking to reduce methane emissions by 30 percent by 2030. Regionally, key energy players have begun collaborating to this end, with PETRONAS from Malaysia, PERTAMINA from Indonesia and PTT from Thailand hosting a series of roundtables to promote and share their respective practices (PETRONAS 2021). On a higher level however, Malaysia lags behind some of her neighbors who have laid out specific targets in their NDCs and have begun pursuing policy targets domestically to mitigate methane emissions.

Oil and Gas by the Numbers

According to official figures, in 2018, trading of crude oil stood at 9239ktoe imported and 15012ktoe exported for a net export of 5773ktoe. For natural gas, it was 6956ktoe imported and 27393ktoe exported for a net export of 20437ktoe (Energy Commision, Malaysia 2020).

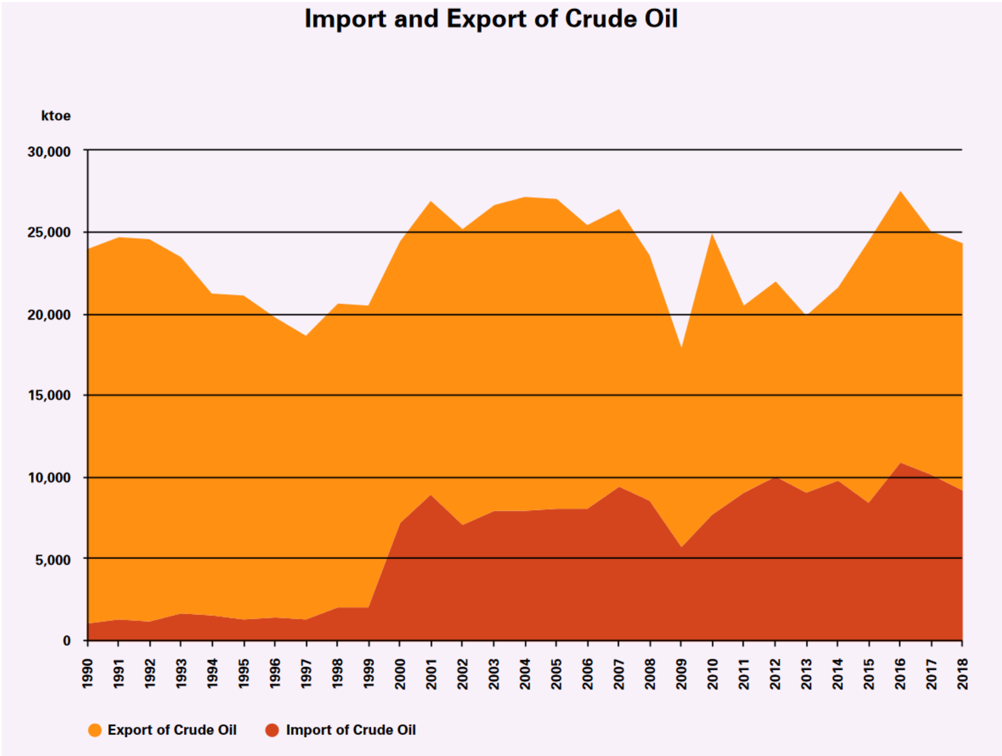


Figure 34: Import and Export of Crude Oil (*National Energy Balance 2018*)

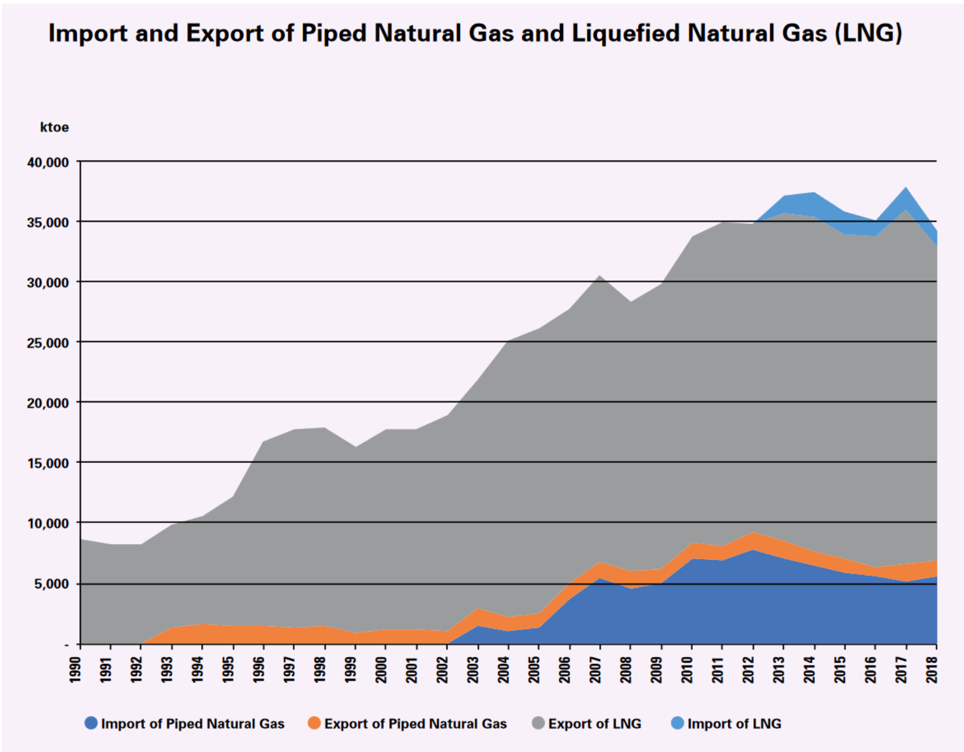


Figure 35: Import and Export of Piped Natural Gas and Liquefied Natural Gas (LNG)
(*National Energy Balance 2018*)

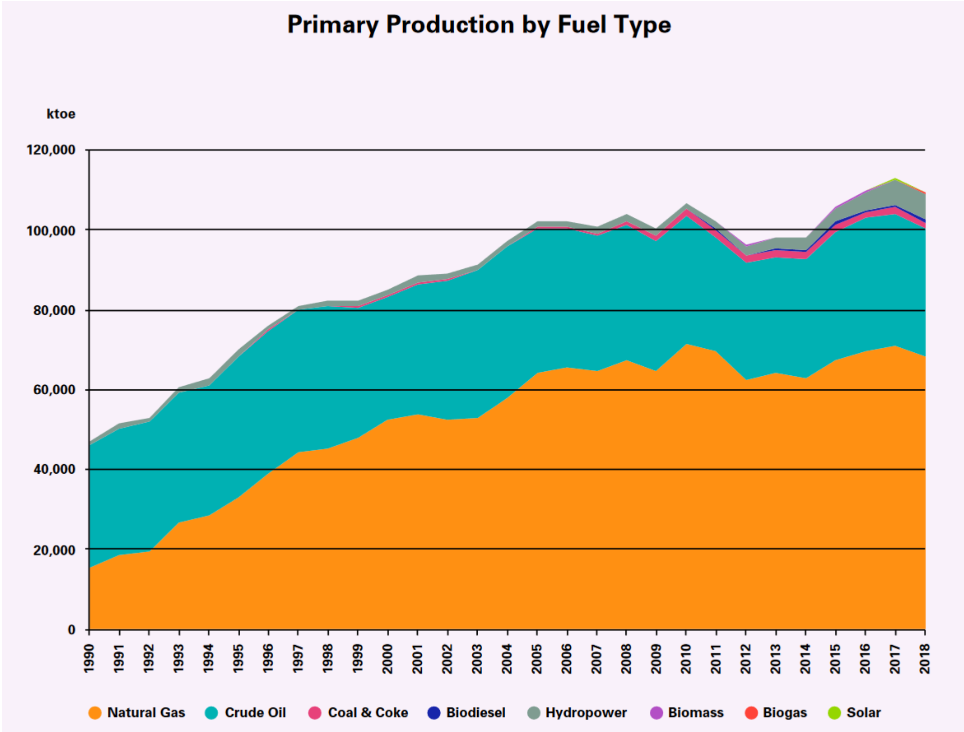


Figure 36: Primary Production by Fuel Type (*National Energy Balance 2018*)

On the production side, at total of 68253ktoe for natural gas and 31996ktoe of crude oil was produced in 2018. This roughly translates to 2.676tcf and 0.234 billion barrels respectively. This rate of production has remained mostly steady in the past decade, with 2021 being the exception, where crude oil production was reduced. Production has since been ramping back up and is on track to return to previous levels. Given the remaining proven reserves (below), it is estimated that the country will have roughly two decades worth of production remaining, assuming a constant rate of production.

Estimates for the remaining proven reserves of crude oil and natural gas vary between sources. For crude oil, it is estimated to be around 3.6 – 4.2 billion barrels while for natural gas it is estimated around 42 – 75 tcf. Below are the official estimates for the remaining oil and gas reserves in Malaysia.

Table 29 (*Malaysia Energy Statistics Handbook 2020*)

Year	Reserves of Crude Oil and Condensates (billion barrels)			
	Peninsula Malaysia	Sarawak	Sabah	Total
2014	2.341	1.566	1.885	5.792
2015	2.205	1.693	2.009	5.907
2016	1.735	1.370	1.925	5.030
2017	1.669	1.290	1.767	4.727
2018	1.612	1.304	1.637	4.553

Table 30 (*Malaysia Energy Statistics Handbook 2020*)

Reserves of Natural Gas (trillion cubic feet)										
Year	Peninsular Malaysia			Sabah			Sarawak			Grand Total
	Non-Associated	Associated	Total	Non-Associated	Associated	Total	Non-Associated	Associated	Total	
2014	25.242	9.688	34.93	10.029	3.724	13.753	48.955	3.024	51.979	100.662
2015	24.022	8.471	32.493	11.884	3.149	15.032	50.034	2.853	52.888	100.413
2016	20.428	6.793	27.221	10.915	2.521	13.436	45.336	1.77	47.105	87.762
2017	19.327	6.333	25.659	11.06	1.487	12.547	43.184	1.508	44.692	82.897
2018	17.266	6.422	23.688	10.504	2.078	12.582	41.754	1.507	43.261	79.531

Methane Abatement

At time of writing, Malaysia has yet to formally adopt any policy measures specific to methane abatement in the oil and gas sector. Within the industry, PETRONAS has pledged to avoid routine flaring in new oil field developments and end routine flaring at existing oil production sites by 2030 (PETRONAS 2021a). While a pledge from within the industry holds some weight, especially given the role that PETRONAS plays, it is still recommended that the government adopt official measures and targets. At minimum, these targets should adhere to the global commitments, i.e., the reduction targets from the Global Methane Pledge. An addition step would be to include these emission targets in the NDCs to ensure additional accountability in achieving these targets. The IEA estimates a possible 73% share of abatement possible with 43% possible at no net cost (International Energy Agency 2022). It is also estimated that adopting policies to ensure zero routine flaring and venting can reduce emissions by up to 46%. Remaining abatement measures cover leak detection and repair (LDAR) as well as the replacement or installation of new devices/technology such as vapor recovery units to capture emissions.

Table 31: Methane Abatement Costs

	IEA Estimates (International Energy Agency 2022)	ISEAS Estimate (Qiu and Wong 2022)
Vapor Recovery Units	-8.40 USD/MBtu (Offshore Oil) -7.45 USD/MBtu (Offshore Gas)	-166 USD/MBtu (Offshore Oil) -90 USD/MBtu (Offshore Gas)
Upstream LDAR	-8.80 USD/MBtu (Offshore Gas)	-321 USD/MBtu (Offshore Gas)
Downstream LDAR	-6.85 USD/MBtu (Gas)	-79 USD/MBtu (Gas)
Replacement – Instrument Air Systems	-9.25 USD/MBtu (Gas)	-116 USD/MBtu (Gas)
Flare Installation	1.12 USD/MBtu (Offshore Oil)	16 USD/MBtu (Offshore Oil)

Based on estimates for the costs of abatement, a majority of methane abatement measures covering a large portion of emissions can be enacted at zero or less cost. Most are likely to even have a small return on investment. Given the pledge for zero routine flaring, most of these technologies will have to be adopted to meet the goal. Given the nature of the industry, it is unlikely that a net zero pathway is possible within the industry itself, however, it is clear that much of the emissions from the sector can be mitigated. Taking into account possible carbon pricing mechanisms as well as changes in the energy sector as a whole, it may be possible to eventually reach near net zero in the future. Further study will be required to map out what pathways are possible.

Carbon Abatement

The production of fuels is inextricably linked to its consumption, with more than half of the total emissions coming from the energy sector and a further third from the transport sector. While carbon emissions within the sector may not be comparatively high, the transition to a low carbon future will inevitably have a huge impact on the production of fuels. With the estimated remaining reserves likely to run dry by the middle of the century, a transition towards alternative energy sources is just a matter of time.

One of the top contenders for the fuel source of the future is hydrogen and its derivative, ammonia. As it stands, both these fuels are already in use within many industries; there are also initiatives in the Japan and S Korea to co-combust ammonia and hydrogen in thermal plants to decarbonize the power sector (Mackenzie 2022). In Malaysia, interest in hydrogen as a fuel source is steady building, with PETRONAS themselves looking to commence hydrogen projects from 2024, starting with blue hydrogen, that is hydrogen produced conventionally with carbon capture included and gradually shifting to green hydrogen (PETRONAS 2021b). This, along with a shift towards solar energy and other renewables, would go a long way to meet the country's target to be carbon neutral by the middle of the century. Of course, these are long term targets, contingent on major overhauls in the energy, industrial and transportation sectors to accommodate the new energy sources. These will be discussed in further detail in their respective chapters.

PETRONAS and the Future of Oil and Gas in Malaysia

For decades, the Malaysian government has relied on revenue generated through rents from the oil and gas industry, primarily through PETRONAS. In recent years, this reliance has only gotten stronger, bordering not only on ecological unsustainability but now also on fiscal unsustainability. In 2020, the portion of the federal government funded via PETRONAS stood at over 20% (Pritish Bhattacharya and Hutchinson 2022). With the current decline of oil and gas worldwide as well as limited reserves in the South China Sea fields, the future of oil and gas looks increasingly uncertain and regionally, the major industrial players are beginning to take note of the shift. Many have begun investing into greener fuels and renewables while reevaluating to costs of legacy fossil fuels. In the present however, short term growth is still possible, and even expected for the industry. Emissions wise, the intensity of methane and carbon output over time has decreased, roughly in step with wide trends globally. However, there is still a long road ahead both for PETRONAS, who will have to navigate an increasingly uncertain environment as their relevance to the economy dwindles, as well as for the Malaysian government, who may have to seek for alternative revenue sources.

2.6 Agriculture

Leong Yuen Yoong and Michael James Platts

Abstract

Agriculture has a much broader role in climate mitigation than has been generally recognized. It is a sector that contributes to fighting climate change through decarbonization (reduce carbon emission) and recarbonization (put carbon back to where it was and grow natural ecosystems). This paper lays out the current and historical emissions in agriculture in Malaysia, discusses the decarbonization commitment (or the absence it) in the agriculture sector, options to reduce agriculture emissions and ensure security of food supply and socio-economic development. The scientific principles of why microbes, soil organic matter and soil organic carbon have important roles in reducing agriculture emission are established, and two pathways that embody the principles – carbon farming and seeding soil with microbes – are outlined.

Current and historical emissions in agriculture

Agriculture is a 10% contributor to Malaysia's economy

In 2019, agriculture directly contributed to 7% of GDP, with a further 3% of GDP created from related downstream industries such as food and beverage processing, rubber manufacturing etc. Agricultural exports accounted for over 6% of total national exports. (WWF-MY and BCG-MY, 2021)

Agriculture is responsible for 10.6 million MT of CO_2 eq of emissions, 3% of the Malaysia's total emissions.

Malaysia's agriculture sector comprises of agriculture products and livestock products. Agriculture products are divided into industrial crops (oil palm, rubber, cocoa and pepper) and agrifood commodities (paddy, fruits, fisheries, coconut, vegetables etc.)

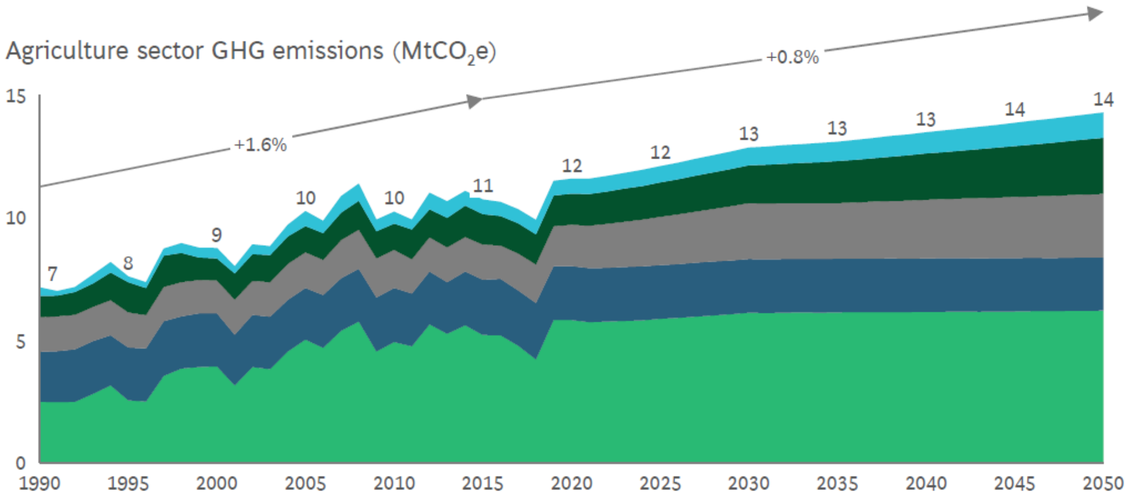
Agriculture sector emissions has been growing at approximately 2% per annum during 1990-2016. The GHG emissions growth rate fluctuated from year to year in tandem with the usage of fertilizers by the sector, particularly by the oil palm plantations. (Ministry of Environment and Water, 2020)

The largest source of emissions from the agriculture sector is N_2O emissions from managed agriculture soil due to fertilizer and animal manure application

N_2O emissions from managed agriculture soil contributed 49% of total emissions and has been growing most rapidly at 3% per annum, relative to other agriculture emission sources (WWF-MY and BCG-MY, 2021). Most of the N_2O emissions stem from fertilizer and animal manure application when the crops cannot utilize all the applied nitrogen because the growth stage does not require all of it. More efficient application of fertilizer will reduce overall use but does not change the thinking paradigm concerning what contributes to soil fertility.

Within an oil palm plantation, fertilizer and nitrous oxide's contributions to GHG emission are 2% and 4% respectively (Table 32)

The next significant sources of emission from the agriculture sector are rice cultivation (22%), enteric fermentation from livestock (13%), manure management (11%) and urea and biomass burning (5%). (Figure 37)



Sources of agriculture sector GHG emissions	2016 emissions ($MtCO_2e$)	1990-2016 CAGR (%)	2016-2050 CAGR (%)
Urea	0.6	+1.8	+1.8
Manure management	1.2	+1.3	+1.9
Enteric fermentation	1.4	-0.2	+1.9
Rice cultivation	2.3	+0.5	-0.2
Managed agricultural soil	5.2	+2.9	+0.5

Figure 37: Agriculture emissions in Malaysia (WWF-MY and BCG-MY, 2021; Ministry of Environment and Water, 2020)

Table 32: Sources of oil palm plantation's GHG (*Kulim (Malaysia) Berhad, 2016*)

Sources of Oil Palm Plantation's GHG	%
Oil palm planting	
Land clearing	65.2
Peat	6.6
Nitrous oxide	4.0
Fertilizer	2.0
Palm oil production	
Palm oil mill effluent	20.2

Industrial crops take up 89% of the agricultural land in Malaysia. Oil palm takes up 82% of industrial crop land.

Agricultural land Malaysia was reported at 26.1 % of total land area in Malaysia in 2018 (World Bank 2022). **Table 33** shows that 7.7 million hectares or 89.3% of the agricultural land is used for industrial crops, with oil palm taking up the lion's share (5.7 million hectares or 82%). In 2020, Malaysia exported USD 10.6 billion in palm oil, making it the

2nd largest exporter of palm oil in the world (OEC 2022). The country accounted for 25.8% and 34.3% of world's palm oil production and exports, respectively (MPOC 2022).

The next most significant industrial crop is rubber, which takes up 17% of industrial crop land usage area. In 2020, Malaysia exported USD 901 million in rubber, making it the 4th largest exporter of rubber in the world (OEC 2022).

The most significant agrifood commodity is paddy, which takes up 45% of agrifood commodities land usage area

In 2020, Malaysia exported USD 48.2 million in rice, making it the 34th largest exporter of rice in the world (OEC 2022).

Table 33: Land usage by industrial and agrofood commodities (2010-2020) (*Ministry of Agriculture and Agro-based Industry*)

Commodities	'000 Hectare			Average annual growth rate (%)		
				10 MP		11MP[1]
	2010	2015	2020	Target 1	Achieved	
Industrial commodities						
Rubber	1,020.4	1,087.6	1,197.6	2.2	1.3	1.9
Oil palm	4,853.8	5,480.0	5,672.0	1.9	2.5	0.7
Cocoa	20.1	18.2	23.4	8.4	1.4	5.2
Pepper	14.2	16.3	18.3	4.0	2.8	2.3
Subtotal Industrial commodities	**5,908.5**	**6,602.1**	**6,911.3**	**2.0**	**2.2**	**0.9**
Agrofood commodities						
Paddy	444.3	394.2	368.2	-2.4	-2.4	-1.4
Vegetables	39.3	38.4	45.7	2.4	-0.4	3.5
Fruits	239.4	203.1	206.9	-0.5	-3.2	0.4
Coconut	105.7	85.8	77.6	-3.4	-4.1	-2.0
Fisheries[2]	33.8	46.8	116.6	4.0	6.8	20.0
Others[3]	7.1	9.6	10.2	5.2	6.4	1.1
Subtotal Agro-food	**869.6**	**777.9**	**825.2**	**-1.4**	**-2.2**	**1.2**
Total land use	**6,778.1**	**7,380.0**	**7,736.5**	**1.4**	**1.9**	**0.7**

MP: Malaysia Plan, which is developed by the Malaysian government every five years.

Malaysia's decarbonization commitment in agriculture

Malaysia's self-sufficiency levels (SSL) targets for key crops and livestock populations will lead to an increase of 3 Mt CO_2e from now to 2050

Inputs from the National Agrofood Policy 2.0 (2021-2030) was used to estimate potential planted area impact for each of Malaysia's key crops, and livestock populations, based on target self-sufficiency levels (SSL), which were assumed to hold until 2050. Emissions are expected to increase by 3 $MtCO_2e$ to 14 $MtCO_2e$ by 2050 due to increased production. (WWF-MY and BCG-MY, 2021)

Proposed capping of oil palm cultivation at 6.5 million hectares went silent

In March 2019, the Plantation Industries and Commodities Ministry proposed to the cabinet to cap oil palm planted area at 6.5 million hectares by 2023. In 2018, the total planted area stood at 5.8 million hectares, with more than 19.5 million tonnes of crude palm oil produced. There was no further news on what happened to the proposal.

Table 32 shows that land clearing contributes to 65% of an oil palm plantation's GHG emissions. Malaysia's net-zero target will not be met without changes in how it determines land use. Land laws and administration in Malaysia are based on the National Land Code (NLC) of Peninsular Malaysia, the Sabah Land Ordinance, and the Sarawak Land Ordinance. The Land Capability Classification (LCC), introduced between 1963 and 1976, is similar across the three regions. It divides land use into the following five land capability classes – in a declining order of priority - based on potential productivity and economic yield: (Mojiol 2006, Thomas, Lo and Hepburn 1976)

I. Land with high potential for mineral development
II. Land with a potential for agriculture with a wide range of crops
III. Land with a moderate potential for agriculture with a restricted range of crops
IV. Land with no mining or agricultural potential, but a potential for forest resource exploitation and best suited for this purpose
V. Land with no potential for mining, agriculture or forest resource exploitation and is generally best suited for conservation or recreational purposes

Malaysia's Constitution stipulates that the state – and not the federal government - has constitutional right over forestry matters. The key decisionmaker is typically the *menteri besar*, or chief minister of each state. Degazetting of Permanent Forest Reserves (PFR) can happen to make way for agriculture or mining.

In 2011, Malaysia's neighbour, Indonesia, issued a temporary moratorium on granting permits to clear primary forests and peatlands for plantations or logging. This moratorium was made permanent in 2019. Although loopholes in the moratorium that lead to forest clearing remain, it is nevertheless a significant step in the right direction.

Conservation sits at the bottom of the land use priority ladder because policymakers have adopted a human-centric worldview that maximizes utilization and development of land for the highest monetary return on development.

Options to reduce agriculture emissions and ensure security of food supply and socio-economic development

The sources of agriculture sector GHG emission (**Figure 37**) and agriculture's potential contribution to net carbon emission reduction (**Figure 39**) are used in this paper to inform a view of those pathways which should play a dominant role in the agriculture transition.

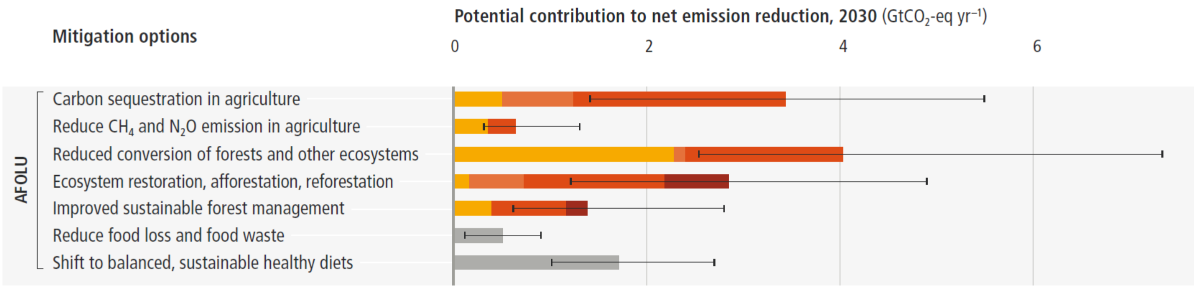


Figure 38: Agriculture's potential contribution to net carbon emission reduction (2030) Gt CO_2-eq yr-1 *(IPCC, 2022)*

The top two mitigation options in **Figure 39** concern reducing forest conversion and carbon sequestration in agriculture. These two mitigation options are linked in a thinking paradigm that views soil fertility as a productive capital asset. Fertile soil leads to higher agriculture productivity, which then reduces the need to convert more forest for new farmland.

Soil fertility is not something poured out of a bag

Modern agriculture simplistically seeks to guarantee high yields by using more nutrients than necessary. N_2O is released directly and indirectly as a result of excessive fertilizer nitrogen inputs into agriculture soil. Surprisingly, despite N_2O from managed agriculture soil contributing 49% of total agriculture emission in Malaysia, IPCC finds that reducing N_2O (and CH_4) emission in agriculture has the second lowest potential contribution to net emission reduction in the agriculture, forestry and land use (AFOLU) universe (**Figure 38**).

This suggests that to address the problem of N_2O emission, the root cause needs to be understood in a more holistic and deeper manner. The following sets out a different thinking paradigm about what contributes to soil fertility.

Malaysia manufactures and uses chemical fertilizer at a higher rate of application than many neighbouring ASEAN countries (Table 25). 83% of fertilizer consumption in Malaysia is for growing oil palm (Figure 39).

Different data sources give fertilizer application rates in Malaysia that range from 700-2000+ kg per hectare per year. The lower range comes dividing the total chemical fertilizer consumption (**Table 36**) over the total farmed land 7,736,500 hectares (**Table 33**) in Malaysia in 2020. The upper range comes from Knoema.com.

Oil palm and rubber are the common major industrial crops, and paddy and coconut are the common major food crops, in Malaysia and Indonesia. Soils in both countries are mostly acidic. One can compare the numbers for these two countries in **Table 34** within this context.

Table 24: Fertilizer consumption per unit of arable land in ASEAN countries (*Knoema*)

ASEAN Countries	Kg per Hectare	
	2018	2016
Singapore	0	30,237.9
Malaysia	2,106.5	1,723.4
Vietnam	415.3	429.8
Indonesia	236.4	231.4
Thailand	148.9	161.7
Philippines	169	157.4
Brunei	141.8	141.8
Myanmar	49.3	17.9
Cambodia	34.3	17.4
Lao PDR	No information	No information

Notes:

- Fertilizer products cover nitrogenous, potash, and phosphate fertilizers (including ground rock phosphate). Traditional nutrients--animal and plant manures--are not included.
- Arable land includes land defined by the Food and Agriculture Organization of the United Nations (FAO) as land under temporary crops (double-cropped areas are counted once), temporary meadows for mowing or for pasture, land under market or kitchen gardens, and land temporarily fallow. Land abandoned as a result of shifting cultivation is excluded.

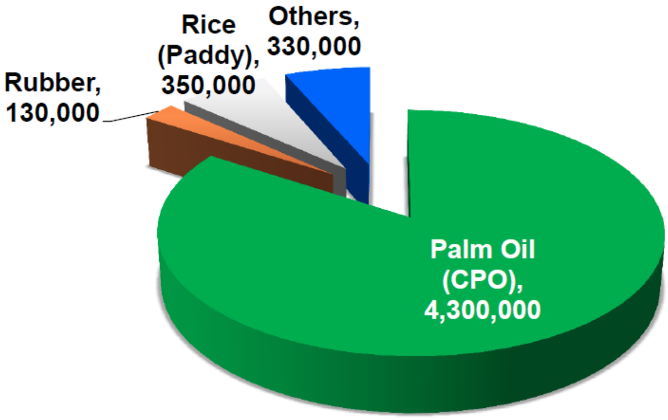
Table 35: NPK Fertilizer Consumption (MT) in Malaysia, 2013-2021 (*Department of Statistics, Malaysia*)

Year	Nitrogen (N)	Phosphorus (P)	Potassium (K)	Total
2013	2,065,000	1,178,000	2,204,000	5,447,000
2014	2,091,000	1,281,000	2,113,000	5,485,000
2015	1,915,000	1,173,000	1,913,000	5,001,000
2016	1,995,000	1,169,000	1,911,000	5,075,000
2017	2,031,000	1,215,000	2,009,000	5,255,000
2018	1,990,000	1,170,000	1,950,000	5,110,000
2019	1,930,000	1,130,000	1,890,000	4,950,000
2020	1,990,000	1,170,000	1,950,000	5,110,000
2021*	2,006,000	1,179,000	1,965,000	5,150,000

Source: Department of Statistics, Malaysia; FIAM and industry estimates
* 2021 – based on industry estimates

Note:

- These figures show mineral fertilizer usage, and exclude manures, composts etc. These are pure chemical elements, not oxides.



(in metric tonnes)
Source: Industry Estimates

Figure 39: Chemical fertilizer consumption by major crops in Malaysia, MT (2020) (*FIAM and industry estimates*)

Productivity is declining despite heavy use of chemical fertilizer

A crucial challenge facing the Malaysian oil palm industry is that the actual fresh fruit bunch (FFB) yield (tonne per hectare per year, t ha^{-1} $year^{-1}$) is well below potential (up to 30 t ha^{-1} $year^{-1}$) and have stagnated over last two decades (Khiabani & Takeuchi, 2020; Sahidan et al. 2021). In fact, **Figure 40** shows decline over the past ten years.

Excessive use of chemical fertilizer has seriously damaged the microbiological ecosystem that is the basis of soil fertility. The chemical fertilizer vicious cycle makes the agricultural system even more dependent on fertilizer and pesticide[37], which have been increasing in prices due to producing countries reducing urea production to protect the environment, control carbon emission, and geopolitical fights.

[37] Spraying pesticides on land has an impact on almost 82-86% of biodiversity, which lives within 12 inches of the topsoil (Chelvi, 2022).

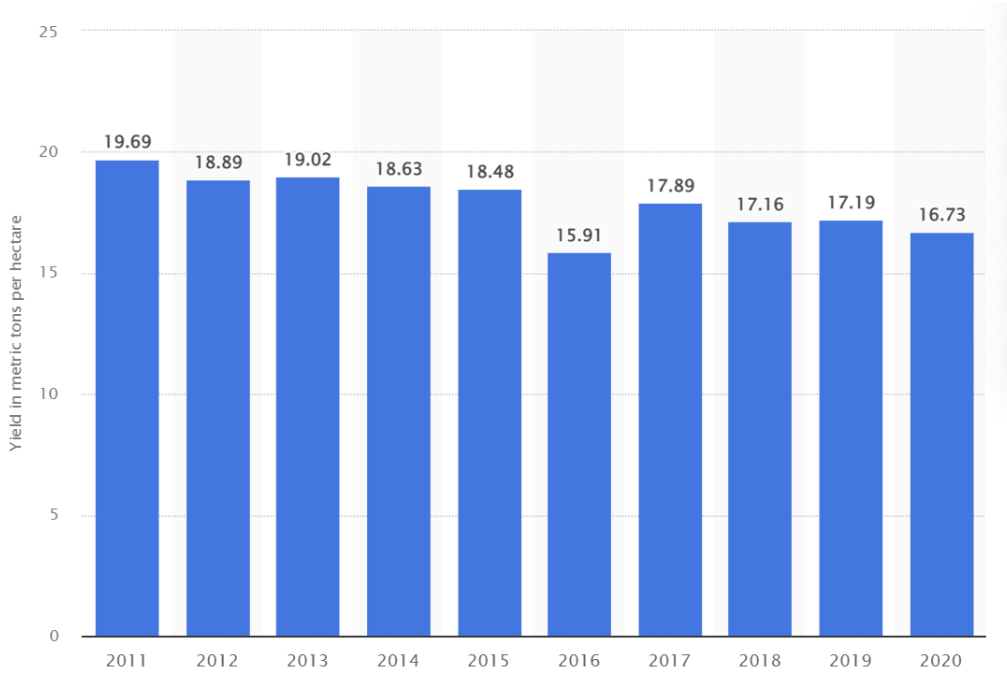


Figure 40: Average yield of fresh fruit bunches in Malaysia from 2011 to 2020 (in metric tons per hectare) *(Hirschmann, 2021)*

'Fertility' needs to be understood as the highly sophisticated 'fertility ecosystem' of microbes that live in the soil and co-exist with the crop roots, symbiotically preparing the nutrients for the crop roots to absorb.

Microorganisms in the soil fulfil a symbiotic role in a healthy plant's life, but this subject is currently absent from most scientific discussion of good farming practice (Platts & Leong, 2020).

Farmers need to change the way they think about soil fertility and work to regenerate the soil fertility using a biological solution that's based on a thorough understanding of the underlying microbiological ecosystem.

It is also critical for policymakers to shift their mindset to treat soil as a living being and feed the symbiotic relationships between microbes and plants. Then, they will be able to shift agriculture investments to nurture this productive capital asset and develop good farming practice.

Microbial life in soil

Life in soil is largely microbial, which needs to be fed and housed

Despite its dirt-like image, soil is a living entity. Since soil is a living being, it needs to be fed. Microbes require carbon to build up energy for their development and nitrogen for building up proteins. Continually feeding the soil with organic material supports the beneficial bacteria, fungi and nutrients plants need and use. (Cahill, 2020)

Crops continuously take up soil nutrients to grow. Soil in intensive agricultural systems like plantations loses carbon when plant material is removed from the land during harvest, and often not replaced. Feeding the soil with chemical fertilizers - nitrogen (N), phosphorus (P) and potassium (K) - does not replenish all the lost nutrients.

Animals used to be part of farmlands and their manure is a food source for microbes. The arrival of farm machineries has encouraged animal-free agriculture.

Besides food, microbes need appropriate housing (e.g. well aggregated soil) to thrive too. An aggressively tilled soil breaks soil pores and aggregates apart. When land is ploughed up to 9-12 inches in depth with tractors and machines and left open, biodiversity is seriously destroyed (Gasch & DeJong-Hughes, 2019; Chelvi, 2022)

When soil organic content falls below a critical threshold, soil turns into sand. Desertification results in loss of farmers' livelihoods, loss of biodiversity, water scarcity, food crises, climate change, floods, conflict and migration.

Soil organic matter or soil organic carbon?

Soil organic matter is material in soil that is derived from living organisms, whether it is a carcass, waste product or other substance released from living organisms (Gasch & DeJong-Hughes, 2019). The terms soil organic carbon and soil organic matter are often used interchangeably because carbon makes up the majority (58%) of organic matter mass (Howard & Howard, 1990).

Organic matter can be classified as active or stable (Table 36).

Table 36: Active organic matter and stable organic matter *(Gasch & DeJong-Hughes, 2019; Well & Brady, 2017; Sylvia, Fuhrmann, Hartel, & Zuberer, 2005; Ontl & Schulte, 2012)*

Active Organic Matter	Stable Organic Matter (humus)
• 10-20% of the total organic matter in the soil • Fuels microbial activity and releases nutrients into the soil, which are easy for microbes to digest and use for their metabolism • Materials are quite young – usually less than five years in the soil	• 60-90% of total organic matter in the soil • Accumulates when active microbes continuously decompose organic matter. Although this is a slow process, the amount of stable organic matter will continue to increase, if organic matter is added each year[38]. • Most of the residue material added to soil is consumed and respired through decomposition within weeks to a few years; only a small portion of organic matter becomes stable each year • Organic matter sticking to clay particles and aggregation are processes that stabilize organic matter in soil • Ancient, stable soil organic carbon has gone through thousands of microbial ingestions and transformations • When microbes die, the nutrients and carbon in their bodies are released and consumed by other microbes, or they may become fixed to clay particles, which makes them resistant to further decomposition, thus contributing to the stable organic matter pool.

There is a general statistic that *soil organic content* in Malaysia is less than the minimum amount required, which is 3-6% (Paramaselvam, 2022). It would be helpful to clarify the following:

- Does this refer to agricultural soil only?
- Does this refer to soil organic matter or soil organic carbon?
- Soils are hugely heterogenous, and thus has large variability. It would be helpful to separate soil into two categories – organic soil and mineral soil – and understand their soil organic matter and soil organic carbon content separately. Mechanisms to address their soil organic content could be specific to the soil type.

Soil carbon sequestration is an investment that can pay for itself. Increasing soil organic carbon by just 0.4% annually would increase global production of major food crops by 20-40% per year (Larbodière, et al. 2020)

Besides improving nutrient availability, organic matter acts like a sponge, which can drain excess water as well as hold water that can be used for plant uptake. This means that plants grown on soil with higher organic matter content can go on for more days without rain. This can make a critical difference to agricultural yield when water stress is a major and growing concern in the age of climate change.

Increasing organic carbon content in agricultural soils worldwide would also increase their water storage capacity by up to 37 billion m^3, which leads to ~4% reduction in

[38] Only for a certain period of time, which is dependent on the starting level of SOC. It will not continue indefinitely in aerated soils, instead further addition will only maintain soil organic carbon level as decomposition begins to balance sequestration.

irrigation needs globally and potential savings of US$44 billion per year (Larbodière, et al., 2020).

An annual 0.4% increase in soil carbon content leads to an additional 1 giga tonne of carbon being sequestered per year on average (Larbodière, et al. 2020)

Since the Intergovernmental Panel on Climate Change (IPCC) was established by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) in 1988, soil carbon sequestration in agriculture and nature has been included under climate change mitigation. Agriculture has a pivotal role in soil carbon initiatives because almost 40% of the world's soils are currently used as cropland and grassland.

Storing carbon in soils as a measure to mitigate climate change is gaining momentum, for example the "4 per 1000" Initiative launched by the French government at COP21 Paris climate summit in 2015, and carbon farming practices under the Common Agricultural Policy (CAP) and other EU programmes such as LIFE and Horizon Europe, in particular under the Mission "A Soil Deal for Europe".

According to an International Union for Conservation of Nature (IUCN) report, an annual 0.4% increase in soil carbon content leads to an additional 1 giga tonne of carbon being sequestered per year on average, which is about one tenth of global human-induced carbon emissions based on 2017 numbers. This contribution is estimated to bring society USD 600 billion per year of savings in present value terms over the 2020-2050 time horizon. (Larbodière, et al., 2020)

Skeptics caution the need to be realistic about what soil carbon sequestration can achieve, and for how long because gains are time limited due to the capacity of the soil. It also has issues around permanence. Hence, some climate change researchers do not include soil carbon gains in their decarbonization pathways but consider soil measures and their role in reducing use of agricultural inputs.

A plausible response to the critique on the permanence of soil carbon storage is that if the carbon is being utilized through plant growth, harvested and sequestered in a continuous organic cycle, it does not matter that carbon storage is not permanent because carbon moves within a closed loop. What becomes a problem is when carbon leaves an organic cycle and becomes permanent resident in the atmosphere.

Soil carbon sequestration is a recarbonization pathway that sustains the health of ecosystems, which then manifests as soil fertility, agricultural productivity and wider services beyond production that soil underpins. This will reduce the demand for chemical fertilizers and hazardous pesticides, which come with high carbon footprints. Correct framing is important because recarbonization and decarbonization pathways have different characteristics and need to be valued differently.

Towards net zero for agriculture

After establishing the scientific principles of why microbes, soil organic matter and soil organic carbon have important roles in reducing agriculture emission, we will look at two pathways to do it – carbon farming and seeding soil with microbes.

Carbon farming

Commission a study on how to set up and implement result-based carbon farming mechanisms in Malaysia

Carbon farming – also known as regenerative agriculture – optimizes carbon capture on working landscapes by implementing practices that increase the CO_2 removal rate from the atmosphere by storing it in plant material and/or soil organic matter. The underlying system dynamics and positive feedback processes "regenerate" soil fertility and improve farm productivity.

A study in the EU concluded that result-based carbon farming can make a significant contribution to tackling climate change, bring benefits in terms of carbon sequestration and storage and other co-benefits, such as increased biodiversity and preservation of ecosystems. (European Commission, n.d.)

The proposed study in Malaysia shall explore impact on yields, key issues, challenges, trade-offs and design options to develop carbon farming. It can also explore how a widespread adoption of carbon farming can be triggered in Malaysia and Southeast Asia.

Pilot initiatives can then be developed at local or regional level to build experience for upscaling carbon farming

There is a learning curve that all stakeholders will need to scale to design such an initiative well, for example in certifying carbon removals, expanding stakeholders' knowledge and understanding of the potential benefits for them.

Develop a framework for robust and transparent carbon accounting | new agricultural policy | ecological schemes | funding

Governments need to develop a regulatory framework for certifying carbon removals based on robust and transparent carbon accounting to monitor and verify the authenticity of carbon removals.

Malaysia and Southeast Asia need new agricultural policy, ecological schemes and funding that reward agricultural practices that fight the climate and biodiversity crises.

Carbon farming can be a new green business model that creates a new source of income for farmers and other actors in the bioeconomy in Malaysia and Southeast Asia, based on the climate benefits they provide.

A carbon farming technology pathway example

This technology pathway concerns composting, which is a microbial process that converts agricultural residue into a more usable organic soil amendment or mulch. Traditional composting has many challenges, as summarized in the second column of **Table 37.** These shortcomings, which prevented the widespread and large-scale use of compositing in agriculture, have been overcome by an enzymatic organic waste processing technology developed in East Asia, as illustrated in the third column of **Table 37**.

Table 37: Comparisons between traditional composting technology and an organic waste processing technology (*Industry*)

Issues	Traditional Composting	Enzymatic Organic Waste Processing Technology
Operation	Complicated	Easy
Time required	Long (3-6 months)	Short (less than 3 hours)
Space required	Large	Small (1/10)
Hygiene	Bad smell, wastewater	No pollution
Carbon loss during composting	Yes (loss > 20%)	No (zero loss)
Land cost	High	Low
Equipment cost	High	Low (1/3)
Pathogens	Exist	Free
Nutrient loss	N loss 50%	Zero N loss
Production %	~50%	100%

The following assumptions are used to develop a scenario of partial chemical fertilizer substitution:

- The enzymatic technology preserves nearly 100% of the raw material content after decomposition
- 1/3 of chemical fertilizer can be replaced with organic fertilizer produced via the enzymatic technology[39]
- Since 84% of the synthetic fertilizer consumed in Malaysia goes into oil palm, we assume using palm EFB as the raw material for producing the organic fertilizer

Pile abandonment of EFB in the fields around palm oil mills is a common practice in Malaysia, Indonesia and Thailand, which leads to generation of unpleasant odours and methane due to anaerobic decomposition (Fujita, Nakano, & Hambali, 2019).

Replacing chemical fertilizer with organic fertilizer has the triple benefits of:

1. Sequestering carbon in the soil
2. Avoiding GHG emission due to anaerobic decomposition of EFB
3. Reducing the carbon footprint of chemical fertilizer, which has a carbon intensive manufacturing process

There is a critique that inorganic vs organic fertilizer cannot be considered like for like, i.e. organic fertilizer will likely have lower levels if NPK needed for crop maintenance and higher levels of C. This is true in the thinking paradigm that fertility is something poured out of a bag. However, in the thinking paradigm that the microbes are the soil's fertility, healthy and vigorous microbes play a role in preparing the nutrients that a plant needs, ready for absorption through the roots. This is a symbiotic relationship between the roots

[39] Critique: inorganic vs organic fertilizer cannot be considered like for like because the latter will likely have lower levels of NPK needed for crop maintenance and higher levels of C.
Response: this scenario is built on the understanding that fertility is not NPK poured out of a bag, but as a highly sophisticated 'fertility ecosystem' of microbes that live in the soil and co-exist with the crop roots, symbiotically preparing the nutrients for the crop roots to absorb.

and the surrounding microbial population that lives with it, which farmers need to understand and support. (Platts and Leong 2020)

Sequestering carbon in the soil

Fixed carbon under proximate analysis is the carbon found in a material which is left after volatile materials are driven off. Total carbon under ultimate analysis includes some organic carbon that escapes as gaseous volatile matter during combustion.

Table 38: Proximate and Ultimate Analysis of Empty Fruit Bunch (EFB) under Optimumt Conditions

Sample	Proximate analysis (wt%)				Ultimate analysis (wt%)			
	Moisture	Volatile	Fixed carbon	Ash	C	H	N	O*
Raw EFB	2.44	73.63	18.67	5.26	48.48	7.14	0.64	43.74
Activated carbon EFB	7.53	15.23	67.66	9.58	68.32	3.12	2.12	26.44

* Oxygen by difference

Proximate and ultimate analysis of empty fruit bunch (EFB) under optimum conditions

EFB fixed carbon content = 18.67%

Total chemical fertilizer used (2016) = 1995000 (nitrogen) + 1169000 (phosphorus) + 1,911,000 (potassium) = 5,075,000 MT

Table 39

Year	Organic Fertilizer (MT)	Carbon Content (MT)
2016	1,522,500 (Assume 30% substitution of chemical fertilizer)	284,250.8

Avoid GHG emission due to anaerobic decomposition of EFB

Malaysia produces 22.43 million MT of EFB per year (MIGHT, 2020). Millers typically send half for mulching and dispose or incinerate the other half (SEDA Malaysia, 2021). No quantitative data on the GHG effects of mulching is available. Several studies concluded mulching to be carbon neutral (Brinkmann Consultancy, 2009; ERIA, 2007; Nikander, 2008; Searchinger, et al., 2008)

In the scenario of disposal / landfilling / field abandonment of EFB, the CO_2 equivalent GHG emissions per kg of EFB (methane emission) = 2.136 kg CO_2 eq (Fujita, Nakano, & Hambali, 2019)

GHG emission that would have resulted from the anaerobic decomposition of 1,522,500 MT of EFB = 1,522,500 x 2136 = 3,252,060 MT CO_2 eq (3.25 million MT CO_2 eq)

Reduce carbon footprint of chemical fertilizer

The manufacturing related carbon footprint of the chemical fertilizers are calculated using the emission factors shown in **Table 40**. Malaysia's total GHG emission for 2016 = 316.83 million MT CO_2 eq (Ministry of Environment and Water, 2020)

Table 40: Emission factors of chemical fertilizer (*Fertilizers Europe, 2019; Kulim (Malaysia) Berhad, 2016*)

Fertilizer	Manufacturing Related Carbon Footprint
Urea (46-0-0) per tonne of N	3623 kg CO_2eq/MT nitrogen (for Southeast Asia region)
Ground rock phosphate	44 kg CO_2eq/MT
Muriate of Potash	200 kg CO_2eq/MT

Emissions from agriculture in 2016 were 10.6 MT CO_2 eq (Ministry of Environment and Water, 2020)

Manufacturing related GHG emission of fertilizers used in MY (2016) =

$$\frac{1995000 \text{ x } 3623 + 1169000 \text{ x } 44 + 1{,}911{,}000 \text{ x } 200}{1000} = \frac{7227885000 + 51436000 + 382200000}{1000} = 7.66 \text{ million MT } CO_2 \text{ eq}$$

(2.42% of Malaysia's total GHG emission in 2016)

30% of 7.66 million MT CO_2 eq = 2.30 million MT CO_2 eq

The calculation for the manufacturing related GHG emission of organic fertilizer produced via the enzymatic route is not available yet. Our hypothesis is that organic fertilizer is less carbon intensive to manufacture compared to chemical fertilizer due to the reasons summarized in **Table 41**

Table 41: Comparisons between chemical and organic fertilizers

	Chemical Fertilizer	Organic Fertilizer
Production temperature	Ammonia: 450-500°C	85°C
Production pressure	Ammonia: 200 atmospheres	Ambient pressure
Transport distance	Centralized production → long transport distances	In situ treatment of organic waste → in situ application of organic fertilizer
Raw materials	Fossil fuels: natural gas (mostly methane)	Organic waste → prevents GHG emissions due to mis-handling of organic waste

Note: Ammonia is a basic building block for ammonium nitrate fertilizer, which releases nitrogen, an essential nutrient for growing plants. About 90% of ammonia produced worldwide is used in fertilizer.

Seeding the soil with microbes

Create a soil research group

i. Research the core soil fertility issues. For example, how to identify in detail, and measure the microbial life in the soil that is its fertility?
   - These issues are wider than fertility. The research can be reframed as soil health and address how this can deliver benefits for the wider environment and resilience in the face of a changing climate, alongside mitigation

ii. Develop and manage a global database that shares this information globally and gives an information and advisory service to smallholders and others, wherever they are.
   - The detailed science explaining this symbiosis can be used to develop 'best practice agriculture' acknowledging the importance of nourishing this 'fertility ecosystem' in the soil, rather than depleting it.
   - This pragmatic approach was well demonstrated in Malaysia in the experimental trials undertaken previously by OrganiGro, where 'seeding' the soil with the right microorganisms doubled the yield of rice smallholdings and completely transformed the economics of rice production on those smallholdings (Platts & Leong, 2020). Increases in yields could then be used to release land from production in other areas.

Create the Malaysian Soil Foundation

Funding needs to be channeled towards creating a Malaysian Soil Foundation (MSF), which will fund the adding of soil ameliorant into the soil to rejuvenate the soil holistically throughout Malaysia

MSF will also fund scholarships to train Malaysian scientists and technicians to develop and implement the underlying science and technology and run continuous and widespread assessment trials so that Malaysia can become a global centre of excellence leading development in both the scientific understanding, and the soil fertility and associated good farming practices needed to feed a hungry planet.

Time | Mindset

Both mitigation measures discussed in this paper – carbon farming and seeding the soil with microbes - can be done today. The obstacle is not in technology, but in mindset.

Major decision makers and economic actors have largely ignored the living ecosystems of soils. This could be observed in Malaysia's Ministry of Agriculture and Food Industries' (MAFI) thinking about improving food production, which focuses on the following areas:

- Smart agriculture mechanization, automation and integrated data systems in line with the Industrial Revolution 4.0;
- Optimising the use of agricultural land to increase productivity, e.g. developing unused land, consolidating land management and integrating farms;
- Enhancing the effectiveness of the agrofood value chain through research and development, commercialization and innovation, prioritising food safety and quality and the development of agricultural inputs.

Similarly, one can see from Malaysia's Ministry of Planation Industries and Commodities' (MPIC) initiatives that the symbiotic relationship between soil microbes, soil organic carbon and soil fertility is not on the Ministry's radar yet.

- For example, the two incentives launched by MPIC this year are the Oil Palm Integrated Farming Scheme (ITa) and the Agro Bank-MPOB Easy Financing Scheme - to encourage oil palm planters to plant cash crops and optimize land use so that excess production costs due to rising fertilizer prices could be covered.
- Under the ITa, oil palm planters who plant pineapples are eligible for incentives of RM7,000 per ha, while those who grow bananas, watermelon, corn and papayas receive RM3,000 per ha.

Malaysia should invest time and effort into establishing soil as a valuable productive capital asset so that it can continue to create consumable value for a long time

Farmers need to be educated to see soil as a productive capital asset (Platts & Leong, 2020) and incentivized to restore and protect this vital capital for long-term profitability as well as for the wider benefit of society.

Governments have an instrumental role to play in designing policies, transparent and robust regulatory frameworks, and financing mechanisms to enable and encourage such actions.

Circular and symbiosis thinking are gateways to better land use

Land is a finite resource. By increasing soil fertility, productivity and efficiency, it is possible to stabilize the total land area under agriculture. Land can also be released from agriculture and turned over to carbon sequestration measures.

By adopting circular and symbiosis thinking, we can increase the biodiversity in agricultural landscapes, reduce pollution and GHG emissions. Agriculture is one of the few sectors that have a chance to make a net positive impact on key indicators of biodiversity by 2030 and be an effective catalyst for wider progress towards sustainability.

2.7 Forestry

Justin Liew

Abstract

Within the LULUCF sector in Malaysia, the most significant needle mover is forestry, which accounted for 94% of the sector's carbon absorption. Forests provide a crucial global service of absorbing carbon dioxide, which helps to slow down global warming and climate change. Tropical rainforests are especially productive carbon sinks, the three largest of which lie in the Amazon, the Congo River Basic, and Borneo – all within developing countries. These countries face a steep economic opportunity cost to conserve these forests as they forsake modes of mainstream economic development such as planting crops and building infrastructure. International carbon deals provide an equitable and efficient way to conserve these forests. While past deals have met various challenges, the governing mechanisms and frameworks are rapidly developing and being refined over time.

In Malaysia, most existing economic instruments for climate policy are 'second-best instruments' which produce some environmental benefit without fully addressing market failures. However, there has been a recent shift in focus towards 'first-best instruments' such as Carbon Pricing Instruments (CPIs), Ecological Fiscal Transfers (EFTs), and Payments for Ecosystem Services (PES). These mechanisms are well suited for protecting forests from economic pressures of deforestation. However, the chronic lack of federal funding greatly limits Malaysia's ability to utilize these mechanisms to their full potential. Therefore, this paper recommends increasing efforts on accessing larger-scale international carbon markets to protect its remaining rainforests. This paper recommends the prioritization of (1) international carbon markets, (2) national carbon markets, and (3) EFTs and PES; while developing all three concurrently.

Current and historical emissions

Net absorber of 200-250 MtCO2e

According to Malaysia's Third Biennial Update Report (BUR3) to the UNFCCC in 2020, its land is categorized as follows (data is for 2016):

Table 42: Land Types and area in Malaysia (2016) (*Malaysia's Third Biennial Update Report (2020)*)

Land type	Area (hectares)	Cover
Forest	17,661,716	59%
Crop	7,892,909	26%
Grass	100,000	0%
Settlements	4,410,797	15%
Total	30,065,422	100%

Malaysia's BUR3 highlights estimations of anthropogenic emissions and removals across various sectors, as well as mitigation actions and their effects. It is prepared by the Ministry of Environment and Water (KASA, for Kementerian Alam Sekitar dan Air), in collaboration with many other government ministries and agencies. Land type data in the BUR3 is obtained from the Ministry of Energy and Natural Resources (KeTSA, for Kementerian Tenaga dan Sumber Asli).

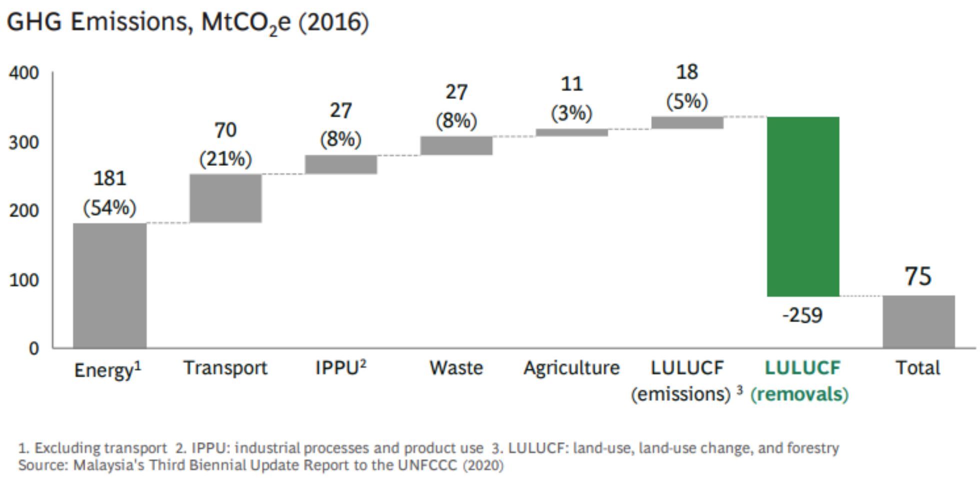


Figure 41: Greenhouse gas (GHG) emissions by sector in Malaysia (2016) (*WWF / BCG (2021), "Securing our future: Net zero pathways for Malaysia"*)

Overall, the LULUCF sector was estimated to have absorbed 77% of national greenhouse gas emissions in 2016 (WWF & BCG, 2021). The vast majority of this is through our forests, which is the most common and significant land type in Malaysia in terms of emissions. Malaysia is blessed with abundant rainforest, which makes up 54% of total land area in 2022 (WWF, 2022). Deforestation in Malaysia peaked in the 1960s and 70s, when 2.5 million hectares of forests was logged (Macaranga, 2020).

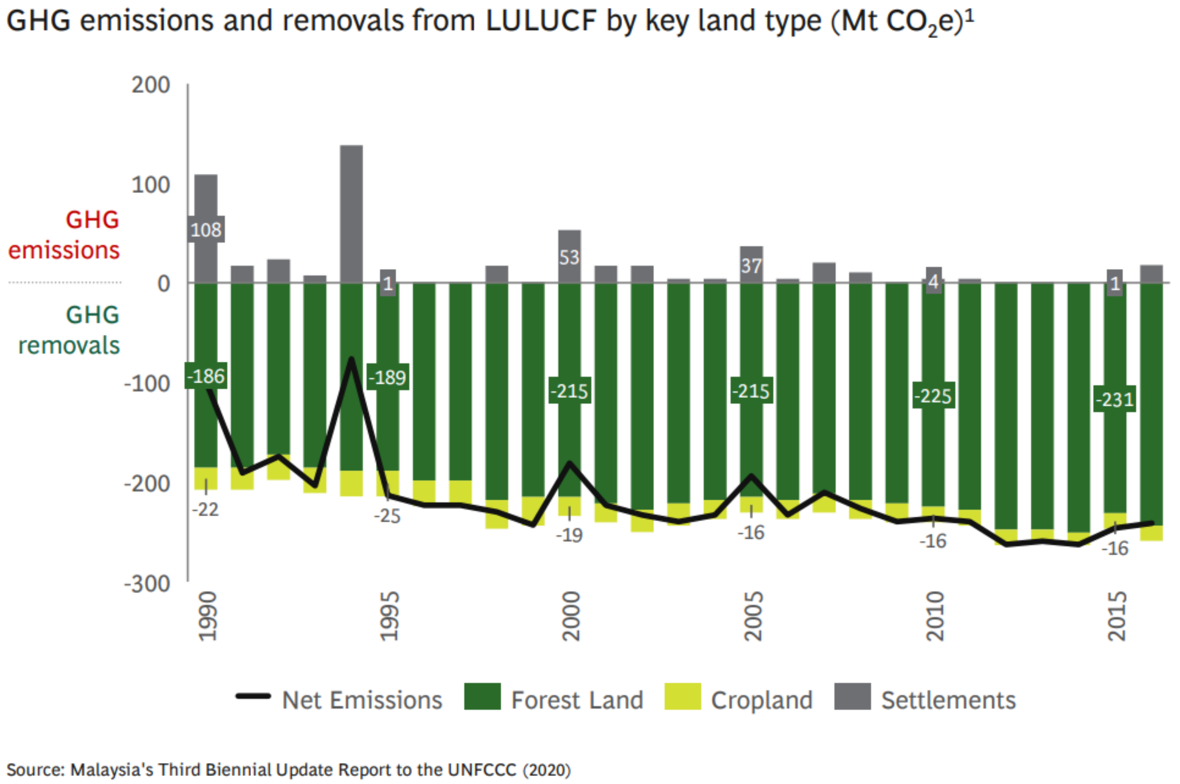


Figure 42: GHG emissions and removals from LULUCF by land type in Malaysia (*WWF / BCG (2021), "Securing our future: Net zero pathways for Malaysia"*)

Malaysia's decarbonization commitment for the sector

Minimum 50% national forest cover

The National Forestry Policy reclassified most of our forests as Permanent Reserve Forests (PRFs) in 1978, which helped slow down deforestation. In PRFs, only large trees can be logged; roads are limited; clear-cutting is banned; and logged sites are left alone for 25-30 years to regenerate. Over the past three decades, forest cover decreased just marginally from 57% in 1990 to 54% in 2019 (Macaranga, 2020). Nevertheless, the PRF status is not bulletproof – in Malaysia, states have the sole authority over land and forests, and can excise PRFs.

At the 1992 Earth Summit, Prime Minister Dr Mahathir Mohamad pledged to retain at least 50% of forest cover in Malaysia – a promise still echoed on the website of Ministry of Energy and Natural Resources up until today. Although this pledge by the federal government is not bound by any law that can be enforced upon the states, the forest policies of individual states generally have a forest cover target above 50%. Sarawak's forest policy targets 56% forest cover (Sarawak Forest Policy, 2019), with official data showing 62% cover in 2020 (Forest Department Sarawak, 2020). Meanwhile, Sabah's forest policy cites 59% of forest cover in 2018, with a commitment to maintain at least 50% (Sabah Forest Policy, 2018).

Some third-party forest watchdogs such as Global Forest Watch and Hutanwatch have noticed discrepancies between official records and reality – for example, one might find buildings where forests are recorded. Policy fixes that can reduce deforestation include making gazettes freely available, making all logging concessions long-term (30 years) to incentivize sustainable logging, and amendments to the National Forestry Act including higher penalties and compulsory public consultations before excisions (Law, 2020).

There have also been concerns about the accuracy of Malaysia's estimated emissions, particularly in the LULUCF sector. The Washington Post reported that Malaysia is vastly overestimating its annual forest carbon sink to be four times of similar forests, and underestimating emissions from drained peatland (The Washington Post, 2021). The same report also mentions that actual satellite imagery shows evidence of higher-than-reported forest clearing activities. The environment and water minister Tuan Ibrahim Tuan Man defended their data, saying that numbers in the BUR are in line with IPCC guidelines and have undergone the UNFCCC technical review process (Free Malaysia Today, 2021).

Options to reduce emissions

Agroforestry, increased soil organic carbon content, increased food productivity, and carbon markets

In 2019, The Intergovernmental Panel on Climate Change (IPCC) released a special report on climate change and land, which estimates that LULUCF is responsible for 11% of total net anthropogenic emissions globally from 2007 to 2016 (IPCC, 2019). The report also evaluated various response options for land management, based on five factors: mitigation, adaptation, desertification, land degradation, and food security.

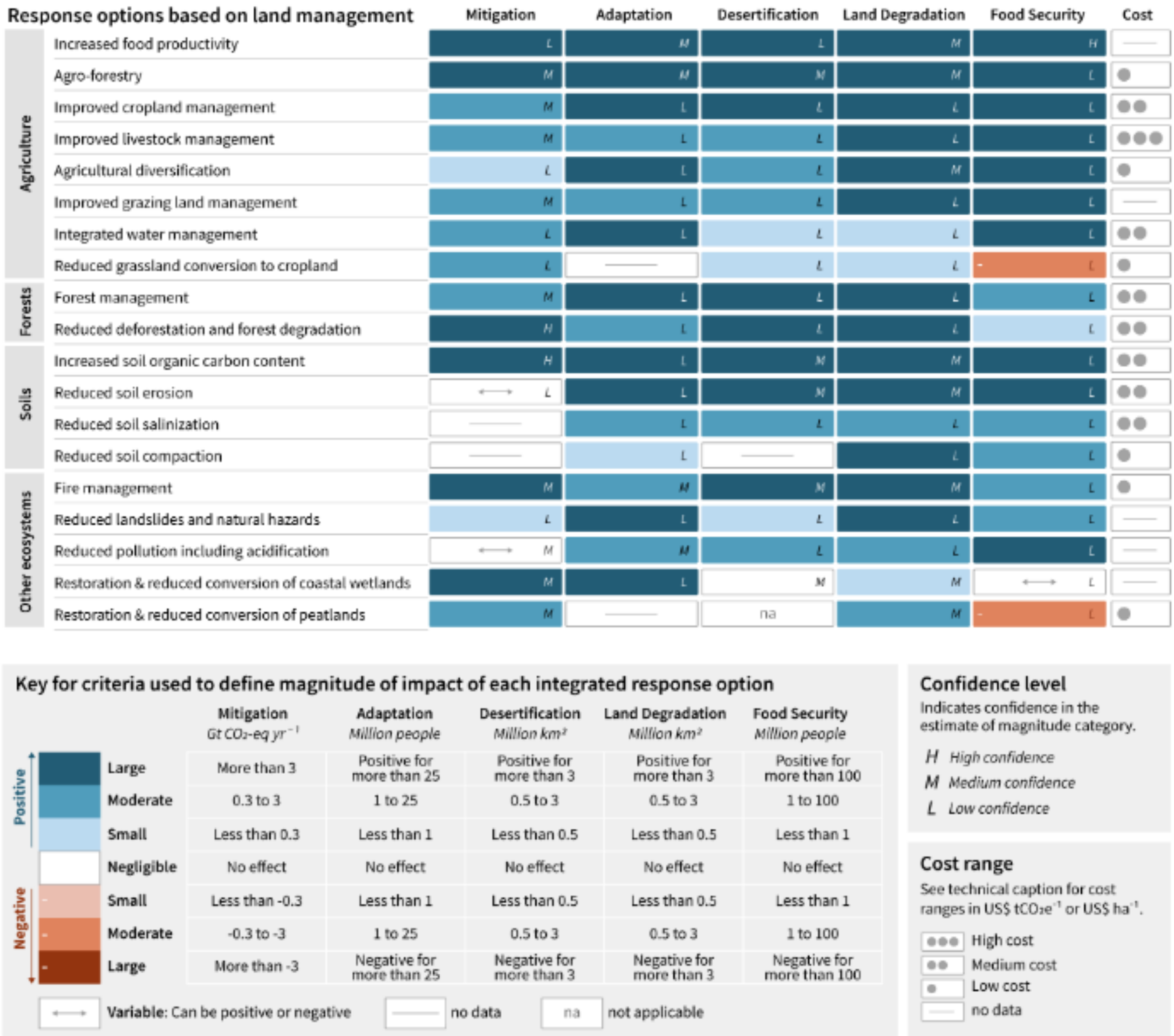


Figure 44: Land management response options and its potential global contribution to mitigation, adaptation, desertification, land degradation, and food security (*IPCC Special Report on Climate Change and Land (2019)*)

Only three response options had large positive impact across all five factors, which are defined as:

1. Mitigation: More than 3 Gt CO2-eq per year
2. Adaptation: Positive for more than 25 million people
3. Desertification: Positive for more than 3 million km2
4. Land degradation: Positive for more than 3 million km2
5. Food security: Positive for more than 100 million people

The three response options are agroforestry, increased soil organic carbon content, and increased food productivity. While each of these options are well worth exploring in more detail, they are focused on improving land by the hectare, which requires intensive skilled labour. These strategies are more suited for developed countries with low forest cover and a highly skilled workforce.

As a developing country with high forest cover, the priority for Malaysia should be to protect its remaining forests. However, economic pressures to convert forest to cropland (for example, oil palm plantations) continue to drive deforestation. A high-potential pathway to solve this situation is by accessing carbon markets, particularly international carbon markets, which have a far larger scale than a national one. This pathway will be explored in more detail in the next section.

The balanced net zero pathway for the sector

International carbon markets are the best bet to protect forests

The largest remaining rainforests are in developing countries, which face an economic cost to keep them intact

Global forests absorbed twice as much carbon dioxide as they emitted between 2001 and 2019, sequestering a net 7.6 billion metric tonnes of carbon dioxide annually. Tropical rainforests are more productive carbon sinks than temperate or boreal forests. The three largest tropical rainforests are the Amazon, Congo River Basin, and Borneo. However, due to deforestation, only the Congo rainforest remains a strong net carbon sink, sequestering a net 600 million metric tonnes of carbon dioxide annually (Harris & Gibbs, 2021).

World Bank data (sourced from FAO) over the past three decades shows decreasing forest cover in Brazil, Indonesia, Congo, and Malaysia – countries with abundant tropical rainforests. On the other hand, more developed Western countries such as the United States, Germany, France, Italy, and the United Kingdom have increasing forest cover. Nevertheless, the remaining forest cover remains much higher in the developing countries at 49-64% mentioned above compared to the developed ones, which stand at 13-34% (World Bank, 2020).

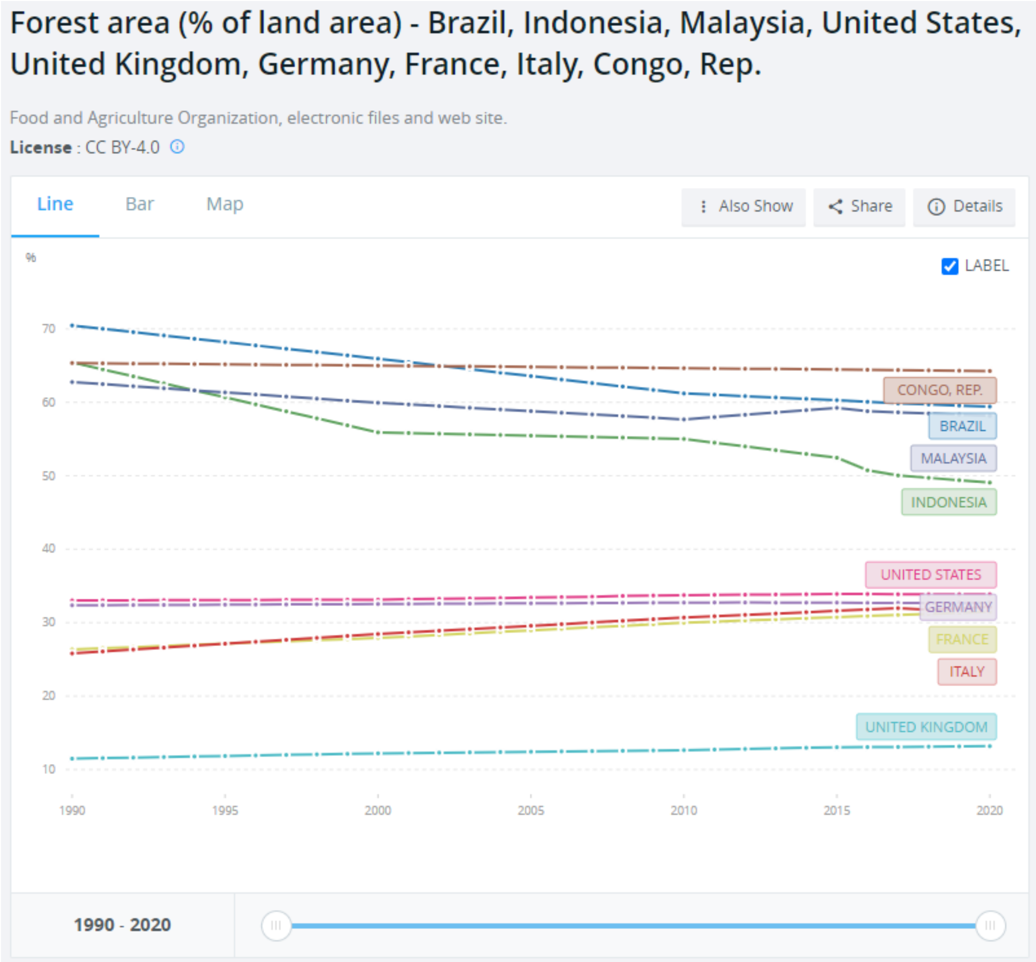


Figure 43: Forest area (% of land area) – Brazil, Indonesia, Malaysia, United States, United Kingdom, Germany, France, Italy, Congo, Rep. (1990 to 2020). (*World Bank / Food and Agriculture Organization (2020)*)

However, keeping forests intact comes at an economic opportunity cost for developing countries. In Malaysia, the economic net present value of forest land use is estimated at RM16,564 per hectare, even after accounting for commercial, social, and other environmental services.[40] However, the economic net present value of palm oil land use ranges from RM103,700 to RM141,200 per hectare, even after accounting for conversion, setup, and labour costs. (WWF & BCG, 2021). This represents an opportunity cost of RM87,136 to RM124,636 per hectare, or a total of RM1.6 trillion to RM2.3 trillion for the whole of Malaysia[41] – more than its annual Gross Domestic Product.

[40] Commercial value includes wood, fiber, and non-wood products sale value. Social value includes subsistence value to community e.g., food. Other environmental value includes soil and water system regulation and ability to absorb harmful particles.

[41] Using latest figure of 18,273,487 hectares of forest in Malaysia in 2018. Sourced from the Ministry of Energy and Natural Resources (updated 3 November 2020) at https://www.ketsa.gov.my/en-my/KetsaCore/Forestry/Pages/Total-Forested-Areas-in-Malaysia.aspx

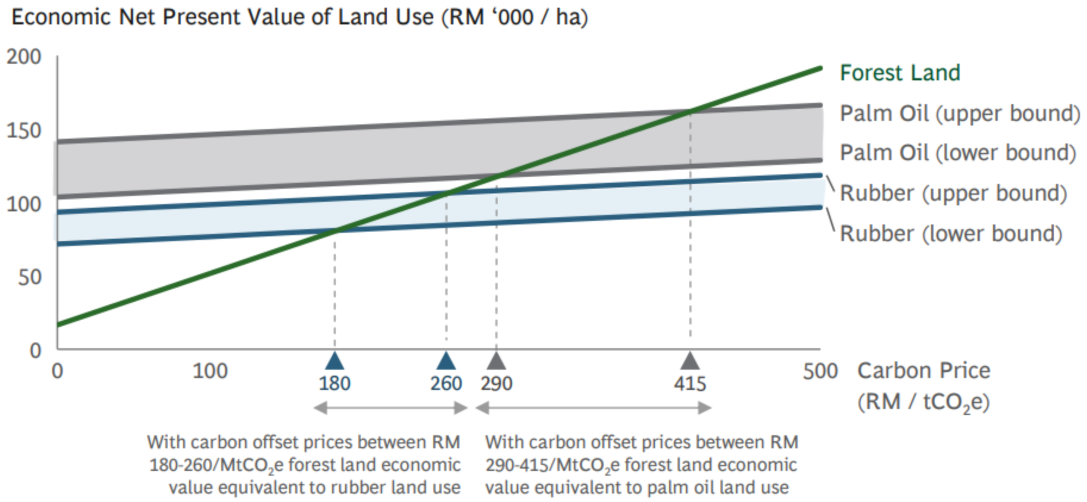


Figure 44: Economic Net Present value of land use in Malaysia (*WWF / BCG (2021), "Securing our future: Net zero pathways for Malaysia", pg. 51*)

These calculations do not include the value of carbon sequestration, which depends on a carbon price. The WWF / BCG report calculates a carbon offset price of RM290-415 per tonne of carbon dioxide equivalent (RM/tCO2) for the economic value of forest land to converge upon that of palm oil land. The current price of European Union (EU) Carbon Permits is 83.85 Euros, or RM373.03 at spot exchange rates[42] is squarely within the range in the report that is necessary to incentivize forest conservation in Malaysia. The EU carbon price is on the high side of carbon prices around the world, and comparable to the range of USD 40-80/tCO2 recommended by experts to meet the 2°C goal (World Bank, 2021).

International carbon markets can help protect the world's forests

Carbon prices differ widely around the world, ranging from less than USD1 in Poland and Ukraine, to USD137 in Sweden in 2021 (World Bank, 2021). There is a general correlation of more developed countries being able to afford higher carbon prices. From the perspective of a just transition, this is fair because developed countries tend to have much higher emissions per capita and hence should shoulder a larger responsibility in leading the way towards decarbonization. Additionally, developed countries have historically been responsible for the majority of global carbon emissions (Our World in Data, 2019).

[42] Retrieved 14th July 2022

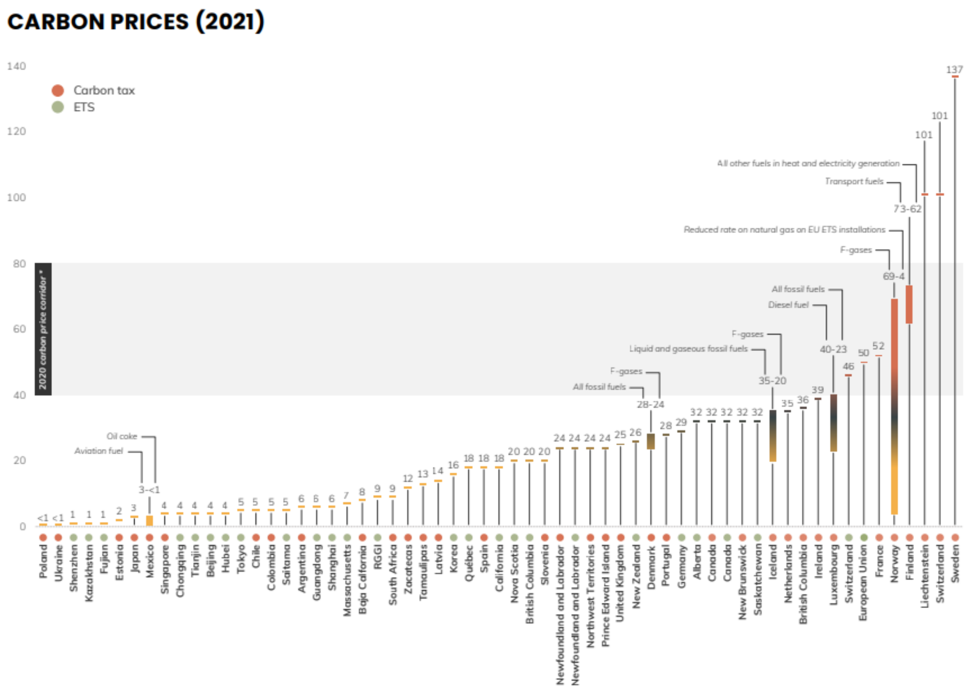


Figure 45: Carbon prices around the world (2021) (*World Bank (2021), "State and Trends of Carbon Pricing 2021", pg. 13*)

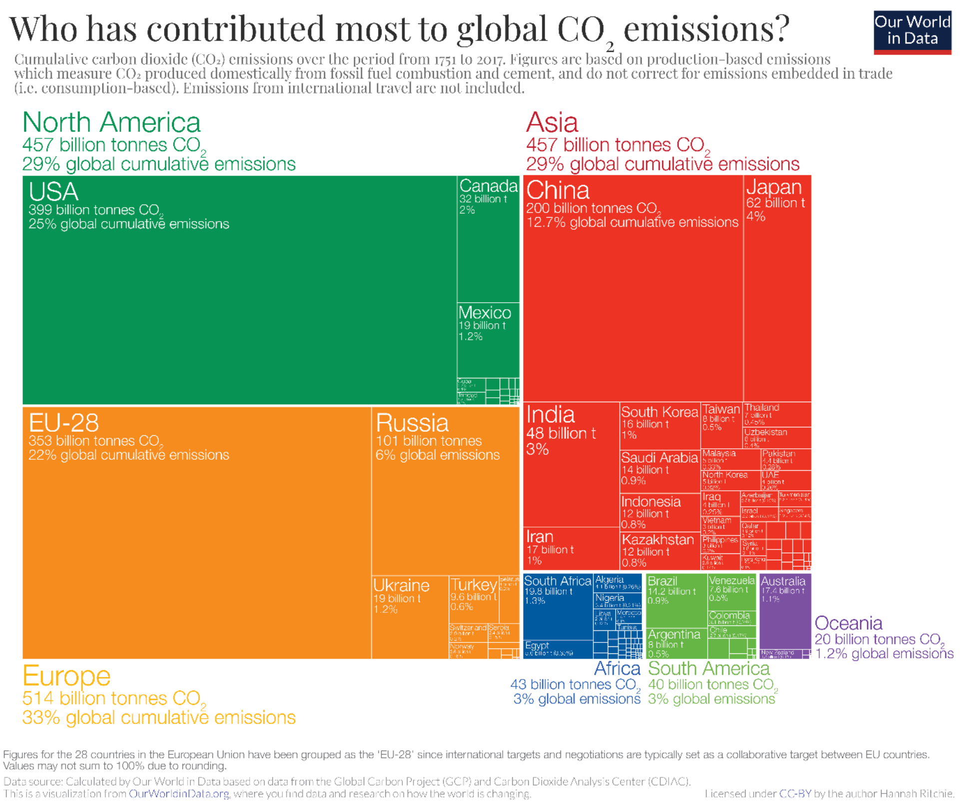


Figure 46: Cumulative carbon dioxide emissions by region (*Our World in Data (2019), "Who has contributed the most to global CO2 emissions?"[43]*)

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[43] Calculated by Our World in Data based on data from the Global Carbon Project (GCP) and Carbon Dioxide Analysis Center (CDIAC)

Developed countries made rapid economic progress fuelled by oil, coal, and deforestation during the Industrial Revolution, which allowed them to advance towards more service-based economies. It is unreasonable to expect developing countries to develop completely without these methods, unless proper financing and technology transfer is provided. Developed countries have fallen well short of their pledge to channel US$100 billion a year of climate financing to less wealthy nations by 2020, with some estimates going as low as US$20 billion, a fifth of what was promised (Nature, 2021).[44] Providing financing via international carbon markets is one way to right this wrong.

Over the long run, converging upon a global carbon price will smoothen carbon trading across borders. It is desirable for international carbon markets to compensate developing countries for keeping their forests intact at the expense of economic development, since these forests serve a crucial global role of absorbing carbon. Article 6 of the Paris Agreement outlines a robust framework for common accounting rules across borders, and was finally approved at the 26th Conference of Parties (COP26) in Glasgow in 2021.

International carbon deals face challenges which can be overcome

Indonesia and Norway enjoyed a decade-long cooperation in reducing emissions from deforestation and forest degradation (REDD), A UN-created mechanism targeting forest management in developing countries. In 2020, Indonesia received $56 million from Norway for preventing the emission of 11.23 million tonnes of carbon dioxide equivalent (CO2e) through reducing its rate of deforestation (Jong, 2020). Although the deal collapsed in 2021 due to disagreements over the size of the pay outs, it was revitalized in September 2022 after more negotiations between the two countries (AFP, 2022). A study calculated that Norway effectively paid just $1 per tonne of prevented carbon emissions, which is grossly inadequate to compete with potential palm oil revenue (Groom et al., 2021).

Similar projects in Cambodia, Peru, and Congo were also dogged by controversy, purportedly failing to involve local communities and deliver on promised benefits (Horton, 2021). Concerns of REDD typically includes difficulty in proving additionality, monitoring and verifying forest resources, navigation of intricate environmental agencies and laws in developing countries, and the participation of indigenous peoples.

Nevertheless, Indonesia has soldiered ahead with its carbon ambitions, inking a Memorandum of Understanding with Singapore in March 2022 to explore cooperation in carbon pricing and markets. It has also proceeded with a carbon tax and a carbon cap-and-trade system in late 2021, aiming for a fully-fledged domestic carbon market in 2025 (Suroyo & Munthe, 2021).

In Malaysia, Sabah has attempted to forge such a deal before, but it fell through due to a lack of transparency and questionable terms. The carbon deal aimed to sell credits from ecosystem services provided by 2 million hectares of Sabahan forest for the next 100 years, which is overly ambitious for a pilot project. Additionally, indigenous communities living on that land were not consulted (Cannon, 2022).

[44] The Organization for Economic Co-operation and Development's (OECD) estimate is $80 billion, although this is based on reports from the wealthy nations themselves. Oxfam adjusted this estimate downward by only counting benefits from loans below market rate, and excluding non-climate-related development aid

However, more recently, another carbon exchange deal has been successfully made after 10 years of deliberation, and covers 80,000 hectares of Sabah forest land. Some advance payment has been made by a UK-based partner of the state government, although no figures were disclosed. Meanwhile, Sabah has also formed an interim committee on climate change to develop carbon exchange regulation that regulates any carbon deals in the state (FMT, 2022).

Carbon exchange deals and mechanisms is a rapidly developing space and will continue refining over time. These can be accelerated with digital infrastructure using Monitoring, Reporting, and Verification (MRV) systems with GHG emissions and reductions data that are linked to national and international registries. Jordan is the first developing country to successfully build MRV and GHG registry systems to international standards. The software of its system is open source, with Palestine and Sri Lanka already replicating the system (World Bank, 2022).

Global demand for voluntary carbon credits could increase by a factor of 15 by 2030 and a factor of 100 by 2050, up to as much as 13 gigatons per year. While there is ample potential supply of carbon credits from all around the world, high-quality carbon credits are scarce due to challenges in accounting and verification methodologies (McKinsey, 2021). Therefore, any early movers into this space are likely to be rewarded with more stable, long term deals.

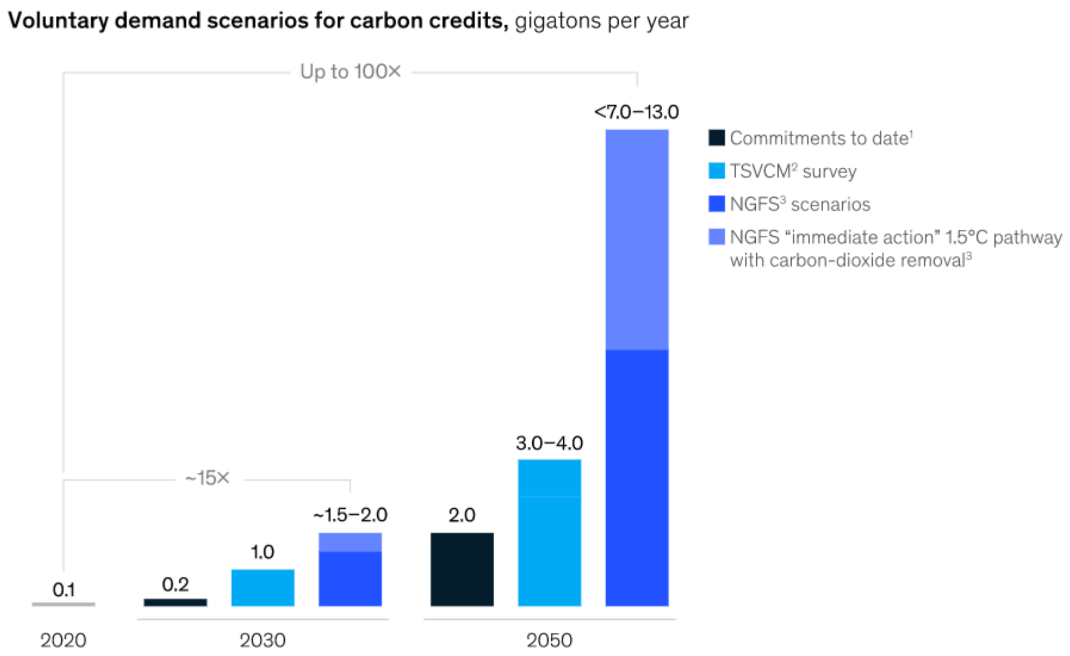

Figure 47: Voluntary demand scenarios for carbon credits (*McKinsey (2021), "A blueprint for scaling voluntary carbon markets to meet the climate challenge"*)

Malaysia's local carbon market is insufficient to protect its forests

Malaysia's existing economic instruments for climate policy are 'second-best instruments' which engender some environmental benefit without fully addressing market failures, with many seeking to boost growth in low-carbon sectors such as renewable energy and energy efficiency[45]. However, there has been a recent shift in focus towards 'first-best instruments' such as Carbon Pricing Instruments (CPIs), Ecological Fiscal Transfers (EFTs), and Payments for Ecosystem Services (PESs) (ISIS, 2022).

In September 2021, Malaysia announced its intention to launch a Domestic Emissions Trading Scheme (DETS), with an emphasis on avoiding double-counting (i.e., the same emissions reductions cannot be reported by two different entities). The DETS platform will be initially voluntary, and will be eventually harmonized with international carbon control mechanisms such as the Carbon Border Adjustment Mechanism (CBAM) by the EU (Hazim, 2021). Carbon credits sold on the DETS will be certified by Verra, a reputable standard setter, with the first batch of carbon credits targeted to be sold through auction by the end of 2022 (Tan, 2022).

Sunway Group is a Malaysian corporation that is an early adopter of carbon pricing. As part of their goal to reach net zero emissions by 2050, Sunway has set an internal carbon pricing mechanism at RM15 per tonne of carbon dioxide above a pre-defined threshold level for each of its business units. The carbon price will be readjusted progressively over time, and departmental bonuses are dependent upon meeting decarbonization targets (Bursa, 2022). Early movers into carbon pricing can make businesses more competitive globally as they are able to export into markets which set carbon tariffs.

EFTs are intergovernmental fiscal transfers where revenues are redistributed among different levels of government, such as from national to state. In Malaysia, the first EFT began in 2019 with a RM70 million allocation, which was then increased to RM100 million in 2021. While this is a good start, it is a far cry from the RM17.1 billion requested by Pahang to keep its forests intact, and dwarfed by the RM22 billion timber industry (Nambiar, 2022). The amount provided at the federal level for the whole country represents less than 1% of what is needed by just one state to protect its forests.

PESs are payments for environmental services (such as food production, water catchment and purification, and air quality regulation) to farmers or landowners for managing the land and sharing these benefits with other parties. While there have been efforts to set up PES systems in Sarawak, Perak, Penang, and Kedah, there is an ominous lack of reporting regarding their progress or success. It is possible for an EFT to also be a PES – for example, Kedah requested for RM100 million from the federal government to keep the Ulu Muda forest reserve as a water catchment area.

A notable PES case study was China's "Grain for Green" programme in 1999, which successfully converted 15 million hectares of farmland and 17 million hectares of barren mountainous wasteland back to vegetation by 2010 (Delang & Yuan, 2015). This reduced flooding and soil erosion, which was affecting the economy of the region, although it costed a whopping US$95 billion (Pacific Standard, 2017). Other successful case studies include Costa Rica's *Pagos por Servicios Ambientales*, and the United States Department of Agriculture's Conservation Reserve Program.

All of these instruments are well suited for protecting forests from the economic pressures of deforestation. EFTs in particular could be useful in Malaysia to rebalance the federal-state equilibrium, where states own forest land but the federal government

[45] Technological support instruments include the feed-in tariff, large-scale solar, and net energy metering. Financial instruments include the Green Technology Financing Scheme (GTFS), Green Investment Tax Allowance (GITA), and Green Investment Tax Exemption (GITE).

holds most of the funding. CPIs such as a national carbon trading scheme could offer incentives for local companies to pay forest owners and managers and offset their own carbon emissions, while safeguarding Malaysian economic competitiveness against international carbon tariffs such as the CBAM.

While these 'first-best instruments' hold much potential, effectiveness will largely depend on design and implementation. This includes prioritising climate goals over financial outcomes, as well as ending perverse incentives such as fossil fuel subsidies (ISIS, 2022). Furthermore, the implementation of EFTs will be greatly influenced by federal-state dynamics. In Malaysia, such a relationship is vulnerable to corruption whereby states held by the same governing coalition in parliament might be favoured at the expense of opposition-led states.

A larger obstacle stands in the fact that the Malaysian federal government is simply unable to afford funding such programmes. The national debt-to-GDP ratio has ballooned from 39.8% in 2008 to 63.8% in 2022[46], with 18.4% of the government's revenue spent to service the debt (The Star, 2022). Given the limited amount of funds available at the local and national level, it is more prudent to focus efforts on accessing larger-scale international carbon markets such as Indonesia's deals with Norway and Singapore.

The path forward: Prioritize accessing international carbon markets while continuing to develop local carbon pricing mechanisms

While the government should continue developing its nascent EFT and PES programmes, forming a national carbon market can have a larger impact as it can access the Malaysian corporate sector, whose national income is almost 10 times of fiscal revenue.[47] Furthermore, being able to freely trade carbon credits is an efficient way to price carbon with minimal market distortions, and is less vulnerable to corruption compared to programmes whereby specific beneficiaries have to be chosen.

When developing a national carbon trading scheme, it is prudent to start small, and then gradually expand and refine over time. The EU's Emissions Trading System (ETS), one of the world's most developed and sophisticated carbon schemes, was implemented in stages. Its first phase from January 2005 to December 2007 was "learning by doing", with subsequent phases gradually expanding in scope to cover more sectors and greenhouse gases. A clear plan from the government will make it easier for stakeholders to be involved with minimal disruption to the economy. Therefore, this paper makes the following recommendations in setting up a Malaysian carbon market:

1. Use a gradual step-up approach with clear milestones on specific dates that stakeholders can plan and prepare for:
    a. Start with a Voluntary Carbon Market (VCM) before transitioning towards a Compliance Carbon Market (CCM) which is mandatory
    b. Start with the main greenhouse gases of carbon dioxide and methane before expanding to include other greenhouse gases
    c. Start with key emitting sectors before expanding to include other sectors
    d. Start with a lower carbon price before increasing it gradually (through control of credit supply) to minimize the price gap against international

[46] As of June 2022

[47] Malaysia's tax-to-GDP ratio is 10.9% in 2020, falling from 19.8% in 1997. Retrieved from World Bank database https://data.worldbank.org/indicator/GC.TAX.TOTL.GD.ZS?locations=MY

carbon tariff mechanisms such as the CBAM and improve export competitiveness of Malaysian producers;

2. Consult with various stakeholders at each step of the process, including representatives from the corporate and non-profit sectors, various levels of government, and academia;
3. Engage with other countries which have successfully implemented carbon trading schemes such as the UK, China, and Indonesia, to learn best practices and avoid the same mistakes;
4. Partner with a reputable verifier of carbon credits to maintain high quality of credits in the system; and
5. Explore the possibility of linking the carbon trading system with other similar systems around the world, such as the linking of the EU and Swiss ETS

One advantage of a carbon trading scheme over EFTs and PESs is that it can be revenue generating if permits were auctioned (instead of being allocated freely). Since the trading platform itself is not too expensive to create, such a system can be easily self-funded, and even raise additional funds which can be used to fund other low-carbon technologies, or subsidize vulnerable segments of society from any potential increase in power prices.

A domestic carbon trading scheme in Malaysia will take at least a few years to achieve scale that is able to generate significant impact. It is also unclear if Malaysian corporations will be willing to invest large amounts of money into reducing their emissions without government regulation that forces or incentivizes them to do so. However, some places like the EU and the UK have clear net zero targets written into their Constitution. Entities based there will be seeking carbon offsets from around the world. The Norway-Indonesia and Sabah-UK[48] deals mentioned in this paper are examples of such arrangements. The capital for these deals is already readily available and the contract can be set up relatively quickly.

The magnitude of funding is also much larger since it accesses global capital and not just domestic. Global carbon markets were worth USD 270 billion (RM1,216 billion) in 2020 (MSCI, 2022) – over two thirds of the Malaysian GDP. A fully-fledged Malaysian emissions trading system could capture RM673 million, which is about 0.2% of Malaysian GDP.[49] Malaysia's Ecological Fiscal Transfer in 2021 from the federal to state government was RM100 million. The diagram below compares the potential magnitude (in millions of RM) of the various financing mechanisms discussed in this paper:

[48] UK-based partner of the state government

[49] The EU's Emissions Trading System generated USD 37 billion of revenue in 2021, which is 0.2% of EU's GDP of USD17.9 trillion.

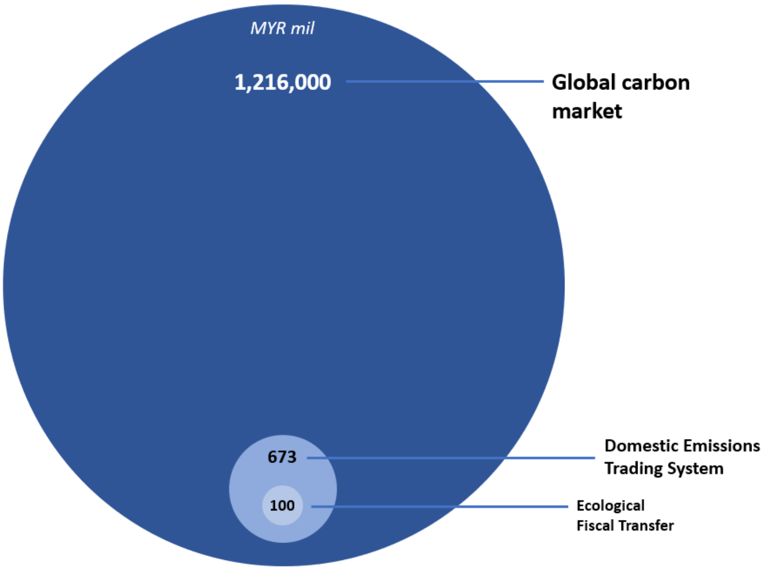

Figure 48: Potential magnitude of financing mechanisms to protect Malaysian forests[50]
(*MSCI (2022), Nambiar (2022), Author's calculations*)

Given the much larger relative size of the global carbon market, its potential to protect Malaysia's forests is also more significant. Therefore, efforts to pursue this strategy should be increased. Governing principles and frameworks from Article 6 of the Paris Agreement and REDD+ can be used in negotiations. Various deal precedents have been set and mentioned in this paper, which can be referred to by the Malaysian government. The Ministry of Finance's sophisticated machinery can be utilized in the valuation and execution of such a deal.[51]

Malaysia lags behind its Southeast Asian neighbours when it comes to carbon credit issuances (McKinsey, 2022). Therefore, there is much room to further develop its carbon markets. The engagement of Verra as an independent carbon credit verifier for its nascent DETS is key to ensure the quality of its carbon credits. Once internationally recognized, these credits can be sold on the global carbon market to firms or governments looking to offset their emissions.

It would be advisable to formulate distinct strategies when going global with carbon credits, depending on the type of entity being targeted. Government-to-government deals will require existing cordial relations, tactful diplomacy, and clear terms to avoid falling through. Government-to-business deals can be done through global voluntary carbon markets. Regardless of who the buyer is, careful planning, reporting, and verifying is key to success.

[50] Circle area is illustrative and not drawn to scale.
[51] The Ministry of Finance (Incorporated) controls much of the Malaysian economy. One of its subsidiaries includes Khazanah Nasional Berhad, Malaysia's sovereign wealth fund. Khazanah's objectives are (1) to grow financial assets and diversify revenue sources for the nation, and (2) hold strategic assets which bring long-term economic benefits – both of which would fit perfectly with an international carbon deal.

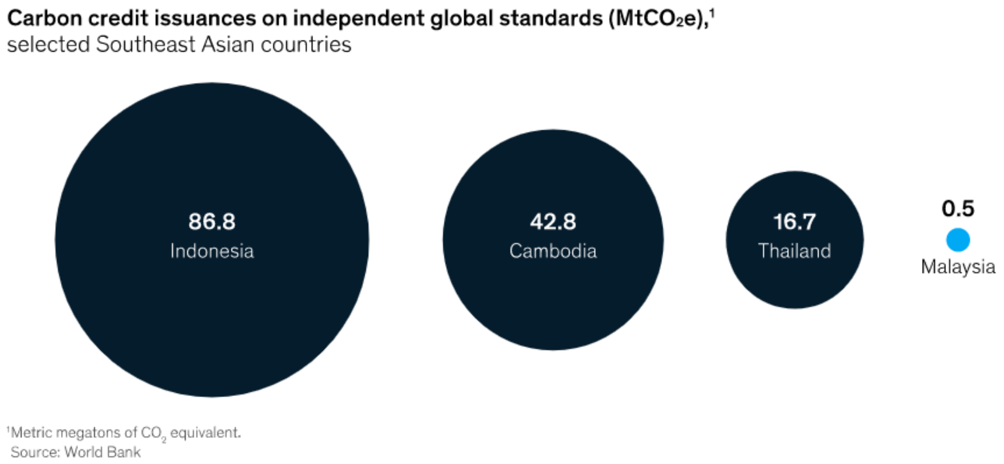

Figure 49: Carbon credit issuances on independent global standards (MtCO2e), selected Southeast Asian countries (*McKinsey (2022), "How carbon markets can help Malaysia achieve its climate targets"*)

Timeline to end state

Below is a suggested timeline for the various mechanisms discussed in this paper:

Table 43: Suggested Timeline

Mechanism	2022 – 2024	2025 – 2030	2031 – 2050
International carbon markets *(First priority)*	• Draft internal carbon deal framework[52] • Determine eligible forests for carbon offset schemes[53] • Begin certification process with an internationally recognized standard	• Initiate diplomatic talks with target countries for government-to-government deals[54] • Placement of verified Malaysian carbon offsets on global VCMs	• Post-deal monitoring to ensure criteria are met and payouts are fairly received • Ideally, all Malaysian forests that can be certified are protected under a carbon credit scheme[55]
DETS *(Second priority)*	• Trading platform is open to all and running smoothly • Approval and certification process by internationally recognized standard (e.g. Verra) is established • Plan for transition towards compliance market	• Transition towards compliance market • Start with a few key sectors and GHGs[56] • Early signals and communication to corporates and other stakeholders to minimize market disruption • EU's CBAM import tariff starts in 2026	• Gradually expand scope to cover more sectors and GHGs • Gradually increase carbon prices (e.g. by reducing supply of credits in a cap-and-trade programme) to narrow gap with higher carbon prices in more developed carbon markets[57]
EFT and PES *(Third priority)*	• Continue EFT payouts from the federal to state governments, in accordance to fiscal budgetary constraints • Develop PES framework by quantifying various ecosystem services		

[52] Who gets paid (e.g. landowners vs land managers)? What protocols are in place to ensure indigenous communities are not displaced? Who are the target buyers and what are the strategies to attract them?
[53] Satisfies carbon standards criteria such as additionality, permanence, and exclusive claims.
[54] Malaysia can learn much from its ASEAN neighbors Indonesia, Cambodia, and Thailand, which have issued much more carbon credit than Malaysia.
[55] Permanent Reserve Forests (PRFs) might not be certified as it might not meet the additionality requirement.
[56] This paper recommends starting with CO2 and methane emissions, before expanding to include other GHGs.
[57] Narrowing the gap with global carbon prices will mitigate carbon tariffs that will be implemented against importers from countries with a low carbon price.

3. Moving Forward

This interim report captures the understanding and insights achieved by the ASEAN Green Future – Malaysia (AGF-MY) team in 2022. Moving forward, sectoral models will be built, and integrated assessment modelling done for the entire economy.

	Further Sectoral Work
Electricity generation	Based on the sectoral understanding developed thus far, conduct "what if" analyzes of the cost of decarbonization and the appropriate role of new technologies. Use a power system planning model suited for designing and studying future power systems that have large shares of RE, storage and/or demand response to optimize investment decisions for renewable and conventional generation, battery or hydrogen storage, hydro and other assets. Identify the least-cost system design to meet policy goals such as carbon or renewable energy targets while maintaining a reliable supply of power.
Surface transport	Detail the studies of energy efficient vehicles (EEVs) and quantify the GHG reduction in adopting such scheme. Restructure the data collection of vehicle registrations, disposal, kilometre travelled and emissions by Road Transport Department. Create a holistic monitoring mechanism of all mode of public transportation and their emissions.
Marine transport	Analysis is complete for phase 2. Moving from nearly zero CO_2 emissions to net zero requires a 100% renewable energy mix by 2050. Decarbonization can be accelerated, and ambition can be raised beyond the climate goals by adopting relevant and timely coordinated international policy measures. Stakeholders must establish strategic partnerships and develop new business models in energy-intensive industries, as well as power suppliers and the petrochemical sector 1. The decarbonization of international marine transportation needs to be fuelled by investment in an efficient, safe, reliable and affordable supply of renewable fuels for the shipping sector via sector coupling mechanisms among bunkering service companies, port authorities, utilities and the renewable energy sector. 2. It is critical to devote efforts to develop least-cost renewable power plants for the production of green H_2 -based fuel, understand the disaggregation of such costs and propose sustainable configurations that enable the production of powerfuels at competitive costs for the maritime shipping sector.

	3. It is critical to enable a level playing field by establishing a realistic carbon levy. Each fuel must have a carbon price that may be adjustable over time as the market becomes more favourable towards renewable fuels. Taking early action will not only foster the deployment of renewable fuels but also prevent investments in fossil fuel infrastructure that risk becoming stranded. 4. Fully map out and engage stakeholders associated with the marine transport sector, and ensure they are working towards the establishment of strategic partnerships and common goals. 5. Seek synergies and enhance international collaboration among all stakeholders involved in the field of powerfuels: marine transport, aviation and energy-intensive industries (e.g. cements, iron and steel), as well as power suppliers and the petrochemical sector. 6. Promote strict local regulations to limit airborne emissions at ports and inland waterways and make shore power systems (cold-Ironing) at ports compulsory wherever available. 7. Establish a mandate comprising the progressive increase of renewable fuels within bunkering fuel blends. Start immediately with advanced liquid biofuels and biomethane and follow with the implementation of effective incentives to encourage vessel fleets to shift to green H_2-based fuels 8. Enable affordable lines of credit and introduce incentives to foster the development of carbon-zero new vessels and financing of retrofits in existing vessels. 9. Allocate national resources to support the identification of geographical areas with high renewable energy potential and devote significant efforts to understanding the production costs of renewable powerfuels in the short and long term. 10. Marine transport/shipping decarbonization won't happen without new skills. The push for decarbonization will be much harder unless we look more forensically at the challenges to be solved at organization level and recruit the skills to solve them. Old attitudes are unhelpful. Decarbonizing the marine transportation industry will only happen if we decarbonize the entire value chain. Quantifying the cost of different decarbonization pathways is necessary to make better investment decisions and it surely needs political support.
Manufacturing	Analysis is complete for phase 2. Advocate for the key recommendations which are: a. For the near term: i. For the iron and steel industry: No more new blast furnace capacity beyond what have already been approved, use Electric Arc Furnaces to recycle scrap steel and reduce demand by

	improving material usage efficiency ii. For the cement industry: Increase clinker substitution with fly ash and reduce demand by improving material usage efficiency b. For the long term: Activate the Technology Mechanism and enhance subsidized funding for developing countries under the Paris Agreement framework, to enable the scale-up of near-zero emission technologies for the hard to abate iron and steel, and cement industries
Fuel supply	Further examine the impact of financial instruments and regulatory measures that can affect the viability of decarbonization in the sector (e.g. carbon financing). If possible, estimate the cost difference under different financial and regulatory environments.
Agriculture	Based on the selected measures that drive decarbonization or recarbonization, generate a carbon abatement pathway for agriculture Develop an understanding of the following in Malaysia: - Efficiency of fertilizer use - Practice of soil testing before fertilizer application - Efficiency measures that could be introduced to reduce the use of fertilizer Alongside soil approaches, explore opportunity to bring increased vegetation into farmed landscapes Develop an understanding of how to place regenerative agriculture techniques in a Malaysia and Southeast Asia context
Forestry	Quantify other LULUCF levers (i.e. agroforestry, organic soils, and food productivity) Reach out to forestry departments for feedback and to discuss policy ideas Finish the LULUCF sector decarbonization pathways model

References

Adnan N, Nordin S, Rahman I, 2017, “A market modeling review study on predicting Malaysian consumer behavior towards widespread adoption of PHEV/EV”, Environ Sci Pollut Res, Heidelberg.

AFP (2022). “Indonesia, Norway ink deal to reward rainforest protection”. Retrieved 29 September 2022. https://www.france24.com/en/live-news/20220912-indonesia-norway-ink-deal-to-reward-rainforest-protection

Anderson, Jared, and James Bambino. 2021. Miscalculated levelized cost of electricity data has overvalued power plants: study. March 15. https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/electric-power/031521-miscalculated-levelized-cost-of-electricity-data-has-overvalued-power-plants-study#:~:text=Coal%3A%20By%202030%2C%20corrected%20LCOE,estimate%20of%204.1%20cent.

AP. 2022. Russia’s Energy Clout Is Not Just From Oil And Gas, It’s A Key Nuclear Supplier. March 20. https://www.outlookindia.com/international/russia-s-energy-clout-is-not-just-from-oil-and-gas-it-s-a-key-nuclear-supplier-news-187729.

AQPER. 2022. How much energy is there in biogas? https://www.aqper.com/en/how-much-energy-is-there-in-biogas#:~:text=Each%20cubic%20meter%20of%20biogas,and%20applied%20to%20other%20uses.

ASEAN Secretariat 2019, “ASEAN Fuel Economy Roadmap for the Transport Sector 2018-2025: with Focus on Light-Duty Vehicles”, ASEAN, Indonesia.

Atmo, Gigih Udi, Takashi Otsuki, and Eri Nurcahyanto. 2022. "Modelling low carbon electricity generation of an." IOP Conference Series: Earth and Environmental Science 997 (012011).

Axelson, Matilda, Isobel Robson, Tomas Gilberte Wyns, and Gauri Amarsinh Khandekar. "Breaking through-industrial low-CO2 technologies on the Horizon." 2018.

Azreen, Hani. 2022. TNB to retire selected coal plants earlier than scheduled. August 2. https://themalaysianreserve.com/2022/08/02/tnb-to-retire-selected-coal-plants-earlier-than-scheduled/.

Battle, Thomas, Urvashi Srivastava, John Kopfle, Robert Hunter, and James McClelland. "The direct reduction of iron." In Treatise on process metallurgy, pp. 89-176. Elsevier, 2014.

BCG-WWF. “Securing our future: Net zero pathways for Malaysia”, 2021.

BEIS and Ofgem. 2021. Transitioning to a Net Zero Energy System: Smart Systems and Flexibility Plan 2021. Department for Business, Energy and Industrial Strategy; Office of Gas and Electricity Markets.

Bernama. 2022. TNB expects Green Electricity Tariff quota to increase in 2023. September 28. Accessed October 1, 2022. https://www.theedgemarkets.com/article/tnb-expects-green-electricity-tariff-quota-increase-2023.

Bioenergy Insight. 2020. FGV opens biogas plant at Malaysian palm oil mill. October 29. https://www.bioenergy-news.com/news/fgv-opens-biogas-plant-at-malaysian-palm-oil-mill/.

Bloomberg NEF. 2020. Hydrogen Economy Outlook. Bloomberg New Energy Finance. https://data.bloomberglp.com/professional/sites/24/BNEF-Hydrogen-Economy-Outlook-Key-Messages-30-Mar-2020.pdf.

Borneo Post. 2014. Palm Oil Mills' Biogas Capture Implementation In Sarawak A Major Challenge - Soppoa. Prod. Borneo Post Online. November 5. http://www.theborneopost.com/2014/11/05/palm-oil-mills-biogas-capture-implementation-in-sarawak-a-major-challenge-soppoa/#ixzz3IFYpFjwM.

Briggs, H & Hau, L, M2016, "Malaysia Stocktaking Report on Sustainable Transport and Climate Change: Date, Policy and Monitoring", GIZ, Kuala Lumpur.

Brinkmann Consultancy. 2009. Greenhouse Gas Emissions from Palm Oil Production: Literature review and proposals from the RSPO Working Group on Greenhouse Gases. Hoevelaken, The Netherlands: Brinkmann Consultancy.

Bursa (2022). "The Case of Sunway: Getting to Net Zero by 2050". Retrieved 5 September 2022. https://bursasustain.bursamalaysia.com/droplet-details/sustainability/speaking-to-sunway-getting-to-net-zero-by-2050-20-jan

Cahill, Danita. 2020. The Care and Feeding of Soil Microbes. July 16. Accessed October 23, 2021. https://organicfarmermag.com/2020/07/the-care-and-feeding-of-soil-microbes/.

Cannon (2022). John Cannon, "NGOs alert U.N. to furtive 2-million-hectare carbon deal in Malaysian Borneo". Retrieved from Mongabay 30 August 2022. https://news.mongabay.com/2022/03/ngos-alert-u-n-to-furtive-2-million-hectare-carbon-deal-in-malaysian-borneo/

Carbon Tracker. 2021. "Do Not Revive Coal: Planned Asia coal plants a danger to Paris." https://carbontracker.org/reports/do-not-revive-coal/.

Carbon Trust and Imperial College London. 2021. "Flexibility in Great Britain." 106. https://www.carbontrust.com/resources/flexibility-in-great-britain.

Carbon Trust. n.d. "Briefing: Flexible energy systems." Accessed August 19, 2022. https://www.carbontrust.com/resources/briefing-flexible-energy-systems.

Cardoso, João, Valter Silva, Jos´e Antonio Mayoral Chavando, Daniela Eusebio, and Matthew J. Hall. 2022. "Numerical modelling of the coal phase-out through ammonia and biomass co-firing in a pilot-scale fluidized bed reactor." Fuel Communications (Elsevier Ltd.) 10 (100055).

Carrington, Damian. 2017. 'Death spiral': half of Europe's coal plants are losing money. December 8. Accessed October 2, 2022. https://www.theguardian.com/environment/2017/dec/08/death-spiral-half-of-europes-coal-plants-are-losing-money.

CCC. 2018. Biomass in a low-carbon economy. Committee on Climate Change.

Channel News Asia (CAN). "Once in 100 years' flood: 7 killed and more than 50,000 displaced in Malaysia", 20 Dec 2021. Available at https://www.channelnewsasia.com/asia/malaysia-flood-deaths-selangor-pahang-over-people-displaced-2390856 (Accessed on 2 July 2022).

Chelvi, S.Tamarai. 2022. Can We Save the Soil? The Sun Daily. April 27. https://www.thesundaily.my/style-life/can-we-save-the-soil-DX9132621.

Chu, Mei Mei. 2022. Malaysian palm oil board sees 2022 production at 19 mln tonnes. Reuters. January 12. https://www.nasdaq.com/articles/malaysian-palm-oil-board-sees-2022-production-at-19-mln-tonnes.

Collins, Leigh. 2021. 'Green hydrogen will be cost-competitive with grey H2 by 2030 — without a carbon price'. April 27. https://www.rechargenews.com/energy-transition/green-hydrogen-will-be-cost-competitive-with-grey-h2-by-2030-without-a-carbon-price/2-1-1001867.

Conca, James. 2019. Can Vanadium Flow Batteries beat Li-ion for utility-scale storage? September 4. https://energypost.eu/can-vanadium-flow-batteries-beat-li-ion-for-utility-scale-storage/.

Dalton, David. 2020. Generation IV / Economic Modelling Compares Costs Of SMR To Conventional PWR. October 15. https://www.nucnet.org/news/economic-modelling-compares-costs-of-smr-to-conventional-pwr-10-4-2020.

Dan Rutherford, X M (2020). Limiting engine power to reduce CO2 emissions from existing ships. ICCT.

Daud, Farrah & Ponrahono, Zakiah & Aziz, Fatiah & Amir, Syakir & Sahrir, Syazwani Y2021. "A Framework of the Energy-Efficient Vehicle Initiative and its Implementation in a Developed Country: the case of Malaysia", Malaysian Journal of Social Sciences and Humanities (MJSSH), 6. 297-312, 10.47405/mjssh.v6i3.715.

Day, Paul. 2021. New nuclear, LTO among cheapest low carbon options, report shows. January 21. https://www.reutersevents.com/nuclear/new-nuclear-lto-among-cheapest-low-carbon-options-report-shows.

Delang and Yuan (2015). Claudio O. Delang, Zhen Yuan. “China’s Grain for Green Program: A Review of the Largest Ecological Restoration and Rural Development Program in the World”.

DNV-GL. 2018. Consultation Serivces On Renewable Energy Penetration Study for Peninsular Malaysia and Sabah: Final Report for Peninsular Malaysia. DNV GL Clean Technology Centre.

EIA. 2021. “Country Analysis Executive Summary: Malaysia.” 2021. https://www.eia.gov/international/analysis/country/MYS.

Energy Commission 2020, “Malaysia Energy Statistics Handbook 2020”, Putrajaya.

Energy Commission, Malaysia. 2020. “Malaysia Energy Statistics Handbook 2020.” https://www.st.gov.my/en/contents/files/download/116/Malaysia_Energy_Statistics_Handbook_20201.pdf.

Energy Commission. 2019. Sabah Electricity Supply Industry Outlook 2019. Putrajaya: Energy Commission.

Energy Commission. 2021. "REPORT ON PENINSULAR MALAYSIA GENERATION DEVELOPMENT PLAN 2020 (2021 – 2039)."

ENTSO-E. 2019. PowerFacts Europe 2019. ENTSO-E. https://docstore.entsoe.eu/Documents/Publications/ENTSO-E%20general%20publications/ENTSO-E_PowerFacts_2019.pdf.

Erbach G., Monitoring, reporting and verification of CO2 emissions from maritime transport, EPRS, European Parliament, October 2020.

ERIA. 2007. "Investigation on sustainable biomass utilization vision in East Asia: life cycle assessment for biomass derived fuel in Malaysia." ERIA Joint Research Project Series 2007.

Estimated from Car Manufacturer Data – An Improved Method”, World Research & Innovation Convention on Engineering & Technology.

European Biogas Association. 2021. European Biogas Association Statistical Report 2021. European Biogas Association.

European Biogas Association. 2022. ¬A way out of the EU gas price crisis with biomethane. February 17. https://www.europeanbiogas.eu/a-way-out-of-the-eu-gas-price-crisis-with-biomethane/.

European Biogas Association. n.d. Record-breaking year for biomethane production – shows EBA/GIE Biomethane Map 2021. https://www.europeanbiogas.eu/record-breaking-year-for-biomethane-production-shows-eba-gie-biomethane-map-2021/#:~:text=Today%2C%20Europe%20has%20around%2020%2C000,of%20biogas%20and%20biomethane%20plants).

European Commission. n.d. Carbon Farming. Accessed August 12, 2022. https://ec.europa.eu/clima/eu-action/forests-and-agriculture/sustainable-carbon-cycles/carbon-farming_en#:~:text=The%20study%20concluded%20that%20result,experience%20to%20upscale%20carbon%20farming.

Faber, J., Hanayama, S., Zhang, S., Pereda, P., Comer, B., Hauerhof, E., Schim van der Loeff, W., Smith, T., Zhang, Y., Kosaka, H., Adachi, M., Bonello, J.-M., Galbraith, C., Gong, Z., Hirata, K., Hummels, D., Kleijn, A., Lee, D., Liu, Y., ... Yuan, H. (2020). Fourth IMO greenhouse gas study. International Maritime Organization. https://docs.imo.org/

Fan, Andrew, Yuen Yoong Leong, and Wing Thye Woo. 2022. "Some Observations on Mitigating Climate Change From Malaysia's Experience." Asian Economic Papers (MIT Press).

Fan, Zhiyuan, and S. Julio Friedmann. "Low-carbon production of iron and steel: Technology options, economic assessment, and policy." Joule 5, no. 4, 2021.

FAO (2021). Land use statistics and indicators statistics. Global, regional and country trends 1990 - 2019. FAOSTAT Analytical Brief Series No 28. Rome. Retrieved 14 July 2022. https://www.fao.org/3/cb6033en/cb6033en.pdf

Farezza, Hanum Rashi. 2021. "TNB's Future-Proof Grid Enables Reliable Power Supply." The Malaysian Reserve, November 26. https://themalaysianreserve.com/2021/11/26/tnbs-future-proof-grid-ensures-reliable-power-supply/#:~:text=WITH%20access%20to%20over%2025%2C000,electricity%20grid%20across%20the%20peninsula.

Fertilizers Europe. 2019. Carbon Footprinting in Fertilizer Production. https://www.fertilizerseurope.com/initiatives/carbon-footprint-calculator/.

FMT (2022). FMT Reporters, "Sabah to have carbon exchange laws within a year". Retrieved from Free Malaysia Today 2 September 2022. https://www.freemalaysiatoday.com/category/nation/2022/08/15/sabah-to-have-carbon-exchange-laws-within-a-year/

Forest Department Sarawak (2020). "Forest cover in Sarawak is 62% in 2020". Retrieved 23 June 2022. https://forestry.sarawak.gov.my/page-0-461-1170-FACTS-FIGURES.html

Fortune Business Insight. 2022. "Market Research Report: Electrolyzer Market." https://www.fortunebusinessinsights.com/electrolyzer-market-103919.

Free Malaysia Today (2021). "Tuan Ibrahim denies Washington Post report of false carbon claim". Retrieved 4 July 2022. https://www.freemalaysiatoday.com/category/nation/2021/11/09/tuan-ibrahim-denies-washington-post-report-of-false-carbon-claim/

Free Malaysia Today 2022, “One-third of 33mil registered vehicles ‘dormant’”, viewed 6 August 2022, https://www.freemalaysiatoday.com/category/nation/2022/06/14/one-third-of-33mil-registered-vehicles-dormant/

Fujita, Haruhiro, Katsuyukil Chaisomphob, Taweep Nakano, and Erliza Hambali. 2019. "Greenhouse Gas Emission of Electricity Generation and Field Abandonment Scenarios Using Empty Fruit Bunches at a Palm Oil Mill, Surat Thani Province, Thailand." Journal of the Japan Institute of Energy 119-123.

Gasch, Caley, and Jodi DeJong-Hughes. 2019. "Soil Organic Matter Does Matter." NDSU Extension (North Dakota State University). https://www.ndsu.edu/agriculture/sites/default/files/2022-08/sf1942.pdf.

GE. 2018. GE's HA turbine recognized for powering world's most efficient power plants in both 50 Hz and 60 Hz segments. March 27. Accessed August 22, 2022. https://www.ge.com/gas-power/resources/articles/2018/nishi-nagoya-efficiency-record.

Georgeff, E., Mao, X., & Comer, B. (2019). A whale of a problem? Heavy fuel oil, exhaust gas cleaning systems, and British Columbia’s resident killer whales. Retrieved from the International Council on Clean Transportation, https://theicct.org/publications/hfo-killer-whale-habitat

Gewin, Virginia. 2020. "How Peat Could Protect the Planet?" Nature. https://www.nature.com/articles/d41586-020-00355-3.

Global Fuel Economy Initiative (GFEI) 2016, “Estimating the fuel efficiency technology potential of heavy-duty trucks in major markets around the world”, GFEI, London.

Global Maritime Forum (GMF). 2020a. Global Maritime Issues Monitor 2020. Available at: https://www.maritimeissues.org/

Global Maritime Forum (GMF). 2021. Five percent zero emission fuels by 2030 needed for Paris-aligned shipping decarbonization. Getting to Zero Coalition Insight Series. Available at: https://www.globalmaritimeforum.org/content/2021/03/Getting-to-Zero-Coalition_Five-percent-zero-emission-fuelsby-2030.pdf

Gomes, Ieda. 2020. "The dilemma of gas importing and exporting countries." OIES Paper, The Oxford Institute for Energy Studies. Accessed July 3, 2022. https://www.oxfordenergy.org/wpcms/wp-content/uploads/2020/08/The-dilemma-of-gas-importing-and-exporting-countries-NG-161.pdf.

Greg, Ruth. 2022. "Peer review comments."

Groom et al. (2021). “Carbon emissions reductions from Indonesia’s moratorium on forest concessions are cost-effective yet contribute little to Paris pledges”. https://cdn.roxhillmedia.com/production/email/attachment/900001_910000/9269cfdc94fa0766f65f948232191cbd9667147a.pdf

Halim, Ronald A., Lucie Kirstein, Olaf Merk, and Luis M. Martinez. 2018. "Decarbonization Pathways for International Maritime Transport: A Model-Based Policy Impact Assessment" Sustainability 10, no. 7: 2243. https://doi.org/10.3390/su10072243

Harris & Gibbs (2021). Forests absorb twice as much carbon as they emit each year. Retrieved from World Resources Institute 14 July 2022. https://www.wri.org/insights/forests-absorb-twice-much-carbon-they-emit-each-year#:~:text=Using%20this%20more%20granular%20information,tonnes%20of%20CO2%20per%20year.

Hazim (2021). Anis Hazim, "Govt agrees for Voluntary Carbon Markets development. Retrieved from The Malaysian Reserve 21 July 2022. https://themalaysianreserve.com/2021/09/20/govt-agrees-for-voluntary-carbon-markets-development/

Hennig, Erhard. n.d. Humus: What is it and how is it formed? Accessed August 17, 2022. https://www.ecofarmingdaily.com/build-soil/humus/humus-how-is-it-formed/.

Hirschmann, R. 2021. Yield of fresh fruit bunches in Malaysia 2011-2020. Statista. August 31. https://www.statista.com/statistics/1093093/malaysia-yield-of-fresh-fruit-bunches/#:~:text=In%202020%2C%20the%20average%20yield,material%20for%20palm%20oil%20mills.

Hoo, Rachel, Leow Foon Lee, and Melissa Low. 2020. "Producing Biogas from Palm Oil Mill Effluent in Southeast Asia—the Green Elephant in the Room?" Policy brief, Energy Studies Institute. Accessed July 17, 2022. https://esi.nus.edu.sg/docs/default-source/esi-policy-briefs/producing-biogas-from-palm-oil-mill-effluent-in-southeast-asia.pdf?sfvrsn=8c0fc404_2.

Horton (2021). Ben Anthony Horton, "Why has Indonesia ended a multi-million euro forest protection deal with Norway?". Retrived from Euronews Green 19 July 2022. https://www.euronews.com/green/2021/10/13/why-has-indonesia-ended-a-multi-million-euro-forest-protection-deal-with-norway

Howard, P.J.A, and D.M. Howard. 1990. "Use of organic carbon and loss-on-ignition to estimate soil organic matter in different soil types and horizons." Biology and Fertility of Soils 9: 306-310.

Hutt, Ben. 2021. The battle for baseload is over – what are the options for peaking capacity? June 4. Accessed September 2022, 30. https://www.ampcapital.com/au/en/insights-hub/articles/2021/june/the-battle-for-baseload-is-over-what-are-the-options-for-peaking-capacity.

IEA (2021), "Fuel Consumption of Cars and Vans", IEA, Paris, viewed 10 July 2022, https://www.iea.org/reports/fuel-consumption-of-cars-and-vans

IEA (2022), Global Energy Review: CO2 Emissions in 2021, IEA, Paris

IEA, "Material efficiency in energy transitions", 2019.

IEA. 2019. The Role of Gas in Today's Energy Transition. IEA.

IEA. 2020. Projected Costs of Generating Electricity 2020. INternational Energy Agency. https://www.iea.org/reports/projected-costs-of-generating-electricity-2020.

IEA; NEA; OECD. 2020. "Project Costs of Generating Electricity." International Energy Agency; Nuclear Energy Agency. https://iea.blob.core.windows.net/assets/ae17da3d-e8a5-4163-a3ec-2e6fb0b5677d/Projected-Costs-of-Generating-Electricity-2020.pdf.

IMO (2018), “Initial IMO Strategy on Reduction of GHG Emissions from Ships”, Adopted on 13 April 2018, https://unfccc.int/sites/default/files/resource/250_IMO%20submission_Talanoa%20Dialogue_April%202018.pdf.

IMO (2018), Initial IMO Strategy on reduction of GHG emissions from ships

IMO (2020), Energy Efficiency Measures, International Maritime Organization, London Available https://www.imo.org/en/OurWork/Environment/Pages/Technical-andOperational-Measures.aspx

IMO (2020), Fourth IMO GHG Study. International Maritime Organization, London Available: https://safety4sea.com/wp-content/uploads/2020/08/MEPC-75-7-15-Fourth-IMO-GHGStudy-2020-Final-report-Secretariat.pdf

INOUE, KEI, SHOHEI DOMEN, TOMO KAWAKAMI, KENJI MIYAMOTO, ISSEI TAMURA, and SATOSHI TANIMURA. 2018. "Development of Hydrogen and Natural Gas Co-firing Gas Turbine." Mitsubishi Heavy Industries Technical Review 55 (2).

Intan, Farhana Zainul. 2021. PetGas to gain from power sector transformation. October 9. Accessed October 3, 2022. https://www.thestar.com.my/business/business-news/2021/10/09/petgas-to-gain-from-power-sector-transformation.

Intergovernmental Panel on Climate Change (IPCC). “Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change”, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2022.

Intergovernmental Panel on Climate Change (IPCC). “Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change”, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2021.

International Advisory Panel on Maritime Decarbonization. (IAP). (2021). Decarbonization Pathways for the Global Maritime Industry: Recommendations for Action and Collaboration. Singapore Maritime Foundation. https://www.smf.com.sg/wp-content/uploads/2021/04/IAPReport_Decarbonization-Pathways-for-the-Global-Maritime-Industry.pdf

International Council on Clean Transportation (2017), Greenhouse Gas Emissions from Global Shipping, 2013 - 2015, International Council on Clean Transportation, Washington DC

International Council on Clean Transportation (ICCT). 2019. Silent but deadly: The case of shipping emissions - International Council on Clean Transportation (theicct.org)

International Energy Agency. 2022. "Methane Tracker Database, IEA, Paris." https://www.iea.org/data-and-statistics/data-product/methane-tracker-database-2022.

International Maritime Organization (IMO). 2020. Report of fuel oil consumption data submitted to the IMO Ship Fuel Oil Consumption Database in GISIS (Reporting year: 2019). MEPC 76/6/1. Retrieved from https://docs.imo.org.

Inus, Kristy. 2022. SESB aims to increase renewable energy generation to 40% from the present 15%. August 17. Accessed September 26, 2022. https://www.thestar.com.my/news/nation/2022/08/17/sesb-aims-to-increase-renewable-energy-generation-to-40-from-the-present-15.

IPCC (2019). Summary for Policymakers. In: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems; Table SPM.1.

IPCC. 2022. Climate Change 2022: Mitigation of Climate Change. Intergovernmental Panel on Climate Change.

IRENA (2021), A pathway to decarbonize the shipping sector by 2050, International Renewable Energy Agency, Abu Dhabi

IRENA. 2020. Green Hydrogen Cost Reduction: Scaling up Electrolysers to Meet the 1.5ºC Climate Goal. Abu Dhabi: International Renewable Energy Agency.

ISIS (2022). Institute of Strategic and International Studies. "Strengthening Economic Instruments for Climate Policymaking in Malaysia".

ITF (2018), "Decarbonizing Maritime Transport: Pathways to zero-carbon shipping by 2035", International Transport Forum Policy Papers, No. 47, OECD Publishing, Paris, https://doi.org/10.1787/b1a7632c-en

Jain, Sarika. 2019. World Biogas Association Malaysia Report. London, March.

Jamaluddin, N, Sim, Ho, Johari N, Jamil, H, Roslan, A, Allyana, S 2020, "Vehicle Kilometre Travelled (VKT) Study of Goods Vehicles: Pusat Pemeriksaan Kenderaan Berkomputer Sendirian Berhad (PUSPAKOM)", MRR No. 359, Malaysian Institute of Road Safety Research.

Jasper Faber, Anne Kleijn, Diederik Jaspers, Delft, CE Delft, August 2020, Publication code: 20.190191E.091http://CE_Delft_190191E_Comparison_of_CO2_emissions_of_MARPOL_Annex_VI_compliance_options_in_2020_FINAL.pdf

Jawatankuasa Perancangan dan Pelaksanaan Pembekalan Elektrik dan Tarif (JPPPET), "Malaysia: Peninsular Malaysia Generation Development Plan (2021-2039)", 2021.

Jean-Paul Rodrigue (2020), New York: Routledge, 456 pages. ISBN 978-0-367-36463-2. https://www.taylorfrancis.com/books/mono/10.4324/9780429346323/geography-transport-systems-jean-paul-rodrigue

Jean-Paul Rodrigue and Dr. Theo Notteboom, The Geography of Transport System. https://transportgeography.org/contents/chapter5/intermodal-transportation-containerization/world-container-throughput/

Jong (2020). Hans Nicholas Jong, "Indonesia to receive $56m payment from Norway for reducing deforestation". Retrieved from Mongabay 19 July 2022. https://news.mongabay.com/2020/05/indonesia-norway-redd-payment-deforestation-carbon-emission-climate-change/

Joshi, D. 2018. "Electric Vehicles in Malaysia? Hold Your Horsepower!". Penang Institute: Kuala Lumpur, Malaysia.

JSTRA & MLIT, Roadmap to Zero Emission from International Shipping, March 2020.

Kamar, Nor Aini Bt Kamarul Zaman. 2010. Sabah Palm Oil Mills Can Produce 120MW Of Renewable Energy. Bernama. https://bepi.mpob.gov.my/news/detail.php?id=6604.

Kaur D 2021, "Malaysia To Have 1,000 EV Charging Stations By 2025", viewed 9 August 2022, https://greenfiscalpolicy.org/malaysia-to-have-1000-ev-charging-stations-by-2025/

Khiabani, Pegah Hashemvand, and Wataru Takeuchi. 2020. "Assessment of oil palm yield and biophysical suitability in Indonesia and Malaysia." International Jounral of Remote Sensing 41 (22).

Knoema. n.d. Accessed August 13, 2022. https://knoema.com/.

Kulim (Malaysia) Berhad. 2016. Carbon Footprint Report. Johor Bahru: Kulim (Malaysia) Berhad.

Kumagai, Takeo. 2021. Japan's JERA to procure 40,000 mt ammonia for 20% co-burning with coal by 2024-25. May 24. https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/petrochemicals/052421-japans-jera-to-procure-40000-mt-ammonia-for-20-co-burning-with-coal-by-2024-25.

Kumar, M, and J Stern. 2020. Gas Industry Reform and the Evolution of a Competitive Gas Market in Malaysia. Oxford Institute for Energy Studies.

Larbodière, L., J. Davies, R. Schmidt, C. Magero, Vidal, A. Arroyo Schnell, P. Bucher, et al. 2020. Common ground: restoring land health for sustainable agriculture. Gland, Switzerland: IUCN.

Law (2020). Law Yao-Hua, “Forest loss: under whose watch?” Retrieved from Macaranga 23 June 2022. https://www.macaranga.org/forest-loss-under-whose-watch/

Lee J, Chong C, Gitano H 2010, “Analysis of Motorcycle Fuel Consumption in Malaysia”, 2010-32-0048, SAE International, Japan.

Lee, Andrew. 2021. 'Our largest energy source': South Korea plans 40 foreign hydrogen bases to meet vast future demand. December 1. https://www.rechargenews.com/energy-transition/our-largest-energy-source-south-korea-plans-40-foreign-hydrogen-bases-to-meet-vast-future-demand/2-1-1110526.

Li, Kang Siew. 2022. TNB, Petronas, IHI achieve success in Malaysia's first ammonia co-combustion test for coal power generation. August 7. https://www.theedgemarkets.com/article/tnb-petronas-ihi-achieve-success-malaysias-first-ammonia-cocombustion-test-coal-power.

Liew, Justin, and Yuen Yoong Leong. 2022. "Is Sarawak’s Ambitious Green Hydrogen Plans Possible to Achieve?" The Edge Malaysia, July 23. https://www.theedgemarkets.com/article/my-say-sarawaks-green-hydrogen-plans-will-take-some-doing.

Lord, S., M.K. Hoare, and N.M. Thompson. 2002. "Composting for zero discharge_NBPOL’s solution." International Oil Palm Conference and Exhibition, Bali,. Bali.

LR and UMAS (2019), Zero-Emission Vessels: Transition Pathways, Lloyd’s Register and University Maritime Advisory Services, https://www.lr.org/en/insights/global-marine-trends-2030/zero-emission-vessels-transition-pathways/ (accessed 15 October 2020)

Mackenzie, Wood. 2022. “Ammonia Co-Firing in Thermal Power Plants Could Be Worth US$100 Billion in 2050.” May 18, 2022. https://www.woodmac.com/press-releases/ammonia-co-firing-in-thermal-power-plants-could-be-worth-us$100-billion-in-2050/.

Mahadin A & Mustafa M 2018, “Utilizing Fuel Cell Technology for Dubai Roads and

Majaski, Christina. 2022. General Agreement on Tariffs and Trade (GATT). September 6. Accessed September 16, 2022. https://www.investopedia.com/terms/g/gatt.asp#:~:text=The%20General%20Agreement%20on%20Tariffs%20and%20Trade%20(GATT)%20was%20signed,to%20make%20international%20trade%20easier.

Malaysia Industrial Development Authority 2021, “Malaysia aims 31% RE capacity by 2025”, viewed 30 June 2022, https://www.mida.gov.my/mida-news/malaysia-aims-31-re-capacity-by-2025/

Malaysian Gas Association. 2022. Natural Gas Market Liberalization: What's Next for Malaysia. February 22. https://www.tnb.com.my/assets/newsclip/08022022a.pdf.

Malaysian Gas Association. n.d. What is Natural Gas. Malaysian Gas Association. https://malaysiangas.com/naturalgas/.

McKinsey (2021). “A blueprint for scaling voluntary carbon markets to meet the climate challenge”. Retrieved 2 September 2022. https://www.mckinsey.com/business-functions/sustainability/our-insights/a-blueprint-for-scaling-voluntary-carbon-markets-to-meet-the-climate-challenge

McKinsey (2022). “How carbon markets can help Malaysia achieve its climate targets”. Retrieved 29 September 2022. https://www.mckinsey.com/capabilities/sustainability/our-insights/how-carbon-markets-can-help-malaysia-achieve-its-climate-targets

Melayong, Galau, and Sylvester Fong. 2016. "Sustainable Oil Palm Planting on Peat Soils in Sarawak." 15th Internatinoal Peat Congress.

Meza, Edgar. 2022. Rising gas prices make green hydrogen cheaper than grey hydrogen. https://www.cleanenergywire.org/news/rising-gas-prices-make-green-hydrogen-cheaper-gray-hydrogen.

MIGHT. 2020. Malaysia Biomass Industry Action Plan 2020: Driving SMEs Towards Sustainable Future. Cyberjaya: Malaysia Industry-Government Group for High Technology.

Ministry Of Energy, Science, Technology, Environment and Climate Change. 2018. “Malaysia Third National Communication and Second Biennial Update Report to the UNFCCC.” https://unfccc.int/sites/default/files/resource/Malaysia%20NC3%20BUR2_final%20high%20res.pdf.

Ministry of Environment and Water 2020, “Malaysia Third Biennial Update Report to the UNFCCC”, Putrajaya.

Ministry of Environment and Water 2021, “Low Carbon Mobility Blueprint 2021-2030”, Putrajaya.

Ministry of Environment and Water, “Malaysia: Third biennial update report to the UNFCCC”, 2020.

Ministry of Environment and Water. 2020. Malaysia Third Biennial Update Report to the UNFCCC. Ministry of Environment and Water, Putrajaya: Ministry of Environment and Water.

Ministry of International Trade and Industry 2020, “National Automotive Policy 2020”, Putrajaya.

Ministry of Transport 2019, “National Transport Policy 2019-2030”, Putrajaya.

Miwil, Olivia. 2022. Sabah to set up own Energy Commission, acquire SESB. August 25. https://www.nst.com.my/news/nation/2022/08/825667/sabah-set-own-energy-commission-acquire-sesb.

MLIT (2020), Roadmap to Zero Emission from International Shipping, Shipping Zero Emission Project, Ministry of Land, Infrastructure, Transport and Tourism, Tokyo, Japan

Mojiol, Andy Russel Immit. 2006. "Ecological Landuse Planning and Sustainable Management of Urban and Sub-urban Green Areas in Kota Kinabalu, Malaysia." Ph. D. dissertation, Faculty of Forest Science and Forest Ecology, Georg-August-Univeristy of Gottingen, Gottingen.

Monsod, Toby. 2022. "Comments."

MPOB. 2022. Economics and Industry Development Division. https://bepi.mpob.gov.my/index.php/en/production/production-2021/production-of-crude-oil-palm-2021.

MPOB. 2022. FFB YIELD & CRUDE PALM OIL YIELD OF OIL PALM ESTATES 2021. https://bepi.mpob.gov.my/index.php/en/yield/yield-2021/yield-2021.

MPOC. 2022. Malaysian Palm Oil Industry. Accessed September 14, 2022. https://mpoc.org.my/malaysian-palm-oil-industry/.

MSCI (2022). “Introducing the Carbon Market Age”. Retrieved 7 September 2022. https://www.msci.com/www/blog-posts/introducing-the-carbon-market/03227158119

Myhre, Gunnar, Drew Shindell, François-Marie Bréon, William Collins, Jan Fuglestvedt, Jianping Huang, Dorothy Koch, et al. 2013. “Anthropogenic and Natural Radiative Forc- Ing. In: Climate Change 2013: The Physical Science Basis.” Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, 82.

n.d. Meteonorm. https://meteonorm.com/en/.

Nambiar (2022). Predeep Nambiar, “RM100mil not enough to gazette more forests, marine areas, say activists”. Retrieved from Free Malaysia Today 21 July 2022. https://www.freemalaysiatoday.com/category/nation/2022/04/28/rm100mil-not-enough-to-gazette-more-forests-marine-areas-say-activists/

National Geospatial-Intelligence Agency. (2019). World Port Index Pub. 150 (No. 27). https://msi.nga.mil/Publications/WPI

National Renewable Energy Laboratory. 2016. India Solar Resource (map).

Nikander, S. 2008. "Greenhouse gas and energy intensity of product chain: case transport biofuel." MSc thesis, Helsinki University of Technology, Helsinki, Finland.

Nuclear Energy Agency. 2020. "Unlocking Reductions in the Construction Costs of Nuclear: A Practical Guide for Stakeholders." https://www.oecd-nea.org/jcms/pl_30653/unlocking-reductions-in-the-construction-costs-of-nuclear?details=true.

OEC. 2022. Palm Oil in Malaysia. Observatory of Economic Complexity . Accessed September 14, 2022. https://oec.world/en/profile/bilateral-product/palm-oil/reporter/mys.

OEC. 2022. Rice in Malaysia. Observatory of Economic Complexity. Accessed September 14, 2022. https://oec.world/en/profile/bilateral-product/rice/reporter/mys.

OEC. 2022. Rubber in Malaysia. Observatory of Economic Complexity. Accessed September 14, 2022. https://oec.world/en/profile/bilateral-product/rubber/reporter/mys?redirect=true.

OEC. n.d. Observatory of Economic Complexity (OEC). Accessed July 1, 2022. https://oec.world/en/profile/bilateral-product/natural-gas-liquefied/reporter/mys.

OECD, “Climate finance provided and mobilized by developed countries: Aggregate trends updated with 2019 data”, 2021.

Ontl, Todd A., and Lisa A. Schulte. 2012. "Soil Carbon Storage." Nature Education Knowledge 3(10):35 3 (10: 35). https://www.nature.com/scitable/knowledge/library/soil-carbon-storage-84223790/.

Onyia, Christie Oby, Joseph C Akunna, Ab Kadir Mohd Omar, A M Uyu, and Nik Norulaini. 2001. "Increasing the fertilizer value of palm oil mill sludge: Bioaugmentation in nitrification." Water Science & Technology 44 (10): 157-62. doi:10.2166/wst.2001.0608.

Our World in Data (2019). “Who has contributed the most to global CO2 emissions?”. Retrieved 30 August 2022. https://ourworldindata.org/contributed-most-global-co2

Pacific Standard (2017). “Mother Nature’s Sum”. Retrieved 30 August 2022. https://psmag.com/economics/mother-nature-s-sum-4226

Paramaselvam, Parameswary. 2022. Malaysia needs agriculture soil revitalization policy. June 20. Accessed August 15, 2022. https://www.malaysiakini.com/letters/625340.

Pavlenko, N., Comer, B., Zhou, Y., Clark, N., & Rutherford, D. (2020). The climate implications of using LNG as a marine fuel. Retrieved from the International Council on Clean Transportation, https://theicct.org/publications/climate-impacts-LNG-marine-fuel-2020

PETRONAS. 2021. “PETRONAS, Key ASEAN Energy Players To Intensify Collaboration In Addressing Methane Emissions.” PETRONAS Global. October 27, 2021. https://www.petronas.com/media/press-release/petronas-key-asean-energy-players-intensify-collaboration-addressing-methane.

PETRONAS. 2021a. “Our Sustainability Agenda: Integrated Report 2021.” https://www.petronas.com/integrated-report-2021/files/PETRONAS-PIR2021-Our-Sustainability-Agenda.pdf.

PETRONAS. 2021b. “PETRONAS Activity Outlook 2022-2024.” https://www.petronas.com/integrated-report-2021/files/PETRONAS-Activity-Outlook-2022-2024.pdf.

Platts, Michael James, and Yuen Yoong Leong. 2020. "Soil Fertility Is a Productive Capital Asset." Agricultural Sciences 744-776. https://www.scirp.org/journal/as.

Platts, Michael James, and Yuen Yoong Leong. 2022. Decarbonizing Technical Systems and Re-carbonizing Ecosystems and Southeast Asia. The Edge Markets. The Edge, September.

Popov, Julian. 2021. Natural Gas is not a transitional fuel, so let’s stop saying it is. December 6. https://www.euractiv.com/section/energy-environment/opinion/natural-gas-is-not-a-transitional-fuel-so-lets-stop-saying-it-is/.

Pritish Bhattacharya, and Francis Hutchinson. 2022. “2022/21 ‘Malaysia’s Oil and Gas Sector: Constant Expectations despite Diminishing Returns’ by Pritish Bhattacharya and Francis E. Hutchinson.” ISEAS-Yusof Ishak Institute. March 2, 2022. https://www.iseas.edu.sg/articles-commentaries/iseas-perspective/2022-21-malaysias-oil-and-gas-sector-constant-expectations-despite-diminishing-returns-by-pritish-bhattacharya-and-francis-e-hutchinson/.

Putra, Nur Azha, and Philip Andrews-Speed. 2018. Prospects for Nuclear Power in ASEAN. June 28. https://thediplomat.com/2018/06/prospects-for-nuclear-power-in-asean/.

Qiu, Jiahui, and Yee Yang Ryan Wong. 2022. Understanding and Reducing Methane Emissions in Southeast Asia. Singapore: ISEAS-Yusof Ishak Institute.

Reed, Ed. 2021. Ammonia: the missing link in the energy transition? Energy Voice. Accessed June 11, 2022. https://www.energyvoice.com/renewables-energy-transition/341719/ammonia-hydrogen-power-shipping/#:~:text=Blue%20ammonia%20costs%20around%20%24250,or%20whichever%20hydrocarbon%20is%20used.

Reuters 2022, “Malaysia aims to fully implement B20 biodiesel mandate by year-end”, viewed 30 June 2022, https://www.reuters.com/business/energy/malaysia-aims-fully-implement-b20-biodiesel-mandate-by-year-end-2022-01-05/

Rissman, Jeffrey, Chris Bataille, Eric Masanet, Nate Aden, William R. Morrow III, Nan Zhou, Neal Elliott et al. "Technologies and policies to decarbonize global industry: Review and assessment of mitigation drivers through 2070." Applied Energy 266, 2020.

RSPO. 2017. The challenges of growing oil palm on peatlands. https://rspo.org/news-and-events/news/the-challenges-of-growing-oil-palm-on-peatlands.

Rutherford, D., & Miller, J. (2019, March 22). Silent but deadly: The case of shipping emissions. ICCT Staff Blog. https://theicct.org/blog/staff/silent-deadly-case-shipping-emissions

Sabah Forest Policy (2018). Retrieved 23 June 2022. http://www.forest.sabah.gov.my/publications/sabah-forest-policy-2018.html

Sahidan, Ainul Shazwin, Ali Zuhusni Ali Nordin, Kamalrudin Mohamed Salleh, Amran Ariffin, and Rahmawati Rasuddin. 2021. FACTORS AFFECTING FRESH FRUIT BUNCH YIELDS OF INDEPENDENT SMALLHOLDERS IN SABAH. September 30. http://opiej.mpob.gov.my/factors-affecting-fresh-fruit-bunch-yields-of-independent-smallholders-in-sabah/#:~:text=The%20yield%20of%20oil%20palm,tonnes%20per%20hectare%20per%20year.

Sarawak Forest Policy (2019). Retrieved 23 June 2022. https://forestry.sarawak.gov.my/page-0-416-1105-Forest-Policy-Of-Sarawak-1954.html

Schlissel, , David, and Dennis Wamsted. 2022. "NuScale’s Small Modular Reactor: Risks of Rising Costs, Likely Delays, and Increasing Competition Cast Doubt on Long Running Development Effort." Institute of Energy Economics and Financial Analysis. https://ieefa.org/wp-content/uploads/2022/02/NuScales-Small-Modular-Reactor_February-2022.pdf.

Schuchardt, F., D. Darnoko, and P. Guritno. 2022. "Composting of empty oil palm fruit bunch (EFB) with simultaneous evaporation of oil mill waste water (POME)." International Oil Palm Conference. Nusa Dua, Bali.

Schuchardt, F., Wulfer, K., D. Darnoko, and T. Herawan. 2008. "Effect of new palm oil mill processes on the EFB and POME utilization." Journal of Oil Palm Research (Special Issue).

Searchinger, Timothy, Ralph Heimlich, R. A. Houghton, Fengxia Dong, Amani Elobeid, Jacinto Fabiosa, Simla Tokgoz, Dermot Hayes, and Tun-Hsiang Yu. 2008. "Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land-Use Change." Science 319 (5867): 1238-1240. doi:DOI: 10.1126/science.1151861.

SEDA Malaysia. 2021. Malaysia Renewable Energy Roadmap: Pathways Towards Low Carbon Energy System. Putrajaya: SUSTAINABLE ENERGY DEVELOPMENT AUTHORITY (SEDA) MALAYSIA.

SEDA. 2022. CO2 Avoidance. https://www.seda.gov.my/statistics-monitoring/co2-avoidance/.

SG H2 Energy. n.d. Technology. Accessed October 4, 2022. https://www.sgh2energy.com/technology/#techheader.

Shabadin A, Megat N, Jamil H 2014, “Car Annual Vehicle Kilometer Travelled

Shabadin, A, Hamidun, R, Allyana, S, Roslan, A, Harun, N, Sarani, R, Ishak, S, Voon, W 2017, “Vehicle Kilometre Travelled Validation Study”, MRR No. 222, Malaysian Institute of Road Safety Research.

Sim, Ho, Roslan, A, Jamaluddin, N, Allyana, S 2020, “Development of a VKT Index for Commercial Vehicles”, MRR No. 369, Malaysian Institute of Road Safety Research.

Siti, Norasyiqin Abdul Latif, Meng Soon Chiong, Srithar Rajoo, , Asako Takada, and Yoon-Young Chun. 2021. "The Trend and Status of Energy Resources and Greenhouse Gas Emissions in the Malaysia Power Generation Mix." Energies 14. Accessed October 9, 2022. doi:https://doi.org/10.3390/en14082200.

Smith, T. et al. (2015), Third IMO GHG Study 2014, International Maritime Organization, London, http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Documents/Third%20 Greenhouse%20Gas%20Study/GHG3%20Executive%20Summary%20and%20Report.pdf

Smoot, Grace. n.d. What Is the Carbon Footprint of Nuclear Power? A Life-Cycle Assessment. https://impactful.ninja/the-carbon-footprint-of-nuclear-power/#:~:text=Per%20kWh%20produced%2C%20nuclear%20power,and%20has%20various%20environmental%20implications.

SMR Nuclear Technology. 2017. SMR Safety. Accessed July 1, 2022. https://www.smrnuclear.com.au/technology-2/smr-safety-2/.

SSAB, 2022. Available at: https://www.ssab.com/en/company/sustainability/sustainable-operations/hybrit-phases (Accessed on 2 July 2022).

Standaert, Michael. 2022. China readies for post-2025 green hydrogen boom. May 9. https://www.energymonitor.ai/tech/hydrogen/china-readies-for-post-2025-green-hydrogen-boom#:~:text=The%20goals%20set%20out%20in,wind%2Dpowered%20electrolysis%20of%20water.

Stocks, Matthew, Reza Fazeli, Llewelyn Hughes, and Fiona J. . Beck. 2021. "Global Emissions Implications from Co-combusting Ammonia in Coal Fired Power Stations: An Analysis of the Japan-Australia Supply Chain." Journal of Cleaner Production. doi:https://doi.org/10.1016/j.jclepro.2021.130092.

Suroyo & Munthe (2021). Gayatri Suroyo & Bernadette Christina Munthe, “Indonesia introduces carbon trading policy to reduce emission”. Retrieved from Reuters 19 July 2022. https://www.reuters.com/business/cop/indonesia-introduces-carbon-trading-policy-reduce-emission-2021-11-15/

Sylvia, D.M.,, J.J. Fuhrmann, P.G. Hartel, and D.A. Zuberer. 2005. Principles and Applications of Soil Microbiology. Pearson.

Tallat-Kelpšaitė, Jurga. 2017. Connection to the grid (Biogas). October 1. Accessed October 1, 2022. http://www.res-legal.eu/search-by-country/lithuania/single/s/res-hc/t/gridaccess/aid/connection-to-the-grid-biogas/lastp/159/.

Tamura, M, , T Gotou, H Ishii, and Riechelmann, D. 2020. "Experimental investigation of ammonia combustion in a bench scale 1.2 MW-thermal pulverized coal firing furnace." Applied Energy. doi:https://doi.org/10.1016/j.apenergy.2020.115580.

Tan (2022). “Carbon: Setting up the first carbon market in Malaysia”. Retrieved 29 September 2022. https://www.theedgemarkets.com/article/carbon-setting-first-carbon-market-malaysia

Teh, Kian Yeong. 2021. "Tenaga Nasional Berhad: Cleaning Up Its Energy." Research by Kenanga, Kenanga .

Tham and Yeoh, “Chinese Steel Investments in ASEAN”, ISEAS Yusof Ishak Institute, 2020.

The Economic Times. 2019. How India in a short period of time has become the cheapest producer of solar power. July 22. https://economictimes.indiatimes.com/small-biz/productline/power-generation/how-india-in-a-short-period-of-time-has-become-the-cheapest-producer-of-solar-power/articleshow/70325301.cms.

The Edge 2022, “MRT Putrajaya line: Phase Two 98% complete, to begin operations Jan 2023”, viewed 30 June 2022, https://www.theedgemarkets.com/article/mrt-putrajaya-line-phase-two-98-complete-begin-operations-jan-2023

The Star (2022). “Country's debts at RM1.045 trillion as of June, says Finance Ministry”. Retrieved 30 August 2022. https://www.thestar.com.my/news/nation/2022/07/21/country039s-debts-at-rm1045-trillion-as-of-june-says-finance-ministry

The Washington Post (2021). “Greenhouse gas emissions built on flawed data”. Retrieved 4 July 2022. https://www.washingtonpost.com/climate-environment/interactive/2021/greenhouse-gas-emissions-pledges-data/

Theo Notteboom, Athanasios Pallis and Jean-Paul Rodrigue (2022) Port Economics, Management and Policy, New York: Routledge, 690 pages / 218 illustrations. ISBN 9780367331559.

Thomas, P, F K C Lo, and A J Hepburn. 1976. The Land Capability Classification of Sabah Volume 4 The Interior Residency and Labuan. Surrey: Labuan Resources Division, Ministry of Overseas Development, 124. https://edepot.wur.nl/487017.

Timperley (2021). Jocelyn Timperley, “The broken $100-billion promise of climate finance — and how to fix it.” Retrieved from Nature 30 August 2022. https://www.nature.com/articles/d41586-021-02846-3

Transport Authority (RTA)”, IEEE 2018 Advances in Science and Engineering Technology International Conferences (ASET), UAE.

Tullo, Alexander H. 2021. Is ammonia the fuel of the future? March 8. https://cen.acs.org/business/petrochemicals/ammonia-fuel-future/99/i8.

UNCTAD (2020), Review of Maritime Transport 2020, United Nations Conference on Trade and Development, United Nations Publication, New York

UNFCCC (2022). Glossary of climate change acronyms and terms. Retrieved 9 June 2022. https://unfccc.int/process-and-meetings/the-convention/glossary-of-climate-change-acronyms-and-terms#l

United Nations (2010), Low-carbon Development Path for Asia and the Pacific: Challenges and Opportunities to the Energy Sector, United Nations Publication, printed in Thailand

United Nations Framework Convention of Climate Change (UNFCCC), “Paris Agreement”, 2015.

United Nations Framework Convention of Climate Change (UNFCCC), “Joint Annual Report of the Technology Executive Committee and the Climate Technology Center and Network for 2021”, 2021b.

United Nations Framework Convention of Climate Change (UNFCCC), “Report of the Conference of the Parties on its twenty-sixth session, held in Glasgow from 31 October to 13 November 2021, 4/CP.26 Long-term climate finance”, 2021c.

US EPA. 2007. Wastewater Management Fact Sheet: Denitrifying Filters. Unietd States Environmental Protection Agency, United States Environmental Protection Agency. https://www.epa.gov/sites/default/files/2019-08/documents/denitrifying_filters_fact_sheet_p100il79.pdf.

Varadhan, Sudarshan. 2022. India plans to produce 5 mln tonnes of green hydrogen by 2030. Reuters. February 18. https://www.reuters.com/business/energy/india-plans-produce-5-mln-tonnes-green-hydrogen-by-2030-2022-02-17/#:~:text=India%20plans%20to%20manufacture%20five,export%20hub%20for%20the%20fuel.

Vemuri, Michael, Isabel Bohn, and Marius Schrade. 2018. From ‘baseload’ to flexible generation: meeting the power generation requirements of the future. Makati City, Philippines: Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH.

Vergara, Sintana E, and Whendee L Silver. 2019. "Greenhouse gas emissions from windrow composting of organic wastes: Patterns and emissions factors." Environmental Research Letters (IOP Publishing Ltd) 14 (12).

Vogl, Valentin, Olle Olsson, and Björn Nykvist. "Phasing out the blast furnace to meet global climate targets." Joule 5, no. 10, 2021.

Watson, Nicholas, and Jeffrey Donovan. 2022. SMR Platform: New Web Portal Facilitates Technical Support. August 17. Accessed September 15, 2022. https://www.iaea.org/newscenter/news/smr-platform-new-web-portal-facilitates-technical-support.

Watson, Nicholas, and Nikoleta Morelova. 2022. Repurposing Fossil Fuel Power Plant Sites with SMRs to Ease Clean Energy Transition. June 16. https://www.iaea.org/newscenter/news/repurposing-fossil-fuel-power-plant-sites-with-smrs-to-ease-clean-energy-transition.

Well, R.R., and N.C. Brady. 2017. The Nature and Properties of Soils. Pearson.

Wikipedia. 2022. Generation IV reactor. June 6. Accessed June 18, 2022. https://en.wikipedia.org/wiki/Generation_IV_reactor.

Wood Mackenzie. 2022. Ammonia co-firing in thermal power plants could be worth US$100 billion in 2050. May 18. https://www.woodmac.com/press-releases/ammonia-co-firing-in-thermal-power-plants-could-be-worth-us$100-billion-in-2050/.

World Bank (2020). Forest area (% of land area) - Brazil, Indonesia, Malaysia, United States, United Kingdom, Germany, France, Italy, Congo, Rep. Retrieved 14 July 2022. https://data.worldbank.org/indicator/AG.LND.FRST.ZS?locations=BR-ID-MY-US-GB-DE-FR-IT-CG&most_recent_value_desc=true

World Bank (2021). State and Trends of Carbon Pricing 2021. Retrieved 14 July 2022. https://openknowledge.worldbank.org/handle/10986/35620

World Bank (2022). “Countries on the Cusp of Carbon Markets”. Retrieved 2 September 2022. https://www.worldbank.org/en/news/feature/2022/05/24/countries-on-the-cusp-of-carbon-markets

World Bank. 2022. “Global Flaring Data.” Text/HTML. World Bank. October 12, 2022. https://www.worldbank.org/en/programs/gasflaringreduction/global-flaring-data.

World Bank. 2022. Agricultural land (% of land area) - Malaysia. https://data.worldbank.org/indicator/AG.LND.AGRI.ZS?locations=MY.

World Bank. 2022. Agricultural land (% of land area) - Malaysia. https://data.worldbank.org/indicator/AG.LND.AGRI.ZS?locations=MY.

World Nuclear Association. 2018. An Effective Export Control Regimae for a Global Industry. World Nuclear Association.

World Nuclear Association. 2021. Storage and Disposal of Radioactive Waste. May. Accessed July 1, 2022. https://world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-waste/storage-and-disposal-of-radioactive-waste.aspx.

World Nuclear Association. 2022. Radioactive Waste Management. January. Accessed July 1, 2022. https://world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-wastes/radioactive-waste-management.aspx#:~:text=Nuclear%20power%20is%20the%20only,other%20thermal%20electricity%20generation%20technologies.

World Nuclear Association. n.d. What is nuclear waste, and what do we do with it? Accessed July 1, 2022. https://world-nuclear.org/nuclear-essentials/what-is-nuclear-waste-and-what-do-we-do-with-it.aspx.

World Resources Institute. 2022. "Climate Watch Historical Country Greenhouse Gas Emissions Data." https://www.climatewatchdata.org/ghg-emissions.

World Shipping Council (2009), The Liner Shipping Industry and Carbon Emissions Policy

Worldometers. n.d. Malaysia Natural Gas. Accessed August 22, 2022. https://www.worldometers.info/gas/malaysia-natural-gas/.

WWF & BCG (2021). "Securing our future: Net zero pathways for Malaysia".

WWF (2022). "Today, forests still cover about 54% of total land area" (in Malaysia). Retrieved 20 June 2022. https://www.wwf.org.my/our_work/forest/

WWF-MY and BCG-MY. 2021. Securing Our Future: Net Zero Pathways for Malaysia. WWF Malaysia and Boston Consulting Group Malaysia.

Zheng, Yibing. 2022. China is building world's first commercial land-based SMR. August 23. Accessed September 15, 2022. https://news.cgtn.com/news/2022-08-22/China-is-building-world-s-first-commercial-land-based-SMR-1cI8GcIqAuY/index.html.

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