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Malaysia's Electricity Decarbonisation Pathways: Exploring the Role of Renewable Energy Policies Using Agent-Based Modelling

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Abstract: Coal's rising prominence in the power industry has raised concerns about future CO_2 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 summarise, energy industries have been the highest emitters of CO_2 emissions, with a 54-percent share. In response to these challenges, the government implemented a series of renewable energy (RE) policy measures. Whether these policies are sufficient in driving Malaysian energy decarbonisation is yet to be seen. In this study, we simulated different scenarios from 2015 to 2050 with an agent-based model to explore the roles of renewable energy policies towards 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 demonstrate that renewable energy policies are less effective in driving Malaysian electricity towards desired low-carbon pathways. Furthermore, it is evidenced that no single approach can achieve the emission reduction target. Therefore, a combination of energy efficiency and renewable energy policy measures is unavoidable to decarbonise the electricity sector in Malaysia.

Keywords: agent-based model; electricity sector; renewable energy policies; energy decarbonisation; simulation

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1. Introduction

Decarbonising the electricity sector is a crucial step in mitigating the impacts of climate change and achieving sustainable development. Globally, the electricity sector is a major contributor to greenhouse gas emissions, accounting for approximately 25% of global emissions [1]. However, there has been a significant shift towards decarbonisation in recent years, driven by policy incentives, technological advancements, and growing public awareness of the need to address climate change. According to the International Energy Agency (IEA), the share of renewables in global electricity generation is projected to increase from 50% between 2019 and 2024 to about 2400 GW by 2027 (an 85% increase from the previous five years), with solar and wind energy playing a particularly significant role in this transition. The European Union mainly drives this forecast, as well as the United Kingdom, the United States, India, and, most importantly, China. These countries are all reforming the energy market, implementing existing policy measures and quickly introducing new ones in response to the current global energy crisis [2,3].

Despite these positive trends, the electricity sector in other parts of the world, including Malaysia, still faces significant challenges in achieving smooth decarbonisation. Fossil fuels, particularly coal and natural gas, dominate electricity generation. There are barriers to the widespread adoption of renewable energy technologies, such as high upfront costs and the need for infrastructure investments. Natural gas and coal have long been mainstays in Malaysia's power-generating mix, with the latter's share forecasted to rise from 48% in 2015 to 66% by 2023 [4]. Financial cost factors and the nation's goal to improve earnings by being a prominent liquefied natural gas exporter are driving Malaysia's switch from gas to coal-fired power generation [5]. Meanwhile, coal's rising prominence in the power industry has raised concerns about future 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 [6]. In contrast, Malaysia has significant coal resources, with 1843 Mtoe in 2006, of which just 1 percent is in the Malaysian Peninsula, with 16 percent in Sabah and 83 percent in Sarawak. Coal production in the country has remained uneconomical due to the current structure and high extraction costs [7]. Currently, Malaysia relies on imports of coal from China, South Africa, Australia, and Indonesia, leaving it vulnerable to fluctuations in global coal supply caused by climate change policies [7] and, more recently, the COVID-19 pandemic [8]. These factors provide more impetus for Malaysia to decarbonise its electricity by switching to renewable energies for power generation.

In the Association of Southeast Asian Nations (ASEAN), previous researchers have approached decarbonisation from different perspectives, from drawing the transition roadmaps and their implications to evaluating energy transition technologies. Lau, using the Integrated Assessment Tool (IAT), assessed decarbonisation technology's readiness, security, affordability, and sustainability and revealed that switching to natural gas could reduce the emissions intensity of countries that heavily rely on coal-powered plants by half [9]. This study only draws out decarbonisation roadmaps for countries without examining potential implications. In another study, the author reviewed the implications of decarbonisation by performing technology mapping exercises and demonstrated that efforts should be geared towards expanding renewable energy in power generation and low-carbon technologies in the industrial sector [10]. However, these studies focus on the entire economy, making it difficult to capture sectoral decarbonisation details, especially for power [11]. To overcome this limitation, a recent study developed a low emissions analysis platform (LEAP) model for simulating net-zero emission pathways of ASEAN electricity sectors. The research findings show that untapped renewable energy resources need to be quickly utilised and energy storage and renewable energy technologies are more cost-effective than carbon capture and storage for net-zero emissions by 2050 [12].

For the electricity sector in Malaysia, previous studies have mainly used qualitative research techniques to study the progress, prospects, and challenges of electricity decarbonisation. Drawing on extensive interactions and interviews with private and public stakeholders, Susskind et al. used qualitative modelling frameworks based on multi-year analyses of Malaysia's decarbonisation pathways to reveal key factors for breaking out of carbon lock-in [13]. Long et al. explored the strengths and weaknesses of global electricity decarbonisation methodologies using content analysis to propose unique Malaysian energy transition conditions by developing frameworks for the community and the government [14]. More specific to biomass, Zamri et al. provided an extensive review of the progress, prospects, and challenges of electricity decarbonisation using palm oil biomass [15]. Their study calls for a synergistic approach to decarbonise the electricity sector, with biomass estimated to be under 40% efficiency to generate approximately 5 gigawatts of power. Mohd Idris et al. took further steps and analysed the cost implications of co-firing biomass with coal-powered plants using an optimisation modelling approach. By co-deploying bioenergy with existing fossil-fuelled plants, biomass costs can be reduced up to 27%. Hence, bioenergy deployment is key to decarbonising Malaysia's power sector [16]. For meeting projected electricity demand by 2050, Haiges et al. developed a bottom-up optimisation model (TIMES) using linear programming to generate the least-costly long-term electricity generation options that ensure efficient energy transition in Malaysia. Their study found that abundant renewable resources can meet the projected 2050 electricity demand, and the unreliable nature of renewable energy sources can be resolved with storage system integration [17]. Other studies took different dimensions and analysed the decarbonisation pathway by simulating and integrating nuclear power in the energy mix [18], exploring diversification of energy sources and new technology adaptations [19], and forecasting power generation capacity using the auto-regressive integrated moving average (ARIMA) econometric model [20]. They all either emphasised that adopting sustainable energy technology to decarbonise Malaysia's electricity could reduce the cost of power generation or analysed the progress, prospects, and future challenges of the transition without exploring the potential policy effects over the simulated period.

Interactions viewed as relationships severed or mutual influences among actors in energy transition have been the subject of previous studies [21,22]. However, in Malaysia, no study has analysed complex agent interactions in the electricity sector except the work of Babatunde et al., which studied policy interactions (energy efficiency and natural gas subsidy) using an agent-based computational economic model [23]. Compared to previous studies on electricity decarbonisation, this research contributes to the existing literature on it, specifically by building on the modelling framework and scenario analysis of Babatunde et al. [23], with an in-depth exploration of renewable energy policy scenarios. An agent-based model was used to study the behaviour of autonomous agents involved in the energy system, such as power producers, consumers, and the government (policy makers) and how their decisions and actions influence the electricity system. For example, we took into consideration how producers and consumers adjust and adopt different technologies and behaviours in response to changes in government policies and how these reactions influence the power sector's CO2 emissions, electricity, and energy mix [24–26]. Our main objective was to examine the role of renewable energy policies in decarbonising the electricity sector under the four pathways and evaluate how they impact the electricity price and capacity with use of technology (energy mix). This allowed us to verify if a renewable energy policy could drive full decarbonisation in Malaysia's power sector.

2. Renewable Energy Policies in Malaysia

Concerted efforts towards renewable energy development started to take root in the Eighth Malaysia Plan in 2001 [27]. This was the first time in Malaysia that renewables under the "Five-Fuel Diversification Policy" were recognised as part of Malaysia's electricity generation energy mix [28]. The National Biofuel Policy followed this in 2006 as a measure to instigate the use of biodiesel in the transport sector. Despite Malaysia's remarkable expansion of biofuel production, its sustainable development has been a source of intense debate among experts [29].

In 2010, the Tenth Malaysia Plan ushered in the National Renewable Energy Policy and Action Plan as a policy measure towards promoting the deployment of indigenous renewable energy in the country. As one of the vital policy tools, the Feed-in-Tariff (FiT) was launched in 2011 under the auspices of SEDA to propel achievement of the renewable energy target (e.g., 985 MW by 2015). Renewable energy deployment goals in the country remain very ambitious [30]. The renewable energy initiative has not been as successful as desired in Malaysia because, as of 30 September 2015, the scheme only achieved 319.55 MW, less than 35% of the target [31–33]. The path to a complete energy transition requires fully utilising the renewable energy available in the country. Although renewable energy development has had mixed success, here are four main policy measures introduced in the last decades: the Feed-in Tariff (FiT) scheme, net energy metering (NEM), large-scale solar auction (LSS) and self-consumption (SELCO).

The FiT scheme was introduced in 2011 to allow the sale of power produced from renewable resources such as biogas, biomass, small hydropower, solar photovoltaic resources, and geothermal resources to energy companies at a stipulated price for a certain period [27,34]. The FiT was later replaced in 2017 by net energy metering (NEM), which enables a prosumer—an energy customer and producer—of solar photovoltaics (PVs) to consume first and export in case of excess power generation to the national grid on a "one-on-one" basis for offsetting. All categories of TNB customers are eligible for the scheme based on different quotas [35–37]. Due to significant government efforts, power generation from renewables has increased considerably. Implementing complementary programs such as LSS and SELCO has boosted the contribution of sustainable electricity generation in the energy mix, especially solar PV. It is no wonder that most studies have focused mainly on solar PV, from its potential [32,38] and business models [39–41] to the factors affecting its adoption [42,43]. With high investment in agricultural activities, Malaysia has been advised to explore its biomass potential [44,45]. Others investigated the roles of government policies in promoting renewable energy sources [46,47]. Thus, the share of renewable energy in Malaysia's electricity generation remains moderate. As of 2020, the renewable energy installed capacity stands at 8450 MW, equivalent to 23.5 percent of the total installed capacity in Malaysia [48,49].

3. Methodology

Existing models (such as econometrics, computable general equilibrium (CGE), system dynamics, etc.) have had some success. They have certain strengths, but fundamental issues in examining energy transition (i.e., the dynamic features of the climate change socio-economic system) remain unsolved [50,51]. In addition, [52] points out that each approach, particularly CGE, has benefits and disadvantages regarding how equilibrium is handled, the ethics espoused by the model, and the presence or absence of a monetary system. The standard economic equilibrium model does not capture some features of carbon regulations and the power grid. The conventional method is also inadequate for fully characterising the features seen in the power industry (e.g., the socio-technical aspect of the electricity sector). In contrast, the standard method relies heavily on mathematics, as in equilibrium theories. However, this is typically achieved at the expense of providing a genuine representation of technology and social features [53]. Multiple equilibria, company heterogeneousness, information asymmetry, and imperfect competition are all examples of social characteristics, as outlined by Tesfatsion [54].

3.1. Agent-Based Modelling

A model often used to study energy decarbonisation is to simulate dynamically different agents' (e.g., electricity producers and consumers, the government, the electricity market, the fuel market) behaviour via ABM. The literature on energy and technology has steadily used agent-based models to model complex emergent phenomena such as energy transition [21,55,56]. To answer why an ABM is a valuable tool for modelling low-carbon pathways, we must first consider why this is the case. Individual behaviour at the micro level is captured by an ABM, which predicts the emerging behaviour (such as a transition) on a macro scale [22]. However, linear models are inadequate for capturing the complex dynamics of decarbonisation. Transition behaviour 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, analysing 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 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) [57,58]. We employed agent-based simulation models (ABM) to analyse energy transition policies' implications on the electricity sector in Malaysia for the next four decades, as recommended by Babatunde et al. [59] and Wooldridge et al. [60].

3.1.1. 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 Figure 1. Agent actions are updated yearly based on the design. Therefore, the simulation time step or unit is a year.

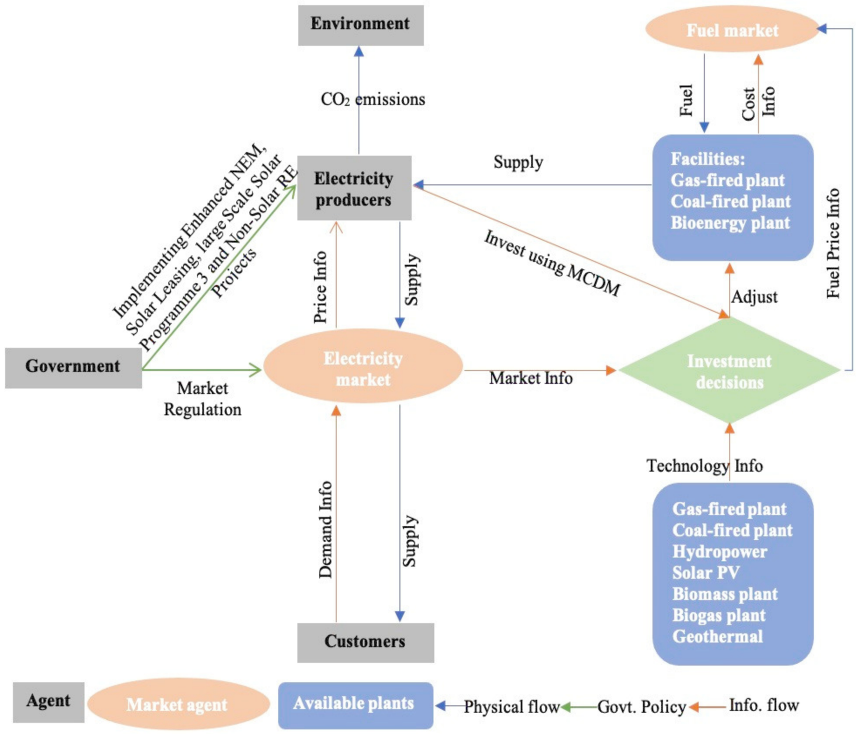

Figure 1. Model structure: There are six different kinds of agents in our concept. Rectangles represent agents, and ovals represent two markets. The physical movement of goods (fuel inputs and energy), as well as CO_2 emissions, are indicated by the blue arrows. The flow of cost and price information, 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. In conclusion, the first rounded blue rectangular box displays different types of electricity generation plants that are now accessible in Malaysia. In contrast, the last blue round box lists the carbon-emitting generating technologies.

i. Electricity Producer agent

Power producers that own and manage power stations serve as the model's primary agents. Using both strategic and tactical behaviour, producers seek to maximise profit. Electricity producers choose their power supply at the start of each period based on secured contract(s). Power is then sold, and the producers either gain or lose. Based on how the plants operate and the need for capacity growth, the producers determine whether to open or shut down a facility at the end of each year. Twelve major power-producing firms were considered to represent Malaysia's electricity market. Although the producers' management approaches varied, they all had a similar structure for making decisions. As a result, the agent displayed both strategic and operational management philosophies.

Strategic management in the energy business is vital because it allows electricity producers to decide whether to invest or close. The decommissioning of power plants occurs concurrently with the selection of the time and preferred investment. We decided to divide this procedure into segments that follow one another for practical reasons. First, there are two practical decisions to be made by electricity producers. The first is a divestment decision. Electricity producers use the following factors to determine whether power plants need to be decommissioned: first, if the power plant's technical lifespan passed; and second, if the power unit consistently resulted in an operating loss for 5 to 9 years.

The second is an investment decision. Producers invest by determining if a new electricity production infrastructure is required based on whether the outdated plants need to be replaced or capacity expansion is required due to increasing demand. Capacity augmentation is necessary if the power demand comes near the industry output. The demand–supply indicator (DSI) represented the criterion for this measurement. A trigger for investing, the DSI value, was a number between 0 and 1. A producer who took more risks and made investments when there was not yet a scarcity of power was indicated by a lower DSI. A producer was considered risk-averse if their DSI was closer to 1.

Meanwhile, maximum concurrent investments (MCI) referred to the most simultaneous power plants companies can invest in at once. Every agent could give different weights to DSI and MCI, giving them a different management approach. As a result, these values depended on each agent. Figure 2 displays the computational stages for each producer. The producers choses the preferable technology for the investment once the choice to invest was taken. Because autonomous agents were expected to utilise more than one factor to select the best power plant, the decision on what type of plant will be invested in was based on a multi-criteria decision making (MCDM) methodology [61,62]. To choose its favourite technology, an agent used the technique for order preference by similarity to ideal solution (TOPSIS), the most extensively used and practical MCDM approach (Figure 2).

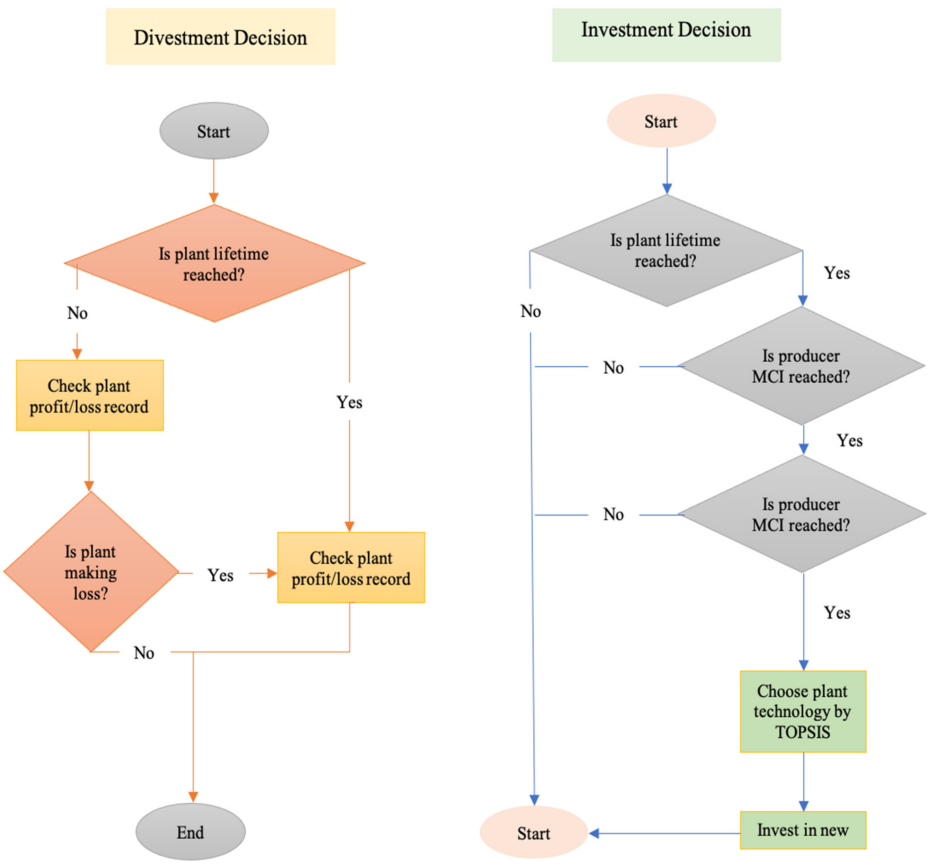

Figure 2. Computational stages of the producer's investment and divestment activities. Note: The electricity producer starts by checking if the power plant has reached its useful lifetime. If yes, shut

down the plant; otherwise, profit and loss records are reviewed to know if the plant is making a profit. Close the power plant if losses are recorded for 5 to 9 consecutive years. Investment decision follows immediately by checking if the producer's MCI is reached and the DSI level is met. Choose the preferred power plant technology using TOPSIS and invest in a new plant. Otherwise, maintain the existing production mix for the next production year.

ii. Government

Energy policymakers and regulators' main goals are energy security, reasonable energy prices, and low-carbon electricity generation. The government regulates the power market through its agency by establishing renewable energy policies such as enhanced net energy metering (NEM), Large-Scale Solar Programme 3 (LSS3), solar leasing, and non-solar renewable energy projects. Other agents are electricity consumers, the electricity market, the fuel market, and the environment, for which detailed descriptions can be found in the work of Babatunde et al. (2021) [23].

3.1.2. ABM Algorithm

ABM, a dynamic model, was always executed on a computer with the evolution of time calculated as an iterative process—an algorithm—in which autonomous agents were updated following the defined principles. Our model presented some algorithms to ensure smooth energy decarbonisation (Figure 3).

```
production year, ProdYear
producers, Prods
projected electricity supply, ProElectSup
secured contract, SecCont
electricity market, ElectMar
subsidised price, SubPrice
international market rate, IntMarRate
government natural gas subsidy. GovNatGasSub
actual electricity supply, ActElectSup
electricity price information , ElectPriInf0
aggregate electricity demand, AggElectDem
government implement energy efficiency policies, GovImpEneEffPol
Normal demand, NorDem
Managed demand, MangDem
CO₂ emissions, CO2Emi
Environment, Env
total cost, TotalCost
total revenues, TotalRev
end production year, EndProdYear
power plants, PowPla
producer management styles. ProdMantStyle

Begin
    for each ProdYear,  Prods Do
      get(Prods, ProElectSup)
        ProElectSup ← (SecCont(ElectMar))
      if (GovNatGasSub == true)
        buy(Prods, SubPrice)
      else
        buy(Prods, IntMarRate)
      end_if
      determine(Prods, ActElectSup)
        ActElectSup ← (ElectMar(ElectPriInfo, AggElectDem))
        if (GovImpEneEffPol == true)
          AggElectDem = MangDem
        else
          AggElectDem = NorDem
        end_if
      Released Into(CO2Emi,Env)
      Sell (Prods ,(Elect(Market))
      Estimate(Prods,TotalRev)
        TotalRev ← subtract(ActElectSup,TotalCost)
        if (TotalRev>0)
          make(company,profit)
        else
          incurred(company,lost)
          recorded(lost, EndProdYear)
        end_if
      while(EndProdYear == true)
        decide(Prods, (PowPla  ← (Close OR/AND Invest))
        if(Plant ← (LifeExpired OR MakingLost(N Yesrs))
          PowPla ← Close
        end_if
        if(Plant ← (LifeExpired OR demand(Mar,StaisfyGrowing))
          PowPla ← invest(New)
          use(prods, TOPSIS)⇒ select (prods , PowPla)
        end_if
      end_while
    end_for
end
```

Figure 3. ABM algorithm.

3.2. Data

Following the availability of data, 2015 was selected as the reference year. Every electric power market configuration was based on values from 2015 (initial values). As of December 2015, 44 operating power plants with a combined capacity of 25,064 MW were included in the reference year generating capacity [63,64]. For the business-as-usual (BaU) scenario, the annual electricity demand growth rate of 3.1% was used based on the electricity supply outlook forecast by the Energy Commission [64]. Hence, there is currently no one source that entirely covers the necessary details of all power plants. Therefore, to generate a dataset of all cost information, a mix of sources that are complementary and combinable was essential. The cost and other power plant information utilised in this paper are summarised in Babatunde et al. (2021) [23]. Due to the performance of the global and national economies, we controlled depending on the economic circumstances ("Economic-Trend"). The initial variable values were established using data from the Malaysian electrical industry from 2015, while the trend was established using in-depth literature reviews [65].

3.3. Policy Scenarios

Based on the existing energy market structure, we ran 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 were defined to explore the effects of energy policies on Malaysia's electricity sector in various economic situations until 2050. First, the scenarios varied based on the state of the economy ("Initial-value" and "Economic-trend"). The agents' virtual environment was designed using scenarios (Table 1). Consequently, a scenario was characterised by well-defined limiting conditions on government regulations and the input data of the 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

The scenarios were also based on the prevailing economic conditions. To provide clarity and consistency, Tables 2 and 3 show the precise specifications of energy policy and the current economic circumstances anticipated in various scenarios. Since transition paths under RE policies are highly dependent on the world and Malaysian economic conditions, we adjusted for two main economic conditions. First, the different economic scenarios regarding the fuel price level (i.e., coal, gas, biogas, and biomass) and renewable energy investment costs (except for hydro, which was regarded as an established technology) are presented in Table 3. During a period of economic expansion, these criteria assisted in mapping out decarbonisation pathways.

Table 2. Overview of scenarios used and what they mean.

Scenario Codes	Definition
BaU	Business-as-usual is the reference scenario without policy implementation and is used for comparison against the alternative scenarios.
REP	Renewable energy promotion policies are implemented throughout the simulation period.

Table 3. Economic conditions.

	INVA	ECOT
Fossil fuel price	Initial value	Increase
RE investment cost	Initial value	Decrease

Beginning with the future costs of renewable investment, the scenario's assumptions were quite optimistic ("Economic Trend"). In all scenarios relating to economic trends, we assumed that renewable investment costs declined over time, with less mature RE technologies seeing a greater rate of cost degression than more established RE technologies. However, investing in renewable energies varied greatly between original investment costs and economic trend scenarios. Predictably, the disparity between the scenarios was greater for less established renewable technologies, which are often associated with greater uncertainty.

4. Results

Power decarbonisation 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 favourable and supportive investment environment to boost private investment in technologies that may shift power generation towards renewable energies. Without articulating renewable energy policies, cost-effective decarbonisation of the power sector will be difficult, if not impossible. Finally, long-term market mechanisms should be considered when providing a level playing field for sustainable energy technologies. The government should implement renewable policies and programs as it is currently doing through a feed-in tariff, net energy metering, large-scale solar, self-consumption initiatives, and other RE incentives such as green income tax exemption and green investment tax allowance.

4.1. Installed Capacity Levels by Technology

As presented in Figure 4, the generation capacity for the INVA-3 and ECOT-4 scenarios was expected to increase from 25,064 MW in 2015 to a value between 72,425 MW and 73,071 MW by 2050 for the INVA and ECOT scenarios, respectively. In the INVA scenario, the share of gas-fired plants fell from 47% in 2015 to about 16% by 2050, just as coal-fired counterparts increased from 35% in 2015 to 56% by 2050. Electricity fuelled by renewable sources also increased to 12% by 2050. However, generation fuelled by natural gas was retired from the electricity system by 2044, while coal-fired power plants increased from 8696.9 MW (35%) in 2015 to 42,400 MW (59%) by 2050. An imminent increase in capacity was observed in renewable deployment from 0% in 2015 to 2% and 18% for bioenergy and solar PV by 2050 (see Figure 4).

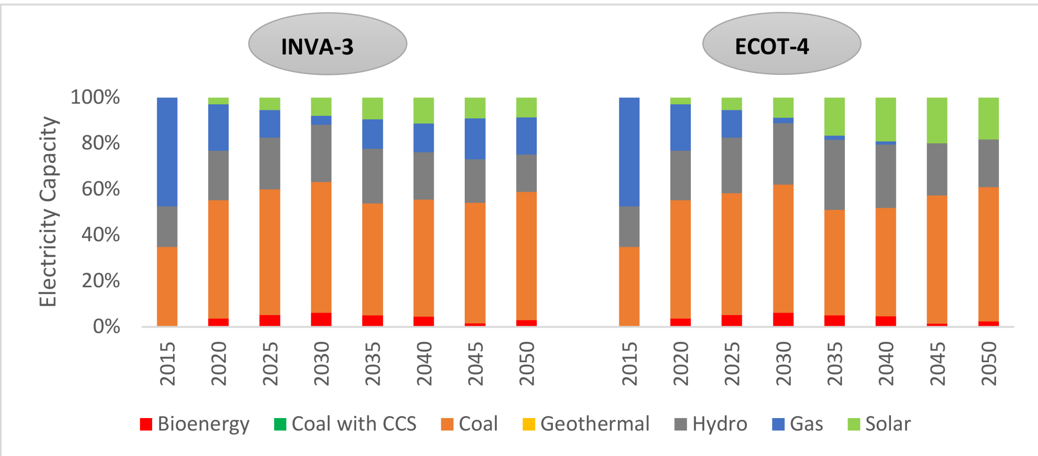

Figure 4. Electricity capacity by technology under renewable energy policy consideration.

4.2. Electricity Generation and Price

A comparison of electricity generation by fuel type between INVA and ECOT scenarios under renewable energy policies is provided in Figure 5. If we zoom in to 2050 in the INVA scenario, the coal power plant is the dominant power generator at 79%, followed by solar

PV at 10% and hydro at 10%. It is also observed that natural gas, geothermal, and bioenergy plants are not part of the generation mix by the end of the simulation period. In the ECOT scenario, similar energy mix profiles as per INVA are observed; however, a noteworthy observation is an increase in electricity generation from 285.82 TWh to 472.79 TWh by 2050. The second observation is that coal power generation dominance is reduced to 56%. The decline in coal power generation is projected to be compensated for by a combination of hydro, solar PV, bioenergy, and natural gas at 22%, 12%, 2%, and 8% by 2050, respectively (see Figure 5).

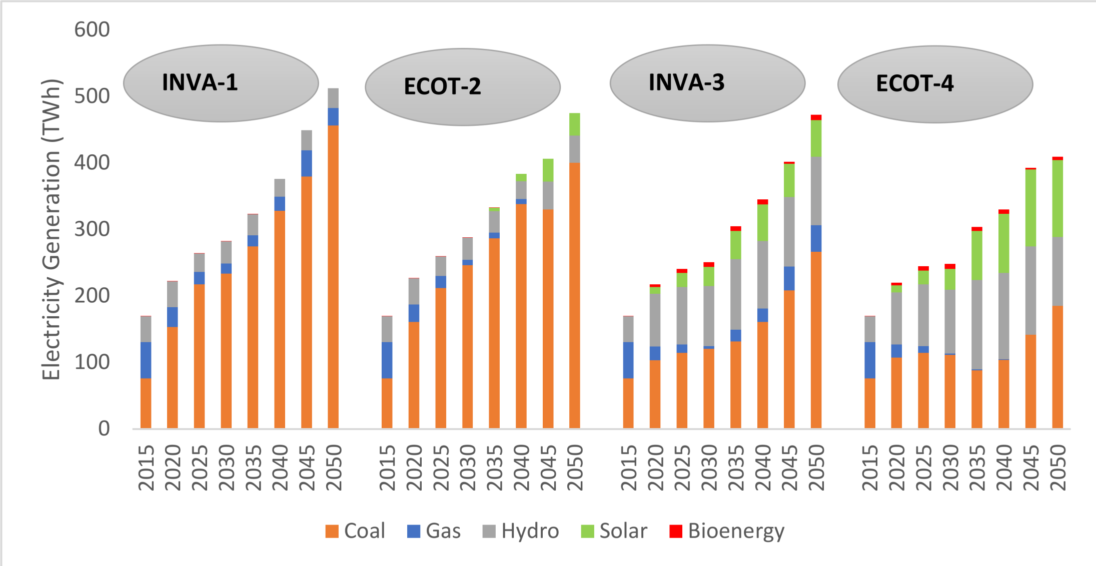

Figure 5. Electricity generation by technology under renewable energy policy consideration.

Figure 6 shows the impact of renewable energy policy measures. The injection of more renewables comes with high prices compared to baseline scenarios because some renewable technologies became competitive after government policy intervention.

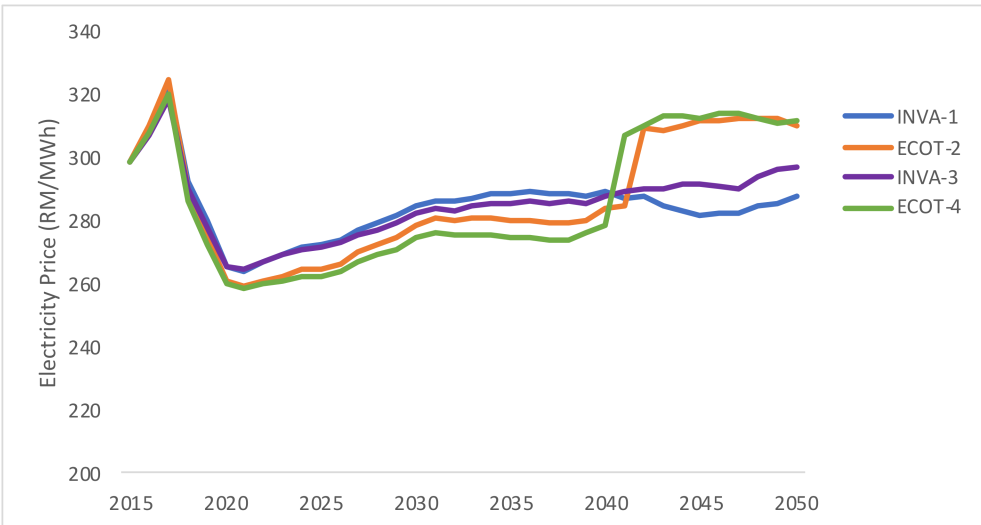

Figure 6. Electricity prices under renewable energy policy.

4.3. 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 was generated through fossil fuels, compared with 59% in the ECOT scenario, by 2050, against 82% in the reference year. Intensity generally increased as more fossil fuels were used to generate electric power. In the INVA RE policy scenario, carbon intensity improved from 0.549 in 2015 to 0.447 (18.6% decrease) by 2040 before deteriorating again to 0.507 (13.4%) by 2050, with a small change of 7.7% between 2015 and 2050 (see Table 4). At the same time, carbon intensity in the ECOT scenario experienced 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 reduced the intensity by 31% and 26% by 2035 and 2050, respectively (Table 4). When this result is viewed from the government's ambitious unconditional emission intensity target of 45 percent against the gross domestic product (GDP) by 2030 based on the 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 decarbonisation.

Table 4. Electricity carbon intensity under renewable energy policy scenario.

Operating Year	BaU Scenarios		Renewable Energy Policy Scenarios	
	Initial Value	Economic Trend	Initial Value	Economic Trend
	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

4.4. Electricity Carbon Emissions

Figure 7 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 is capped at 360 Mt for the ECOT-2 scenario, with averages of 199 Mt, 268 Mt, and 317 Mt for the periods between 2021 and 2030, 2031 and 2040, and 2041 and 2050, respectively. However, with renewable energy policies in place, emissions increase slower than the baseline scenario. Under INVA-3, emissions only increase 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 projects the best in terms of emissions trajectory at 173 Mt by 2050.

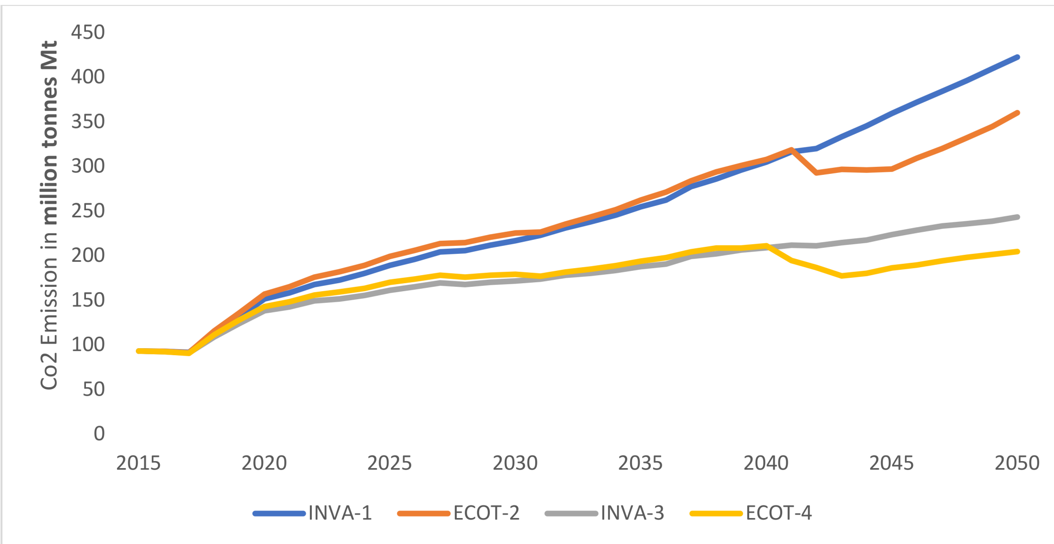

Figure 7. CO_2 emissions under renewable energy policy.

5. Discussion

We present the results of four scenarios based on renewable energy policies in Malaysia. Two main decarbonisation indicators are considered: absolute emissions and carbon intensity, even though the government only targets emission intensity reduction. Different factors are expected to affect Malaysia's electricity decarbonisation pathways by 2050, even in an INVA scenario. The most influential is the increasing population and growing economy. By 2050, the Department of Statistics Malaysia [66] projects the Malaysian population to be around 42.3 million, and the gross domestic product (GDP) growth rate is forecasted to be 4 percent. Electricity demand is modelled to increase annually by 3.1% throughout the simulation period. Based on the Energy Commission forecast, electricity demand is expected to double by 2040 and reach 58.288 TW by 2050 if the government does not implement any form of demand-side management measures.

The average value of the simulation results between 2015 and 2050 for each scenario was considered. This was born from the desire to present the whole picture of the renewable energy policy impacts. Our results reveal that renewable energy policies such as feed-in tariffs, net energy metering, and others can play a partial role in promoting the adoption of renewable energy sources and decreasing the carbon intensity of the electricity sector. However, it is important to note that the effectiveness of these policies can vary depending on their design and implementation and the specific context in which they are applied, as well as the country's context and resources. Compared with countries with deeply decarbonised energy, Malaysia lacks carbon pricing mechanisms to reinforce renewable energy technologies. For instance, Iceland has priced about 80 percent of its CO_2 from energy, with about 83 percent of Norwegian carbon emissions covered under the effective carbon rate as of 2021 [67,68].

6. Conclusions and Policy Implications

We built a model of the Malaysian electricity market and developed an agent-based computational economic model for renewable energy policies. We present key policy findings and directions to drive the electricity sector towards decarbonisation. The reference year, 2015, is characterised by different shares of natural gas, coal, and hydroelectric power in a well-interconnected, extensive system, which is representative of Malaysia's electricity system. This study aims to provide quantitative insights into the long-term effects of renewable energy on electricity decarbonisation pathways. Four scenarios were constructed. Finally, analysing these scenarios offers a powerful approach for highlighting and identifying policy requirements for energy transition.

The reason for considering renewable energy scenarios was to see how renewable target achievement would impact the decarbonisation 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 were implemented, more electricity was generated from RE sources such as hydro, solar PV, and bioenergy. Specifically, in scenario 3, the electricity system experienced an injection of solar PV complemented by hydroelectric power with a combined share of 1/5 of electricity generation. The RE situation became better in scenario 4, with 2 percent hydro, 12 percent solar PV, and 2 percent bioenergy shares of power generation by 2050. The deployment of RE sources came at the expense of fossil fuel power generation. The RE influence, on the one hand, and the increasing cost of natural gas electricity generation, on the other hand, were 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 was assumed to result from production subsidy, which reduced the investment cost of all RE sources except hydro, which was considered a matured technology.

The simulation results indicate that when all RE policy initiatives are well articulated and the 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 fluctuated around baseline values with insignificant effects in both scenarios.

Successful energy policies and an ambitious emissions reduction target cannot get off the ground without well-articulated renewable energy policy measures. However, the simulation results demonstrate that renewable energy policies are less effective in driving Malaysian electricity towards desired low-carbon pathways. Furthermore, it is evidenced that no single policy can achieve the emission reduction target. Therefore, a combination of energy efficiency [69], renewable energy [16], and carbon policy measures is unavoidable to decarbonise the electricity sector in Malaysia, as is the case for most European countries [70,71] and China [72]. This 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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