Modelling Malaysia’s energy transition pathways: The role of renewable energy policy measures

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Abstract. Coal’s rising prominence in the power industry has raised concerns about future CO2 emissions and energy reliability. As of 2017, it is estimated that Malaysia’s existing natural gas production can only be maintained for another 40 years. Consequently, the carbon intensity of electricity production has increased due to the increasing share of coal-fired plants and electricity infrastructure inefficiencies. To sum it up, energy industries were the highest emitters of CO2 emissions, with a 54 percent share. In response to these challenges, the government implemented series of Renewable Energy (RE) policy measures. Whether these policies are sufficient in driving Malaysian energy decarbonization is yet to be answered. In the study, we simulate different scenarios from 2015 to 2050 with an agent-based model to explore the roles of renewable energy policies toward emission reduction in the energy sector. The simulation results reveal that when all renewables initiatives were implemented, the share of RE increased to 16 percent, and emissions intensity fell by 26 percent relative to its level in 2005, albeit with increasing absolute carbon emissions. This milestone is still far below the government’s 45 percent reduction target. The simulation results demonstrated that renewable energy policies alone are less effective in driving Malaysian electricity toward desired low-carbon pathways. Furthermore, it is evidenced that no single policy can achieve the emission reduction target. Therefore, a combination of energy efficiency and renewable energy policy measures is unavoidable to decarbonize the electricity sector in Malaysia.

Introduction

Energy markets are developing across the globe, from vertically integrated monopolies to liberalized market structures that encourage high competitiveness among electricity producers and allow customers freedom of services and choice [1]. As part of the continuous transformation, the liberalization of the distribution, transmission, and most critically producing sectors creates potential for new companies in the industry. Economic theory teaches that if market mechanisms function efficiently, this will provide greater productivity in terms of higher quality services and goods at lower costs. Malaysia's energy industry has been partly liberalized and labeled a quasi-competitive one [2]. However, due to the conclusions of several scientific studies indicating traditional fossil fuel power systems are not ecologically and economically sustainable, sustainable electricity generation and consumption are the subject of policy debates among environmental economists and policymakers [3–5]. The fear of depletion of natural resources such as coal, oil, and natural gas and global warming has made the green economy an urgent issue.

Renewable energies are the backbone of any energy shift toward net zero. As countries across the globe progressively turn away from carbon-emitting fossil fuels, knowing the present role renewable energy plays in the energy transition is crucial to maintaining a smooth pathway to net zero [6,7]. Renewable sources, notably solar and wind power, play a significant role in energy decarbonization. According to a recent international Energy Agency report, renewable energy capacity expansion driven by solar energy reached another annual record of about 290,000 megawatts (MW) in 2021. This exceptional capacity expansion is 3 percent greater than in 2020. More than half of all renewable energy expansion in 2021 came from solar energy alone, followed by hydropower and wind [8]. In the next two decades, renewable energy is projected to be the fastest-growing low-carbon energy source worldwide, accounting for almost 66 percent of global investment in electricity generation until 2040 [9].

Significant transformations will be needed in all economic sectors, including resource extraction, manufacturing, transportation, and hospitality, to ensure a timely transition to a low-carbon economy [10,11]. Renewable energy is essential for low-carbon transitions, yet despite increases in renewable energy use, the pace of decarbonization is still low. Energy transition initiatives have been affected by policy misalignments and lack of leadership [12,13]. Malaysia's economy, from the industrial, commercial, transportation to agricultural sectors, is largely supported by the country's electricity sector. A significant level of economic damage can result from interruptions in the energy supply, as was seen during the 1992 widespread blackout in Peninsular Malaysia. As a result, no sector is more important to the economy than power. However, given the current population and economic growth rate, the rapidly rising demand for power [14] and the growing proportion of coal-fueled power in the energy mix raises grave concern [15].

Consequently, the carbon intensity of electricity production has increased due to the increasing share of coal-fired plants and electricity infrastructure inefficiencies [16–18]. To sum it up, energy industries were the highest emitters of CO2 emissions, with a 54 percent share. Meanwhile, emissions of CO2 by the energy industry were mainly due to the fuel used by the power sector [19]. Thus, a significant reduction in electricity-related CO2 emissions must be the core of the climate change policy thrust of the government. Reducing carbon emissions and the national transformation agenda (TN2050) pose unique and tremendous problems for Malaysia's energy transition. No wonder the decoupling of carbon emissions from economic growth has been challenging, with the government prioritizing energy security, albeit low-carbon sources. Opening two locks with one key, the electricity sector plays a significant role in addressing economic and environmental issues. Therefore, implementing the Renewable Energy Policy for the smooth transformation of the power sector is inevitable. However, it is less clear what their potential impacts will be on Malaysia's power sector. Thus, exploring their effects on the electricity generation mix, electricity price, and carbon emissions within an established framework could contribute to formulating policies that could address greenhouse gas emissions while sustaining long-term energy security in Malaysia. The agent-based simulation model provides such a framework [20].

Agent-based Modelling

A model often used to study energy decarbonization is to simulate dynamically different agents' (e.g., electricity producers and consumers, government, electricity market, fuel market) behavior by ABM. The literature on energy and technology has been on a steady rise in using agent-based models to model complex emergent phenomena like energy transition. To answer why an ABM is a valuable tool for modeling the low-carbon pathways, we must first consider why this is the case. Individual behavior at the micro level is captured by an ABM, which then predicts the emerging behavior (like a transition) on a macro scale [21, 22]. However, linear models are inadequate for capturing the complex dynamics of decarbonization. Transition behavior is both an economically rational process and a highly complex system with different heterogeneous actors, preferences, social network effects, time, and learning processes from experiences. An ABM provides a simple platform for simulating and, therefore, analyzing such complicated decision systems, taking into account autonomous actors, a changing set of parameters, the influence of social interactions, and the interdependence of individual agents. As a result, there are numerous possibilities for technological development throughout the time that analytical tools and cross-sectional investigations cannot capture. The unpredictable and non-linear character of technological change can be accommodated by a social simulation (i.e., ABM) [23-27]. Agent-based simulation models (ABM) are employed to analyze energy transition policies' implications on the electricity sector in Malaysia for the next four decades, as recommended by Babatunde et al. (2017) [28] and Wooldridge et al. (1995) [29].

Agent description and interaction

Actors, markets, and environments are the three autonomous and active agents that comprise the model structure. Producers of electricity, the government, and customers are the key actors. The model's key components are the electric power market and the fuel market, where commerce is enabled, and players engage with each other by acquiring fuels and trading electric power, as shown in Fig. 1. Agent actions are updated yearly based on the design. Therefore, the simulation time step or unit is a year.

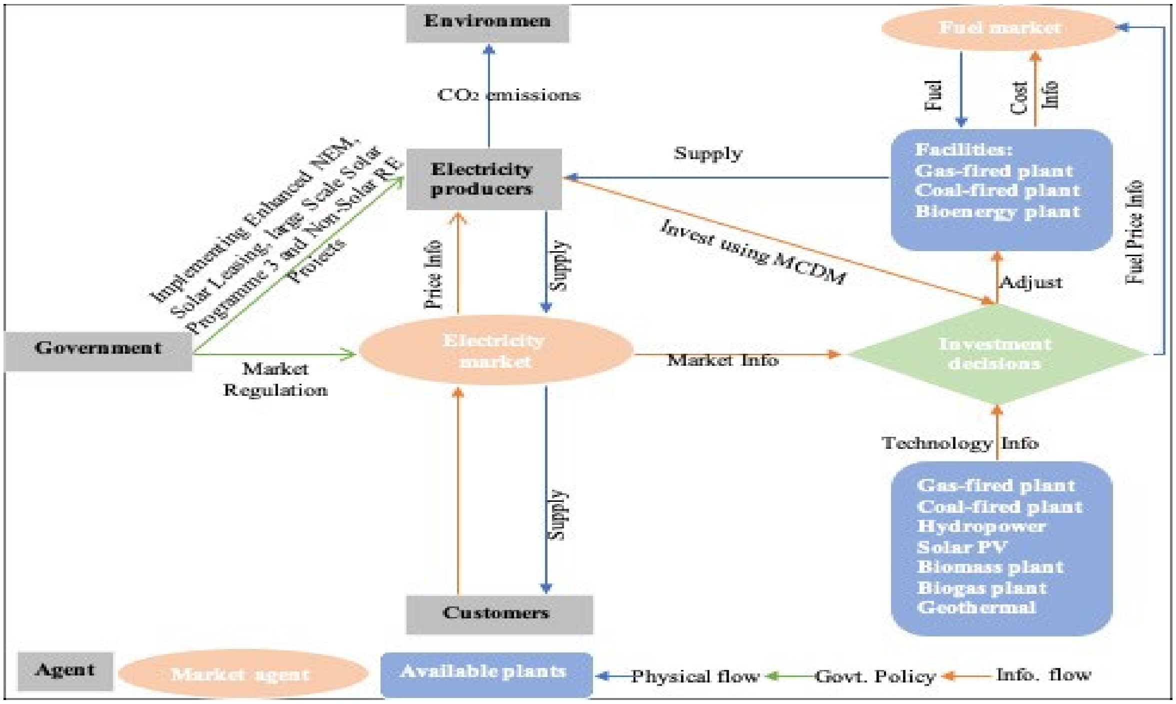

Fig. 1. Model structure

There are six different kinds of agents in our concept. Rectangles represent agents, and ovals show two markets. The physical movement of goods (fuel inputs and energy), as well as CO2 emissions, are shown by the blue arrows. The flow of cost and price information, governmental actions, and investment decisions by electricity producers are represented by peach arrows. Government agents oversee the electricity market and create rules. Based on legally binding contracts from the electricity market, energy producers buy fuel from the global market and ensure a steady electricity supply to the market. After the generation phase, emissions are discharged into the atmosphere, and producers determine whether it is necessary to shut down power plants or build new ones. If it is decided to build a new one, the producer uses the Multi-Criteria Decision Making (MCDM) technique to choose the preferred power plant. Finally, the customer receives electricity from the electrical market. Last but not least, the first rounded blue rectangular box displays different types of electricity generation plants that are now accessible in Malaysia. In contrast, the last blue rounded box lists the carbon-emitting generating technologies.

Policy Scenarios

Based on the existing energy market structure, we run a series of economically and politically significant scenarios to examine the implications of renewable energy policy and its influences on the electrical sector's transition to low-carbon pathways. Four scenarios are defined to examine the effects of energy policies on Malaysia's electricity sector in various economic situations until 2050. First, the scenarios vary in accordance with the state of the economy ('Initial-value' and 'Economic-trend'). The agents' virtual environment is designed using scenarios (Table 1). Consequently, a scenario is characterized by well-defined limiting conditions on government regulations and the input data of an energy system.

Table 1 Number of Scenarios Considered

Scenarios	Government policy	Economic	Conditions
	Renewable Energy	Initial-Value (INVA)	Economic-Trend (ECOT)
Business-As-Usual (BaU)	No	INVA-1	ECOT-2
Policy implementation	Yes	INVA-3	ECOT-4

Results and Discussion

The decarbonization of power will necessitate a substantial shift in the existing policy framework. It begins with the alignment of energy policy with emission reduction goals, followed by creating a favorable and supportive investment environment to boost private investment in technologies that may shift power generation toward renewable energies. Without articulating renewable energy policies, cost-effective decarbonization of the power sector would be difficult, if not impossible. Finally, long-term market mechanisms should be considered when providing a level playing field for sustainable energy technologies.

Business-As-Usual Scenario

This section focuses on baseline scenarios since they provide the basis for evaluating the impacts of policy scenarios. These scenarios aim to elucidate what carbon emissions and intensity, electricity price, and portfolio will likely be in 2050 without government interventions. We developed projections for electricity transition indicators under two baseline scenarios. The first baseline, an Initial-Value (INVA) scenario, assumes that the initial values of parameters remain unchanged throughout the simulation period. While the second baseline, Economic Trend (ECOT) scenario, considers the trend of economic parameters such as rising prices of fuels and falling costs of renewable energy through the simulation period.

Renewable Energy Policy

This is a case when the government implements renewable policies and programs as it is currently through a feed-in tariff, net energy metering, large-scale solar, self-consumption initiative, and other RE incentives such as green income tax exemption and green investment tax allowance.

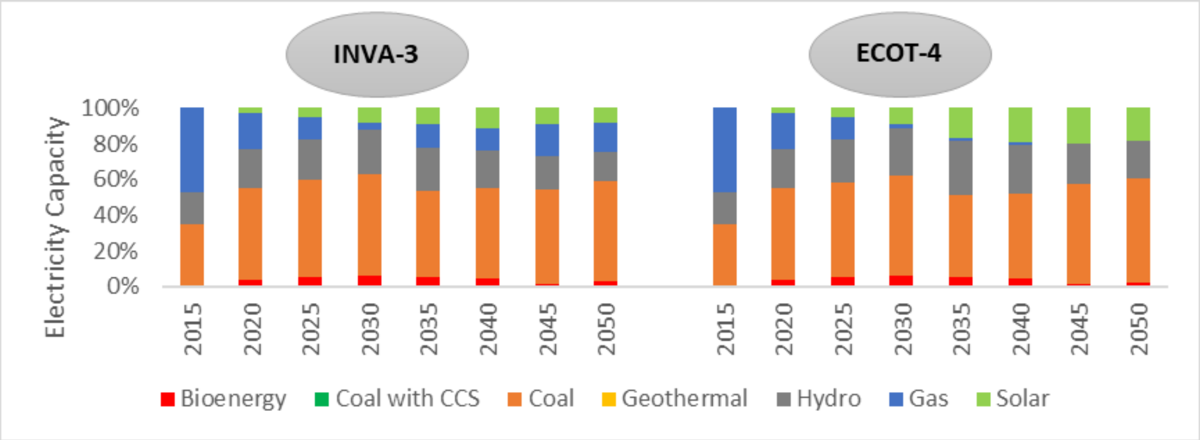

Fig. 2. Electricity Capacity by Technology under Renewable Energy Policy Consideration

Installed Capacity Levels by Technology

As presented in Fig. 2. the generation capacity for INVA-3 and ECOT-4 scenarios is expected to increase from 25064 MW in 2015 to a value between 72425 MW and 73071 MW by 2050 for INVA and ECOT scenarios. In the INVA scenario, the share of gas-fired plants falls from 47% in 2015 to about 16% by 2050, just as coal-fired counterparts increase from 35% in 2015 to 56% by 2050. Generators fueled by renewable technology from almost 0% to 3% and 9% for bioenergy and solar PV between 2015 and 2050. However, the generation fueled by natural gas will be retired from the electricity system by 2044, while coal-fired power plants will increase from 86,96.9 MW (35%) in 2015 to 42,400 MW (59%) by 2050. An imminent increase in capacity is observed in renewable deployment from 0% in 2015 to 2% and 18% for bioenergy and solar PV by 2050 (see Fig. 2).

Electricity Carbon Intensity

More than 45% of CO2 emissions from energy combustion are from electricity generation. The reason for this is the sector's over-reliance on non-renewable energy sources such as coal and gas for its electricity production. In the INVA scenario, about 72% of the electricity is generated through fossil fuels compared with 59% in the ECOT scenario by 2050 against 82% in the reference year. Intensity generally increases as more fossil fuels are used to generate electric power. In the INVA RE policy scenario, carbon intensity improves from 0.549 in 2015 to 0.447 (18.6% decrease) by 2040 before deteriorating again to 0.507 (13.4%) by 2050, making a small amount of 7.7% between 2015 to 2050 (see Table 2). At the same time, carbon intensity in the ECOT scenario experiences noticeable improvement throughout the simulation period. Although the RE policy could not fully drive the sector towards achieving a 45% emissions intensity target of 0.291, it reduces the intensity by 31% and 26% by 2035 and 2050, respectively (Table 2). When this result is viewed from the government's ambitious unconditional emission intensity target of 45 percent against Gross Domestic Product (GDP) by 2030 based 2005 level, the renewable energy policies only achieved a 26 percent reduction. This indicates that renewable energy policies and programs remain integral to the policy consideration for electricity decarbonization.

Table 2 Electricity Carbon Intensity Under Renewable Energy Policy Scenario

	BaU Scenarios		**Renewable Energy Policy Scenarios**	
	Initial Value	**Economic Trend**	**Initial Value**	**Economic Trend**
Operating Year	**INVA-1**	**ECOT-2**	**INVA-3**	**ECOT-4**
2015	0.549	0.549	0.549	0.549
2020	0.681	0.693	0.472	0.479
2025	0.750	0.766	0.452	0.440

2030	0.770	0.783	0.441	0.409
2035	0.787	0.787	0.415	0.364
2040	0.810	0.804	0.447	0.385
2045	0.800	0.732	0.507	0.375
2050	0.824	0.758	0.545	0.390

Electricity Carbon Emissions

Fig. 3 displays emissions from the power sector under renewable energy scenarios. Emissions under the baseline (INVA-1) scenario increase from 93 Mt in 2015 to 423 Mt in 2050, while the increase would be capped at 360 Mt for the ECOT-2 scenario with an average of 199 Mt, 268 Mt, and 317 Mt for the period between 2021 to 2030, 2031 to 2040 and 2041 2050 respectively. But with renewable energy policies in place, emissions increase slower than the baseline scenario. Under INVA-3, emissions only increased from 93 Mt in 2015 to 243 Mt in 2050 with an average of 178 Mt compared to 246 Mt in the BaU scenario, while ECOT-4 projected the best in terms of emissions trajectory at 173 Mt by 2050.

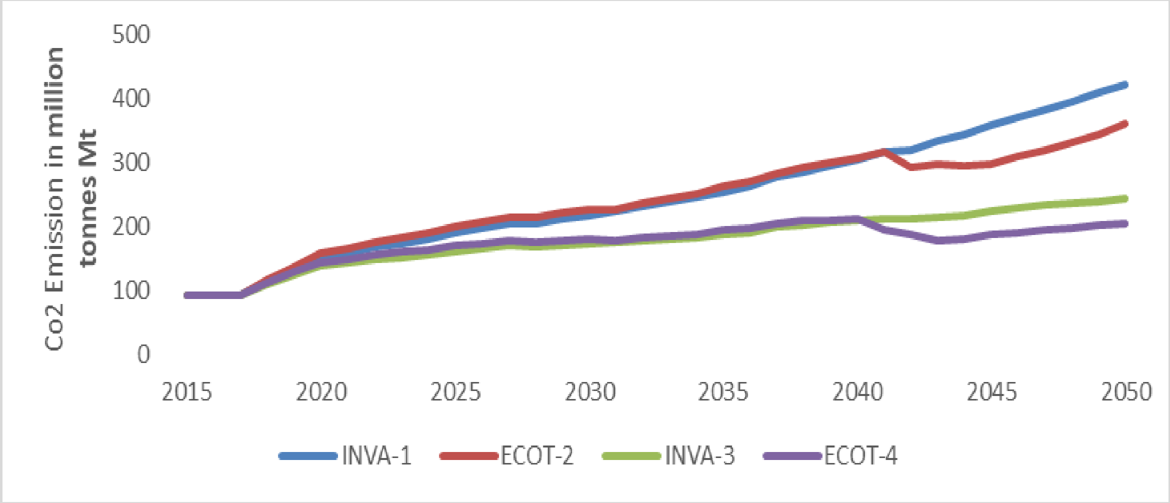

Fig. 3. CO2 Emissions under Renewable Energy Policy

Conclusion and Policy Implications

The reason for considering renewable energy scenarios is to see how renewable target achievement will impact the decarbonization process. One of the government's renewable energy policy initiatives is to increase the share of power generation from renewable sources. Scenarios INVA-3 and ECOT-4 capture these effects. When RE policies are implemented, more electricity is generated from RE sources such as hydro, solar PV, and bioenergy. Specifically, in scenario 3, the electricity system witnesses the injection of solar PV complemented by hydroelectric power with a combined share of 1/5 of electricity generation. The RE situation becomes better in scenario 4 with 2 percent hydro, 12 percent solar PV, and 2 percent bioenergy share of power generation by 2050. The deployment of RE sources has come at the expense of fossil fuel power generation. The RE influence, on one hand, and the increasing cost of natural gas electricity generation, on the other hand, are responsible for the early elimination of gas-fired plants from the generation mix as of 2044 with a reduced role for coal-powered plants. The improvement in the share of RE electricity generation is assumed to result from production subsidy, which reduces the investment cost of all RE sources except hydro, which is considered a matured technology.

The simulation results reveal that when all RE policy initiatives are well-articulated, and renewable energy share of electricity generation is at least as presented above, emissions intensity will fall by 26 percent relative to its level in 2005, albeit with increasing absolute carbon emissions.

However, this milestone is still far below the government's 45 percent reduction target. As a result, RE deployment effects on electricity prices fluctuate around baseline values with insignificant effects in both scenarios.

Successful energy policies and an ambitious emissions reduction target can't get off the ground without well-articulated renewable energy policy measures. However, renewable energy policies alone have proven less effective in driving Malaysian electricity toward desired low-carbon pathways. The simulation results demonstrated that renewable energy policies alone are less effective in driving Malaysian electricity toward desired low-carbon pathways. Furthermore, it is evidenced that no single policy can achieve the emission reduction target. Therefore, a combination of energy efficiency and renewable energy policy measures is unavoidable to decarbonize the electricity sector in Malaysia. The energy transition will be achieved if energy policymakers and related government agencies with a climate change plan can review the existing energy policy instruments to achieve emissions reduction targets.

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