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Breaking the carbon lock-in: Identifying pathways for Malaysia towards a low-carbon future

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ABSTRACT

The Paris Agreement requires countries to break away from carbon lock-in, a particular challenge for traditional oil and gas producers. How can these countries overcome path-dependencies to shift from a fossil fuel heavy system to one relying on renewable energy? Malaysia epitomizes this challenge: the country is the second-largest oil producer in Southeast Asia whilst the fossil fuel energy sector takes up nearly 80 % of total greenhouse gas (GHG) emissions, with coal energy occupying the largest share. To identify leverage points of energy transitions, we model the structural components influencing the Malaysian energy system and assess the dynamics of interrelating factors. Based on stakeholders' input, we identify main factors influencing Malaysia's energy transition, explore their interactions, and use Cross Impact Balances (CIB) to create scenarios. Our analysis reveals the need to simultaneously disperse the centralized political power to a more diverse set of actors whilst introducing green growth recovery packages to break the carbon lock-in. Whilst focused on Malaysia, the findings contribute more generally to our understanding how fossil fuel reliant emerging economies can break path-dependencies inhibiting the clean energy transition.

1. Introduction

The world will not be able to reach net zero by 2050 without the decarbonisation of emerging economies. Yet, emerging economies face additional challenges (Goldthau et al., 2020) which make it even harder to break from the carbon lock-in, the systematic forces that perpetuate fossil fuel-based infrastructure, backed by institutions that reinforce the status quo (Unruh, 2000). The continued economic growth in emerging economies has been accompanied by a growth in carbon emissions. One example are the Asian tiger states (Indonesia, Malaysia, Singapore, Thailand, South Korea and Taiwan) that more than doubled their emissions between 1990 and 2014 from 0.7 to 1.9 billion tonnes. Similar patterns can be observed in India (0.7 to 2.3 billion tonnes) and China, with China having the biggest increase (2.4 to 10.6 billion tonnes). These numbers are partially driven by population growth, which ranges between 15 % in South Korea to 46 % in India and, in particular, increases in emissions per capita, which in the case of China more than doubled (Olivier et al., 2015). At the same time frame, annual growth rates averaged between 4.52 % in Thailand to 9.75 % in China (World Bank, 2023). As emerging economies catch-up with developed nations, their emissions per capita may also rise if recent infrastructure investments and political choices favour the use of fossil fuels. Choices which will be harder (and costlier) to revert in the future because of the path-dependencies they create. If the targets of the Paris Agreement are to be achieved, emerging economies need to break this pattern and decarbonize now (Thompson, 2020).

A country that epitomizes this challenge is Malaysia. Malaysia has seen continued economic and population growth that was accompanied by increased carbon emissions. Whilst Malaysia has great renewable energy potential, its energy system is dominated by fossil fuels and the key energy players of the country are state-owned enterprises, which wield significant political clout. Around 80 % of total greenhouse gas (GHG) emissions in Malaysia are contributed by the energy sector (Ministry of Energy, Science, Technology, Environment and Climate

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Change, 2018), where 71.5 % of that is coal energy generation and 27.2 % from natural gas (Joshi et al., 2023). Coal power plants in Malaysia tend to be of larger capacity and of more recent construction than most alternatives, as shown in Table 1.

Coal's dominance in Malaysia's energy matrix is a recent development. It surpassed natural gas in 2016 and has since steadily increased its total share in the country's power generation. The recent surge in investments in coal power plants will have long-term consequences, as the operational life of these assets can span three decades or even more. Thus, Malaysia suffers from path dependencies in the energy sector which make it hard to break the carbon lock-in. Studying how Malaysia can break the carbon lock-in can provide valuable insights for other emerging economies on how to shift from fossil fuel dependencies to low carbon resources.

As an upper middle income country with a GDP per capita of just above USD 10,000 (World Bank, 2021) and a strong manufacturing base, Malaysia can aspire to capture the opportunities of a green development strategy more readily than developing countries that lack the same educated workforce and financing conditions. Further, the country has vast potential for renewable energies from solar, to hydro, geothermal and biomass and ambitious policies to foster the growth of renewable energy and to achieve net zero by 2050 (SEDA Malaysia, 2021). Whilst the clean energy sector has been growing slowly but steadily since 2001 (Oh et al., 2018), this growth is not sufficient for Malaysia to transition to a low-carbon future (see Fig. 1 for overview of policies and energy mix). Malaysia's energy consumption per capita is the second highest in Southeast Asia, excluding the small oil-rich Sultanate of Brunei, and has been increasing (IEA, 2022). This, combined with the Malaysian government historically lacking in enforcement and implementation of renewable energy policies (Oh et al., 2018) resulted in only 8 % of Malaysia's energy consumption being generated by renewables despite a goal of reaching 20 % by 2025 (Vaka et al., 2020), placing doubts on the achievability of the net zero goal by 2050.

Current energy systems depend to varying degrees on fossil fuels and stakeholders committed to energy reforms find it hard to break path-dependencies to shift towards a less carbon-intensive system. Malaysia is one case of a particularly challenging carbon lock-in. The national economy traditionally depends strongly on fossil fuels which has been used to ensure energy security and reduce energy poverty (Oh et al., 2018). The energy sector is dominated by carbon intensive production and consumption. In 2020, fossil fuels (oil, gas, and coal) accounted for 84 % of total energy production and more than 90 % of energy consumption (BP, 2022). Petroleum and gas are important for not only energy provision, but for local employment. Around one quarter of all jobs in Malaysia are connected to the fossil fuel energy sector (Bhattacharya and Hutchinson, 2022; Economic Planning Unit Prime Minister's Department, 2022). Malaysia is a regional exporter of petroleum products and crude oil, whilst also importing natural gas, coal, and petroleum products. Malaysia is the second-largest oil producer in Southeast Asia and the third largest exporter of liquified natural gas globally. Fossil fuel extraction and refining are an important part of the economy. State-owned oil and gas corporation Petronas provides almost 50,000 jobs alone, supplemented by another 59,000 jobs in upstream, midstream, and downstream activities along the oil and gas value chain. There are about 4000 oil and gas companies operating in the country (Bhattacharya and Hutchinson, 2022). The importance of the sector became very clear when Malaysia was hit hard by the COVID-19 pandemic. The fiscal response packages and recovery measures centred on the job-intensive fossil fuel-based sectors (International Monetary Fund (IMF), 2021) – further deepening, rather than challenging, its carbon lock-in.

Table 1
Average age and capacity of active power plants in Malaysia as of 2023.

Fuel	Total number	Average age (in years)	Average capacity (in MW)
Coal	9	14.6	1355
Gas	36	19.7	512
Dual-fuel	1	38	600
Oil	7	24.42	37.4
Solar	99	5.6	18.5
Biopower	41	10	4.48
Hydro	25	26.16	107

(Source: Authors' calculations based on data from GlobalPower of 218 active power plants.)

The continued far-reaching use of carbon-intensive energy has been justified by government officials as driven by the need to ensure affordable energy and supply energy security. In 1979 a specific National Energy Policy was enacted with the goal to balance the energy trilemma: ensuring adequate supply of energy, efficient use of fuel, and minimize its negative impact to the environment (Economic Planning Unit Prime Minister's Department, 2022). Any attempt to decarbonize the economy will have to break these structures whilst at the same time ensuring that the poorer part of the population does not get left behind.

Clearly, there is no universal solution to break carbon lock-ins, and policy approaches need to be country-specific. The contribution of the present study lies in a contextualised assessment of potential leverage points[1] for shifting towards a low carbon future, using Malaysia as a case. Malaysia is an emerging economy that is heavily reliant on fossil fuels, whilst having a vast potential for renewables, even having a solar PV industry, and a long history of policies to shift towards green growth but the share of renewable energy is still well below 10 % (Economic Planning Unit Prime Minister's Department, 2022; Oh et al., 2018). Liwan et al. (2019) use a quantitative model to produce growth scenarios to analyse the impacts of substitution renewable energies for fossil fuels by modelling GDP, emissions, renewable energies, and population growth. Yet, they do not consider structural barriers that might lead to a carbon lock-in. Zaid et al. (2015) analyse the risk of a carbon lock-in in the Malaysian building sector due to missing policies and legislation. Susskind et al. (2020) use semi-structured expert interviews to identify policy areas and policies that can help to break Malaysia's carbon lock-in, with one of the policy areas being renewable energy. Given Malaysia's track record of having low-carbon energy policies but falling short of delivering, the identification of those polices can only be a first step. The logical and academically relevant next step is to model the main structural components that influence the energy transition, with a view to identifying leverage points that can tilt Malaysia towards a low-carbon future. The results, as the paper will demonstrate, are relevant to fossil-fuel rich developing economies in the Global South more generally, and the (energy) policy choices taken there.

To understand the system dynamics of the Malaysian energy sector and how its carbon lock-in could be overcome, we model structural components that influence the Malaysian energy sector. To identify those and their interactions we engage local energy experts with diverse backgrounds in academia, policy, industry, finance, and civil society. With their inputs, we identify the main factor influencing the energy transition and model the Malaysian energy system dynamics by employing cross impact balance (CIB). By performing succession analysis, we identify leverage points that enable Malaysia to pursue a successful energy transition. We find that several factors are key, among which fiscal stimulus through COVID-19 recovery packages directed towards green growth has been identified as necessary but not sufficient to shift to a low-carbon energy system. Rather, it is essential to simultaneously move away from state-centred to a more market coordinated economy. This shift would unlock the Malaysian energy system by breaking well-established path-dependencies, thus enabling the green recovery packages to unfold their full potential.

The remainder of the paper is structured as follows: Section 2 discusses the Malaysian energy sector, Section 3 entails the methodology,

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[1] We use the concept of leverage points as „places within a complex system (a corporation, an economy, a living body, a city, an ecosystem) where a small shift in one thing can produce big changes in everything“(Meadows, 1999).

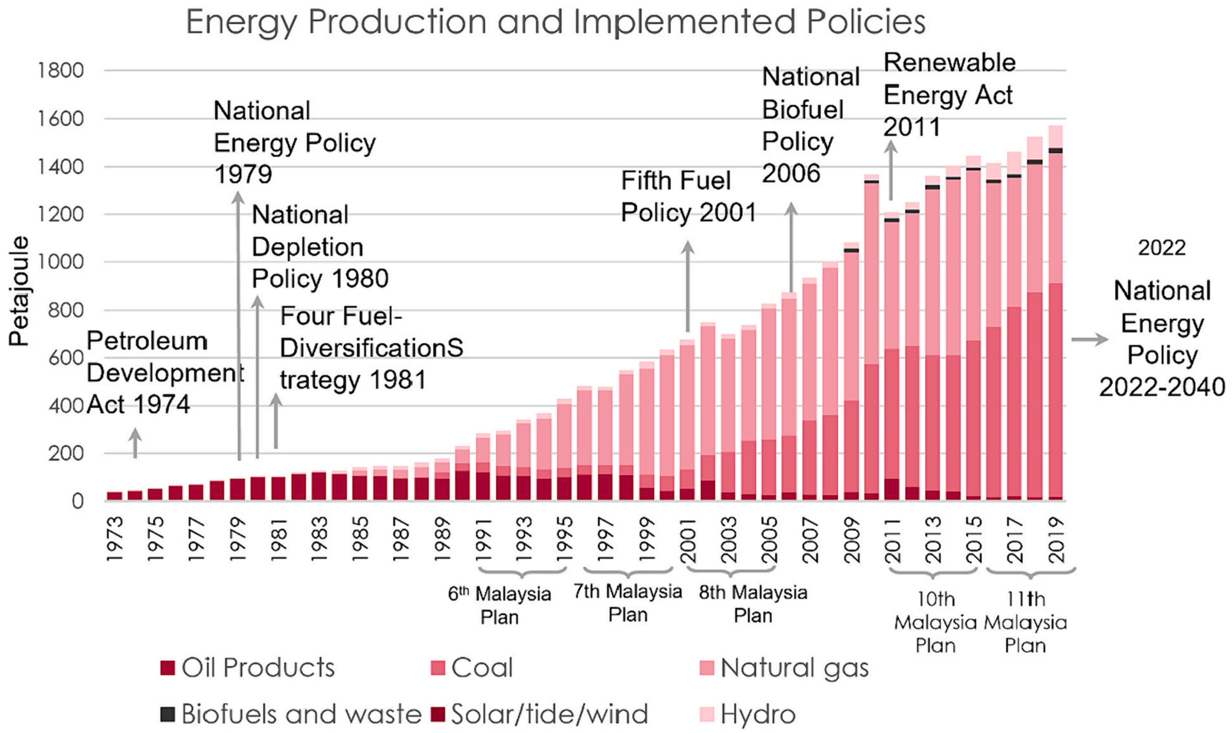

Fig. 1. Overview of Malaysian energy policies and energy sources (based on IEA Sankey Diagram, 2019).

Section 4 presents the results, and Section 5 concludes.

2. Malaysian energy system, policies, and transition barriers

The state and fossil energy are deeply entwined in Malaysia and the centralized system of power makes change difficult. Malaysia is a constitutional elective monarchy with a federal state parliamentary but the power concentrates heavily on the Office of the Prime Minister (Croissant, 2022). This power concentration also impacts the energy transition in Malaysia via different channels such as policies, ownership, or infrastructure.

The Malaysian energy sector is regulated by three main governmental entities. The key policymaker is the Ministry of Energy and Natural Resources (KeTSA) (Ministry of Energy and Natural Resources, 2022) but its work is complemented by the Energy Commission which is responsible for the regulation of energy supply activities and safety (Parliament of Malaysia, 2001) and the Sustainable Energy Development Authority (SEDA) whose main task is to develop the renewable energy sector. Further, in the oil & gas sector, the national oil company. PETRONAS, is both a regulator and operator of upstream activities, and also has significant footprint in the rest of the value chain like refining and petrochemicals (Bowie, 2001).

Deliberate policies on energy production started in the 1974 with the formation of the Petroleum Development Act 1974 (see Fig. 1), leading to the formation of PETRONAS (Abdul-Manan et al., 2015). The Malaysian government has policy plans that aim to increase and diversify renewable energy, ramp up biofuel production, develop the renewable energy sector, and conserve the environment (Abdul-Manan et al., 2015). In September of 2022, the government published a new National Energy Policy 2022–2040, with a stated bold ambition towards driving Malaysia to a low-carbon development pathway. The policy includes both renewable and non-renewable sources of energy, aims to strengthen existing energy-related policies and future-proof Malaysia's energy sector to align with the global transition towards environmental sustainability, green growth, and net zero carbon. One key proposal is the setting up of National Energy Council as a policy and coordinating body, to be chaired by the Prime Minister (Economic Planning Unit Prime Minister's Department, 2022). This plan, as the others before, has commendable goals, yet, whether these will be reached will depend strongly on the different government entities breaking away from traditional working modes.

The dominant role of the state is particularly prominent in the electricity market (see Fig. 2 for overview). Malaysia currently adopts a Single Buyer model, where a government-backed central authority procures electricity from power suppliers through contract, but within the largest state-owned power producer, TNB. The Single Buyer is mainly in charge of planning and managing generator agreements for procuring electricity, whilst preparing demand forecast reports and long-term capacity (Single Buyer, 2017), buying electricity on a least-cost approach. Grid System Operator serves to manage and regulate the grid, according to the Grid Code to ensure the proper functioning of the electric grid system (Grid System Operator Malaysia, 2022), with the transmission and distribution through the grid being owned by TNB in Peninsular Malaysia (Kumar et al., 2021). Both the Single Buyer and Grid System Operator are regulated by the Energy Commission. From the energy generation side, the energy sector is heavily reliant on state-owned enterprises such as TNB for Peninsular Malaysia, Sarawak Energy Berhad (SEB) for Sarawak and Sabah Energy Corporation (SEC) in Sabah. Independent power producers (IPPs) were introduced in 1993 through the award of licences to build, operate, and own power plants in an effort to match energy generation demand (Kumar et al., 2021; Lima-De-Oliveira and Varming, 2020; Sibeperegasam et al., 2021).

Not only is the energy supply infrastructure carbon-intensive, it is also owned by the state. Even though there have been changes implemented that aim at the diversification of energy producers as well as the kind of energy produced, the whole sector is still very state-centred. This state-dominance leads to a strong institutional lock-in since the state is the main producer of energy, whilst also being the single electricity buyer and designer of policies. The country's GHG inventory (for the baseline year 2014) estimates total emissions as 317 Mt. (CO_2eq), 80 % of which comes from the energy sector, and a growing trend across all sectors (energy, industry, agriculture, waste) between 2005 and 2014

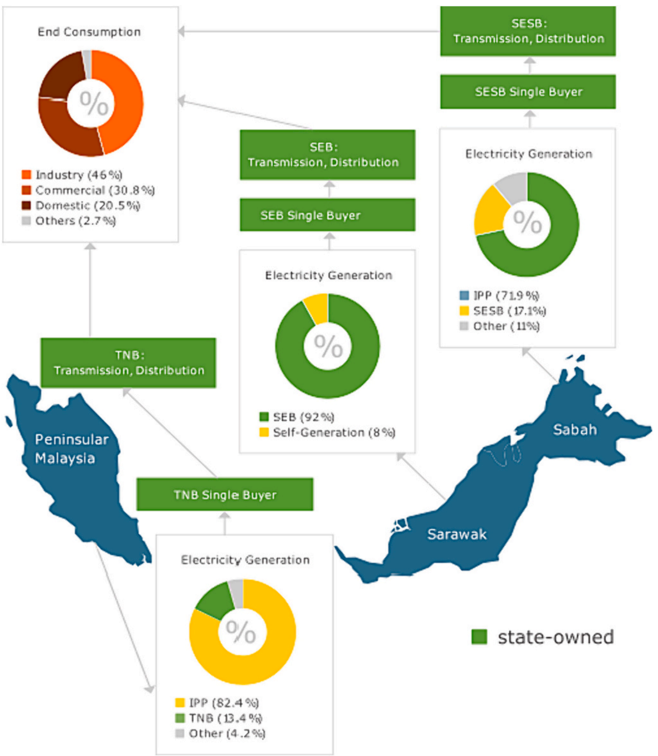

Fig. 2. The Malaysian electricity sector.

Note: The Malaysian electricity sector: state-owned companies as well as independent electricity producers are involved in production. The respective state-owned single buyer purchases the produced electricity and state-owned companies are responsible for transmission and distribution. Numbers taken from Suruhanjaya Tenaga (Energy Commission), 2020.

(28 %, 34 %, 8 %, 29 %) (Ministry of Energy, Science, Technology, Environment and Climate Change, 2018). In sum, Malaysia is still heavily reliant on fossil fuels and projected to remain so, despite a long history of policies that aim to decarbonise the system and plenty of natural resources to generate renewable energy. Given the complexity of carbon lock-in, it is necessary to analyse structural components that affect the Malaysian energy transition.

3. Methods

3.1. Overview

To understand the system dynamics of the Malaysian energy sector, we identified and modelled structural factors as variables that could impede or promote energy transitions. Many of these variables can only be described qualitatively and are hard to quantify but are clearly key to systemic change, such as the "political economy structure" and "electricity market structure". To analyse the influence of these variables on energy sector outcomes, we used a scenario analysis technique called Cross Impact Balances (CIB) (Weimer-Jehle, 2006, 2023). Importantly, CIB allows modelling the interaction of the pertinent variables (or *descriptors*, in CIB parlance), and their respective end-states (i.e., how the variables unfold in the future). It therefore enables the assessment of systemic changes of that sector depending on distinct combinations of variables and their potential future development.

To apply CIB, we first identified variables that are important for energy transition dynamics, globally as well as more specifically in the Southeast Asian context. Next, we conducted semi-structured interviews with Malaysian energy experts to assess which of these pre-identified variables are the most influential for the Malaysian energy transition. The selected variables serve as the descriptors in the scenario development process. Subsequently, we organized a two-day workshop with Malaysian energy experts where they co-produced influence diagrams, showing how different descriptor-variants influence one another. These diagrams were then translated into a matrix for formal CIB analysis to produce internally consistent scenarios for the Malaysian energy sector by 2050. Lastly, we analysed how to get to the most desirable scenarios using succession analysis and identified leverage points to move the energy transition towards a desirable state (see Fig. 3 for overview of research process).

3.2. Variable selection

To identify key variables, we held a global two-day online energy expert workshop in February 2021 (Fig. 3, step 1). Here, 22 experts from different backgrounds and country expertise (we refer to them as global experts) debated in a plenary setting which variables are of particular importance for energy transition dynamics and how these variables may differ between regions. A smaller sub-group of energy experts with regional expertise then discussed which variables are most relevant for Southeast Asian countries, and how the variables could change by 2050 (see Kurniawan et al. (2022) for details). Results from the workshop informed the selection of the variables (or descriptors) and their end-states (or variants). End-states are mutually exclusive depictions for how each variable would unfold; for example, the political economy as a variable can either resume the end-state of a liberal, a coordinated, or a centralized market.

Next (Fig. 3, step 2), we consulted Malaysian energy experts from different backgrounds such as policy, research, finance, industry, and civil society.[2] Rather than relying on literature and/or international academics who are often from the Global North, we worked with local experts directly since they can provide deeper insights into the local context. Ten Malaysian experts were engaged in semi-structured interviews to discuss which of the predetermined variables from the global workshop would be relevant to explain Malaysian energy transition dynamics. The experts ranked the different variables based on how influential they are for energy transition processes until 2050. To do this, experts placed these de-contextualised global variables in the local Malaysian context. We also encouraged the experts to suggest any other variables that might be particularly influential in the Malaysian context that had not been identified in the regional workshop transition (see Appendix A.2 A.2 List of variables and end-states including definitions and A.3 for an overview of interview questions and variablesA3 Interview questions). The six variables with the highest ranking were chosen as descriptors for the CIB scenario analysis. Additionally, we added three descriptors (value chain participation, investments in renewables, technology knowledge sharing) that were previously identified as highly influential in energy transition dynamics (Eicke and Goldthau, 2021; Zhang and Gallagher, 2016) and specifically for countries of the Global South (Goldthau et al., 2020). In total, we used nine descriptors for CIB analysis to produce energy transition scenarios. These descriptors were

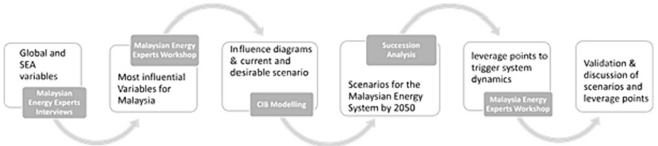

Fig. 3. Data collection and analysis overview.

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[2] Experts kindly agreed to take part in our study under the precondition that their affiliations and names be kept anonymously since they did not speak on behalf of their organization but rather as individuals that have expertise in the sector.

namely "Value Chain Participation", "Investments in Renewables", "Technology Knowledge Sharing", "Political Economy Structure", "Energy Projects", "Political Stability", "COVID-19 Recovery", and "Infrastructure Development" (see Table 2 for definitions).

3.3. Consistent participatory scenario development

Developing consistent scenarios using CIB can be done in a participatory manner. In this research, we deployed the participatory CIB approach developed by Kurniawan et al. (2022). Accordingly, we engaged participants to co-create influence diagrams based on a morphological analysis. The latter was translated into a CIB matrix for subsequent scenario development and analyses. We ran a two-day stakeholder workshop in November 2021, involving Malaysian energy experts from various sectors such as public service, research, finance, industry, and civil society (Fig. 3, step 3). The participants were selected based on their role as key stakeholders within the Malaysian energy sphere, identified by locally based cooperation partners, notably the well-reputed Institute of Strategic & International Studies (ISIS) Malaysia and the Asia School of Business (ASB). The workshop was attended by 22 participants across relevant sectors.

Table 2
Overview of descriptors, their definitions, and variants.

Descriptors (variables)	Definitions	Variants (end-states)
V1: Value Chain Participation	This variable describes whether and how Malaysia (Malaysian companies or companies located in Malaysia) is part of a global value chain of renewable energy technologies, such as wind turbines or solar panels.	1) Only Manufacturing 2) Only Knowledge (R&D) 3) Only Resource/Raw Material Producers 4) Combination of Segments 5) No Participation
V2: Investments in Renewables	The variable refers to the amount of national and international, public, and private investments in renewable technologies in Malaysia.	1) High 2) Medium 3) Low
V3: Tech Knowledge Sharing	The degree to which the producers of renewable energy technologies engage in knowledge transfer with Malaysia.	1) No Skill or Knowledge Sharing 2) Some Skill Sharing 3) Extensive Knowledge Sharing
V4: Political Economy Structure	The degree to which firms, collective actors or state institutions shape the country's economic structure.	1) Liberal Market Economy 2) Coordinated Market Economy 3) State-centred Capitalism
V5: Electricity Market Structure	The organization of the electricity market, based on the number and structure of market participants	1) Monopoly 2) Oligopoly 3) Perfect Competition
V6: Energy Projects	The characteristics of energy installations: what kinds of fuel they use, and how centralized they are.	1) Mostly Centralized Fossil Fuels 2) Mostly Centralized Renewable Energies 3) Mostly Decentralized Renewable Energies
V7: Political Stability	Political stability in the course of a country's energy transition. Political stability can refer to stability of the political system, the absence of protest and peaceful changes in government.	1) High 2) Medium 3) Low
V8: COVID-19 Recovery	The impacts of COVID-19 and government recovery policies on the economy: whether there will be stagnation, fast (mainly green) growth, or fast (mainly "coal-fired") growth.	1) Stagnation 2) Fast and Mainly Green Growth 3) Fast and Mainly "Coal-fired" Growth
V9: Infrastructure Development	The degree to which infrastructure (e.g., in cities, buildings, and transport systems) growth is sustainable in terms of the use of non-renewable resources.	1) Sustainable Expansion 2) No Growth 3) Unsustainable Expansion

During the workshop participants discussed how given descriptors interact with each other by drawing arrows linking the pertinent descriptor-variants (see Fig. A 1 for overview of all variants and their definitions). Participants focused on direct promoting or enabling influences only. For example, when participants agreed that 'high' political stability (V7) would directly and positively promote 'high' investments in renewables (V2), an arrowed line from V7 (High) to V2 (High) would be drawn. For this task, participants worked in smaller subgroups. Each group consisted of a diverse set of participants with different backgrounds to minimize biases. Within these groups, unanimity on the connections drawn was encouraged. When there were disagreements, further elaborations on the feasibility of the connections were discussed in the plenary.

The second part of the two-day workshop was allocated to verifying the influence diagrams produced on day one. Participants worked in different subgroups to assess the influence diagrams. More specifically, they discussed which connections were valid and invalid. The invalid connections would be flagged for deletion. The final consensus decision to keep or delete connections was taken in the plenary as a group. By the end of the workshop, the deliberation resulted in influence diagrams that were drawn and validated by energy expert participants from Malaysia.

Next, the influence diagram was translated into a CIB matrix using CIB software - ScenarioWizard (Weimer-Jehle, 2018) to search for internally consistent scenarios (Fig. 3, step 4). The matrix documents how the variants of the descriptors (rows) influence other descriptor variants (columns). Since the influence diagrams were produced based on participants' inputs, the CIB matrix reflects expert judgments. The latter were translated using a 5-points Likert scale where '0' denotes no influence, 'positive (+)' denotes promoting influences (+1: weakly promoting, +2 strongly promoting), and 'negative (−)' denotes inhibiting influences (−1: weakly inhibiting, −2 strongly inhibiting). As mentioned previously, we elicited from participants only the promoting influences. For example, high investments in renewables (V2) were deemed to promote or encourage centralized or de-centralized renewable energy projects (V6: variant 2 and 3). Because the high investments would promote variant 2 and 3 of V6, we assumed that variant 1 (centralized fossil fuel) would be concurrently discouraged as a result. This adhered to the CIB theoretical foundation that the sum of all judgments for such an interaction will be 'balanced'. In the above example we assigned a + 1 to the effect of high investments in renewables as well as on centralized or de-centralized renewable energy, and, to keep this judgment group balance (i.e. the sum of all judgments equal zero), a − 2 would be assigned to centralized fossil fuels. Having thus transformed qualitative judgments into numerical values in the matrix, CIB analysis computed the resulting interactions between these qualitative variables. The internally consistent scenarios in CIB comprise one variant from each descriptor. The requirement of an 'internal consistency' refers to a scenario that has its descriptor-variants self-reinforcing. That means the descriptor-variants collectively are promoting or inhibiting one another creating causal loops. In contrast, inconsistency refers to the fact that there are no self-reinforcing causal loops in the system (see Fig. A 2 for an example). The algorithm used in ScenarioWizard evaluates the internal consistency of scenarios by calculating the 'impact balance' score (IS). This score is the columnar sum of all highlighted matrix cells for a selected scenario combination (denoted by highlighted rows in Fig. A 2). When a scenario has lower descriptor-variants than others, that descriptor is flagged as inconsistent (see Fig. A2, V04 for an example of an inconsistent descriptor). After having identified inconsistent descriptors, the CIB algorithm searches for more consistent descriptors, referred to as succession step in CIB parlance. A combination of consistent descriptor-variants is considered to be an internally consistent scenario. CIB algorithms also provide a measure of the plausibility of the scenario by computing the 'total impact balance score' (TIS) (the sum of the impact balance scores) of each consistent scenario (Weimer-Jehle et al., 2020). A scenario with a higher TIS is considered more likely to unfold in the future compared to other scenarios with lower TIS.

To analyse the scenarios for Malaysia by 2050, we also asked participants to identify scenarios that would best describe (1) the most desirable future for Malaysia by 2050 and (2) the current condition in 2021 (Fig. 3, step 4). This serves a dual purpose; first, it provided a reference frame for the scenarios identified through CIB and, second, it ensures this reference frame is contextualised. By allowing participants to define how the Malaysian energy system should look like by 2050, we avoided imposing our ideas and, thus, potentially biasing our results. For the current and desirable scenarios, we took the variant with the most votes and in the case of a very narrow difference we report both variants (e.g., decentralized and centralized renewable energy systems, see Table 3).

We use succession analysis to identify descriptors in the system that, when they are changed, could trigger a cascading effect (Fig. 3, step 5). Succession analysis starts with a scenario lacking internal consistency, the succession steps move to different scenarios (by changing the inconsistent variants), arriving finally at one of the consistent scenarios. Hence, succession analysis is useful in studying system's dynamics through assessing scenarios lacking internal consistency. We began the succession analysis with current scenario that represents the existing conditions in Malaysia 2021 (column 2 in Table 2). Then, we introduced a change in one of the descriptor-variants and observed the steps taken for the succession steps to arrive at the desirable scenario for Malaysia 2050 (column 3 in Table 2). In our case, the desirable scenario is an inconsistent scenario; therefore, the succession steps would preferably arrive at one of the consistent scenarios that are the closest to the desirable scenarios: scenario #13 and #14 (column 4 in Table 2). Upon arriving at the consistent scenarios, the change of the descriptor-variant initiated at the beginning is a leverage point to arrive at the consistent scenario. What resulted in desirable or undesirable scenarios from the current scenario can be associated with what first triggered the change.

To understand how to get to a low-carbon future desirable future, we changed one descriptor-variant at the time and recorded the consistent scenario resulting from this change. Interestingly, the change in one descriptor-variant did not necessitate the outcome of arriving at the desirable scenarios (see discussion in Section 4.3). Hence, we took another step in running the succession analysis by changing two descriptor-variants at the same time to arrive at the scenario closest to the desirable scenario. Changing two descriptor-variants means that there are two leverage points that simultaneously trigger changes in the system towards a desirable state. We validated the results by holding another expert workshop where we presented and discussed the scenarios and the identified leverage points (Fig. 3, step 6).

4. Results and discussion

4.1. Factors shaping the Malaysian energy system

By applying CIB analysis on the main nine descriptors representing the Malaysian energy system we were able to identify active and passive descriptors. Active descriptors are those that impact or influence a large number of other descriptors. Changing the variant of the active descriptors would potentially change the overall system's behaviour, whereas passive descriptors only receive influences from other descriptors. Hence the change in variants of passive descriptor would least likely change the system's behaviour. Political economy structure (V4) has the most influence system-wide, followed by political stability (V7) and post COVID-19 recovery measures (V8) (with high active sum, see Fig. 4). Interestingly, and somewhat counterintuitively, the investment in renewable energy (V2) and the type of energy projects (V6) are the two most passive descriptors (with high passive sums, see Fig. 4). Thus, increasing investments in renewable energy (changing the variants from low to either medium or high) through, for example, policies, will not trigger a systemic shift in the system, but changing the variants of the active descriptors will. COVID-19 recovery measures, political stability, and political economy structure can be shaped by policies. We, therefore, adopted these three active descriptors as the starting points for succession analysis. To anticipate the potential system dynamics, we next discuss the produced scenarios for 2050, identify those scenarios that are deemed desirable, and analyse how we can achieve those scenarios by triggering changes in the system.

4.2. Energy scenarios for 2050

Overall, the CIB analysis identified 26 consistent scenarios on how the Malaysian energy sector could develop until 2050. The most consistent scenarios (that is, with the highest TIS) are scenario #1, #2, and #3, but these scenarios are the least aligned with the desirable scenarios (Fig. 5). None of the scenarios identified were dominated by fossil fuels by 2050. Out of the 26 scenarios, only 6 scenarios depict a future in which the Malaysian energy system runs mainly on decentralized renewable energy, whilst all others project a centralized renewable energy system. The majority of scenarios in which the

Table 3
Important scenarios to analyse the energy transition in Malaysia.

Scenarios/descriptor	Current: Malaysia 2021	Desirable: Malaysia 2050	Scenario(s) closest to desirable Energy System (13/14)	Scenario close to desirable Energy System (5)
Value Chain Participation (V1)	Combination	Combination	Combination	Combination
Investments in Renewable Energy (V2)	Low	High	High	High
Int. Tech Knowledge Sharing (V3)	Some	Extensive	Extensive	None
Political Economy Structure (V4)	State-centred	Coordinated market	Coordinated market	State-centred
Electricity Market Structure (V5)	Monopoly	Oligopoly	Oligopoly	Oligopoly
Type of energy projects (V6)	Mainly centralized fossil fuels	De-/centralized renewable energy	De-/centralized renewable energy	Centralized renewable energy
Political Stability (V7)	Medium	Medium	Medium	High
COVID-19 Impacts (V8)	Stagnation (or very little growth)	Fast green growth	Fast green growth	Fast green growth
Infrastructure development (V9)	Unsustainable expansion	Sustainable expansion	Unsustainable expansion	Sustainable expansion

Notes: *Current* refers to how participants defined the energy system landscape in 2021. *Desirable* depicts where participants would like to see Malaysia by 2050. *Closest to Desirable* identifies those scenarios that the CIB found to be stable, are closest to the desirable but cannot be achieved within our model, and *Close to Desirable* scenario is the scenario that out of all the scenarios identified is closest to the desirable and can be achieved within our model.

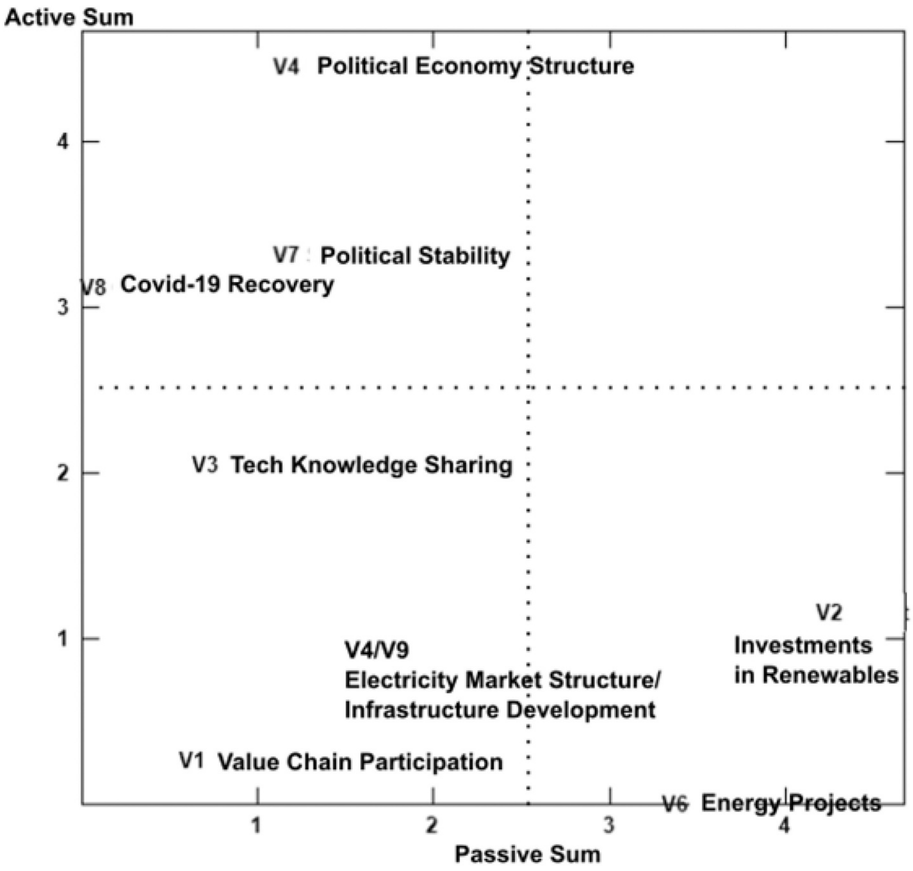


Fig. 4. Active and passive components of the Malaysian Energy System.

COVID-19 recovery packages stimulate green growth also have high investments in renewables (7 out of 11), but only two show a sustainable infrastructure development. We also find no scenario in which the electricity market is a monopoly, 23 scenarios projected an oligopolistic market.

The desired scenario (Fig. 5, yellow boxes), indicates clearly that the goal to shift from a mainly fossil fuel based economy to a system that is mainly fuelled by renewable energy. It is less important whether the system is centralized or decentralized. Further, the ideal scenario highlights that the COVID-19 recovery packages should foster fast green growth, infrastructure development should become more environmentally sustainable, and people see the need to increase the investments into renewable energy in general. Lastly, the current state-centred political economy structure should move to a coordinated market system. The current electricity market is mainly characterized as a monopoly which should be broken up to change to an oligopoly (Table 3).

The scenarios with the highest plausibility (highest TIS) are characterized by state-centred capitalism (Fig. 5 V4; scenario #1 to #11). These scenarios indicate that it is hard to change to a coordinated or even liberal market which is what was indicated as desirable. Further, these scenarios indicate that investments in renewables (V2) will remain low whilst international technology knowledge sharing (V3) is either non-existent or low. Yet, even in these scenarios we find that Malaysia might manage a shift towards an energy system with mainly centralized renewable energies. The caveat is that the enabling factor seems to be low political stability. This could indicate that a potential political vacuum might be used to push for more renewable energy.

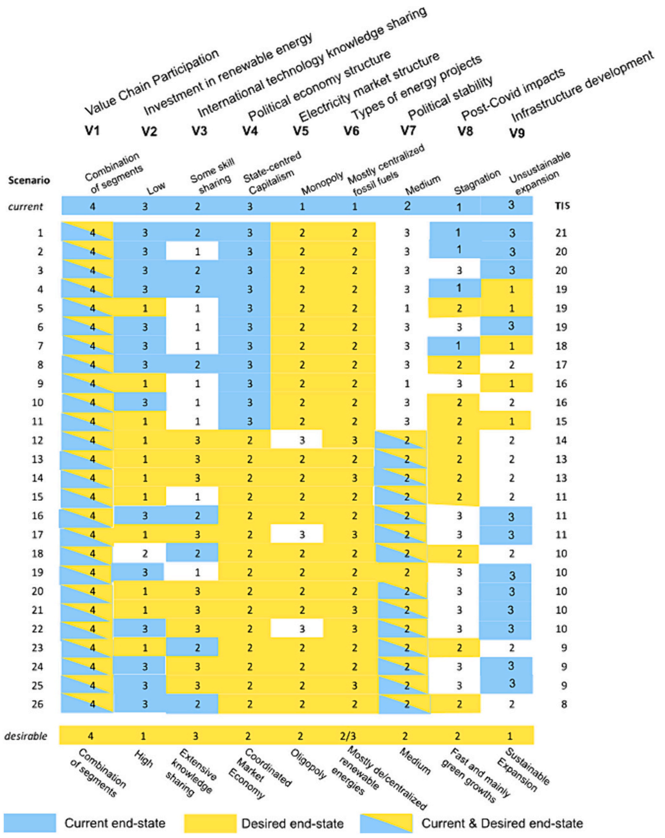
Of course, political instability is not a future state that is deemed desirable. The two scenarios closest to the desired one (centralized renewable energy for scenario #13, decentralized renewable energy for scenario #14) report medium political stability and differ only in infrastructure development (V9) from the desirable scenario. Nonetheless, both scenarios still depict an infrastructure development (V9) that is unsustainable. Although scenarios #13 and #14 are the closest aligned to the desirable scenario, these two scenarios have lower consistency scores (TIS = 13). In other words, when left alone the scenario #1 would be the highest plausible depiction of the Malaysian's energy future. Yet, scenario #1 is not the future that Malaysia would like to envisage. The question therefore remains: how to get to a scenario that is closest to the desirable ones?

4.3. Identifying leverage points

In order to identify the variables that are crucial for achieving the favourable outcomes for Malaysia, we use succession analysis to detect leverage points that can trigger system dynamics to shift to a more desirable scenario. We started with the configuration identified as the current scenario by the stakeholders and applied succession analysis to identify descriptors that trigger cascading effects in the system, starting with the active descriptors.

The COVID-19 recovery (V8) was found to be an active descriptor that can easily be changed with policy instruments. The succession analysis started by changing the variant of V8 from stagnation to green growth. Subsequent succession steps triggered changes that lead to scenario #10, in which infrastructure development (V9) sees no growth, and investment in renewable energy (V2) is low. Additionally, other descriptors such as technology knowledge sharing (V3), political economy structure (V4), and political stability (7) are not aligned with the desired scenario (Fig. 6, Part A). This suggests that even with proper measure for COVID-19 recovery by pursuing green growth, the outcome would not lead to the desirable scenario.

We further observed the outcomes of succession analysis when changing other active descriptors. Given the prominent role of political economy structure (V4) in the Malaysian energy system, which is also an



Scenario	V1 Value Chain Participation	V2 Investment in renewable energy	V3 International technology knowledge sharing	V4 Political economy structure	V5 Electricity market structure	V6 Types of energy projects	V7 Political stability	V8 Post-Covid impacts	V9 Infrastructure development	TIS
	Combination of segments	Low	Some skill sharing	State-centred Capitalism	Monopoly	Mostly centralized fossil fuels	Medium	Stagnation	Unsustainable expansion	
current	4	3	2	3	1	1	2	1	3	TIS
1	4	3	2	3	2	2	3	1	3	21
2	4	3	1	3	2	2	3	1	3	20
3	4	3	2	3	2	2	3	3	3	20
4	4	3	2	3	2	2	3	1	1	19
5	4	1	1	3	2	2	1	2	1	19
6	4	3	1	3	2	2	3	3	3	19
7	4	3	1	3	2	2	3	1	1	18
8	4	3	2	3	2	2	3	2	2	17
9	4	1	1	3	2	2	1	3	1	16
10	4	3	1	3	2	2	3	2	2	16
11	4	1	1	3	2	2	3	2	1	15
12	4	1	3	2	3	3	2	2	2	14
13	4	1	3	2	2	2	2	2	2	13
14	4	1	3	2	2	3	2	2	2	13
15	4	1	1	2	2	2	2	2	2	11
16	4	3	2	2	2	2	2	3	3	11
17	4	1	3	2	3	3	2	3	3	11
18	4	2	2	2	2	2	2	2	2	10
19	4	3	1	2	2	2	2	3	3	10
20	4	1	3	2	2	2	2	3	3	10
21	4	1	3	2	2	3	2	3	3	10
22	4	3	3	2	3	3	2	3	3	10
23	4	1	2	2	2	2	2	2	2	9
24	4	3	3	2	2	2	2	3	3	9
25	4	3	3	2	2	3	2	3	3	9
26	4	3	2	2	2	2	2	2	2	8
desirable	4	1	3	2	2	2/3	2	2	1	
	Combination of segments	High	Extensive knowledge sharing	Coordinated Market Economy	Oligopoly	Mostly de/centralized renewable energies	Medium	Fast and mainly green growths	Sustainable Expansion	

Fig. 5. Scenario overview for Malaysia by 2050 in comparison to current and desirable scenarios. (For interpretation of the references to colour in this figure, the reader is referred to the web version of this article.)

active factor through CIB, we introduced a change from state-centred to liberal or coordinated market to assess whether the changes would be sufficient to trigger the wanted system dynamics. Yet, whilst a shift away from a state-centred economy would trigger some changes (oligopoly in the electricity market structure (V5) and the type of energy projects (V6) are mainly renewables), the other descriptors in the system appear too rigid and unchanged. We also find that these changes in the political economy are not permanent since we ended up with a scenario depicting a state-centred economy again (Fig. 6, Part B1 and B2).

We tested all descriptors individually but did not identify a single factor that is able to put Malaysia on a trajectory that leads to a scenario that is deemed most desirable by participants. However, one mechanism observed in every succession analysis is that changing electricity market structure (V5) from monopoly to oligopoly (or liberalised market) is necessary promote a shift to mainly renewables (either centralized or decentralized).

Subsequently, we performed succession analyses again, but this time we introduce changes to two descriptors. We introduced changes with combinations of two (out of three) active descriptors and observed the outcomes leading to the desirable scenario (i.e. scenario #13 or #14 are the closest to the desirable scenario). We found that shifting away from a state-centred political economy (V4) whilst setting COVID-19 impacts (V8) to stimulate green growth unlocks the system. However, scenarios #13 and #14 are still unattainable. Instead, the most feasible outcome is scenario #5, which is the closest to the desirable scenario. To be able to utilize the COVID-19 recovery packages to stimulate green growth (energy systems mainly running on renewable energy, sustainable infrastructure development) it is necessary for the state to disperse some of its power. We find that an initial shift towards a more liberalised economy triggers the wanted changes (from state-centred to a liberalised economy). Our analysis suggests that simultaneously changing political economy structure (V4) to liberalised market and COVID-19 recovery (V8) to green growth would result in high investments in renewables (V2), oligopoly in the electricity market (V5), centralized renewable energy projects (V6), and sustainable infrastructure development (V9). Having achieved these changes, high political stability (V7) and the switch back to state-centred from liberalised market (V4) would proceed (Fig. 6, Part C). The succession steps present a pathway leading to scenario #5 where, the government would have to disperse its influence on the market economy to achieve a liberalised market initially and thereafter reconsolidates its market influence again, reverting back to a state-centred economy.

5. Conclusion and policy recommendations

5.1. Conclusion

Achieving a transition towards renewable energy is a challenge for any country but especially for emerging economies like Malaysia that produce and rely on carbon intensive energy. Breaking this carbon lock-in poses challenges, especially for countries from the Global South since they struggle with access to technology and capital, managing the energy trilemma whilst also having to ensure that internal structures and policies allow a shift towards renewables. Whilst these challenges apply to a lot of countries, the solutions can be vastly different. Thus, modelling the structural components for individual countries is necessary to identify leverage points. Expanding this analysis to more countries in the Global South can provide input on commonalities and thus guide policy makers.

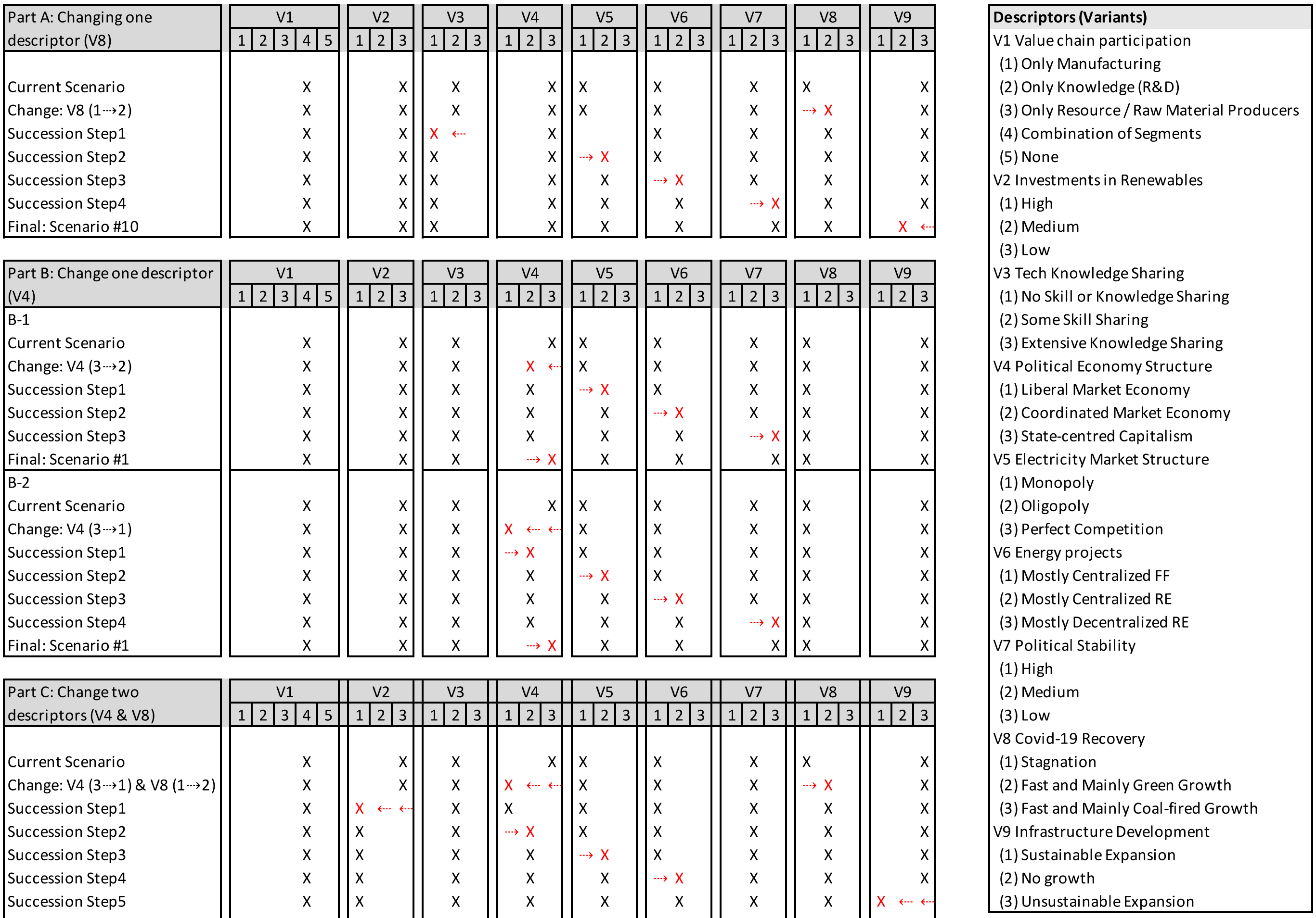
By modelling the main internal and external features of the Malaysian energy sector we are able to identify the leverage points that unlock the system. One of these are post COVID-19 recovery measures, which can be used to channel funding and redirect policies towards a green growth trajectory. Yet, these measures are not sufficient to unlock the system just as Smith et al. (2021) had cautioned. Whilst we modelled COVID-19 measures explicitly, our results can be applied in a wider context. These measures can be seen as an example for any big fiscal policy measure and its potential limitations. We can clearly see that ramping up investments without structural change might not yield the envisioned results.

With the aid of CIB, we model the Malaysian energy system and find a high institutional and infrastructural path-dependency. Our results confirm that the state-centred nature of the Malaysian energy system contributes to carbon lock-in. Systemic change therefore requires a concerted effort of different actors within the political system and the inclusion of new actors. In order for the COVID-19 relief measures to successfully shift the energy system out of the carbon lock-in towards renewable energies, these path-dependencies need to be broken up.

Whilst our results are in line with the literature, they can only inform us to a certain extent. Even though utmost care was taken to include a diverse range of stakeholders, this is still only a small sample of all the stakeholders that could have been asked which means potential for somewhat biased results. But, by ensuring that all present stakeholders agreed on the connections drawn, we are confident that we have captured the main dynamics of the system. Another caveat is the limited number of variables included. Clearly, there are more than nine factors that are important in the Malaysian energy sector. Yet, to be able to elicit meaningful connections and also model them, the number of variables had to be restricted. By going through a rigorous, stakeholder-based process of identifying the most important variables we anticipate that we captured the most important factors.

5.2. Policy recommendations

The potential exists for COVID-19 recovery measures to support the Malaysian energy transition, but relying on existing structures to implement systematic change towards green growth might not deliver



Part A: Changing one descriptor (V8)	V1					V2			V3			V4			V5			V6			V7			V8			V9		
	1	2	3	4	5	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Current Scenario				X				X		X				X	X			X				X		X					X
Change: V8 (1⇢2)				X				X		X				X	X			X				X		⇢	X				X
Succession Step1				X				X	X	⇠				X				X				X			X				X
Succession Step2				X				X	X					X	⇢	X		X				X			X				X
Succession Step3				X				X	X					X		X		⇢	X			X			X				X
Succession Step4				X				X	X					X		X			X			⇢	X		X				X
Final: Scenario #10				X				X	X					X		X			X				X		X			X	⇠

Part B: Change one descriptor (V4)	V1					V2			V3			V4			V5			V6			V7			V8			V9		
	1	2	3	4	5	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
B-1																													
Current Scenario				X				X		X				X	X			X				X		X					X
Change: V4 (3⇢2)				X				X		X			X	⇠	X			X				X		X					X
Succession Step1				X				X		X			X		⇢	X		X				X		X					X
Succession Step2				X				X		X			X			X		⇢	X			X		X					X
Succession Step3				X				X		X			X			X			X			⇢	X	X					X
Final: Scenario #1				X				X		X			⇢	X		X			X				X	X					X
B-2																													
Current Scenario				X				X		X				X	X			X				X		X					X
Change: V4 (3⇢1)				X				X		X		X	⇠	⇠	X			X				X		X					X
Succession Step1				X				X		X		⇢	X		X			X				X		X					X
Succession Step2				X				X		X			X		⇢	X		X				X		X					X
Succession Step3				X				X		X			X			X		⇢	X			X		X					X
Succession Step4				X				X		X			X			X			X			⇢	X	X					X
Final: Scenario #1				X				X		X			⇢	X		X			X				X	X					X

Part C: Change two descriptors (V4 & V8)	V1					V2			V3			V4			V5			V6			V7			V8			V9		
	1	2	3	4	5	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Current Scenario				X				X		X				X	X			X				X		X					X
Change: V4 (3⇢1) & V8 (1⇢2)				X				X		X		X	⇠	⇠	X			X				X		⇢	X				X
Succession Step1				X		X	⇠	⇠		X		X			X			X				X			X				X
Succession Step2				X		X				X		⇢	X		X			X				X			X				X
Succession Step3				X		X				X			X		⇢	X		X				X			X				X
Succession Step4				X		X				X			X			X		⇢	X			X			X				X
Succession Step5				X		X				X			X			X			X			X			X		X	⇠	⇠
Succession Step6				X		X				X			X			X			X		X	⇠			X		X		
Succession Step7				X		X				X			⇢	X		X			X		X				X		X		
Final: Scenario #5				X		X			X	⇠				X		X			X		X				X		X		

Descriptors (Variants)
V1 Value chain participation
(1) Only Manufacturing
(2) Only Knowledge (R&D)
(3) Only Resource / Raw Material Producers
(4) Combination of Segments
(5) None
V2 Investments in Renewables
(1) High
(2) Medium
(3) Low
V3 Tech Knowledge Sharing
(1) No Skill or Knowledge Sharing
(2) Some Skill Sharing
(3) Extensive Knowledge Sharing
V4 Political Economy Structure
(1) Liberal Market Economy
(2) Coordinated Market Economy
(3) State-centred Capitalism
V5 Electricity Market Structure
(1) Monopoly
(2) Oligopoly
(3) Perfect Competition
V6 Energy projects
(1) Mostly Centralized FF
(2) Mostly Centralized RE
(3) Mostly Decentralized RE
V7 Political Stability
(1) High
(2) Medium
(3) Low
V8 Covid-19 Recovery
(1) Stagnation
(2) Fast and Mainly Green Growth
(3) Fast and Mainly Coal-fired Growth
V9 Infrastructure Development
(1) Sustainable Expansion
(2) No growth
(3) Unsustainable Expansion

Fig. 6. Succession steps for three different conditions of change.

the anticipated results. It could well be that COVID-19 recovery packages lead to higher emissions without the necessary structural changes (le Billon et al., 2021; Smith et al., 2021). Thus, it is necessary to widen the range of actors involved in the energy sector to make room for new policy initiatives to unfold. Whilst the diversification in the production and consumption has already made some progress, the decision-making is still held firmly by the state. Ideally, diversifying the actors involved in the decision-making process would mean a shift from top-down to a more cooperative or even bottom-up decision making. By including different stakeholders' views, it is possible to break away from those institutional path-dependencies.

The engagement of different stakeholders in decision-making processes needs to be designed in a way that enables also groups that might have been traditionally marginalized to have a say. Further, the diversification needs to happen in early stages of the discussion. It is not sufficient to consult stakeholders once the policies are designed. We note that Malaysia's National Energy Policy 2022–2040 proposes the establishment of a National Energy Council as a forum for planning and coordination of actions related to the energy sector. Our results indicate that such forum should be inclusive in order to support a low-carbon trajectory. If the Malaysian government is serious about breaking the carbon lock-in, COVID-19 recovery policies can provide the means to do so. Yet, it is also clear that the envisioned structural change in the energy market requires a structural change in decision-making first.

CRediT authorship contribution statement

Esther Schuch: Writing – review & editing, Writing – original draft, Visualization, Methodology, Formal analysis, Data curation, Conceptualization. **Maria Apergi:** Writing – review & editing, Data curation, Conceptualization. **Deborah Yik Kuen Chow:** Data curation. **Laima Eicke:** Writing – review & editing, Data curation. **Andreas Goldthau:** Writing – review & editing, Supervision, Project administration, Funding acquisition, Conceptualization. **Jude H. Kurniawan:** Writing – review & editing, Formal analysis, Data curation, Conceptualization. **Renato Lima-de-Oliveira:** Writing – review & editing, Writing – original draft, Data curation. **Zhai Gen Tan:** Writing – review & editing, Writing – original draft, Visualization, Data curation. **Silvia Weko:** Writing – review & editing, Writing – original draft, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.techfore.2024.123331.

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