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UNIVERSITI TEKNOLOGI MALAYSIA

# PATHWAYS TO CARBON NEUTRALITY IN 2050 FOR MALAYSIA AND KUALA LUMPUR





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## Executive Summary

Malaysia has committed to reducing its carbon intensity against GDP by 45% by 2030 relative to 2005 levels and has informally announced a goal of achieving carbon neutrality as early as 2050. To accomplish this, the country will need to strategically reduce its emissions across all sectors. In 2020, Malaysia emitted approximately 310 MtCO<sub>2</sub>e, with the largest sources of emissions including electricity (42% of total emissions), transportation (19%), and industry (14%) (Climate Watch, 2023). This report seeks to explore pathways to carbon neutrality by 2050 to help inform the possible outcomes of implementing policies, investments, and measures across the power, transportation, industry, and building sectors. Through our research, we arrive at the following key conclusions:

### **Strategies to reach carbon neutrality by 2050 rely heavily on electrification across sectors and decarbonization of the power sector.**

Malaysia's greatest reductions in emissions can come from decarbonizing power generation and electrifying end-use sectors. In a carbon neutral scenario, 42% of total emission reductions come from the power sector, decreasing power emissions by 95%. Indirect emissions, or sectoral emissions that are sourced from electricity, make up 91%, 44%, and 21% of business-as-usual emissions for the building, industry, and transportation sectors, respectively. Large-scale electrification coupled with deep decarbonization is therefore a critical strategy for reaching carbon neutrality as early as 2050. Renewable energy will play a key role here, with substantial increases in solar and hydropower driving these changes.

### **Energy efficiency and demand-side measures will significantly contribute to decarbonization efforts.**

Digitalization, smart technologies, and improved energy efficiency will significantly reduce economy-wide energy consumption. By leveraging efficient technologies, Malaysia and Kuala Lumpur can address the challenges posed by rapid urbanization and climate change. Digitalization is a broad category that covers a variety of measures including, for example, the wide adoption of high-efficiency appliances and lighting or improved building energy codes. Similarly, technological improvements can advance industrial energy efficiency, and for transportation, smart technologies cover a shift from private to public transportation and the greater use of electric vehicles. Policies that focus on these categories have the potential to be highly impactful. In a carbon neutral scenario, energy consumption decreases by over one-third across all sectors when compared to a business-as-usual trajectory.

### **Hard-to-mitigate sectors will require the use of advanced technologies like carbon capture and storage and hydrogen.**

While renewable energy will play a crucial role in decarbonization, achieving carbon neutrality in certain sectors will be difficult without emerging technologies like carbon capture and storage (CCS) and innovative fuel sources such as hydrogen. For Malaysia to reach carbon neutrality as early as 2050, approximately 55 MTCO<sub>2</sub> of emissions will be captured by CCS technologies, and in the power sector, CCS is used for 11% of total electricity generation. Hydrogen can compose up to 19% of final industrial energy consumption and approximately 8% of final transportation energy consumption; this leads to 8% of total regional final energy consumption sourced from hydrogen in a carbon neutral case. For Malaysia to rely on CCS as a mitigation option, early investment and incentives for the private sector will be critical. This holds for the use of hydrogen as well: investing in the necessary technology, infrastructure, and human capital will allow

Malaysia to position itself as an innovator in the region and leverage these advanced technologies as a key part of its climate strategy. Another possible carbon removal option other than CCS would be increasing its land-use sink; however, given that Malaysia is still developing and may deforest in the near term, this report does not focus on the mitigation potential of land-use change.

**Cities will play a key role in national decarbonization strategies, with multi-level governance an important factor for policy success.**

With its innovative and bold climate plans, Kuala Lumpur is primed to be a leader in regional climate change efforts. Kuala Lumpur is also engaged in several international collaborations to ensure sustainable city development such as the C40 network and the ASEAN Smart Cities Partnership. As such, the city will play a critical role in contributing to Malaysia's overall climate goals and as a policy trendsetter through ambitious, scalable plans. In terms of direct impacts, Kuala Lumpur contributes to 7% of Malaysia's total emissions, accounting for 13% of buildings, 2% of industrial, and 13% of transportation emissions. Kuala Lumpur's major sources of emissions include the transportation sector (54% of total baseline emissions) and indirect emissions from buildings (33%). With targeted policies, these emissions can be reduced significantly, thereby greatly contributing to emissions reduction at the city and country levels.

One key factor here is that Kuala Lumpur has full control over its building guidelines, allowing for ambitious policies resulting in significant emissions reductions. However, in other sectors, Kuala Lumpur has less direct control over regulations; for example, power generation and integration of renewable energy are largely in the hands of the Malaysian government. With a small industry sector, made up mostly of light manufacturing, Kuala Lumpur's contributions to industrial emissions reductions will be limited. And, while Kuala Lumpur has control over local transportation policies like increasing access to and quality of public transportation, broad shifts in transportation will stem from national policies. As such, multi-level governance should be an integral component of Malaysia's climate strategy and coordination between local and national governments will be essential for reducing emissions and achieving other climate goals.

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## Acronyms and Abbreviations

ACMV	Air conditioning and mechanical ventilation
ASEAN	Association of Southeast Asian Nations
BAU	Business-as-usual
CCS	Carbon capture and storage
CO <sub>2</sub>	Carbon dioxide
EJ	Exajoule
EV	Electric vehicle
GCAM	Global Change Analysis Model
GDP	Gross domestic product
GTMP	Green Technology Master Plan
KLCAP 2050	Kuala Lumpur Climate Action Plan 2050
KLLCSBP 2030	Kuala Lumpur Low Carbon Society Blueprint 2030
KLSP 2040	Kuala Lumpur Draft Structure Plan 2040
LCNA 2040	Low Carbon National Aspirations 2040
LDV	Light duty vehicle
LED	Light-emitting diode
MS 1525-2019	Malaysian Standards 1525-2019: Energy Efficiency And Use Of Renewable Energy For Non-Residential Buildings
MyRER	Malaysia Renewable Energy Roadmap
MtCO <sub>2</sub>	Million tons of carbon dioxide
MtCO <sub>2e</sub>	Million tons of carbon dioxide equivalent
NDC	Nationally determined contribution
UNFCCC	United Nations Framework Convention on Climate Change

## Contents

Executive Summary .....	i
Acknowledgments .....	iii
Acronyms and Abbreviations .....	iv
1.0 Introduction .....	1
2.0 Methods .....	2
2.1 City scale modeling within a global model .....	2
2.2 Scenario development .....	2
2.3 Policies and targets .....	3
2.3.1 Buildings .....	4
2.3.2 Electricity generation .....	5
2.3.3 Industry .....	5
2.3.4 Transportation .....	5
2.3.5 Emission constraints .....	6
3.0 Results .....	7
3.1 Emissions overview .....	7
3.2 Electrification and decarbonization .....	9
3.3 Energy efficiency and demand side measures .....	11
3.3.1 Buildings .....	11
3.3.2 Industry .....	12
3.3.3 Transportation .....	12
3.4 Advanced technologies: CCS and hydrogen .....	14
3.5 Kuala Lumpur's contributions .....	15
4.0 Recommendations .....	17
4.1 Electrification and decarbonization .....	17
4.2 Energy efficiency and demand side measures .....	17
4.3 Leveraging advanced technologies .....	18
4.4 Benefits of engaging in multi-level governance .....	18
5.0 Conclusions .....	19
6.0 References .....	20

## Figures

Figure 1. An overview of direct and indirect emissions in Malaysia in 2050, and the progression of emissions reductions from a BAU to the Policies scenario and from Policies to Carbon Neutral. ....	7
Figure 2. Electricity generation projections for Malaysia in 2050 in the BAU, Policies, and Carbon Neutral scenarios, sectioned by fuel type and sequestration method. Data for 2015 is included as a reference.....	9
Figure 3. Aggregate energy consumption by sector for each scenario in 2050, with 2015 as a reference. The “Other” fuel category includes small amounts of biomass in industry and buildings and solar water heaters in buildings.....	10
Figure 4. The percentage change in electricity prices from 2015 generally decreases, except in the Carbon Neutral scenario. ....	10
Figure 5. Energy consumption by end-use fuel in buildings, industry, and transportation. Note that biomass appears in buildings (rural cooking) and industry, and small amounts of solar are in the buildings sector as solar water heaters. ....	11
Figure 6. Commercial and residential building electricity consumption by sector in Malaysia. ....	12
Figure 7. Industrial energy consumption in Malaysia by fuel for each scenario from 2015 – 2050. ....	12
Figure 8. Energy consumption by fuel for the transportation sector. In a Carbon Neutral scenario, 80% of total energy consumption is sourced from electricity. For freight transportation, 19% of energy comes from hydrogen. Note that the y-axis scale differs between freight and passenger transport. ....	13
Figure 9. Transportation by mode for Malaysia and Kuala Lumpur. Both the Policies and Carbon Neutral scenarios reflect a significant private to public transportation modal shift. ....	14
Figure 10. Reaching carbon neutrality in 2050 will require carbon sequestration for the power sector and industry. The dark grey bars represent CO <sub>2</sub> emissions, and the green bars represent CO <sub>2</sub> sequestration technologies. The dashed, white bars represent emissions that are immediately taken up by CCS so that they never reach the atmosphere. ....	14
Figure 11. Highlighting energy consumption in industry and the transportation sectors, particularly the amount of hydrogen required (approximately 20% for industry and 10% for transportation) in the Carbon Neutral scenario.....	15
Figure 12. Direct and indirect CO <sub>2</sub> emissions in Kuala Lumpur and the reductions between scenarios. Sectoral emissions are color-coded, and indirect emissions from the power sector are represented by hashed bars.....	15

## Tables

Table 1. Scenarios modeled and their corresponding levels of policy action and emissions constraints. ....	2
Table 2. A sample of key Malaysian policies, plans, and commitments related to carbon neutrality. ....	3
Table 3. A detailed list of implemented policies, target values, and policy sources. The colors of the “sector” column will correspond with those used in the figures below. ....	4
Table 4. Direct emissions (by sector and total) for each scenario and reductions (by sector and total) between the three main scenarios. All units are MTCO <sub>2</sub> . ....	8
Table 5. Indirect emissions (by sector and total) for each scenario and reductions (by sector and total) between the three main scenarios. All units are MTCO <sub>2</sub> . ....	8

## 1.0 Introduction

Southeast Asia is undergoing a period of rapid growth and urbanization, largely driven by cities. Cities are a critical component of a country's socioeconomic growth but are also large contributors to climate change. The region has already begun to feel the effects of a changing climate through heat stress and increased floods, drought, and other hazards like landslides. Many ASEAN member states recognize this and have implemented Smart Cities programs. A "smart city" uses technological advancements and digital technologies to improve urban issues; this includes working to mitigate or adapt to climate change. This report will focus on Malaysia and one of its Smart Cities, Kuala Lumpur. As Malaysia's capital and most populous city, Kuala Lumpur is essential to national decarbonization efforts.

Malaysia is aiming for carbon neutrality as early as 2050, and Kuala Lumpur intends to be a carbon neutral city by 2050. In its Nationally Determined Contribution (NDC) to the United Nations Framework Convention on Climate Change (UNFCCC), Malaysia committed to reducing its economy-wide carbon intensity against gross domestic product (GDP) by 45% in 2030, relative to 2005 levels; this reflects the country's "highest possible ambition" (Government of Malaysia, 2021). Kuala Lumpur's decarbonization actions and carbon neutrality goal will therefore bolster Malaysia's efforts as it works towards its targets.

Malaysia will face challenges on the road to deep decarbonization. The energy sector is the main driver of growth for the Malaysian economy, with energy-intensive industries contributing to 28% of GDP and petroleum-related income making up 31% of total fiscal income in 2019 (Economic Planning Unit, 2022). Fossil fuels (oil, natural gas, and coal) made up 91% of Malaysia's primary energy consumption in 2021 (BP, 2022). Malaysia will need to balance increased energy demand from a growing population against its commitments to increasing renewable energy sources and other climate policies. This will require strategic decarbonization with targeted economy-wide efforts. Malaysia and Kuala Lumpur have several existing policies and plans in place to help reduce emissions and energy intensity, targeting sectors including buildings, transportation, industry, and power generation. However, we find that these existing policies will have residual emissions in 2050 when implemented as-is (see section 3 for a detailed discussion).<sup>1</sup>

As such, the Global Change Analysis Model (GCAM) can help Malaysia and Kuala Lumpur on their path to carbon neutrality by providing additional insights about planned and potential policy options. GCAM is an integrated assessment model that represents the interactions between five systems (land use and agriculture, energy, water, climate, and the economy) and can explore future "what if" scenarios. GCAM also highlights trade-offs between different policy and technology options, giving valuable insights to decision-makers on potential impacts. In this work, we use GCAM to analyze the impacts of existing policies to explore pathways to carbon neutrality in Malaysia and Kuala Lumpur.

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<sup>1</sup> These findings are based on modeling results and should not be interpreted as predictions for the future.

## 2.0 Methods

This section will outline how to leverage GCAM to explore different pathways to carbon neutrality, beginning with an overview of city-scale modeling (2.1) and scenario development (2.2). Next, section 2.3 will discuss the policy implementation process in detail and give a sector-by-sector overview of how these policies and targets are represented in GCAM.

### 2.1 City scale modeling within a global model

GCAM is a global model that includes a highly detailed representation of the energy sector and interactions with and between the socioeconomic, climate, water, and land systems. For this analysis, we develop a version of GCAM that includes Malaysia, Kuala Lumpur, and “Rest of Malaysia” as regions within the model, based on historical and projected population and GDP. GCAM uses these core assumptions as the basis for its projections. At the sub-national level, we use GCAM to gain insight into the buildings, transportation, and industry sectors. Primary energy, electric generation, and land and water systems are all modeled at the national level, as individual cities typically have less governance over these areas.

### 2.2 Scenario development

We develop a total of three unique scenarios to provide a set of future pathways that allow us to assess the impact of policies already adopted and additional measures that may be needed to reach carbon neutrality (Table 1). We include a baseline “Business as Usual” (BAU) scenario as a projection through 2050 without any policies or constraints. A “Policies” scenario reflects the implementation of a broad set of current national and city climate policies and plans. Finally, the “Carbon Neutral” scenario specifies that in addition to the policies modeled, CO<sub>2</sub> emissions must reach net zero in Malaysia in 2050; we refer to this requirement as an “emissions constraint.” These scenarios provide a comprehensive overview of potential future pathways for Malaysia and Kuala Lumpur.

Table 1. Scenarios modeled and their corresponding levels of policy action and emissions constraints.

Scenario	Policies	Emissions constraint
Business as Usual	None	None
Policies	Policies representing existing city and national targets	None
Carbon Neutral	Policies representing existing city and national targets	Net zero CO <sub>2</sub> emissions in Malaysia and the rest of the world by 2050

## 2.3 Policies and targets

Designing a scenario requires forcing sectors within GCAM to respond to an imposed policy. A reference case in GCAM includes no modifications, meaning the model solves for a business-as-usual trajectory based on historical data and assumptions about the future. With additional user-defined policies, the model reads in the exogenous information and incorporates it into the solving process. The GCAM policies that we model include changes to the building, industry, transportation, and electricity generation sectors. These policies were sourced from Malaysia and Kuala Lumpur plans and targets (Table 2), with insights and guidance from local partners and stakeholders (the Ministry of Natural Resources, Environment, and Climate Change; Sustainable Energy Development Authority, Kuala Lumpur City Hall, and Universiti Teknologi Malaysia). While the policies modeled here represent the majority of on-the-books plans, note that we did not include *all* policies currently in place in Malaysia or Kuala Lumpur.

Table 2. A sample of key Malaysian policies, plans, and commitments related to carbon neutrality.

Kuala Lumpur	Malaysia
KL Low Carbon Society Blueprint 2030	Green Technology Master Plan
KL Structure Plan 2040	Malaysia Low Carbon National Aspiration 2040
KL Climate Action Plan 2050	Malaysia Renewable Energy Roadmap
	MS 1525-2019
	National Energy Efficiency Action Plan
	National Energy Policy 2022-2040
	National Transportation Policy
	Report on Peninsular Malaysia Generation Development Plan 2020
	Revised NDC to the UNFCCC
	Twelfth Malaysia Plan, 2021-2025

In the “Policies” scenario, we used a numerical target that was explicitly specified in a plan for a given year. To create as realistic of a run as possible with the available data, target values were sourced from both Kuala Lumpur and Malaysia’s policies and plans. This means that for some targets, we applied either city or national values to both regions if there was only data at one level. This distinction is noted in the “Source” column of Table 3, and the following sections will explain the technical implementation of these policies.

Table 3. A detailed list of implemented policies, target values, and policy sources. The colors of the “sector” column will correspond with those used in the figures below.

Sector	Policy	Key Values	Source
Buildings	High efficiency appliances	100% high-efficiency air conditioning and mechanical ventilation (ACMV), 50% solar and electric water heaters in 2050	KLLCSBP 2030, GTMP
	High efficiency lighting	100% high-efficiency lighting by 2050	KLLCSBP 2030, GTMP
	Building envelope efficiency	Decreases shell conductance at an annual rate of 4% (residential) and 4.5% (commercial)	KLCAP 2050, MS 1525-2019
Industry	Hydrogen	Hydrogen introduced in 2030	Twelfth Malaysia Plan, National Energy Policy
	Energy efficiency	Increases overall efficiency of industrial processes by 2.5% annually	KLLCSBP 2030, GTMP
Transportation	Public-private modal shift	In 2050: Kuala Lumpur: 80-20 Rest of Malaysia: 55-45	KLSP 2040, LCNA 2040
	Electric vehicles	Electric vehicle (EV) cost parity in 2030 (passenger) and 2040 (freight)	KLLCSBP 2030, LCNA 2040
Power	Renewable energy shares	In 2050: Solar: 50% Hydro: 16% Biomass: 5%	MyRER, Report on Peninsular Malaysia Generation Development Plan 2020
	Coal phase-out	No new coal after 2020 and 100% coal phase-out by 2050	Twelfth Malaysia Plan

### 2.3.1 Buildings

Kuala Lumpur identified improving new and existing building energy efficiency as a key strategy to achieve carbon neutrality by 2050 in the Kuala Lumpur Climate Action Plan 2050 (KLCAP 2050), and the Malaysian Standards 1525-2019: Energy Efficiency And Use Of Renewable Energy For Non-Residential Buildings (MS 1525-2019) supports this concept at the national level. Approaches to improving energy efficiency in buildings could include improving the building envelope, which attempts to maximize the energy efficiency of a building’s exterior. This can be accomplished by using highly insulated windows or improved airflow control technologies. Here,

we model a gradual betterment of the building envelope by reducing the energy demand for cooling required to keep buildings at a given temperature. Additional measures to improve energy efficiency include increasing the efficiency of specific appliances such as air conditioning and mechanical ventilation (ACMV) systems or using high-efficiency lighting. The Kuala Lumpur Low Carbon Society Blueprint 2030 (KLLCSBP 2030) identifies specific targets for the share of high-efficiency appliances. We reflect this in the model by increasing the share of high-efficiency technologies like air conditioners and ceiling fans and decreasing the share of low-efficiency technology options. Furthermore, in alignment with the KLLCSBP 2030's commitments to only use energy-efficient lighting in new buildings and upgrade the lighting in existing buildings, we implement a phase-out of non-efficient lighting options so that only LEDs are left in the market in 2050.

### **2.3.2 Electricity generation**

Renewable energy is a key enabling factor to meet Malaysia's goal of reducing carbon emissions intensity per GDP by 45% in 2030. The Malaysia Renewable Energy Roadmap (MyRER) outlines the country's plans for reducing the share of coal and gas relative to renewable sources like solar, hydropower, and biomass. GCAM can capture these dynamics by matching the target share of each renewable fuel source each year. Additionally, reflecting Malaysia's 2021 commitment to build no additional coal-fired power plants, we impose a constraint beginning in the year 2020 that prevents new coal-fired power plants from being built in the model.

### **2.3.3 Industry**

Policies for the industry sector target a general efficiency increase in industrial processes and an exploratory hydrogen fuel policy. We gradually increase overall energy efficiency for the industrial sector at a modest rate to reflect developments in industrial technologies like efficient motors and new manufacturing techniques. Because heavy industry is difficult to decarbonize and may require advanced technologies, we also include hydrogen as a fuel source for industry. The Twelfth Malaysia Plan discusses the potential of hydrogen use as an innovative technology and alternate green fuel source, and the National Energy Policy identifies Malaysia's competitive advantage in becoming a net hydrogen exporter. As a long-term hydrogen roadmap is still being developed, we choose to model the introduction of hydrogen to industry in 2030.

GCAM models detailed industrial sectors such as iron and steel, cement, and aluminum. The model also has the option to break out additional sectors like chemicals or food, beverages, and tobacco in line with the significant manufacturing sub-sectors in Malaysia. While focusing on detailed industry was outside the initial scope of this work, this could be an interesting area of future study to pinpoint more specific decarbonization strategies.

### **2.3.4 Transportation**

Finally, transportation policies include a modal shift from private to public transportation and an increase in electric vehicles. The Kuala Lumpur Draft Structure Plan 2040 (KLSP 2040) emphasizes an integrated public transportation system, with goals of 60% public passenger transit in Kuala Lumpur by 2030 and 70% by 2040. This is a significant increase from the current split, which is roughly 80% private and 20% public. In GCAM, this is represented by an increase in kilometers traveled by rail, bus, cycling, and walking and a decrease in kilometers traveled by car. At the national level, the Malaysia Low Carbon National Aspiration 2040 (LCNA 2040) discusses a target of 50% public passenger transit by 2040. We model this shift similarly but with a greater reliance on buses, cycling, and walking than rail. Both plans also emphasize the

importance of scaling up the use of EVs. The KLLCSBP 2030 and LCNA 2040 list goals of 20% EVs by 2030 in Kuala Lumpur and 38% by 2040 nationally, respectively. In GCAM, we model the increase in EVs through a pricing mechanism that lowers the cost of EVs to be equivalent to that of non-EVs in a future year, therefore making them a more affordable and attractive option.

### **2.3.5 Emission constraints**

As described above, both Malaysia and Kuala Lumpur have ambitious carbon neutrality goals. To represent this in GCAM, we require the model to reach a specific level of emissions (also called an emissions constraint) in a particular year. In this case, we want to model net-zero CO<sub>2</sub> emissions for Malaysia in 2050. GCAM calculates the price of carbon needed to reach the constraint in each period and will find the least-cost pathway to satisfy the emissions constraint, in terms of technology deployment. An economy-wide constraint can be used by itself or in combination with additional sectoral policies described above. The Carbon Neutral scenario uses an emissions constraint in addition to the policies implemented in the Policies scenario.

### 3.0 Results

The following section includes a summary of emissions reductions in each scenario, followed by specific insights on power generation (3.2), sectoral energy efficiency (3.3), advanced technologies (3.4), and Kuala Lumpur’s contributions to reaching carbon neutrality (3.5).

#### 3.1 Emissions overview

Through targeted and ambitious policy efforts, Malaysia has the potential to reach carbon neutrality as early as 2050. Figure 1 and Tables 4 and 5 illustrate the progression of emissions reductions from the BAU scenario to the Policies scenario and from Policies to Carbon Neutral. BAU emissions in 2050 total 359 MTCO<sub>2</sub> and are reduced to 190 MTCO<sub>2</sub> after implementing the policies discussed above; this implies that while effective, the policies represented are not sufficient to achieve carbon neutrality in 2050. However, additional investment in large-scale electrification and increased use of advanced technologies like CCS and hydrogen can result in carbon neutrality. The following sections will discuss the details of and key insights from these results.

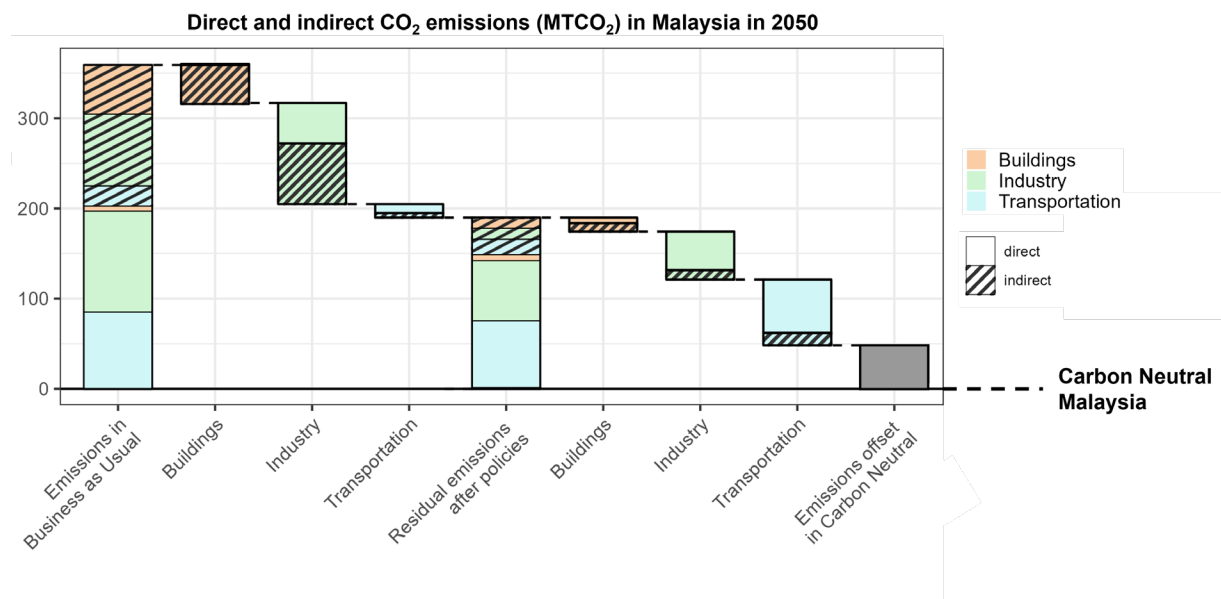


Figure 1. An overview of direct and indirect emissions in Malaysia in 2050, and the progression of emissions reductions from a BAU to the Policies scenario and from Policies to Carbon Neutral.

Table 4. Direct emissions (by sector and total) for each scenario and reductions (by sector and total) between the three main scenarios. All units are MTCO<sub>2</sub>.

Scenario	Buildings	Industry	Transportation	Total
Business as Usual	5.53	112.12	85.05	202.7
Change from BAU to Policies	1.19	-44.88	-10.00	-53.69
Policies	6.72	67.24	75.05	149.01
Change from Policies to Carbon Neutral	-6.17	-42.79	-58.99	-107.95
Carbon Neutral	0.55	24.45	16.05	41.05 CO <sub>2</sub> Sequestration: -41.05 <sup>2</sup>

Table 5. Indirect emissions (by sector and total) for each scenario and reductions (by sector and total) between the three main scenarios. All units are MTCO<sub>2</sub>.

Scenario	Buildings	Industry	Transportation	Total
Business as Usual	54.29	79.59	22.45	156.33
Change from BAU to Policies	-43.29	-67.23	-5.02	-115.54
Policies	11.00	12.36	17.43	40.79
Change from Policies to Carbon Neutral	-9.28	-10.47	-13.89	-33.64
Carbon Neutral	1.73	1.89	3.54	7.16 CO <sub>2</sub> Sequestration: -7.16 <sup>3</sup>

<sup>2</sup> Sequestration needed for residual direct emissions. This does not include emissions from the power sector that are directly captured by CCS.

<sup>3</sup> Sequestration needed for residual indirect emissions. This does not include emissions from the power sector that are directly captured by CCS.

## 3.2 Electrification and decarbonization

The power sector presents significant opportunities and challenges as Malaysia's greatest source of emissions, and both decarbonization and widespread electrification will be key factors in reaching carbon neutrality. Figure 2 describes Malaysia's electricity generation mix in detail. In 2015, most of the power generation in Malaysia was sourced from coal or gas, with only a fraction from renewable sources. In a BAU case, the generation mix does not change drastically into 2050, with a continued significant reliance on coal and gas. In the Policies scenario, overall electricity demand decreases relative to BAU due to policies targeting energy efficiency measures in end-use sectors. Notably, nearly three-quarters of total generation will be sourced from renewables, which reduces power sector emissions by three-quarters compared to the BAU case.

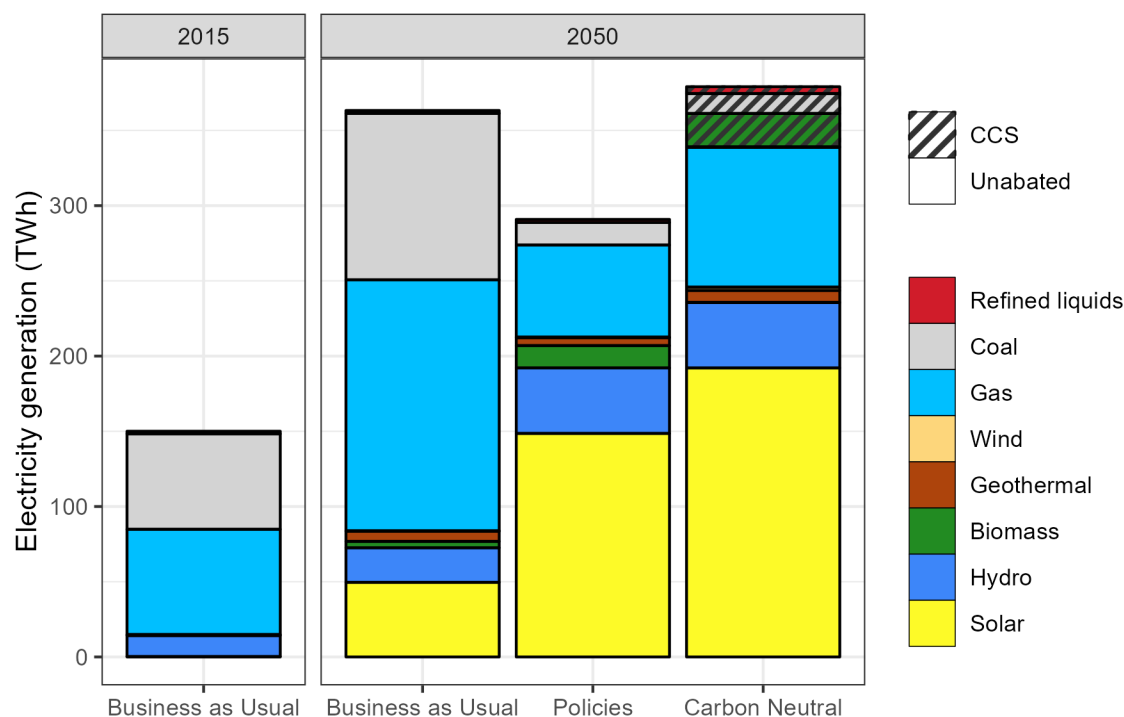


Figure 2. Electricity generation projections for Malaysia in 2050 in the BAU, Policies, and Carbon Neutral scenarios, sectioned by fuel type and sequestration method. Data for 2015 is included as a reference.

In the Carbon Neutral scenario, renewable energy and fossil fuels using CCS technologies make up nearly three-quarters of total electricity demand. However, total electricity demand is greater in the Carbon Neutral scenario compared to the Policies case due to the level of electrification required to achieve carbon neutrality. We find that 97% of the energy consumed in the buildings sector, 80% in the transportation sector, and 42% in the industry sector will need to be sourced from electricity (Figure 3). This drives the high demand for electricity in the Carbon Neutral scenario, which further emphasizes the importance of decarbonizing the power sector. Without clean energy powering the grid, this increase in demand would cause emissions to spike. Instead, we find that 95% of power emissions are reduced in the Carbon Neutral scenario compared to BAU, implying that Malaysia can bring its largest source of emissions down to nearly zero by scaling up the use of solar and hydropower.

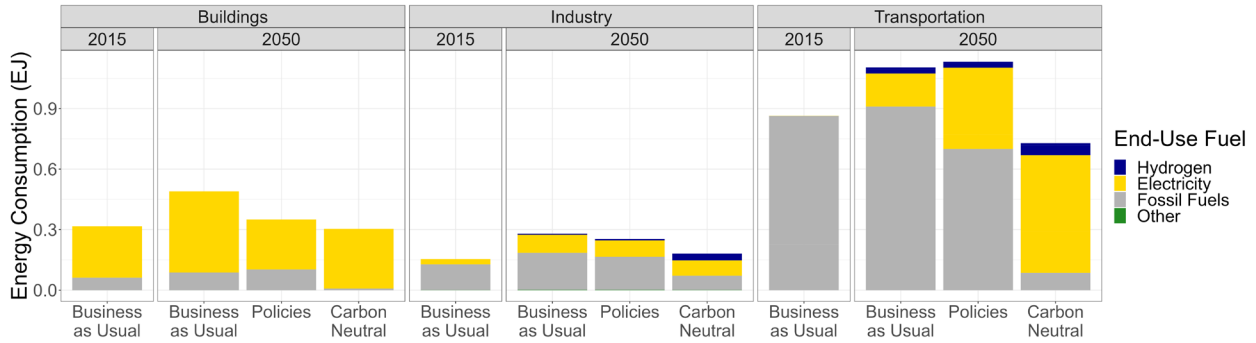


Figure 3. Aggregate energy consumption by sector for each scenario in 2050, with 2015 as a reference. The “Other” fuel category includes small amounts of biomass in industry and buildings and solar water heaters in buildings.

Regarding impacts on the power sector, relative electricity prices increase in the Carbon Neutral scenario (Figure 4). In 2050, the percent change in electricity prices before transmission and distribution costs relative to 2015 levels is 45%. This change is much higher than what would result from a BAU scenario, where future prices decrease. This gap occurs as solar power begins to dominate in the Carbon Neutral case and increased demand for and costs of backup electricity and storage drive electricity prices up. We see a similar increasing trend in the Policies scenario, although the market can benefit from the balance of energy efficiency against solar investment costs, keeping future prices down. While the jump in the Carbon Neutral scenario is a notable increase, consumers will not be paying 45% more than they are now. For example, by 2050, energy efficiency improvements will reduce the amount of electricity consumed, effectively counterbalancing this price increase. For transportation, fuel costs for transportation will be lower per unit, as currently used oil products are more expensive than future electricity.

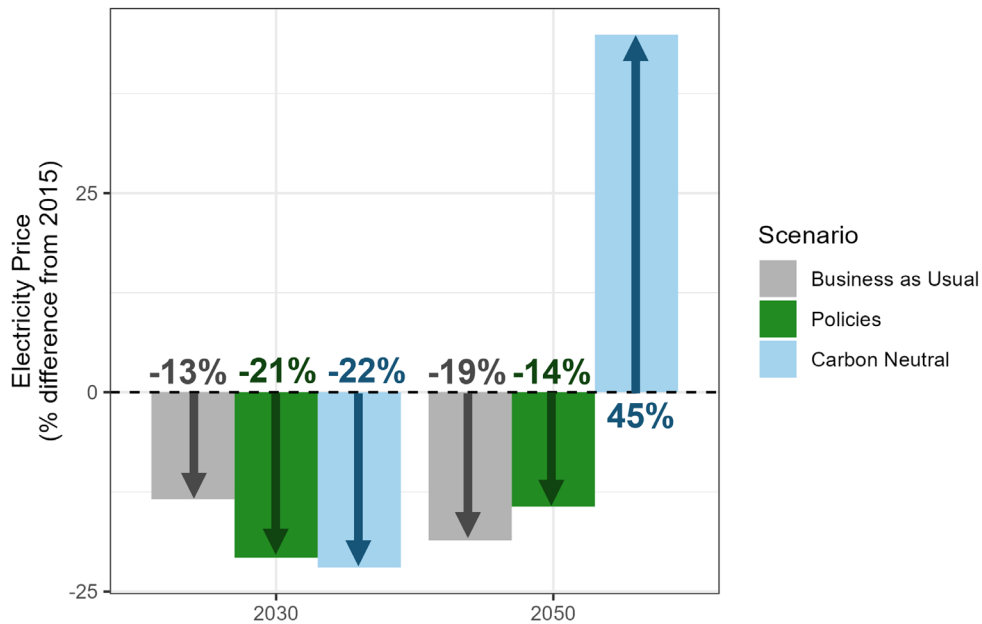


Figure 4. The percentage change in electricity prices from 2015 generally decreases, except in the Carbon Neutral scenario.

### 3.3 Energy efficiency and demand side measures

Demand-side measures to increase energy efficiency in the buildings, industry, and transportation sectors can significantly reduce energy consumption and therefore emissions. Total energy consumption for Malaysia will reach 1.9 EJ in a BAU scenario in 2050; modeled policies and plans can bring this down slightly. Further electrification in the Carbon Neutral scenario reduces total energy consumption to 1.2 EJ in 2050. Figure 5 illustrates these metrics, and the following subsections will discuss these results in detail, by sector.

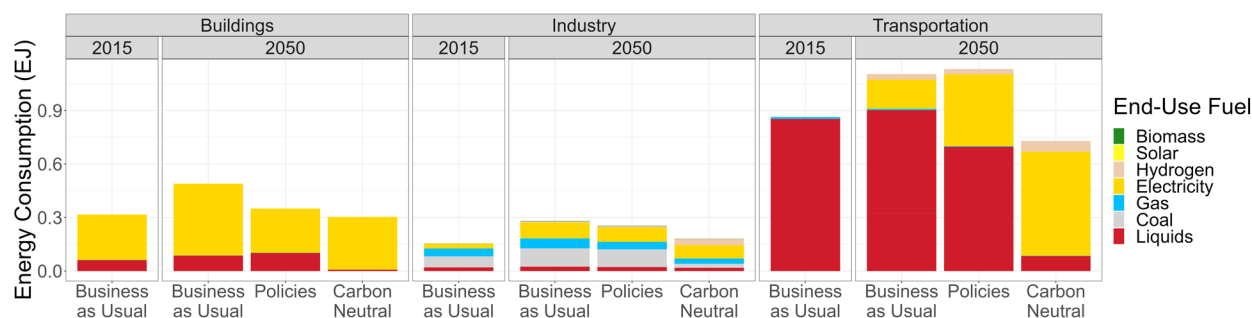


Figure 5. Energy consumption by end-use fuel in buildings, industry, and transportation. Note that biomass appears in buildings (rural cooking) and industry, and small amounts of solar are in the buildings sector as solar water heaters.

#### 3.3.1 Buildings

The buildings sector is already largely electrified, with electricity making up around 80% of energy consumption in a BAU scenario in 2015 and through 2050 (Figure 5). Therefore, there are relatively few direct emissions from buildings and energy efficiency improvements are highly effective at lowering total energy use. In a Carbon Neutral scenario, energy consumption in buildings is reduced by more than a third and nearly 100% of this consumption is from electricity. Even so, electricity use in buildings also decreases by a quarter relative to BAU (Figure 6), reflecting the impacts of energy efficiency improvements driven by the use of efficient lighting and other technologies.

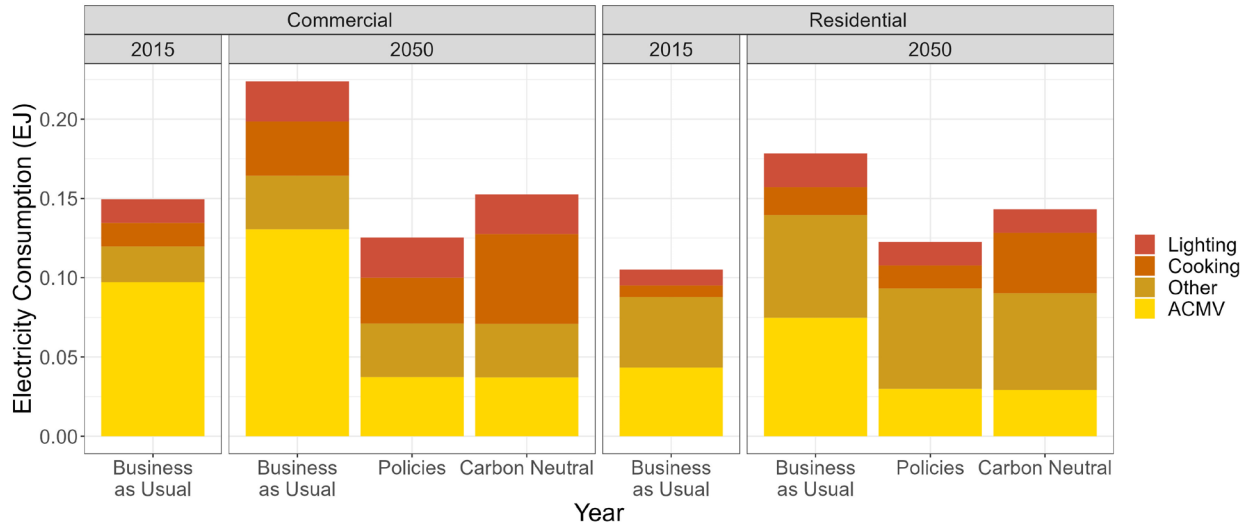


Figure 6. Commercial and residential building electricity consumption by sector in Malaysia.

### 3.3.2 Industry

Industrial energy consumption totaled 0.15 EJ in 2015 and 0.28 EJ in a 2050 BAU case. Industrial energy efficiency improvements and the introduction of hydrogen can lower energy consumption by 10% in the Policies scenario and 35% in the Carbon Neutral case. Furthermore, in the Carbon Neutral scenario, 60% of energy is sourced from electricity and hydrogen, up from about one-third in the BAU and Policies scenarios. Figure 7 shows a time series of industrial energy consumption in Malaysia by fuel, highlighting the significant decrease in fossil fuel use and increase in hydrogen required to achieve carbon neutrality relative to the Policies scenario. In both the BAU and Policies scenario, two-thirds of 2050 energy consumption is sourced from fossil fuels versus about 40% in the Carbon Neutral case, although some of those resulting emissions are curbed by CCS. See section 3.3 for additional details on the importance of advanced technologies in industry.

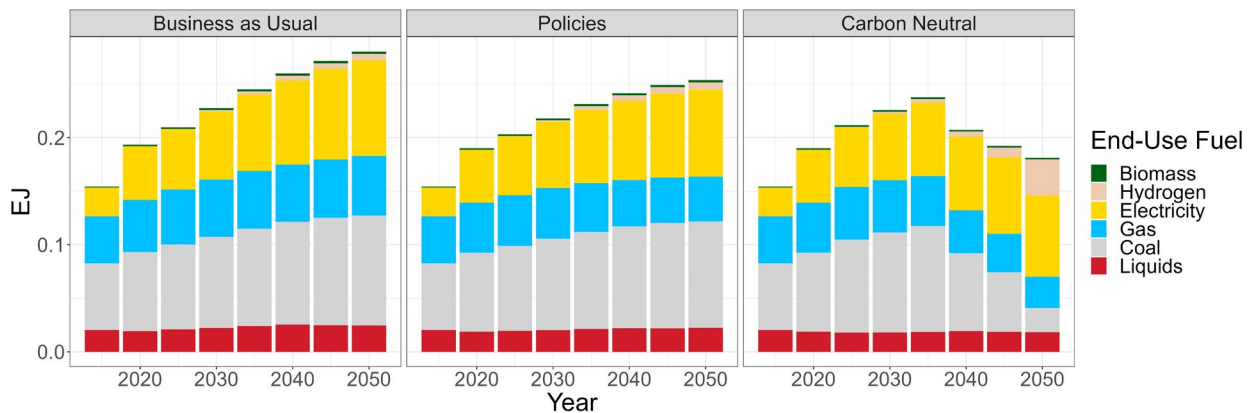


Figure 7. Industrial energy consumption in Malaysia by fuel for each scenario from 2015 – 2050.

### 3.3.3 Transportation

Energy consumption for the transportation sector was 0.86 EJ in 2015 and increases to 1.10 EJ in a 2050 BAU scenario. Through an increase in public transportation and the use of EVs and hydrogen vehicles, transportation energy consumption can be reduced by 15% in the Policies

scenario and up to one-third in the Carbon Neutral scenario. The larger decrease in the Carbon Neutral case can be attributed to the near-full electrification of transportation that would need to occur to reach carbon neutrality. 80% of total transportation energy use comes from electricity, with 8% sourced from hydrogen. This will require a large shift in transportation trends; we find that in a 2050 Carbon Neutral case, two-thirds of passenger and 85% of freight road vehicle kilometers traveled are from electric vehicles, and 12% to 15% of both passenger and freight road vehicle kilometers traveled are from hydrogen vehicles, respectively. Figure 8 highlights this large-scale electrification. With these changes, emissions directly from transportation will be substantially reduced by approximately 80% from BAU as compared to a 12% decrease in the Policies scenario relative to BAU.

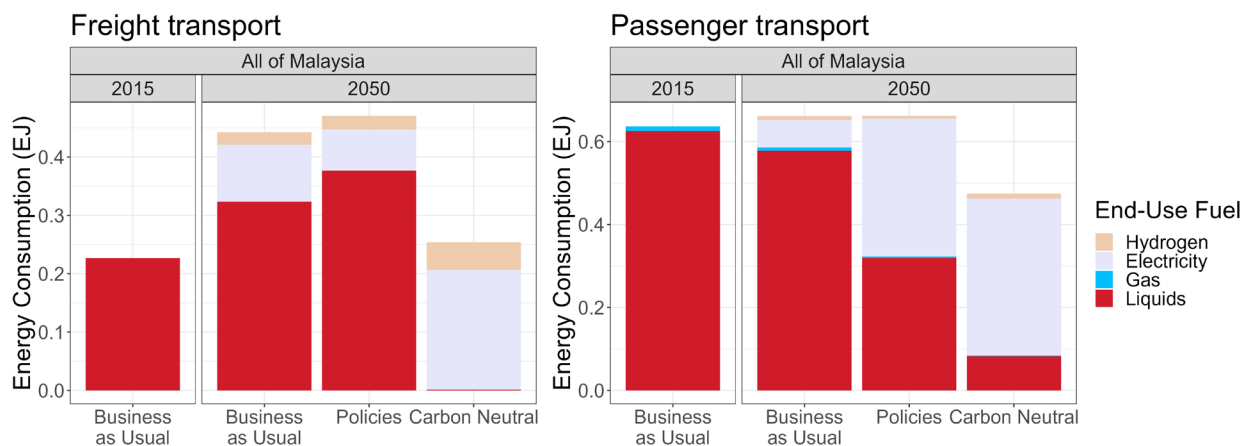


Figure 8. Energy consumption by fuel for the transportation sector. In a Carbon Neutral scenario, 80% of total energy consumption is sourced from electricity. For freight transportation, 19% of energy comes from hydrogen. Note that the y-axis scale differs between freight and passenger transport.

In addition to the increased use of EVs, transportation becomes primarily public over private, with most of the remaining private transportation being electric or hydrogen vehicles, as discussed above. In a Carbon Neutral scenario in 2050, we find that over half of passenger vehicle kilometers traveled in Malaysia are from public transportation, and this increases to nearly three-quarters in Kuala Lumpur. A modal shift and increased use of electric vehicles highlight the importance of incentivizing consumer choice and investing in the necessary infrastructure to enable this kind of transition at a national and sub-national level. Figure 9 shows a detailed breakdown of transportation by mode in both Malaysia and Kuala Lumpur; note that the slight increase in light-duty vehicles (LDV) in the Carbon Neutral scenario is due to the use of hydrogen vehicles.

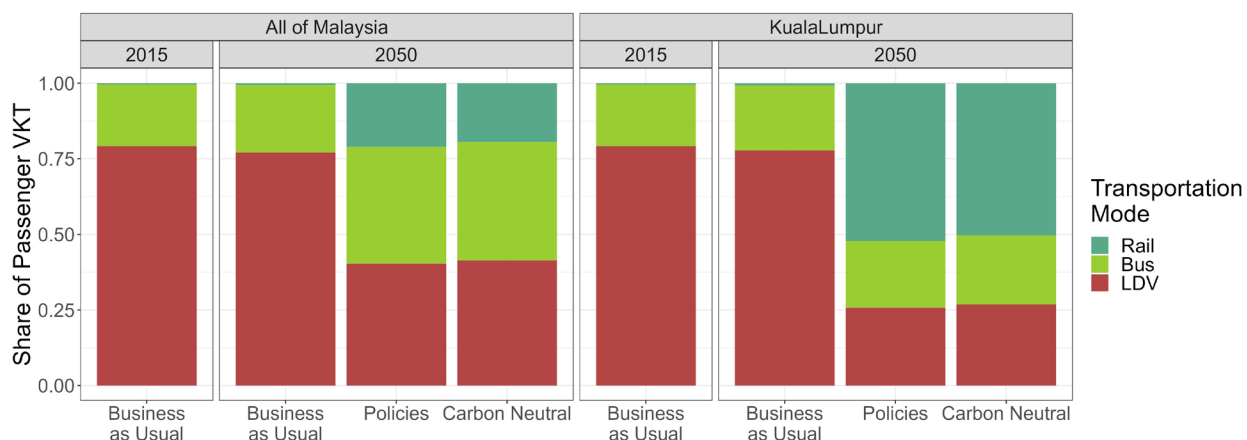


Figure 9. Transportation by mode for Malaysia and Kuala Lumpur. Both the Policies and Carbon Neutral scenarios reflect a significant private to public transportation modal shift.

### 3.4 Advanced technologies: CCS and hydrogen

From Figure 1, we see that the policies implemented are not sufficient to reach carbon neutrality in 2050. Therefore, in the Carbon Neutral scenario, we explore the increased use of advanced technologies including hydrogen and CCS for hard-to-abate sectors. In total, 89 MTCO<sub>2</sub> of emissions are captured in some form, e.g., bioenergy carbon capture and storage, direct air capture, or a change in sinks (Figure 10). This amount is equal to one-quarter of 2050 emissions in a BAU case (Figure 1).

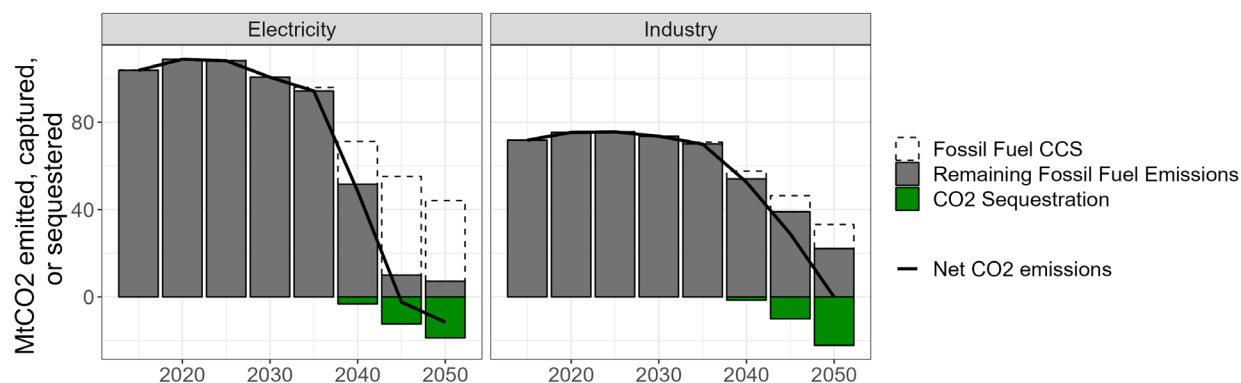


Figure 10. Reaching carbon neutrality in 2050 will require carbon sequestration for the power sector and industry. The dark grey bars represent CO<sub>2</sub> emissions, and the green bars represent CO<sub>2</sub> sequestration technologies. The dashed, white bars represent emissions that are immediately taken up by CCS so that they never reach the atmosphere.

We also explore the impacts of introducing hydrogen in the transportation and industry sectors; Figure 11 shows the breakdown of energy consumption by end-use fuel in the two sectors. In the Carbon Neutral case, hydrogen makes up about 10% of transportation final energy consumption and nearly 20% of industrial energy consumption. This is particularly significant for industry as certain industrial processes depend on the use of fossil fuels, and a shift away from fossil fuels is

necessary to reach carbon neutrality. Introducing hydrogen at a relatively large scale therefore presents an alternate path to decarbonization while maintaining reasonable energy use levels.

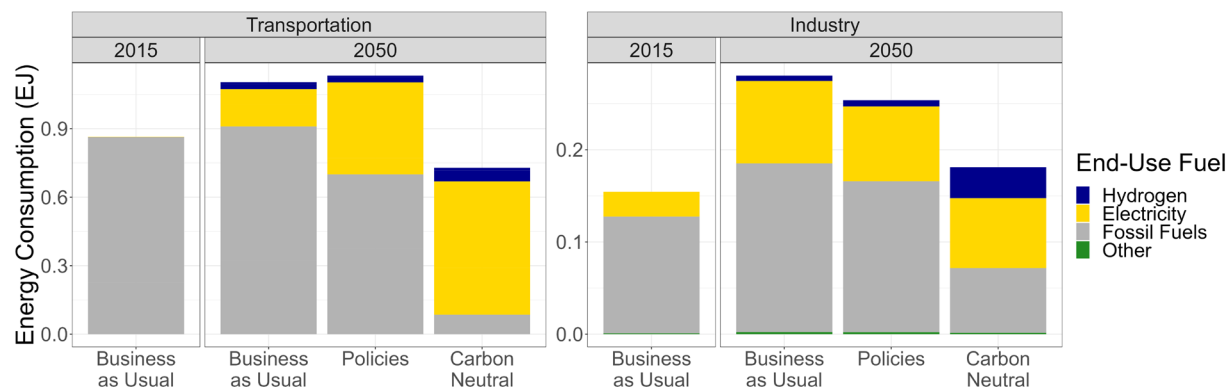


Figure 11. Highlighting energy consumption in industry and the transportation sectors, particularly the amount of hydrogen required (approximately 20% for industry and 10% for transportation) in the Carbon Neutral scenario.

### 3.5 Kuala Lumpur’s contributions

Kuala Lumpur’s direct and indirect emissions in a 2050 BAU scenario total 26 MTCO<sub>2</sub>, or 7% of Malaysia’s emissions. We find that Kuala Lumpur can have a significant impact on Malaysia’s carbon neutrality goal as its emissions reductions make up 7% of total CO<sub>2</sub> reductions across the country. At the city level, Kuala Lumpur reduces nearly 90% of its emissions in the Carbon Neutral scenario relative to BAU. Figure 12 outlines Kuala Lumpur’s emissions in each scenario and the reductions between them. Note that while the city has residual emissions of 3 MTCO<sub>2</sub> in the Carbon Neutral scenario, these are offset by measures at the national level (section 3.3).

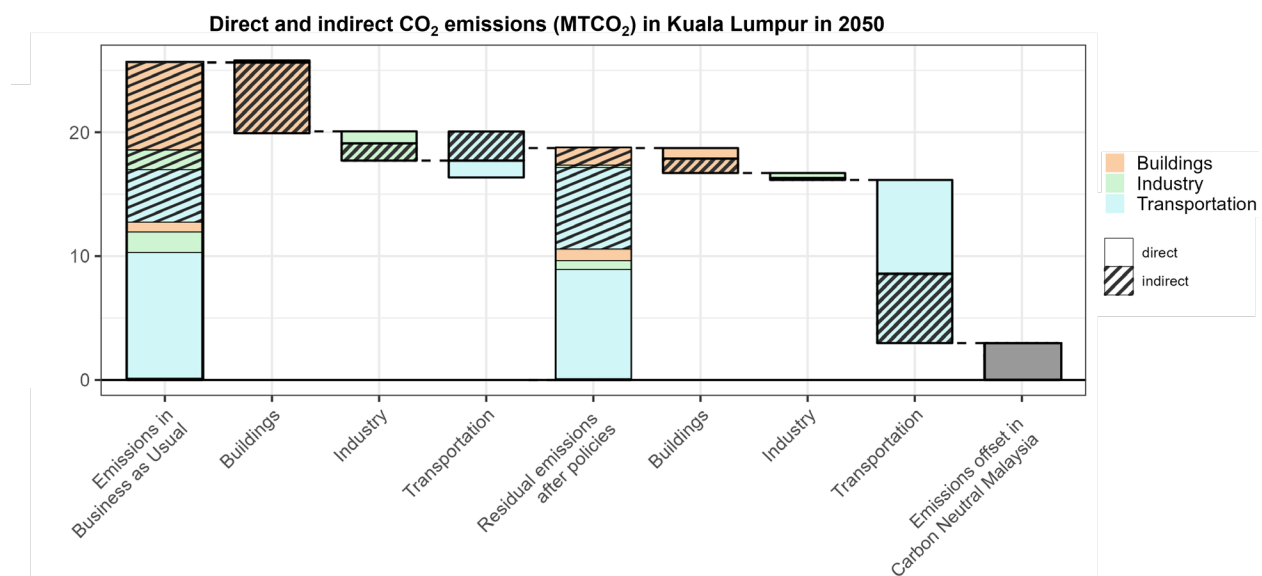


Figure 12. Direct and indirect CO<sub>2</sub> emissions in Kuala Lumpur and the reductions between scenarios. Sectoral emissions are color-coded, and indirect emissions from the power sector are represented by hashed bars.

At the sector level, Kuala Lumpur contributes 13% of Malaysia's total building emissions, 2% of industry emissions, and 13% of transportation emissions in a 2050 BAU case. While industry is a small – but nontrivial – percentage of total emissions, this reflects Kuala Lumpur's relative lack of heavy industry compared to the rest of Malaysia. It is also important to note the impact of indirect emissions in Kuala Lumpur, particularly in the buildings sector. Increased electrification with a scale-up of renewable energy is an extremely powerful mitigation tool, although Kuala Lumpur has limited control over this. Rather, a focus on digitalization and energy efficiency improvements will reduce electricity consumption and therefore, indirect emissions. In the transportation sector, Kuala Lumpur can promote public transportation and electric vehicles, although its influence is limited as it only has jurisdiction within city boundaries; large-scale shifts in transportation need to be supported by the national government.

These two points highlight the importance of collaboration between cities and the national government. Kuala Lumpur can substantially contribute to Malaysia's carbon neutrality goal. However, these efforts need to be supported with similarly ambitious policies at the national level, otherwise, the city's impact will be curbed. Although this work focuses on Kuala Lumpur, this likely applies to Malaysia's other major cities. Therefore, multi-level governance and engagement is a critical element to reaching carbon neutrality, especially as early as 2050.

## 4.0 Recommendations

The following section will build off our model results to provide targeted recommendations in support of the major conclusions discussed above.

### 4.1 Electrification and decarbonization

Malaysia is well positioned to increase renewable energy capacity through solar and hydropower due to abundant sunlight, high rainfall, and its natural topography. Continuing to increase the share of electricity generation from renewables will be a vital component of achieving carbon neutrality as early as 2050. While this transition has begun, Malaysia still relies heavily on fossil fuels. Policy action and early investment can help support a structural shift to renewables. Supporting workers currently employed by oil, gas, and coal companies through vocational training and unemployment benefits could build capacity to support renewable energy infrastructure and garner public support for the transition.

An important part of this transition will be electricity infrastructure that can facilitate and support the distribution of renewable energy produced throughout Peninsular Malaysia to areas where there may not be as much renewable energy potential or storage. Grid modernization and smart grid technologies can be adopted to better utilize existing resources, prevent system failures, and regulate electricity demand and congestion. Tenaga Nasional Berhad, Peninsular Malaysia's largest electric utility company, has taken steps toward grid development, and continued investment will help the utility support Malaysia's energy transition.

Outside of Peninsular Malaysia, Sarawak is increasing its power generation from hydroelectric dams and has plans to expand solar capacity in the next decade. With an abundance of inexpensive, reliable electricity produced from hydropower, Sarawak exports a small amount of electricity to Indonesia. However, exporting to Peninsular Malaysia through undersea cables presents barriers such as high costs and technical obstacles; therefore, while Sarawak's renewable energy infrastructure reduces some of Malaysia's power emissions, Peninsular Malaysia could further reduce emissions by developing its own clean generation methods. Sarawak is also working towards developing green hydrogen, bolstered by its abundance of hydropower; see section 4.3 for a detailed discussion.

### 4.2 Energy efficiency and demand side measures

Adopting newer, energy-efficient technologies and appliances can provide significant opportunities for decarbonizing buildings and industrial processes. For larger companies and real estate portfolios, incentives for sustainable modifications to buildings and compliance with building codes, or disincentives for certain technologies, can successfully reduce energy consumption in buildings. Malaysia has some infrastructure in place here and could expand on the Zero Energy Building Program or MS 1525 to speed up the implementation of energy-efficient appliances and technologies. At the household level, consumers should be reminded that complying with appliance standards and purchasing those that meet minimum energy performance standards will reduce electricity consumption and result in a lower utility bill.

### 4.3 Leveraging advanced technologies

Advanced technologies like CCS and hydrogen can help sequester and reduce hard-to-mitigate emissions. Because these technologies are relatively cutting-edge, early investment, private sector involvement, and strategic planning are necessary to ensure reliable deployment by 2050. Sarawak continues to be a leader here, with funds allocated to research and development of green hydrogen in Malaysia and a strategic plan that includes capacity building and policy support. The state hopes to make hydrogen a competitive energy source by 2030 with a long-term goal of becoming an export hub for green hydrogen. These ambitions may be constrained by limited global demand and high manufacturing costs, although regional cooperation with Korea and Japan may increase the feasibility of Sarawak's plans. In further support of introducing hydrogen to Malaysia, the National Energy Policy 2022-2040 identified creating a clear strategy for developing a hydrogen economy as a priority. An earlier target year for introducing hydrogen will enable an easier transition to carbon neutrality as early as 2050 as the country will experience benefits sooner. A similar approach can be taken for CCS, with an emphasis on early planning and investment and private sector involvement.

Even with proactive planning, the costs associated with these advanced technologies can prevent them from being adopted. Malaysia's tax incentive for CCS capital expenses can help encourage its deployment, as can a carbon price or a policy that regulates emissions from power plants. By putting a price or penalty on emissions, the government can encourage the investment and deployment of CCS. For example, Indonesia has developed a task force to address the facilitation of CCS as well as putting a carbon tax on electricity generated from fossil fuels. This framework (Indonesia's Ministry of Energy and Mineral Resources Regulation 2/2023) covers capturing, transporting, storing, reporting, and verifying carbon. Additionally, Presidential Regulation 98/201 on the Instrument for the Economic Value of Carbon for the Achievement of the NDC and Control addresses a carbon pricing mechanism that ultimately incentivizes CCS. These two regulations may lead to prioritizing investment in CCS and a similar approach could be considered in Malaysia.

### 4.4 Benefits of engaging in multi-level governance

Kuala Lumpur can have a significant impact on Malaysia's emissions, and multi-level governance, cooperation, and synchronization are crucial to align city policies with national goals. Malaysia is currently drafting its Long Term Strategy, opening the door for collaboration with Kuala Lumpur and other major cities like Seberang Perai or Johor Bahru. Greater inclusion and representation from multiple sub-national governments will yield greater buy-in from the cities and can ensure that all parts of the country are represented in the Long Term Strategy. One major benefit of this collaboration is that national policies can facilitate and support city-level action, and in return, cities can contribute to a large share of the national targets and lead the way in implementation. Additionally, opening a dialogue with sub-national representatives allows for a more equitable transition, as a greater number of stakeholders will be heard and accounted for in the strategic planning.

## 5.0 Conclusions

With targeted, ambitious policy action, Malaysia can achieve its goal of carbon neutrality as early as 2050. Our modeling results show that widespread electrification across the building, industry, and transportation sectors is required to reach carbon neutrality. Increased deployment of renewable energy is therefore highly impactful for reducing emissions, considering the significant increase in electricity consumption. On the demand side, energy-efficient measures and smart technologies can significantly reduce energy consumption. This is particularly important for the largely-electrified buildings sector and hard-to-mitigate industrial emissions. In the transportation sector, we find that near-full electrification is necessary to reach carbon neutrality alongside a modal shift. In addition to these measures, carbon neutrality is not attainable by 2050 without the introduction of advanced technologies like hydrogen and CCS. Early investment, and therefore early deployment, is critical. Finally, we see that Kuala Lumpur contributes significantly to Malaysia's emissions and that ambitious city-level policies can have a large impact at the national level. Including cities and a wide range of stakeholders in the development of the country's Long Term Strategy can therefore support Malaysia in achieving its various climate goals.

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