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Research Article

Energy transition and sustainable development in Malaysia: Steering towards a greener future

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Abstract. In the evolving landscape of global energy dynamics, Malaysia stands as a pivotal example of a nation actively transitioning towards renewable energy and sustainable development. This paper provides a comprehensive analysis of Malaysia's energy sector transformation, underpinned by the government's commitment to reducing carbon emissions and mitigating the impacts of climate change. The objective of this research is to delve into the intricacies, opportunities, and challenges of steering Malaysia towards a greener future, with a particular focus on the shift from reliance on fossil fuels to the adoption of renewable energy sources such as solar, wind, and biomass. Employing a mixed-method approach, this study synthesizes existing literature, policy documents, and case studies to examine the current state and historical context of energy use in Malaysia, analyze government initiatives and policy frameworks, explore technological advancements, and assess the environmental and socioeconomic impacts of the energy transition. Results indicate that despite facing challenges such as financial investment, technological advancement, and public acceptance, collaborative efforts between the government, private sector, and communities have led to significant progress in promoting renewable energy. The paper concludes that Malaysia's energy transition represents a critical step towards achieving a balance between economic growth and environmental preservation, setting a precedent for sustainable development in the Southeast Asian region. This transition is not only essential for climate change mitigation but also presents opportunities for economic diversification, energy security, and social inclusivity. The study ultimately calls for continued innovation, supportive policies, and international cooperation to overcome remaining barriers and fully realize the potential of renewable energy in Malaysia.

Keywords: Malaysia, Renewable Energy, Sustainable Development, Energy Security, Climate Change Mitigation.

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1. Introduction

The energy development path of Malaysia, a dynamic nation in Southeast Asia, is at a key point. Oil, natural gas, coal, hydroelectric power, and an increasing focus on renewable energy sources are all parts of the country's present energy landscape (Abdul Latif *et al*., 2021). Malaysia has reaped the economic benefits of its abundant fossil fuel reserves for a long time (The *et al*., 2021). The country is confronted with the daunting task of converting its energy industry to greener, more sustainable sources, even while the world is moving in a more sustainable direction. This article will go into the intricacies, possibilities, and necessity of sustainable development in the Malaysian context as it pertains to this continuous change.

The pressing issue of our times is climate change, which not only poses a significant threat to the environment but also impacts various aspects of human life, including health, economy, and social well-being. Malaysia's energy transition is not only a response to the need for sustainable development but also a crucial strategy in the global effort to combat climate change. By shifting towards renewable energy sources, Malaysia aims to reduce its greenhouse gas emissions, thereby contributing to the mitigation of global warming and the achievement of international climate goals (Kyriakopoulos *et al*., 2023; Bozoudis *et al*., 2022).

The use of fossil fuels in Malaysia's energy industry has long been a driving force behind the country's economic development. The nation is a major actor in the international energy market due to its huge oil and gas reserves (Foo, 2015). A key component of Malaysia's energy mix, mainly for power generation, has also been coal, though in smaller quantities (Khor & Lalchand, 2014). Rising carbon emissions and other forms of environmental degradation are consequences of the over-reliance on fossil fuels, which threatens environmental sustainability. Malaysia has begun to slowly transition to renewable energy sources, such as solar, wind, and biomass, in response to these issues (Abdul Latif *et al.,* 2021). In addition to being a tactical step towards increasing energy security and diversifying energy sources, this transformation is a reaction to environmental concerns.

It is impossible to exaggerate the significance of this energy shift for Malaysia's sustainable growth. Economic growth, environmental preservation, and social welfare are all aims of sustainable development (Duran *et al*., 2015). To achieve this

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equilibrium, Malaysia must move to renewable energy sources. It provides a way to lessen the world's emissions of greenhouse gases, which helps in the fight against climate change. In addition, new business opportunities arise from the expansion of renewable energy sectors, which may stimulate innovation, provide employment, and promote long-term economic progress.

Global environmental initiatives also have a role in shaping Malaysia's energy transformation. As a party to the Paris Agreement, Malaysia has committed to cutting its carbon emissions significantly (Raihan *et al.*, 2022). In order to meet its international commitments and establish itself as a conscientious member of the international community, Malaysia must ensure that its energy policies are in line with these objectives. In addition, Malaysia can move forward with its energy transition in a manner that supports economic and social inclusivity and environmental sustainability by referring to the United Nations Sustainable Development Goals (SDGs). This is especially true of Goal 7, which seeks to guarantee that everyone has access to modern, affordable, reliable, and sustainable energy (Zreik, 2023a).

There are new opportunities and threats that Malaysia must overcome as it makes this change. Several types of renewable energy, especially solar and biomass, can thrive in the country's climate and landscape. To achieve a successful energy transition, it is crucial to take use of these inherent benefits while also utilizing technological progress and governmental backing. Be that as it may, there are challenges along the way. It is important to give serious thought to matters like funding, building infrastructure, and making sure that communities and companies that rely on fossil fuels have a fair transition.

This paper aims to provide a comprehensive review of Malaysia's energy transition, with a focus on its implications for sustainable development and climate change mitigation. Specifically, the objectives of this study are to: (1) examine the current state and historical context of energy use in Malaysia, (2) analyse the government's initiatives and policy framework supporting renewable energy, (3) explore technological advancements and innovations in the energy sector, (4) assess the environmental and socioeconomic impacts of the energy transition, and (5) identify challenges and opportunities for future development. By synthesizing existing literature and policy documents, this paper seeks to contribute to a deeper understanding of Malaysia's energy transition and its role in addressing global environmental challenges.

2. Historical context of energy use in Malaysia

The historical context of energy use in Malaysia is a tale of transformation, marked by evolving consumption patterns and a deep reliance on fossil fuels. This change is a result of the country's improved economy, new technologies, and priorities as a result of worldwide environmental crises.

Malaysia's energy sector has long been characterized by a heavy reliance on fossil fuels, raising concerns about energy security and sustainability. The Resource Dependency Theory provides a lens through which to analyse this dependence and its implications (Cantarero, 2020; Chen *et al.*, 2019). By transitioning towards renewable energy sources, Malaysia can reduce its vulnerability to global energy market fluctuations and enhance its energy independence, aligning with the principles of this theory.

Malaysia relied heavily on traditional biomass and human labour for its energy needs during its early stages of development (Ozturk *et al.*, 2017). But after gaining independence in 1957, the country began a fast track to urbanisation and industry, which drastically changed how much energy it consumed (Moser, 2010). The rapid transformation was hastened when Malaysia became a major participant in the international energy market following the 1970s, when the country's oil and natural gas deposits were discovered and exploited (Brown, 2012). Due to their abundance, these resources were heavily relied upon for both internal consumption and export, particularly oil and natural gas.

Coal played an increasingly important part in power generation in Malaysia during the 1980s and 1990s, as the country's energy mix continued to diversify (Abdul Latif *et al.*, 2021). The economics of the situation dictated this change because coal was more affordable than oil, particularly when it came to generating electricity. Oil, natural gas, and coal made up the bulk of Malaysia's energy usage in the early 21st century, and the country's strong energy infrastructure was built on top of that (Oh, Pang, & Chua, 2010).

Figure 1 illustrates the simulated evolution of Malaysia's energy consumption by source from the 1970s to the present. It

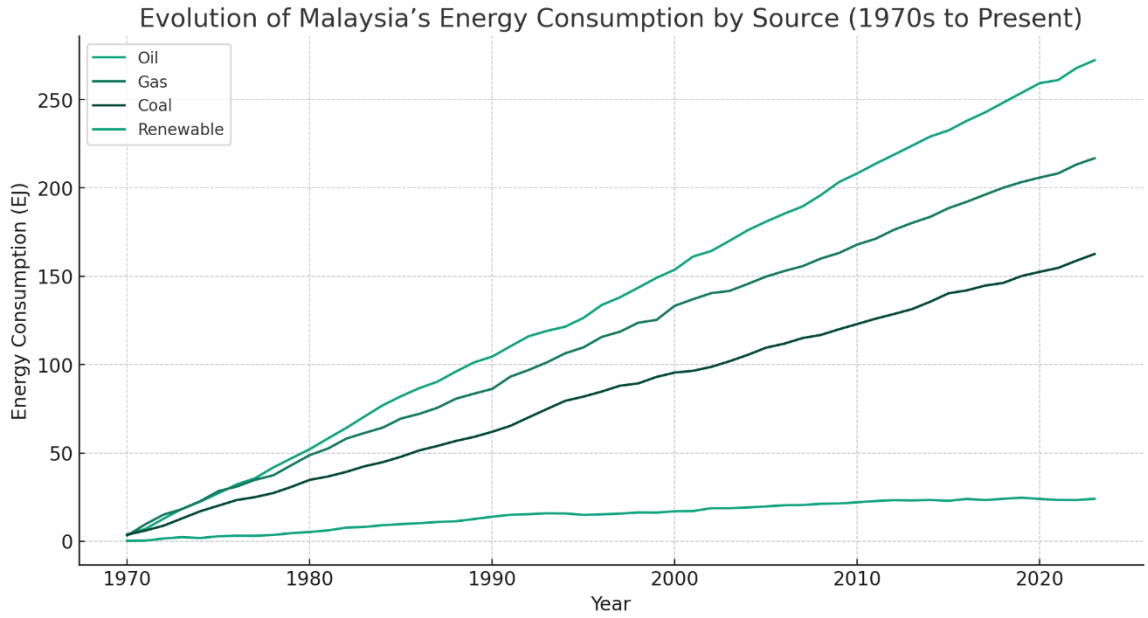

Fig 1. A line graph showing the evolution of Malaysia's energy consumption by source (oil, gas, coal, renewable) from the 1970s to present (Source: Malaysian Ministry of Energy and Natural Resources, 2023)

shows the trends for oil, gas, coal, and renewable energy consumption in Exajoules (EJ) over this period. Values and trends provide a visual representation of how energy consumption patterns have evolved in Malaysia over the years, with a general increase in consumption across all sources, and a notable rise in renewable energy in recent years.

The economics, ecology, and society of Malaysia have all been profoundly affected by this dependence on fossil fuels. Its substantial contributions to the nation's gross domestic product (GDP) and employment levels laid the groundwork for future growth and development. Foreign direct investment (FDI) in the energy industry, especially in the oil and gas sectors, drove economic growth (Badeeb, Lean, & Smyth, 2016). But there were environmental repercussions to this expansion. Greenhouse gas emissions rose due to fossil fuel combustion, which in turn accelerated global warming and worsened air pollution and habitat loss on a local level.

Over time, the environmental consequences of relying on fossil fuels have grown more and more noticeable. Sustaining economic growth while addressing the environmental effects of energy choices is a dual problem that many countries, including Malaysia, have confronted. Because of this, it has begun to rethink its energy policies and move towards renewable energy sources that are less harmful to the environment (Basri, Ramli, & Aliyu, 2015).

Furthermore, energy market dynamics and developments on a worldwide scale have also affected energy consumption patterns in Malaysia. The economy has been frequently impacted by fluctuations in global oil prices, which emphasise the risks of being overly reliant on fossil resources (Yatim *et al*., 2016). The research of renewable energy sources and diversification of the energy mix have been further encouraged by this vulnerability.

3. The imperative for energy transition

Climate change and environmental concerns are driving forces behind Malaysia's energy transformation requirement. Reduced emissions of greenhouse gases and increased participation in international initiatives to combat climate change are two goals to which Malaysia has pledged as a party to the Paris Agreement (Raihan *et al*., 2022). To meet this promise, the nation must drastically reduce its use of fossil fuels and increase its use of renewable energy.

Extreme weather, including heat waves, floods, and unpredictable monsoons, is becoming more common in Malaysia as a result of climate change (Shahid *et al*., 2017). The country's economy is at risk due to these changes, particularly in the climate-dependent industries of agriculture, fishing, and tourism. Additionally, the vast coastline of Malaysia is particularly vulnerable to the effects of increasing sea levels, which endanger both coastal populations and their infrastructure (Mohamad *et al*., 2018).

Degradation of the environment is another important issue that is strongly related to the way the country uses energy. Air pollution, which has repercussions for public health, lowers quality of life, and raises healthcare expenses, is mostly caused by the combustion of fossil fuels (Zreik, 2023b). There are dangers to biodiversity and ecological balance associated with deforestation for energy generation, especially when it comes to biomass energy (Rosillo-Calle, 2016).

One practical way to address these environmental concerns is by shifting to renewable energy sources like solar, wind, and hydroelectricity. Renewable energy sources lessen the negative effects on the environment caused by burning fossil fuels, including contamination of the air and water, and they also cut down on carbon emissions. In order to secure a sustainable and resilient future for the nation, Malaysia must address the crucial concerns of climate change and environmental preservation by shifting to cleaner energy sources.

An energy transition is essential for Malaysia due to economic and energy security concerns. There are a number of possible economic benefits to switching to renewable energy sources. These include the introduction of new technologies, the possibility of new industries being formed, and the creation of new jobs (Gielen *et al*., 2019). Malaysia can diversify its economy away from traditional energy exports and become a major participant in the renewable energy technology industry as the demand for this type of exports increases worldwide. This shift has the potential to strengthen the economy and increase its resilience, allowing it to better weather changes in the global energy market.

Malaysia must diversify its energy mix if it is to ensure its energy security. At present, the nation is susceptible to outside price shocks and supply interruptions due to its substantial dependence on fossil fuels, especially coal and oil imports (Li, Shi, & Su, 2017). The affordability and reliability of energy sources are threatened by this reliance. Malaysia can lessen its exposure to this risk by funding renewable energy projects in the country. Because they are less affected by swings in the worldwide market, renewable energy sources like solar and wind power offer a more reliable and consistent supply of electricity (Zreik, 2024a).

In addition, renewable energy sources have the potential to improve access to electricity, especially in rural and outlying parts of Malaysia where the infrastructure for energy production is either non-existent or unreliable (Jones & Olsson, 2017). Reducing the need for large transmission infrastructure and energy loss during distribution, renewable energy technologies like mini-hydroelectric systems and solar panels enable localised energy generation due to their decentralised nature.

The energy transition initiatives in Malaysia highlight the critical role that Malaysia plays in global sustainability obligations. The Malaysian government has made a public commitment to support international efforts to combat climate change and achieve sustainable development, such as the SDGs and the Paris Agreement (Raihan *et al*., 2022). These pledges bring national policies in line with international sustainability goals and demonstrate the country's commitment to sustainable development and environmental protection.

In accordance with the Paris Agreement, Malaysia has pledged to cut the intensity of its greenhouse gas emissions as a percentage of GDP by 45 percent by 2030 compared to 2005 levels (Rasiah *et al*., 2017). The nation's determination to tackle climate change by implementing sweeping energy policy changes is demonstrated by this lofty goal. Malaysia intends to achieve its goal of reducing emissions while maintaining support for economic growth through shifting to renewable energy sources and increasing energy efficiency (Raihan & Tuspekova, 2022).

The bar chart in Figure 2 demonstrates Malaysia's greenhouse gas emissions over the years, along with the projected reduction targets as per the Paris Agreement. The bars represent the actual emissions, while the red line indicates the target emissions based on Malaysia's commitment to the Paris Agreement. In this illustration, a 45% reduction in greenhouse gas emissions by 2030 relative to the 2005 levels has been assumed as per the agreement's target. The graph visually represents how the actual emissions might have trended historically and how they are expected to decrease to meet the targets set for 2030.

The energy policies of Malaysia are likewise guided by the SDGs, especially Goal 7, which states that everyone should have access to modern, cheap, dependable, and sustainable energy (Zreik, 2023a). The nation is actively pursuing a more renewable energy-centric energy mix, with a focus on improving energy

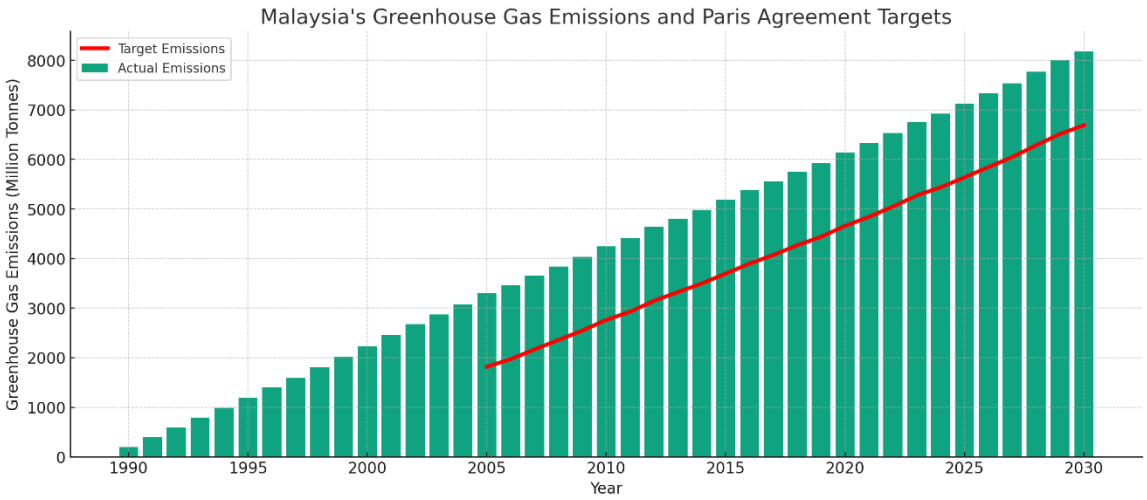

Fig 2. A bar chart illustrating Malaysia's greenhouse gas emissions over the years and the projected reduction targets as per the Paris Agreement (Source: International Energy Agency, 2022)

efficiency and expanding access to energy for all. All of the SDGs, not just those pertaining to health, education, economic growth, and climate action, rely on sustainable energy, which these initiatives help to achieve.

Beyond mere compliance, Malaysia's responsibility in these global agreements is to demonstrate leadership in the Southeast Asian region. As a leader in the fight against climate change and in favour of sustainable development, Malaysia has a responsibility to its neighbours and the world at large to demonstrate a smooth transition to renewable energy sources. This kind of leadership is essential for highlighting the need of community action and shared accountability in addressing sustainability concerns and achieving global goals.

4. Current strategies and policies

4.1. Government initiatives and policy framework

A comprehensive policy framework supporting the promotion of renewable energy and the reduction of dependence on fossil fuels is the foundation of Malaysia's present energy transition strategies and policies, which demonstrate a proactive attitude by the government. At the heart of these endeavours are a number of important programmes and strategies that show how seriously the government takes the issue of sustainable energy development.

The Institutional Theory emphasizes the role of policies, regulations, and institutional frameworks in shaping organizational behaviour and societal change. In the context of Malaysia's energy transition, this theory can be used to examine how governmental actions and institutional changes, such as the establishment of renewable energy targets and incentives, are crucial in promoting the shift towards renewable energy and influencing the overall trajectory of the transition (Dialga, 2021).

An integral part of Malaysia's energy strategy is the Renewable Energy Policy and Action Plan, which lays out specific goals for the implementation of renewable energy sources (Shaikh *et al.*, 2017). Solar, wind, biomass, and hydroelectric power are some of the renewable energy sources that will be prioritised under the plan's efforts to diversify the country's energy portfolio. The Large-Scale Solar (LSS) project is one example of a programme that promotes the use of solar energy by holding competitive bidding processes (Khan & Go, 2020).

The Green Technology Master Plan is another important strategy that will help green technology firms thrive in Malaysia (Abdul Manaf & Abbas, 2019). Although energy is the primary focus of this plan, it does cover a broader range of green technologies, such as improvements to the transportation and building sectors (Saifullah, Kari, & Ali, 2017).

To further encourage the use of renewable energy sources, the government has also instituted a number of incentives. Tax breaks for businesses who put money into renewable energy projects and feed-in tariffs, which provide a set price for renewable energy fed into the national grid, are two of these measures (Wong *et al.*, 2015). To further ease the incorporation of renewable energy sources into the current energy infrastructure, the government has also issued regulations and standards (Petinrin & Shaaban, 2015).

The adoption of co-design principles in policy formulation can significantly enhance the effectiveness of energy transition strategies. By involving a diverse range of stakeholders, including industry players, communities, and academia, in the policy-making process, Malaysia can ensure that its mitigation policies are well-aligned with the needs and aspirations of all groups. This collaborative approach to policy-making not only fosters inclusivity but also enhances the legitimacy and acceptance of energy policies, leading to more successful implementation and outcomes.

A sustainable energy future is a priority for Malaysia, and this is reflected in their initiatives and programmes. The government's sustainability goals, economic growth, and energy security can be achieved by fostering the development of renewable energy sources. In order to adapt to new technologies and shifting energy markets around the world, the policy framework is meant to be flexible and open to changes.

4.2. Investment in renewable energy: solar, wind, biomass

Renewable energy sources, such as solar, wind, and biomass, are attracting increasing amounts of investment in Malaysia as the nation works towards its goal of a sustainable energy transition. To help safeguard the environment and provide reliable energy supply, these investments are vital in spreading out the use of different types of energy and decreasing reliance on fossil fuels.

Government programmes and private investment have contributed to the solar energy sector's meteoric rise. One of the most important government programmes, Large Scale Solar (LSS), has played a significant role in promoting the construction of solar farms through open bidding (Khan & Go, 2020). Solar energy generation would be a perfect fit for Malaysia due to the country's sunny climate and strategic

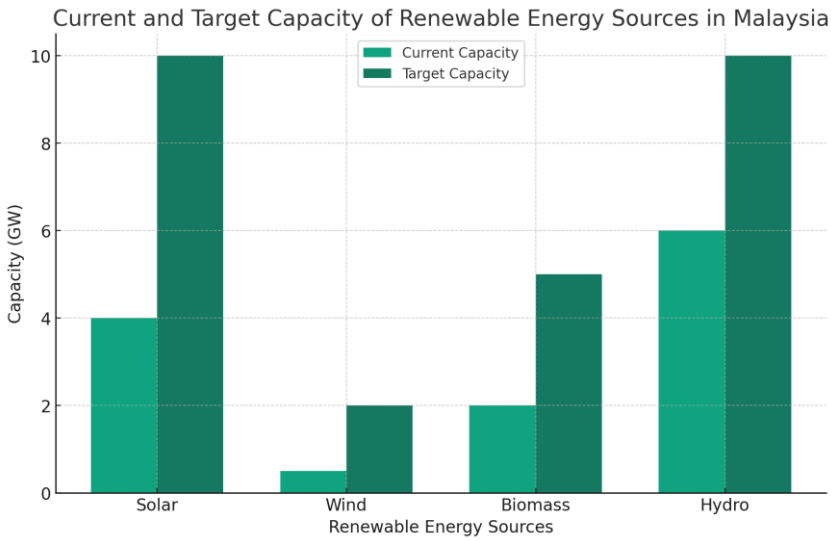

Fig 3. A graph displaying the current capacity of various renewable energy sources in Malaysia (solar, wind, biomass, hydro) and the targets for the next decade (Source: Malaysian Investment Development Authority, 2023)

positioning. There has been an increase in the installation of photovoltaic (PV) systems throughout residential, commercial, and industrial sectors, thanks to the attraction of both local and foreign investors (Ismail *et al*., 2015). Although wind power is still in its early stages in Malaysia in comparison to solar power, it is gaining interest all the same. Research is underway to find suitable locations for wind farms, with a focus on East Malaysia due to its favourable wind conditions (Ho, 2016). As time goes on and prices drop, more and more money will be poured into this industry.

Malaysia is also making strides in the field of biomass energy by using the waste products of its agricultural industry (Teh *et al*., 2021). A considerable amount of biomass material is produced by the country's enormous palm oil sector. Transforming garbage into a lucrative energy resource, biomass power plants have been pushed to flourish by the government through incentives like feed-in tariffs (Wong *et al*., 2015).

The graph presented in Figure 3 displays the current capacity and the target capacity for the next decade of various renewable energy sources in Malaysia, including solar, wind, biomass, and hydro. The left bars (in each pair) represent the current capacity, while the right bars illustrate the targets set for the next decade, all measured in Gigawatts (GW). This visual representation helps to understand the scale of growth and expansion planned for each renewable energy source in Malaysia's future energy strategy.

Renewable energy investments are bringing new economic opportunities to Malaysia while also helping the country achieve its sustainability and environmental goals. Employment opportunities, new technology developments, and increased investment from around the world are all things that could result from the renewable energy sector's rapid expansion. As a result of the government's encouraging policies and incentives, renewable energy has emerged as an important part of Malaysia's long-term plan for economic growth and environmental preservation (Yatim *et al.,* 2016).

4.3. Regulatory and financial incentives

A variety of financial and legal incentives are in place to encourage investment and development in renewable energy in Malaysia, which is helping the country switch to this source of power. To increase the financial viability and appeal of renewable energy projects to investors on a global scale, these incentives are essential.

Solar, biomass, biogas, and hydroelectric power are all examples of renewable energy sources that can be guaranteed a fixed premium price through the feed-in tariff (FiT) system, which is one of the main financial incentives (Lim, Lam, & Hashim, 2015). By guaranteeing a consistent flow of funds, this method encourages investment in renewable energy installations. The FiT tariffs are structured to be more competitive with traditional energy sources by reflecting the cost of producing each form of renewable energy (Aflaki & Netessine, 2017).

To further encourage investment in renewable energy, the Malaysian government also provides a number of tax benefits. Investment tax allowances and income tax exemptions are two examples of these measures aimed at encouraging the acquisition of environmentally friendly technology (Vaka *et al.,* 2020). The total cost of renewable energy projects is reduced by these fiscal measures, making them more economically feasible.

In order to make it easier to incorporate renewable energy sources into the country's system, Malaysia has established regulations that include standards and recommendations. Essential to the dependable and efficient operation of renewable energy systems are rules for interconnection, safety, and performance criteria.

The government has also set up the Sustainable Energy Development Authority (SEDA), an important entity in the administration and management of renewable energy projects like the FiT system. Renewable energy installation performance monitoring and regulatory compliance assurance are part of SEDA's purview. With the help of these financial and legal advantages, renewable energy in Malaysia has a solid foundation upon which to build, paving the way for its expansion. They are vital in drawing investment and propelling innovation in renewable energy technology, and they show that the government is serious about having a sustainable energy future.

5. Technological advancements and innovations

5.1. Development in green technologies

The energy transition in Malaysia is being led by technological developments and innovations in green technologies, which are crucial to the country's move towards sustainable energy solutions. Renewable energy sources are becoming more efficient and practical as a result of these

technologies' fast development, which is fuelling both economic growth and environmental sustainability.

Recent years have witnessed remarkable progress in photovoltaic (PV) technology in Malaysia's solar energy sector (Khan & Go, 2020). The energy yield of solar systems is being enhanced by developments such as more efficient solar panels and bifacial solar cells, which can absorb sunlight from both directions. Solar power is becoming a more dependable power source as its intermittency is being addressed through the incorporation of energy storage technologies (Yao *et al*., 2016).

Recent technical developments have also been beneficial to the biomass industry. Using cutting-edge technology, Malaysia is making better use of its plentiful biomass resources, especially from the palm oil industry, to convert biomass waste into energy (Antar *et al*., 2021). Gasification and anaerobic digestion process innovations are making biomass energy generation more efficient, less wasteful, and less harmful to the environment (Hameed *et al*., 2021).

Although wind energy is still in its infancy in Malaysia, new technologies are anticipated to be pivotal in this field. It is expected that wind turbines that are more efficient and long-lasting will be developed so that they can function in the low-wind circumstances that are common in Malaysia (Ho, 2016). As a result, the nation's renewable energy portfolio would include wind power with more certainty.

To make renewable energy more affordable and competitive with conventional fossil fuels, several technical developments are essential. A more innovative, investment-friendly, and collaborative public-private ecosystem is being created thanks to the government's funding of R&D in these areas. Consequently, Malaysia is making strides towards its own renewable energy targets while also aiding the international movement towards more environmentally friendly technology.

Collaborative approaches, such as the development of energy communities, play a crucial role in driving innovation in renewable energy technologies. By empowering local stakeholders to actively participate in the energy transition, these communities can contribute to the development and implementation of sustainable energy solutions. Energy communities can serve as platforms for sharing knowledge, resources, and best practices, thereby accelerating the adoption of renewable energy technologies and fostering a sense of ownership among participants.

5.2. Integration of renewable energy into the grid

Careful management and technological innovation are necessary to guarantee the efficiency and reliability of renewable energy integration into Malaysia's grid, which is an important part of the country's energy transformation. The intermittent and unpredictable nature of renewable energy sources, such as solar, wind, and biomass, poses distinct issues as they gain popularity. If the nation wants a smooth integration that helps keep the electricity system stable, it has to solve these problems.

In order to incorporate renewable energy sources, improving the grid infrastructure is a key strategy. To accommodate the intermittent demands produced by renewable energy sources, it is necessary to upgrade the distribution and transmission networks. To optimise electricity flow, increase demand responsiveness, and preserve grid stability, advanced grid management technologies are being introduced, such as smart grid systems (Sarker *et al*., 2021).

An integral part of this integration is energy storage systems. By capturing and reusing power during periods of high and low production, they mitigate the unpredictability and intermittent nature of renewable energy sources. Malaysia is seeing a rise in the use of grid-supporting technologies such as flywheel energy storage, pumped hydro storage, and batteries (Isa, Tan, & Yatim, 2018).

The creation of market mechanisms and regulatory frameworks to facilitate the integration of renewable energy sources is another critical component. Grid connectivity rules and regulations, renewable energy price structures, and energy storage solution subsidies are all part of this category. Renewable energy certificates (RECs) are another tool the government is using to boost the usage of renewable power (Chachuli *et al*., 2021).

To get the most out of Malaysia's switch to renewable energy, it's crucial that renewable power be well-integrated into the system. It helps the nation achieve its environmental and economic goals by making sure renewable energy is a dependable part of the energy mix.

5.3. Case studies of successful implementation

Several case studies highlight innovative and effective implementations in Malaysia's journey towards renewable energy integration. The Solar Power Project in Putrajaya is a prime illustration of how solar energy may be effectively integrated into urban environments. The government buildings' rooftops will be covered in photovoltaic panels as part of this project, which will generate a lot of power and set an example for how public infrastructure may use solar energy (Khan & Go, 2020). Not only has this project successfully decreased energy expenses for these buildings, but it has also inspired other efforts nationwide.

Sime Darby Plantation is another noteworthy example; it is an industry pioneer in the use of biomass as an energy source. The company's dependence on fossil fuels has been greatly diminished as a result of their effective conversion of oil palm waste into sustainable energy (Md Dahlan & Mohd Khalid, 2019). They have developed a sustainable energy model that other agricultural sectors might follow by making use of by-products from their palm oil operations. This strategy tackles two important environmental challenges at once: providing a renewable energy source and aiding with garbage management.

One of the most innovative projects in Malaysia's wind energy sector is the Sabah Wind Farm. Kudat, Sabah is home to one of the country's earliest large-scale wind farms. This experiment has shown that wind energy is feasible in some areas of Malaysia, even if the wind speeds in that country aren't very high (Ibrahim & Albani, 2014). This opens the door for more research and development of wind power in Malaysia.

Renewable energy and innovation are priorities for Malaysia, as shown in these case studies. Building a sustainable and resilient energy future requires varied approaches. This includes urban solar projects, biomass energy in plantation sectors, and researching wind energy potentials. Every one of these projects does double duty: it adds to the country's energy mix and models sustainable energy practices for the rest of Southeast Asia.

6. Challenges and barriers

6.1. Financial and economic challenges

Significant financial and economic hurdles must be surmounted if Malaysia is to succeed in its shift to renewable energy. In the beginning, the large financial investment needed to transition from conventional energy infrastructure based on fossil fuels to renewable energy sources might be a big obstacle. Solar farms and wind turbines are examples of renewable energy projects that require substantial initial investment due to the high cost of technology and installation (Kumar *et al*., 2016). Renewable energy has obvious long-term advantages and

reduced operational costs, but the upfront investment required can be prohibitive for some public and commercial entities.

The fossil fuel industry's vested interests and the current fossil fuel subsidies are another obstacle to economic growth. The market is skewed against renewable energy sources because these subsidies artificially make fossil fuels cheap (Li & Sun, 2018). Finding a middle ground between social, political, and economic concerns is no easy task when trying to reduce or reallocate these subsidies to fund renewable energy projects. On top of that, it is required to make sure that businesses and employees that rely on the fossil fuel industry don't get hit too hard financially by shifting the focus to renewable energy sources. In addition, a policy climate that is both stable and favourable is necessary to attract investment in renewable energy projects. Clarity and predictability in policies, rules, and incentives are what investors look for. Renewable energy development might be hindered by policy or regulatory framework fluctuations, which discourage investment (Zreik, 2024b).

In order for Malaysia to make the switch to renewable energy, these economic and financial obstacles must be addressed. The first step is to attract investors and secure the required funds; the second is to foster an economic climate that is conducive to the expansion of the renewable energy industry. Strong public-private partnerships, monetary incentives, and reformed policies are all necessary components of a unified strategy.

6.2. Technological and infrastructural barriers

Significant obstacles to Malaysia's shift to renewable energy come from technological and infrastructure constraints. The existing energy infrastructure is mainly built for centralised power generation using fossil fuels, which is one of the main problems (Oh *et al.*, 2018). Substantial adjustments are necessary to adapt this infrastructure to variable and decentralised renewable energy sources. For instance, to guarantee a steady and dependable supply of electricity, the country's infrastructure must be enhanced to accommodate renewable energy sources like solar and wind, which are inherently intermittent.

Research, development, and deployment are also obstacles to the adoption and development of advanced renewable energy technology. Solar power has been a major success story for Malaysia, but the country's other renewable energy sources, like wind and biomass, are in their infancy (Jones & Olsson, 2017). The country should increase its investment in R&D to tailor these technologies to local circumstances, including processing biomass resources efficiently or dealing with low wind speeds for wind turbines.

The scarcity of qualified experts and technicians versed in renewable energy technology is another obstacle to infrastructure development (Derasid *et al.*, 2021). The optimisation, installation, and maintenance of renewable energy systems can be impeded by this lack of skills. The long-term success of the renewable energy industry depends on the cultivation of a competent labour force. Another infrastructure difficulty is the dispersion of renewable resources around the world (Zreik, 2023b). For instance, it may be necessary to invest in transmission infrastructure in order to efficiently transfer energy from places with strong solar potential or biomass availability to areas that are far from large consumption centres.

The public and commercial sectors must work together to overcome these infrastructure and technology hurdles. Investing in human capital development is a part of it, as is investing in infrastructure renovations and new technologies. In addition, working together with global organisations and partners might be essential in resolving these issues and easing Malaysia's transition to a sustainable energy future.

6.3. Social and political considerations

The transition to renewable energy in Malaysia is not just a technical or economic endeavour; it involves significant social and political considerations as well. Promoting universal energy access is a major social concern. It is of the utmost importance that all demographics, particularly those living in rural or underprivileged areas, reap the benefits of the growing renewable energy infrastructure. Without proper policy and planning, renewable energy innovations run the danger of disproportionately benefiting cities and the well-off, deepening social disparities.

It is equally critical for renewable energy projects to have public support and acceptance (Wüstenhagen, Wolsink, & Bürer, 2007). To do this, it is required to dispel myths and dispel fears regarding renewable energy technologies through open dialogue and active community participation. It is crucial to include the local community in the planning and decision-making processes because their support is often the key to these projects' success.

The political shift to renewable energy sources is fraught with intricate power dynamics and interest groups to negotiate. There are powerful interests in keeping things the way they are in Malaysia's fossil fuel industry, which has shaped the country's economy and politics for decades. A delicate political balancing act is required to wean the world off fossil fuels while also protecting the interests of the energy industry's established players. To win over the public, renewable energy policies and initiatives must also be open and responsible when put into action. This necessitates well-defined policy goals, open and honest project bidding procedures, and safeguards against corruption and unfair competition. To ensure a seamless and prosperous shift to renewable energy in Malaysia, it is essential to address these political and societal factors. To guarantee that everyone in society can reap the benefits of renewable energy and that the shift is widely supported and accepted, laws and efforts must be open, equitable, and transparent.

7. Impact Assessment

Environmental implications, socioeconomic advantages and downsides, and comparisons with other ASEAN countries are all part of the impact assessment of Malaysia's energy transition. The environmental impact of Malaysia's transition to renewable energy sources is substantial. The nation is making strides in combating climate change by decreasing its use of fossil fuels, which in turn reduces its carbon footprint (Li & Sun, 2018). In order to improve air quality and reduce pollution, renewable energy sources like solar, wind, and biomass must be used instead of conventional fossil fuels. Additionally, this shift helps with biodiversity preservation and lessens environmental damage because renewable energy projects often leave less of an ecological imprint than the extraction and combustion of fossil fuels.

Many different aspects of Malaysia's energy transformation will have positive social and economic effects. From administrative and support jobs to more professional ones in engineering and installation, the renewable energy sector is creating new opportunities for employment (Majid, 2020). The economy can become more resilient to changes in global oil prices by diversifying its sources of revenue. Community empowerment, energy security, and the alleviation of energy poverty can all result from the democratisation of energy via distributed renewable energy sources, such as solar panels

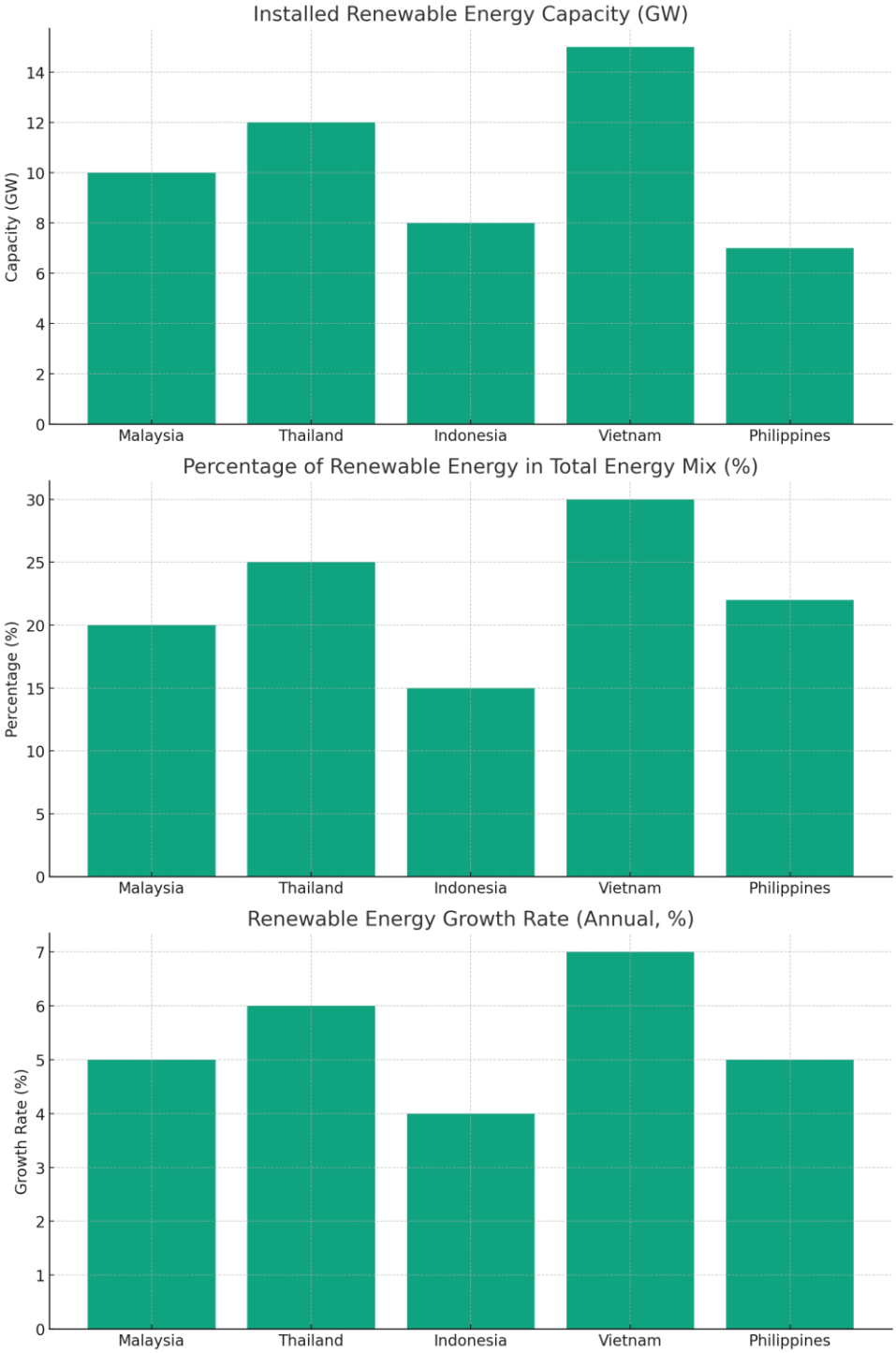

Fig 4. A comparative chart showing key renewable energy metrics of Malaysia in comparison with select ASEAN countries (Source: International Energy Agency, 2023)

(Ismail *et al*., 2015). Nevertheless, possible downsides do exist. Communities and jobs dependent on the fossil fuel industry may be affected by the change, which could disrupt the traditional energy sector. It will need policies that encourage retraining and redeployment of workers in these fields if we are to manage this change fairly. Renewable energy infrastructure also requires large investments and enabling economic policies, which can be costly in the short term.

The energy transition journey of Malaysia provides distinct insights when compared to other ASEAN countries. Some countries have also achieved great achievements in incorporating renewable energy sources, such as solar electricity in Thailand and geothermal power in the Philippines. The Thai solar energy market is among the most advanced in Southeast Asia, thanks to generous subsidies and supportive policies (Chimres & Wongwises, 2016). As a result of its advantageous location on the Pacific Ring of Fire, the Philippines has become a leading global generator of geothermal energy (Pambudi, 2018).

An important aspect of Malaysia's energy transition is the co-benefits associated with mitigation actions, particularly in terms of air pollution reduction. Shifting from fossil fuels to renewable energy sources not only addresses climate change but also significantly improves air quality. The reduction of emissions from coal and oil combustion results in lower levels of particulate matter, sulfur dioxide, and nitrogen oxides, which

are major contributors to air pollution and public health issues. Cleaner air can lead to substantial health benefits, including reduced respiratory and cardiovascular diseases, and lower healthcare costs. Furthermore, enhanced air quality can contribute to better environmental conservation and biodiversity, as well as improved quality of life for the population. These co-benefits reinforce the importance of a holistic approach to energy transition, where climate mitigation efforts are aligned with public health and environmental objectives (Progiou *et al*., 2023).

Bioenergy is a major priority in Indonesia, as it is in Malaysia, due to the country's sizable agricultural economy. Geographical and infrastructural limitations, however, make it difficult for Indonesia to expand its renewable energy sector (Dharmawan *et al*., 2020). Solar power has grown rapidly in Vietnam, thanks to the country's generous feed-in tariffs and other incentives (Do *et al*., 2021). The integration and stability of the grid have been affected by the issues brought forth by this fast expansion.

The comparative chart displayed in Figure 4 showcases key renewable energy metrics of Malaysia in comparison with select ASEAN countries, namely Thailand, Indonesia, Vietnam, and the Philippines. The chart is divided into three sections, each representing a different metric: installed capacity in Gigawatts (GW), percentage of renewable energy in the total energy mix, and the annual growth rate of renewable energy.

- *Installed Renewable Energy Capacity (GW):* This section compares the total installed capacity of renewable energy sources in each country, measured in Gigawatts.
- *Percentage of Renewable Energy in Total Energy Mix (%):* This part illustrates the proportion of renewable energy in each country's total energy mix, expressed as a percentage. It indicates how significant the role of renewable energy is in each country's overall energy scenario.
- *Renewable Energy Growth Rate (Annual,* %): The final section shows the annual growth rate of renewable energy in percentage terms. This rate reflects how rapidly each country is expanding its renewable energy sector.

This chart provides a comparative view of how Malaysia and its ASEAN counterparts are performing in terms of renewable energy development. While all of the ASEAN member states are working towards the same objective of increasing their use of renewable energy, these comparisons reveal that the geographical, economic, and social circumstances of each country present its own set of problems and opportunities. Malaysia exemplifies a paradigm that achieves economic growth while also preserving the environment, thanks to its well-rounded approach to various renewable sources and its emphasis on electrifying both urban and rural areas.

7.1. Comparative analysis with international initiatives

The solar energy market in neighbouring Southeast Asian countries, such as Thailand, has advanced significantly due to generous subsidies and supportive policies. Malaysia can draw lessons from these countries' approaches to incentivizing solar energy and explore similar policy frameworks to accelerate its own solar energy adoption.

In the realm of bioenergy, Malaysia shares common ground with countries like Indonesia, which also prioritizes this renewable energy source due to its large agricultural sector. However, Malaysia's relatively better infrastructure positions it to scale up bioenergy production more efficiently compared to Indonesia, which faces geographical and infrastructural challenges.

Vietnam's rapid growth in solar power, driven by attractive feed-in tariffs, offers insights into how policy incentives can spur renewable energy development. Malaysia could consider revisiting its feed-in tariff rates to boost solar energy investments, similar to the approach taken by Vietnam.

The Philippines' success in geothermal energy highlights the potential of harnessing indigenous renewable resources. Malaysia could explore its geothermal potential, particularly in regions with volcanic activity, to diversify its renewable energy mix.

Implementing attractive incentives, such as feed-in tariffs and tax benefits, is crucial for encouraging investment in renewable energy. Strengthening infrastructure, including grid integration and transmission networks, is essential for accommodating the growth of renewable energy. Identifying and leveraging indigenous renewable resources, such as bioenergy and geothermal energy, can provide a sustainable and localized energy supply. By examining the experiences of these countries, Malaysia can identify strategies to enhance its own energy transition efforts, ensuring a more sustainable and resilient energy future.

7.2. Stakeholder analysis in energy transition

The success of Malaysia's energy transition is influenced by a complex interplay of stakeholders, each with their own perspectives and contributions to sustainable development. This section delves into the mapping and analysis of these stakeholders, shedding light on their roles and perceptions.

The government stands at the forefront, shaping the regulatory landscape and providing incentives for renewable energy. Its policies and priorities are pivotal in steering the direction of the energy transition. Industry players, including energy producers and technology providers, play a crucial role in implementing innovative solutions and driving economic growth. Their investment decisions and technological advancements are key to the transition's success.

Communities and civil society organizations are vital in ensuring social acceptance and advocating for environmental and social justice. Their engagement and participation in decision-making processes ensure that the transition is inclusive and equitable. Academia and research institutions contribute valuable insights and innovations, informing policy and technological development.

The financial sector, including banks and investors, provides the necessary capital for renewable energy projects. Their risk assessments and investment strategies significantly impact the pace and scale of the transition. International organizations and foreign governments also influence Malaysia's energy transition through partnerships, funding, and knowledge exchange.

Each stakeholder group brings unique perspectives and interests to the table. Understanding these dynamics is crucial for developing holistic policies that balance economic growth, social equity, and environmental sustainability. Engaging with stakeholders and incorporating their feedback can lead to more effective and widely accepted energy transition strategies, ultimately contributing to Malaysia's sustainable development goals.

By integrating this stakeholder analysis into your paper, you can provide a comprehensive view of the various factors at play in Malaysia's energy transition and enrich the discussion section with a deeper understanding of the interactions and contributions of different stakeholders.

Energy communities represent a practical application of co-design principles in the context of Malaysia's energy transition. These communities involve local residents, businesses, and institutions in the collaborative development

and management of renewable energy projects. By harnessing the collective expertise and resources of community members, energy communities can contribute to the decentralization of energy production, enhance energy security, and promote social cohesion and local economic development.

8. Future prospects and recommendations

Cleaner, more sustainable energy, is becoming increasingly important around the world, and this trend has significant implications for Malaysia's energy transition and sustainable development plans. For Malaysia, the coming decade is critical as it aims to solidify its progress in renewable energy and find a sustainable way ahead.

The Sustainability Transitions Theory, particularly the multi-level perspective framework, offers a comprehensive approach to understanding Malaysia's energy transition journey. This framework considers the interactions between niche innovations, existing socio-technical regimes, and broader socio-economic contexts (Kabeyi & Olanrewaju, 2022; Ntanos *et al.*, 2018). Analysing Malaysia's energy transition through this lens can help identify barriers and opportunities for sustainable change, including socio-cultural norms, political dynamics, and economic considerations that influence the transition process.

Major changes are in store for Malaysia's energy sector during the next decade. Renewable energy sources, such as solar and biomass, are likely to see a surge in funding. Renewable energy sources including solar photovoltaic (PV) systems and biomass energy conversion technologies are expected to become increasingly appealing as their prices continue to decline. A more significant role for developing renewable energy sources, such as wind and marine power, in Malaysia's energy mix may emerge in the future as technology develops.

Additionally, advancements in energy storage technology are anticipated, which are vital for controlling the intermittent nature of renewable power sources. More steady integration of renewables into the grid may be possible with the widespread use of improved battery technology and creative alternatives such as pumped hydro storage (Javed *et al.*, 2020). Better demand management and increased efficiency are two additional benefits of digitalizing energy systems using smart grids and Internet of Things (IoT) applications (Hashmi, Ali, & Zafar, 2021).

Malaysia must employ a comprehensive policy strategy if it is to maintain and expedite its energy transition. First, it needs to keep subsidising and incentivizing renewable energy projects so they can compete with fossil fuels. Policies should also aim to reduce subsidies for fossil fuels, doing so in a way that causes as little economic disturbance as possible as they are phased out.

Second, the renewable energy industry is in need of a trained workforce, which Malaysia may provide by funding educational and training programmes. Workers in the traditional energy sectors will find this programme helpful in making the shift, and thus it will have a reliable supply of skilled specialists thanks to it.

In addition, the national grid's ability to include renewable energy sources must be supported by more robust regulatory frameworks. Standards for the connectivity of decentralised energy sources, energy storage, and grid stability rules are all part of this. Another way to speed up the implementation of renewable energy technology is to promote public-private collaborations.

In light of the COVID-19 pandemic, it is crucial to consider its repercussions on Malaysia's energy transition. The pandemic has presented both challenges and opportunities for the renewable energy sector. On one hand, economic slowdowns and supply chain disruptions have temporarily hindered progress in renewable energy projects. On the other hand, the pandemic has underscored the importance of resilient and sustainable energy systems, leading to increased interest in decentralized renewable energy solutions. The post-pandemic recovery presents a unique opportunity for Malaysia to accelerate its energy transition as part of a 'green recovery' strategy, aligning economic stimulus measures with long-term sustainability and climate goals. Therefore, the COVID-19 pandemic, while disruptive, could serve as a catalyst for Malaysia to reinforce its commitment to renewable energy and sustainable development (Papadogiannaki *et al.*, 2023; Progiou *et al.*, 2022).

Finally, energy efficiency and new forms of renewable energy should be areas of focus for Malaysian research and development. Academic institutions and worldwide research organisations could form alliances to do this.

In the context of Southeast Asia, Malaysia has the potential to spearhead the group's shift to renewable energy sources. Malaysia can help address energy concerns in the region by sharing its knowledge and implementing best practices for renewable energy. Joint research projects, policy discussions, and capacity-building initiatives might all benefit from this kind of leadership.

On a global scale, Malaysia is in sync with other nations fighting climate change because of its dedication to sustainable development and renewable energy (Shahid *et al.*, 2017). Malaysia can help shape worldwide energy policies by being an active participant in global conferences and projects. Furthermore, renewable energy projects in Malaysia have the potential to entice investors and technological partners from around the world, leading to increased international cooperation.

9. Conclusion

The fact that Malaysia is actively working towards energy transition and sustainable development shows that the country is serious about creating a better, more environmentally friendly future. In response to growing environmental concerns and calls for a more sustainable economic model, the nation is moving away from its heavy use of fossil fuels and towards renewable energy sources. Though difficult, this move has put Malaysia in a prime position to lead the international fight against climate change and in favour of sustainable development.

Examining the energy landscape of Malaysia, from its past reliance on fossil fuels to its present policies and plans, reveals a country going through a period of profound transformation. Achieving energy security and environmental sustainability can be achieved by the government's initiatives and investments in renewable energy sources such as solar, wind, and biomass. Financial, technical, infrastructural, and social obstacles are all being tackled by implementing all-encompassing legislation and adopting inclusive approaches. Collaboration in tackling global environmental concerns is something that Malaysia is deeply committed to, as shown by its involvement in regional and global sustainability programmes. Insights and lessons for regional cooperation can be gleaned from the comparative analysis with other ASEAN countries, which shows a heterogeneous landscape of energy transformation.

This study lays out a road map for future sustainable growth based on prospective advancements and policy suggestions. Other countries can learn from Malaysia's experience as it aggressively adopts renewable energy technology, strengthens its policy frameworks, and cultivates international partnerships.

This energy shift is more than just a challenge; it's a chance for Malaysia to reimagine its place in the world, encourage creativity, and create the groundwork for a sustainable future. The people of Malaysia, the business community, and the government must all work together if this change is to be a success. With its unwavering commitment to this route, Malaysia serves as an inspiration for the potential of sustainable development in a world that is always evolving. While this study provides valuable insights into Malaysia's energy transition and its role in sustainable development, it is important to acknowledge its limitations. One such limitation is the scope of the analysis, which primarily focuses on the national level, potentially overlooking the nuances of regional or local initiatives. Additionally, the rapidly evolving nature of renewable energy technologies and policies may limit the long-term applicability of our findings. Future research could address these limitations by conducting more granular analyses at the regional or community level and by continuously updating the study to reflect the latest advancements in technology and policy. Moreover, further exploration of the social and economic impacts of the energy transition on different segments of the population could provide a more comprehensive understanding of its implications. By acknowledging these limitations and suggesting avenues for future work, this study aims to contribute to the ongoing dialogue on sustainable energy transition and climate change mitigation.

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