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Review

Review of the Effects of Fossil Fuels and the Need for a Hydrogen Fuel Cell Policy in Malaysia

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Abstract: The world has relied on fossil fuel energy for a long time, producing many adverse effects. Long-term fossil fuel dependency has increased carbon emissions and accelerated climate change. In addition, fossil fuels are also depleting and will soon be very costly. Moreover, the expensive national electricity grid has yet to reach rural areas and will be cut off in inundation areas. As such, alternative and carbon-free hydrogen fuel cell energy is highly recommended as it solves these problems. The reviews find that (i) compared to renewable energy such as solar, biomass, and hydropower, a fuel cell does not require expensive transmission through an energy grid and is carbon-free, and hence, it is a faster agent to decelerate climate change; (ii) fuel cell technologies have reached an optimum level due to the high-efficiency production of energy, and they are environmentally friendly; (iii) the absence of a policy on hydrogen fuel cells will hinder investment from private companies as they are not adequately regulated. It is thus recommended that countries embarking on hydrogen fuel cell development have a specific policy in place to allow the government to fund and regulate hydrogen fuel cells in the energy generation mix. This is essential as it provides the basis for alternative energy governance, development, and management of a country.

Keywords: alternative energy; climate change; carbon emission; fossil fuel; hydrogen fuel cell

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1. Introduction

Sustainable energies are essential to any country's development. Sustainable energy can be defined as the means by which a country provides affordable, reliable, environmentally friendly, proactively regulated, and socially acceptable energy services to end users [1]. To equip a country with lasting energy resources, a sound energy policy from the government is very much needed. In this regard, energy policy can be defined as a strategy formulated by the government that is clearly explained in detail to regulate the current and future energy resources [2]. Furthermore, it is a way an entity (usually the government) decides to deal with energy development, including its generation, distribution, and consumption [3]. By that definition, energy policy is essential as it provides the basis for energy development and management in the country.

For decades, and across the globe, people have depended on fossil fuels for energy production. However, using gasoline as an energy source puts users in a dilemma. On the one hand, humans desire rapid development to change their living standards. On the other hand, humans also wish to pursue their social objective of having clean air and a healthy environment. If a balance is achieved, it would be possible to achieve pollution-free air since development involves opening new industries, increasing residential areas, and high transportation usage. However, these activities use fossil fuel resources for energy generation, and air pollution is inevitable. Hence, a shift towards carbon-free energy is timely in this forever-developing world.

Many businesses have used renewable energy, such as wind turbines and hydropower, in their plants to make the production process cleaner and carbon neutral and reduce

the impact of climate change. Compared to renewable energy sources, such as solar and wind turbines, the hydrogen fuel cell is not influenced by environmental factors such as temperature, season, and geology. Vehicles powered by hydrogen fuel cells can reduce greenhouse gas and air pollution from the transportation sector as they are carbon-free.

The following discussion explains the adverse effects of fossil fuels in the present energy generation mix. It then compares renewable energy, such as solar, biomass, and hydropower, with energy generated from hydrogen fuel cells. It is proven that fuel cell technologies have reached an optimum level due to the high-efficiency production of energy and they are environmentally friendly. Nevertheless, the absence of a policy on hydrogen fuel cells has hindered investment from private companies as the industry needs to be appropriately regulated.

2. Methods

This doctrinal research explores the materials needed from primary sources (such as laws and policies) and secondary sources (such as online databases) using keywords such as "energy policy", "carbon emission", "energy depletion", "climate change", 'fossil fuel", and "fuel cells" in databases and on other research platforms. Using the qualitative analysis software Atlas.ti 8, a set of themes was developed through the review analysis in discussing the effects of dependency on fossil fuel as the primary energy source. The thematic analysis assesses the recent development in hydrogen fuel cell technology. The thematic analysis is a qualitative research method that can be widely used across a range of epistemologies and research questions. It is a method for identifying, analyzing, organizing, describing, and reporting themes within a data set [4]. This is useful for this article as it evaluates the feasibility of using alternative carbon-free energy in reducing carbon emissions and climate change.

3. Findings

3.1. Thematic Analysis from Atlas.ti 8

After grouping the journal articles obtained from online databases using keywords such as "energy depletion", "carbon emission", and "climate change", the journal articles were then analyzed using the qualitative analysis software Atlas.ti 8 in order to see whether they were relevant for this research. The process produced three "word clouds" based on the terms "energy depletion,", "carbon emission", and "climate change", as shown in Figures 1–3, respectively.

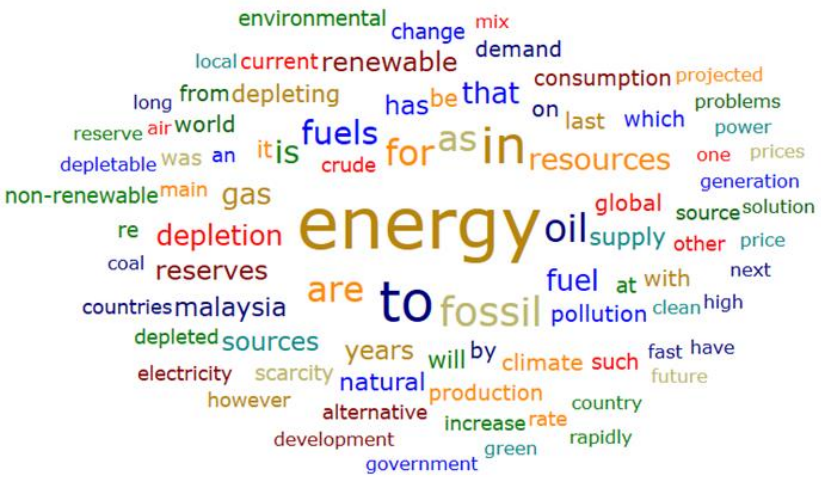

Figure 1. Word cloud based on "energy depletion".

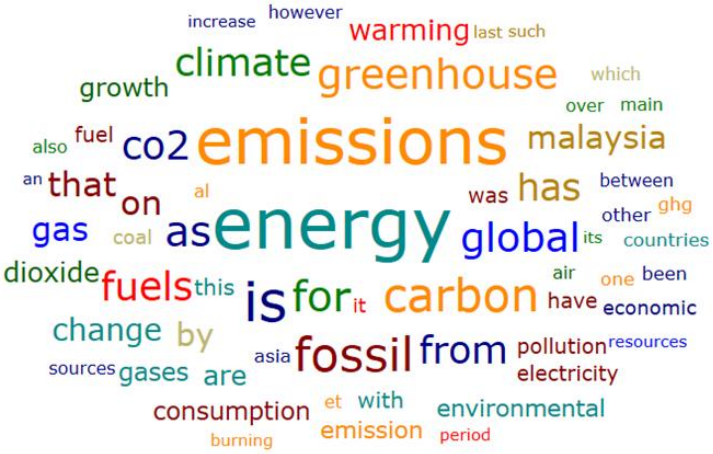

Figure 2. Word cloud based on "carbon emissions".

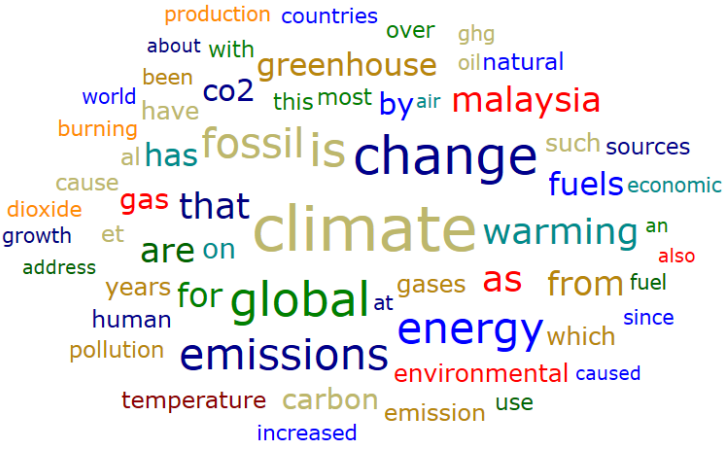

Figure 3. Word cloud based on "climate change".

All the above figures show that some words appear more prominently than others. For example, the words "energy" and "depletion" in Figure 1, the word "emissions" in Figure 2, and the words "climate" and "change" in Figure 3 are among the most prominent. These words are the keywords in identifying the effects of fossil fuels, and they provide reasons for finding alternative energy sources.

3.2. Depleting Fossil Fuel

In line with rapid development, energy consumption from fossil fuels has also increased dramatically [5,6]. Judging by fossil fuel production rates, global crude oil and natural gas reserves are expected to last up to 41.8 years and 60.3 years, respectively [7]. Looking at the percentage of total electricity generation in Malaysia for 2018, fossil fuels dominate that percentage [8]. The depletion of fossil fuels has caused countries to search for alternative energy resources, such as renewable energy [9].

One factor that hastens fossil fuel depletion is oil subsidies given by many governments, which has led to excessive energy consumption by its population [10]. Oil reserves in Malaysia, for instance, are expected to be depleted within 15 years at the current consumption rate [3]. Studies have also confirmed that conventional energy resources are on the decline [1,11–13], while fossil fuels are limited and can only last for another 70–150 years [14]. The continued use of non-renewable fossil fuels has led to their depletion, prompting the government to import them to meet the country's energy demand [15].

Reliance on fossil fuels, drastically diminishing as an energy source, is not sustainable since crude oil is quickly exhausted [16–19]. In addition, conventional power stations use depleting fossil fuels [20–22]. As a result, oil exploration companies scramble to find

new oilfields [22]. In Malaysia, realizing the importance of a stable energy supply, the government introduced the Malaysian Fifth-Fuel Policy in 2000 [23]. The introduction of various policies by the Malaysian government shows that it is making efforts to overcome the problem of depleting energy resources [24] and to reduce carbon emissions by 40 percent per GDP in its 2030 Sustainability Goal [13].

Considering that fossil fuels are depleting and their prices are increasing, all countries will compete to secure the remaining fossil fuels. Thus, countries should seek and shift to other sources of energy, such as renewable ones [8]. The rising oil and gas prices, among others, have raised concerns about an uninterrupted energy supply to sustain economic development [9]. In addition, rising fossil fuel prices will inevitably lead to an increment in electricity tariffs. To avoid this, the global community is now turning to energy-efficient appliances [25].

Further evidence has shown that dependence on fossil fuels as a source of energy in Malaysia was a burden to the government's annual subsidies when the government spent MYR 2.4 billion annually on electricity subsidies [26] and about MYR 40 billion in 2007 to subsidize fuel [27]. Figure 4 shows that almost 50% of Malaysia's total subsidies in 2022, almost MYR 40 billion, were spent on petrol, diesel, LPG, and electricity. Meanwhile, Figure 5 shows how billions were spent from the Malaysian government's coffers to subsidize petrol, diesel, and LPG from 2010 until 2022.

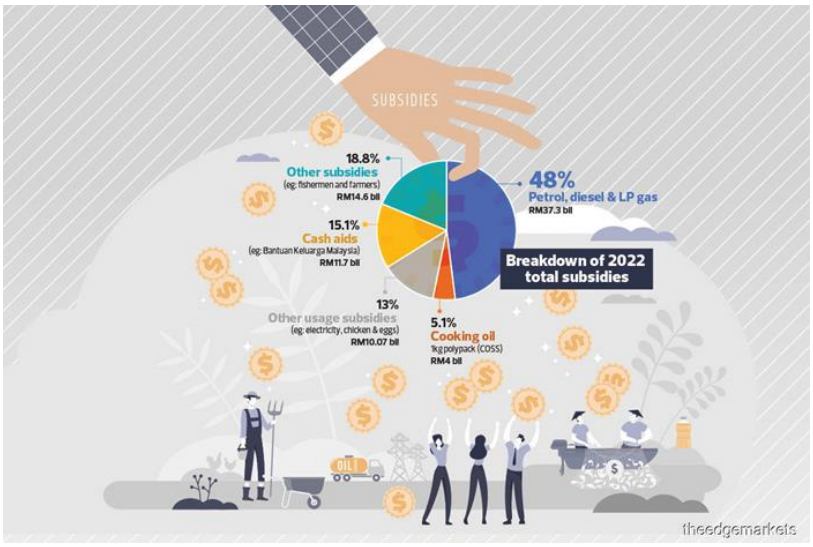

Figure 4. Breakdown of Malaysia's total subsidies in 2022 [28].

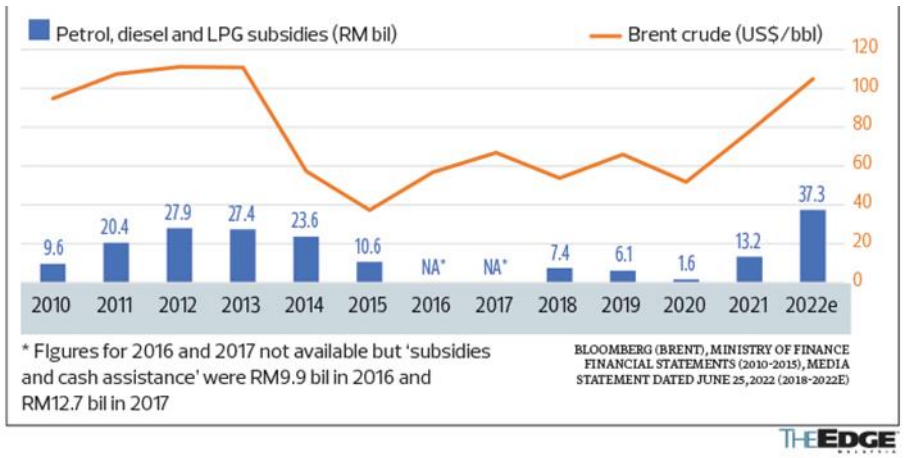

Figure 5. Subsidies for petrol, diesel, and LPG in Malaysia from 2010 until 2022 [28].

The perception that renewable energy is costlier than conventional energy can be rebutted since conventional energy has been heavily subsidized [29,30]. Regarding the energy subsidy ratio in the government budget, Malaysia had the highest ratio among ASEAN countries at around 32.9 percent, which is much higher than the world average of 8.1 percent. Furthermore, the subsidies for energy products cause consumers to be less aware of energy conservation since subsidized energy prices do not reflect the actual cost of energy supply and do not disclose sufficient information that the resources are depleting [10].

Other countries, such as China, also face high costs as they need to spend large sums of money on subsidies to stabilize fossil fuel prices [30]. The increased cost of treating drilled oil makes the oil drilling process more expensive [31]. The search for energy alternatives was due to the oil crisis that occurred in 1973, which led to skyrocketing oil prices [5], while the reliance on depleting fossil fuels has caused an increase in prices for these commodities [16,32].

3.3. Carbon Emission and Environmental Degradation

Carbon dioxide is one of the leading gases contributing to the global greenhouse gas increase [33]. Malaysia ranked among the world's largest emitters of greenhouse gases, with an average compounded growth rate of 7.9 percent from 1990 to 2006 [6]. It was also found that carbon dioxide emissions from energy use have increased since the 1980s, making Malaysia one of the countries emitting the most carbon dioxide in the world [26,34]. Another study indicated that in 2003, Malaysia was one of the largest countries to release carbon dioxide in Southeast Asia, taking third place after Indonesia and Thailand [23], with the electricity sector remaining the largest culprit of carbon dioxide emissions [35]. Figure 6 shows that Malaysia has always been just behind Indonesia and Thailand, except in 2020.

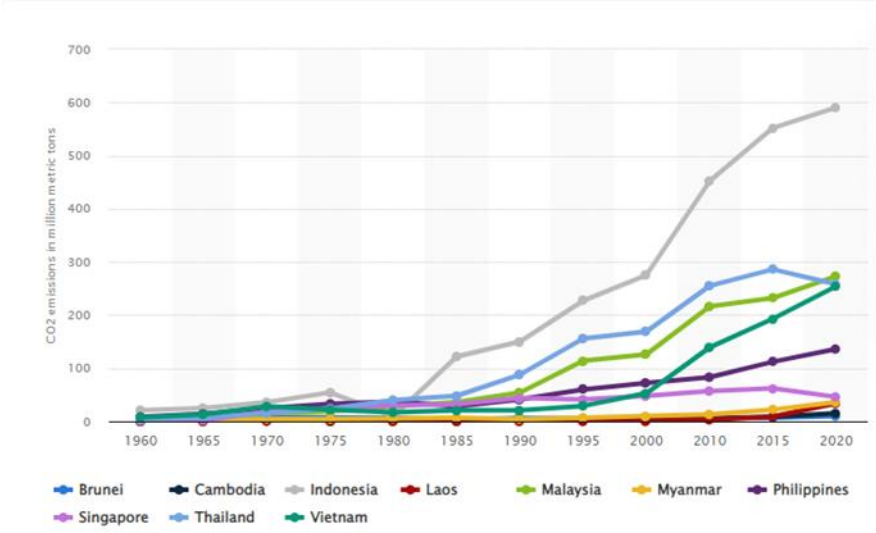

Figure 6. ASEAN's countries' CO_2 emissions from 1960 until 2020 [36].

Carbon emissions have had a detrimental impact on the environment, and the link between energy consumption and economic growth leads to more carbon emissions, which is the primary cause of global warming [37]. Based on the Statistical Yearbook for Asia and the Pacific 2013, the carbon emission growth rate in the region is 26.2 percent. A study also found that electricity generation significantly contributed to the increase in carbon emissions from 1990 to 2005 in the seven countries studied, including five Asia Pacific countries [38]. While countries struggle to reduce their reliance on fossil fuels, carbon emissions have been showing an upward trend, with growth rates of 6.8 percent from 1971 to 2015 [39]. Thus, shifting to non-conventional energy sources can help reduce greenhouse gas emissions [1,40].

The global greenhouse gas emissions due to the burning of fossil fuels comprised 54 billion tons of carbon equivalent (Gt CO_2-eq) in 2010, and it is estimated to reach 70 Gt CO_2-eq by 2050 [41]. Although a sustainable electricity supply positively affects economic growth, producing electricity using fossil fuels is a source of greenhouse gas emissions since more than one-third of greenhouse gas emissions are due to fossil fuel combustion to generate electricity [5]. Other studies have also supported that the energy system is responsible for most carbon emissions [42,43].

Considering that electricity generation contributes 54.04 percent of the country's carbon emissions, it is thus crucial for countries to explore alternative ways to reduce their carbon footprint in the energy sector [44]. Additionally, carbon emissions from burning fossil fuels are also one of the causes of air pollution [11,14,45,46]. This is backed by a study that asserted that in the energy sector, natural gas and coal are the primary sources that contribute to greenhouse gas emissions [47]. However, most countries still depend on coal despite realizing that coal is a significant contributor to greenhouse gas [14,17].

The government's desire to reduce carbon emissions indicates that the government wishes to shift to greener energy sources [12,18]. Creating a special fund from levies imposed on all carbon producers can assist and bankroll the transition to alternative energy sources [48]. A study showed that greenhouse gas emissions that cause climate change also impact fishermen's livelihoods [49]. In addition, government policies to reduce greenhouse gas emissions will affect the real estate sector [20].

3.4. Climate Change and the Water–Energy–Food Nexus

Transportation remains the most significant contributor to carbon emissions, with 61.6 million tons [24]. Fumes from vehicles release carbon dioxide gas, one of the greenhouse gases causing thinning of the ozone layer. The depletion of the ozone layer causes the Earth to absorb more heat, contributing to climate change and global warming [50]. High energy consumption is associated with high emissions of greenhouse gases, as most of our energy sources come from burning fossil fuels [51].

Concerns about the adverse environmental effects, particularly those related to climate change due to using fossil fuels, have driven a shift to green energy sources. Studies have proven that human activity's increased atmospheric temperature is linked to economic development [52]. It has also been found that some countries have already reduced fossil fuel consumption and are focusing on efforts to reduce carbon emissions by using renewable energy [53]. Climate change has also affected coastal areas [54], the tourism industry [45], and the real estate sector [20]. In addition, a greenhouse tax on producers can be used to deal with climate change issues [55]. This is pertinent because climate change will impact national food production [34,56].

The release of greenhouse gases from fossil fuel energy generation has been the leading cause of climate change [5,14,16,21] and has affected the environment through air pollution, ozone depletion, and global warming [10,46], along with heatwaves and floods [57]. Indeed, humans are the primary culprits [32,47,49], and actions to deal with climate change have become a global agenda [38]. Countries, including China, strive to reduce climate change's impact by diversifying their energy resources [12]. In the United States of America, growing demands for energy consumption have shown that energy resources are limited, and the search for alternative energy sources has multiplied, focusing on hydrogen as a fuel source [58].

In April 2015, the Goddard Institute for Space Studies confirmed that human activities are the leading cause of global warming. Globally, carbon dioxide gas accumulation entrapped heat rapidly in recent years and is higher than it was 3 million years ago. The Arctic Climate Assessment reported that Greenland was melting in the previous two to three years faster than anyone could have imagined [59]. The rise in greenhouse gases in the Earth's atmosphere has also contributed to the rise in global surface temperature, causing unpredictable climate change in the form of frequent floods and droughts [60].

The chain effect of carbon emissions from fossil fuels has extended to climate change with more floods and drought seasons forecasted. It will eventually affect the water, energy, and food sectors. The warming climate has increased evaporation rates and precipitation, intensified the hydrological cycle, and created more heat waves, droughts, and tropical cyclones. Figure 7 shows that Brunei Darussalam, Cambodia, Indonesia, Lao DPR, and Malaysia have observed an increase in rainfall, resulting in floods. These countries have predicted that by 2100, more extreme droughts and floods are going to occur because of climate change. In 2007, the Intergovernmental Panel on Climate Change (IPCC) predicted increased contraction of snow-covered areas but a gradual decrease in water in many arid and semi-arid areas. This will eventually affect other sectors, such as the energy and food sectors, depending on the sustainable water supply. The water–energy–food nexus raises concerns for future water, energy, and food security, especially in a rapidly developing state, such as China [61,62]. Thus, fossil fuel use must be downsized due to its extensive chain effects, while carbon-free energy, such as hydrogen fuel cells, must be explored and enhanced.

Country	Observed			Projections until 2100			
	Temperature	Precipitation	Observed extreme events	Temperature	Precipitation	SLR	Projected extreme events
Brunei Darussalam	0.6 °C rise between 1970 to 2014	10.8 mm increase per year until 2100 (RCP8.5)	Frequent and significant flash floods, forest fires, strong winds and landslides	0.5 °C per decade in the next 30 until 2100 (RCP8.5)	10.8 mm per year until 2100 (RCP8.5)	0.44-0.45	Increase in sea level rise in next 30–50 years. Increase in unpredictable extreme rainfall events resulting in flash floods and landslides
Cambodia	0.8 °C since 1960	General increase in rainfall	Riverine and extreme rainfall floods, high rainfall variability, and droughts were observed	1.6 °C (SRES-B1); 2.5°C (SRES A2)	3–35% increase (SRESA2)	1.7 cm/ year (SRES A2)	Increase in extreme rainfall events, droughts, and floods
Indonesia	0.01–0.06 °C per year since 1950	-2–3% since 1990	Extreme rainfall events, increase in floods, storms, and droughts	Increase by 0.75 °C (RCP2.6) and 2.7°C (RCP8.5)	10–30% in Sumatra, Borneo by 2080	0.5 m by 2040 (RCP4.5)	Increase in ENSO episodes, coastal flooding, wildfires
Lao PDR	0.05 °C per year in the past 40 years	Increased	Increase in extreme rainfall events, drought, and flood events	1.4–4.3 °C	10–30% in eastern, southern parts	Not relevant	Increase in extreme flood and drought events
Malaysia	0.13–0.24 °C per decade since 1969	Unclear long-term trend	Increase in rainfall intensity	1.2–1.6 °C (SRES) by 2050	7.1% to 10.6% increase by 2050	0.11–0.21 m (SRES) by 2050	Frequent extreme dry spells, extreme rainfall events, extreme floods in specific river basins

Figure 7. Climate change's observed effects and projections until 2100 in some ASEAN countries [63].

3.5. Energy Accessibility in Rural and Inundated Areas

Dependence on conventional energy sources exacerbates poverty in developing countries because conventional energy sources can only be supplied to some places. This is due to the high cost of extending the energy grid in difficult terrains and dense forests [16]. In Malaysia, for instance, 809 of 10,000 schools, most of which are located in remote areas in Sabah and Sarawak, do not have a 24-h electricity supply [64]. Thus, renewable energy sources could be utilized in areas outside of the national grid route [9].

Electricity is critical to economic development and improving society's standard of living. Thus, Malaysia must provide electricity to remote areas without impacting the environment [7]. Reliance on fossil fuel as an energy source is also impractical, as transporting fuel to remote areas is difficult [65]. The government is aware of rural electricity and established a Rural Electrification Program to intensify energy accessibility by 99 percent in 2020 [1,11,17,40].

Accessibility issues are also a global concern. In China, 80 percent of its 1.2 billion citizens live in rural areas, and electricity supply to rural areas is vital to improving people's lives and economy [66–69]. Rural areas need more industrial infrastructure and policies to support electricity grid development [70]. However, the cost of expanding the grid

networks to rural areas will be a significant obstacle [71]. Studies have indicated that 20 percent of the world's population still does not have electricity, and 80 percent live in rural areas. In 2012, 1.1 billion people had no electricity supply [72,73].

Effective measures are needed to overcome this problem. One initiative is to carry out electrification programs for rural areas, such as in South Africa [74]. The State Grid Corporation in Tibet has also implemented a "Power for Every Household" project to solve the problem in rural areas that do not have electricity [75]. In Ghana, however, grid expansion has become a financial burden to the government [76], while in Nigeria, a study stated that most Nigerians live in rural areas where the terrain is rugged, and they have no access to fossil fuels or electricity grids due to poor road conditions [9].

In Argentina, rural areas are switching to non-conventional energy sources [77]. This should be the way forward for people living in rural areas in Myanmar and Yemen, too, since the percentage of those receiving electricity is 29 percent in Myanmar [78] and 40 percent in Yemen [79]. In Iran, access to electricity is limited due to high transmission and maintenance costs [80]. In contrast, in the Amazon region, the electricity supply is limited due to harsh geographical factors and a lack of incentives for electrification programs, causing utility companies to lose interest in investing in these rural areas [81], with 22 million people lacking accessibility [82].

Out of the 1.4 billion people who do not have access to electricity, 585 million are in sub-Saharan Africa, and the rest live in Asian countries, with 400 million in India, and 96 million in Bangladesh [83]. Nevertheless, people in the sub-Saharan Africa region have the potential to introduce a grid-less solar energy system [84]. Factors include long distances from large urban populations, limited access to utility grids, and poor road and transportation systems for infrastructure development [85–87].

The potential to introduce a grid-less renewable energy system is bigger than just for people in rural areas. Electrical infrastructure will be affected in flood-prone areas, with intensifying rainfalls causing higher flood depths, affecting electricity grids [88]. In Malaysia, climate change has increased flood-risk impact on basic infrastructure, such as transportation, electricity, and water supply [89]. On many occasions, the grid system will be disconnected to reduce the potential incident of electrical shock, while electrical failure will disrupt essential services until emergency equipment is installed [88,89]. Floods will also bring more sedimentation, damaging old infrastructures and reducing the city's resiliency against climate change [88]. This will not be the case for hydrogen fuel cells since they can be supplied without the grid.

4. Discussion

4.1. Hydrogen Fuel Cell to Mitigate Climate Change

Climate change is of great concern to countries around the world, and all except a few, have ratified the United Nations Framework Convention on Climate Change and the Kyoto Protocol, both of which aim to reduce the greenhouse gas emission rate worldwide [40,90,91]. Recently, the Paris Agreement was promulgated to tackle global climate change issues [92]. Many cities around the world have committed to ensuring their cities are low-carbon, and one of the most effective ways to do that is to reduce the number of vehicles on the road and increase the renewable energy or carbon-free vehicles in their cities [93–96].

Hydrogen fuel cells create energy through an electrochemical reaction between hydrogen and oxygen while releasing water or water vapor as its byproduct [12,97]. This method protects the environment as it has zero emissions and low noise operation and pollution [98]. In 2003, President Bush proposed USD 1.2 billion in funding to build hydrogen-powered vehicles [99]. The desire to commercialize fuel cells in recent years is due to the perception that fuel cells offer a significant advantage to the environment compared to conventional energy production at a time when air quality is a problem in most cities. This is in line with efforts to address climate change and global warming.

In realizing many countries are committed to reducing carbon emissions and becoming carbon-free countries, countries need to focus on using carbon-free hydrogen fuel cells

as alternative energy. In the United States of America, the U.S. Department of Energy confirmed that hydrogen has the potential to meet the U.S.'s energy needs while reducing carbon emissions [100]. Although hydrogen needs to be extracted from its original forms, such as from water or hydrocarbon, the fact remains that hydrogen is among the most abundant element on Earth. Furthermore, the electricity generated by the combination of hydrogen and oxygen produces only carbon-free water vapor. This will eliminate carbon emissions, global warming, and climate change.

When fuel cell technology is used in electricity generation, it comes from a clean energy source, hydrogen, and a highly efficient alternative to fuel burning in the automobile industry [51]. Suppose hydrogen replaces fossil fuels as a future energy source. Then, many matters must be considered, including safety issues beyond the automotive industry [101]. This is because fuel cells can also power up individual, governmental, and industrial premises.

The hydrogen fuel cell can be used in remote areas without a power grid as hydrogen can be stored in a hydrogen-fueled unit for off-grid power circulation [97]. These stationary off-grid fuel cells provide base-load electricity from hydrogen, act as an alternative to diesel generators, and thus, reduce emissions [98]. Off-grid hydrogen is also helpful for flood-prone countries such as Malaysia. The electrical power supply is usually disconnected during a heavy flood to avoid electric shock. If this happens, fuel cell energy can be used as it is grid-less and highly reliable under extreme climate conditions and seasonal variations [98].

The general public perceives that the cost of constructing new hydrogen infrastructure is very high [60]. However, fuel cell technology has been developed over the years. Hence, a low operating cost over a long lifetime and the minimal need for regular maintenance requires comparably less expenditure than grid connection and expansion [98]. The company GenCell [102] claims that it has reduced infrastructure costs to USD 0.50/kWh by using ammonia to generate hydrogen, which is far cheaper and cleaner than conventional fossil fuel [103]. Table 1 further illustrates the different costs of using different sources of energy.

Table 1. Energy source, cost/kWh, emission/kWh.

Energy Source	Cost/kWh	Emission
Gasoline/fossil fuel	USD 0.60/kWh	8,887 gCO_2/gallon (vehicle) [104]
Hydrogen	USD 0.50/kWh	122 gCO_2(eq.)/kWh (produced using electrolyser) [105]
Diesel/fossil fuel	USD 0.30/kWh	1.27 $kgCO_2$/kWh (generator) [106] 10,180 gCO_2/gallon (vehicle) [104]
Solar photovoltaic	USD 0.20/kWh	6 gCO_2(eq.)/kWh [107]
Wind	USD 0.09/kWh	6 gCO_2(eq.)/kWh [107]
Hydropower	USD 0.05 to USD 0.07/kWh	18.5 gCO_2(eq.)/kWh [108]

The hydrogen fuel cell is a highly potential zero-emission technology that can be a sustainable solution for reducing greenhouse gas emissions and carbon emission intensity. However, in developing the hydrogen infrastructure, these challenges have been identified: (a) there is a high cost of deploying fuel cells and developing hydrogen infrastructure; (b) Malaysian standards and policies regarding hydrogen fuel cells are non-existent; (c) the resources for development effort are insufficient; and (d) consumer confidence is low towards hydrogen fuel cell safety. One critical issue that needs to be carefully considered by policymakers is safety. Public perception still needs to be clarified regarding the safety issue of this technology, especially in hydrogen transport and storage.

Hydrogen fuel cell infrastructure has two primary considerations: (1) hydrogen as a transportation fuel and (2) hydrogen for generating electricity. Both considerations require

hydrogen to be stored for long-term usage. Hydrogen can be delivered as a compressed gas or as a liquid from off-site storage, the latter of which can later be transformed into gas and compressed for on-site storage upon arrival at the locations. National standards and policies on the safety of hydrogen usage will be required for all features in the infrastructure design, including the storage tubes/tanks/vessels, dispensers, compressors, and the hydrogen generation module and fuel cell module.

4.2. The Blueprint for Fuel Cell Industries in Malaysia

In 2017, the Academy of Sciences Malaysia (ASM) released The Blueprint for Fuel Cell Industries in Malaysia ("the Blueprint"). It is a comprehensive plan with short-term (2020), medium-term (2035), and long-term (2050) goals for developing hydrogen infrastructure, fuel cell applications, and emerging fuel cell technologies. The Blueprint is a result of an in-depth discussion with the experts and stakeholders in the fuel cell industries. It specifies that high cost is the main problem in establishing hydrogen infrastructure, marketing fuel cell applications, and supporting emerging fuel cell technology. In this regard, existing research can be advanced in developing reasonable hydrogen infrastructure, while the massive production of fuel cell applications can lead to a lower application price. New resources are needed to replace the expensive imported components and establish a pool of expertise in the industry [108].

Besides the high cost, another common problem faced by the existing fuel cell industry is inadequate standards and guidelines for hydrogen infrastructures and fuel cell applications. The lack of laws and policies governing the fuel cell industries will also hinder investors from investing. As such, the government must establish proper guidelines and regulations, while a national policy is needed to show the government's commitment to include hydrogen as one of the national priorities. This will eventually increase investors' confidence and financial support, improve capacity building in the sector, improve public awareness, and ensure safety measures throughout the hydrogen fuel cell industry [108]. Further recommendations have been formulated in the Blueprint to improve and nurture the fuel cell and hydrogen industries, as shown in Table 2.

Table 2. Recommended strategies in the Blueprint for Fuel Cell Industries in Malaysia [106].

Sector	Recommendations
Hydrogen infrastructure	1. Improve components in the fuel cell and hydrogen industries; 2. Develop comprehensive guidelines, regulations, and policies according to global standards; 3. Hold public awareness and advocacy campaigns; 4. Develop local codes and standards for hydrogen safety; 5. Establish robust policies to support hydrogen infrastructure; 6. Pursue responsible institutions on fuel cell technology; 7. Develop local supply chain and specific market penetration; 8. Build adequate capacity building in human resources for the hydrogen industry; 9. Establish national priority in hydrogen infrastructure for the electricity generation and transportation sectors.
Fuel cell applications	1. Obtain proven high track records of involvement in hydrogen energy industries; 2. Establish a policy structure that supports the new application of fuel cell technology; 3. Carry out development efforts with cost considerations; 4. Advance hydrogen usage in conventional fuel cell applications; 5. Organize large-scale campaigns to ensure continuous funding; 6. Secure strong and stable support from all stakeholders to maintain progress and growth; 7. Advance R&D to be a robust regional market leader; 8. Develop the fuel cell transportation industry; 9. Develop a model city powered by fuel cell technology.

Table 2. *Cont.*

Sector	Recommendations
Emerging fuel cell technologies	1. Develop policies, standards, and guidelines for novel fuel cell products and components; 2. Ensure financial support from various stakeholders; 3. Appoint champions for the fuel cell industry; 4. Set up a monitoring body to align collaboration between research institutes, government, and industry; 5. Target specific market segments for the local industry; 6. Plan for education programs in higher education institutions; 7. Replace raw materials from expensive imports with new indigenous resources.

4.3. Prospect and Challenges in Regulating Hydrogen Fuel Cells in Malaysia

Malaysia has diversified its energy sources into renewable or alternative energy sources through these policies: Four-fuel Diversification Policy in 1981, Fifth-fuel Diversification Policy in 2000, National Biofuel Policy in 2006, National Green Technology Policy in 2009, National Renewable Energy and Action Plan 2010, New Energy Policy in 2010, Sustainable Energy Development Act 2011, Renewable Energy Act 2011, National Biomass Strategy 2020 in 2013, and the National Energy Efficiency Action Plan in 2014 [21]. Very recently, the National Energy Policy 2020–2040 was launched to spearhead the sustainable energy sector in the country. Although hydrogen was briefly introduced as a potential energy source in the future, it provides a good basis for developing a proper action plan for the growth of the hydrogen industry in the country.

The Hydrogen Roadmap in Figure 8 demonstrates the hydrogen industry journey in Malaysia (Malaysian Investment Development Authority (MIDA) 2021). Several universities in Malaysia have established their research centers on hydrogen with MYR 40 million in R&D funds allocated from 1997 to 2013. Telecommunication companies have also employed hydrogen in their stationeries' backup systems and developed the respective technical codes, while Sarawak has launched a hydrogen bus.

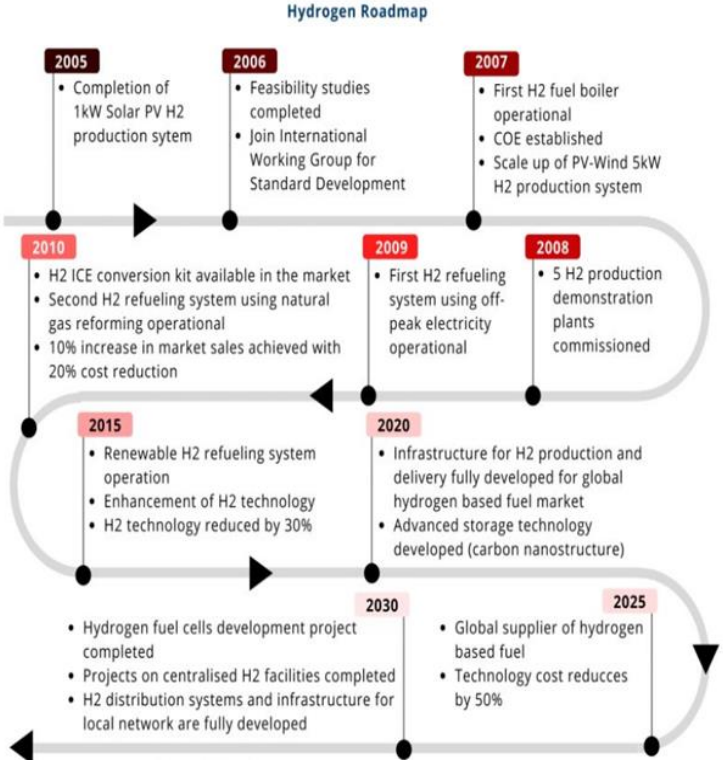

Figure 8. Hydrogen roadmap [109].

One challenge faced by the industry is the fragmented and disintegrated energy management sector. Examples include the existence of the Sustainable Energy Development Authority (SEDA) and the Energy Commission, both of which promote renewable energy, energy conservation, and efficient energy consumption. Both agencies were created under the Ministry of Energy and Natural Resources. Nevertheless, under the Ministry of Housing and Local Government, the local government is tasked with implementing low-carbon initiatives in cities. This impedes effective communication between stakeholders when investing in low- or zero-carbon projects. Apart from that, policymaking and its implementation are two separate branches, with policies at the federal level and implementation at the state and local levels. Thus, clear policy and implementation guidelines are needed to promote and commercialize alternative energy industries [21].

Malaysian policies, regulations, safety mechanisms, and measures must be realigned and formulated to be compatible with global standards. For example, in the Road Transport Act 1987, i.e., with amendments up to 2006, the Ministry tasked with transport will regulate the use of any fuel for propelling motor vehicles. This will have to include imported fuel cell vehicles when hydrogen is used as transportation fuel in the future. Safety concerns must also be in place regarding production, delivery, storage, customer interface, and onboard hydrogen storage. Comparative legislative analysis between countries with thriving hydrogen industries can assist in developing a suitable legislative framework in countries such as Malaysia [110].

5. Conclusions

Continuous reliance on fossil fuels has led to their depletion and become an expensive energy source. This reduces its accessibility to the poor and marginalized, especially those who live in remote areas. Regarding sustainable development, fossil fuel has yet to tick the positive boxes as it is the main contributor to carbon emissions, leading to climate change. In its efforts to move towards sustainable alternative energy, Malaysia needs a sufficient policy framework to reduce its dependence on fossil fuels and shift to a carbon-free society. Currently, Malaysia does not have a specific policy related to applying fuel cells as an alternative energy in Malaysia. Thus, it is imperative for Malaysia to make a policy for the application of fuel cells towards achieving a carbon-free society in the world.

Robust governmental policies and national priority need to be established for hydrogen safety. In addition, the sustainability of hydrogen infrastructure and an increase in public acceptance must also be ensured through high-profile measures to initiate and nurture the fuel cell and hydrogen industries for the necessary transition steps to a hydrogen economy for the nation. This requires further deliberation as it will influence diverse matters such as hydrogen production, storage, conversion, delivery, and applications in terms of policy, standards, education, and program outreach in hydrogen energy.

Researchers in Malaysia should explore using hydrogen to support renewable energies, which are emerging sluggishly in the country. Despite efforts and financial incentives to invest in solar power, there are two key concerns: limited active market participation and the need for product differentiation. Renewable energy sources also depend on meteorological variables. Hydrogen can be employed to store renewable energy for long periods. Alternatively, electrolyzers can use some of the wind and solar energy to create hydrogen.

The involvement of stakeholders from across the board, including government agencies, industrial players, researchers, and academia, is essential. Stakeholders need to prioritize hydrogen as a potential energy source soon, and the government must give full support to drive the hydrogen industry due to its apparent benefits. Environmental and safety concerns in developing hydrogen infrastructure and the public fear of industrial accidents over known safety concerns due to a lack of awareness also need to be addressed appropriately. This can be done by developing local safety measures, guidelines, regulations, policy structures, and monitoring bodies by constructive integration with the existing global standards [108].

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