Microbial Fuel Cells (MFC) as an Alternative Energy Source: The Perceptions and Attitudes Towards Sustainable and Renewable Energy in Malaysia

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Abstract Due to the exponential rate of waste production worldwide, the development of newly emerging technologies is rising and advancing proportionately. Entailed instalment of sophisticated sustainable and renewable energy development is constantly expanding to meet the socio-economic demands of communities and industries. Innumerable advanced technologies have been introduced to acquire for alternative energy sources and to minimise waste pollution while reducing emissions of greenhouse gases hence, combatting the impact of global warming. Among the energy conversion technologies includes gasification, pyrolysis, incineration, landfill, and bioelectrochemical technologies mainly microbial fuel cell (MFC), microbial electrolysis cells (MECs), and microbial electrosynthesis (MES). This chapter starts off with an overview of the current trend of sustainable and renewable energy in Malaysia. Next, the application of MFC is being discussed in the context of wastewater treatment and its potential application as an alternative source of renewable energy. Finally, the public acceptance and perceptions towards sustainable and renewable energy are also considered and discussed.

Keywords Microbial fuel cell · Alternative energy resources · Public acceptance · Renewable energy

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1 Introduction

As the world population grows, the demand for energy especially for electricity is also on the rise. Coal is the most widely used source of electricity today, accounting for 41% of total electricity generation. However, due to the high degree of pollution (water and air pollution during mining and air pollution when burning) and deplorable working conditions, certain energy source is not considered as sustainable source.

Generally, there are four types of renewable energy (RE) sources which are solar, wind, hydro, and biomass. Although these sources are renewable, their sustainability may be unfeasible. Sustainability is determined by three different parameters: environmental sustainability, social sustainability, and economic sustainability. According to the United Nations (UN), environmental sustainability is about acting in a way that ensures future generations have the natural resources available to live an equal, if not better, way of life as current generations. Being a net consumer of energy, if a renewable energy device costs more energy than it produces during its lifetime, it does not conform as being sustainable.

2 Revolution of Malaysia's Policies

On the other hand, social sustainability calls for safe working conditions and decent wages. As a whole, social sustainability revolves around the fact that we all live on the same planet and have access to enough food and energy to support ourselves. Therefore, it is essential to use the planet's resources effectively and efficiently. Economic sustainability is concerned with policies that promote long-term economic growth without jeopardising the community's social, environmental, and cultural characteristics. Greatly influenced by the aftermath of the 1973 and 1979 oil crises, Malaysian policymakers have shown a remarkable enthusiasm for developing timely and visionary energy plans and policies. Table 1 provides a summary of various energy policies in Malaysia.

Nevertheless, despite the government's effort to diversify the energy mix in the country, energy consumption in Malaysia is still excessively relying on the non-renewable energy sources compare to renewable energy sources. This could be owing to the current availability of natural resources and the high cost of renewable energy. Another reason could be a lack of strategic deployment of renewable energy resources. For example, the insufficient and unrealistic net-metering tariff for solar energy producers, the high priority placed on biomass energy production, the electrical system's incapacity to accept intermittency, and insufficient backup mechanisms to stabilise the electric grid. Figure 1 presents the total primary energy production while Fig. 2 presents the total primary energy supply to Malaysia by fuel type.

To date, the share of RE in Malaysia remained below the global and regional average [2]. As of the end of 2020, RE accounted for 23% of the national power

Table 1 A summary of various energy policies in Malaysia [1]

No	Year	Policies	Objectives
1	1974	Petroleum Development Act	Provide rights to PETRONAS for exploration, development, and production of petroleum
2	1975	National Petroleum Policy	To manage the downstream oil and gas industry through Petroleum Regulations 1974
3	1979	National Energy Policy	Three objectives, i.e., enhanced sufficiency, safety, and cost-effectiveness have been proposed along with the promotion of efficient energy utilisation to curb negative environmental issues
4	1980	National depletion policy	To prolong oil reserves to secure future energy requirements
5	1981	Four fuel diversification strategy	To enhance the lifetime of natural resources of Malaysia by introducing a balanced utilisation policy of oil, NG, hydro, and coal
6	2001	Five fuel diversification strategy	Renewable energy sources (most highlighted solar and biomass) have been included in the primary energy mix to improve the security of natural resources and the environment-friendly nature of RE technology
i	2005–2030	Hydrogen energy roadmap	Generation of hydrogen using RE resource, development of H2 network for H2 fuel cell vehicles
ii	2006	National biofuel policy	To promote palm oil demand and utilisation of biomass resources to produce electricity
iii	2010	National RE policy and action plan	Development of indigenous RE technologies and their enhanced utilisation

installed capacity compared to the global average of 37% and the Southeast Asia regional average of 30%. Hence, there is a crucial need to accelerate RE deployment in Malaysia to meet the committed RE and climate targets, by strengthening existing programmes and introducing new approaches, in parallel with the Government's practices in future-proofing existing electricity market regulations and power sector industry practices.

Recently, the Ministry of Energy and Natural Resources kicks off a new Malaysia Renewable Energy Roadmap is introduced to realise the Government's future sustainable and renewable energy aspiration with an anticipated cumulative investment of MYR 53 billion and 46,336 numbers of job opportunities. Malaysia Renewable

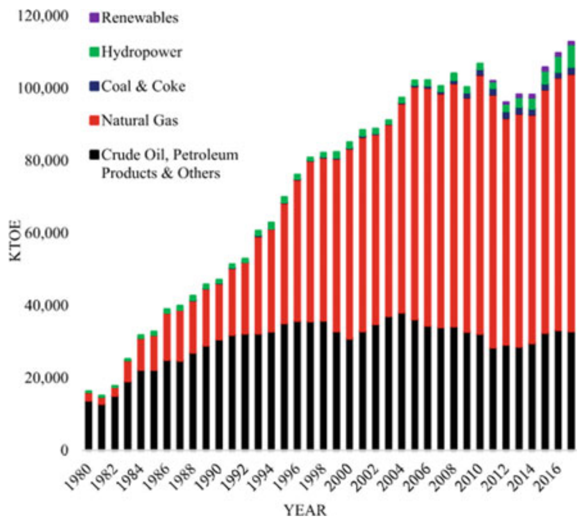

Fig. 1 Total primary energy production in Malaysia. Reprinted from Energy Strategy Reviews, Vol.35, Ahmad M.S., Ali M.S., Rahim N.A., Hydrogen energy vision 2060: Hydrogen as energy Carrier in Malaysian primary energy mix—Developing P2G case, 1–12, Copyright (2021), with permission from Elsevier

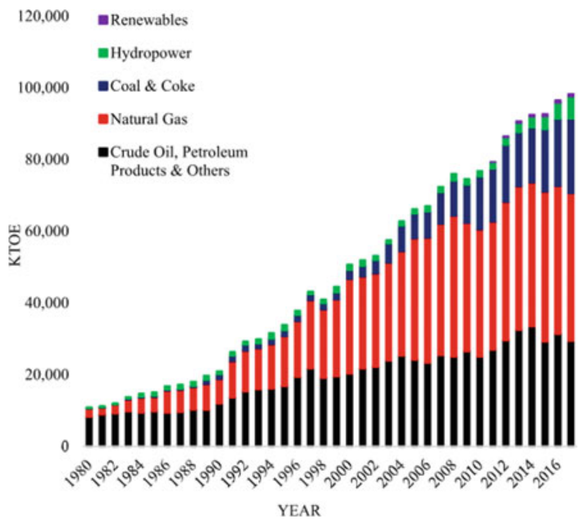

Fig. 2 Total primary energy supply to Malaysia by fuel type. Reprinted from Energy Strategy Reviews, Vol.35, Ahmad M.S., Ali M.S., Rahim N.A., Hydrogen energy vision 2060: Hydrogen as energy Carrier in Malaysian primary energy mix—Developing P2G case, 1–12, Copyright (2021), with permission from Elsevier

Energy Roadmap (MyRER) is a formulation of a strategic framework that aimed to achieve 31% RE share in the national capacity mix by 2025 and attain decarbonisation of the electricity sector by 2035.

The MyRER vision is upheld by 4 technology-specific pillars and 4 enabling initiatives. The strategic framework calls for concerted and coordinated actions from collaborations between various stakeholders in allowing Malaysia to tap into the huge potential made available through RE projects to promote improved economic, environmental, and social outcomes. With the said pillars, it is hoped to ensure the full capacity of the usage of renewable energy as well as the sustainability of these sources.

It is now widely accepted that the world's energy supply must become more sustainable. Thus, it is critical to ensure that the Malaysia Energy Vision 2060s milestones are backed up by state-of-the-art and faultless research schemes. At present, renewable energy accounts for less than 7.8% of the global primary energy supply including wind power, hydropower, solar energy, geothermal energy, and biomass. It is predicted that about half of the global energy demand could be met by renewable sources by the year 2050. Organics in wastewater used in MFCs could be an important renewable resource in the transition from fossil to sustainable fuels as discussed in the next section.

3 Microbial Fuel Cells (MFC) as an Alternative Energy Source

Sustainability has become a global challenge as natural resources such as fresh water and fossil fuels are depleting rapidly. It is imperative to have an effective and efficient water management to ensure its long-term sustainability and meet the needs of future generations [2]. Current wastewater treatment technology consumes between 1 and 3% of the total electrical energy output of a country [3], of which would require a 20% of public utilities' electrical energy consumption for its operation [4]. Moreover, energy consumption is expected to rise significantly soon. For example, the energy use by water utilities in Australia is estimated to grow between 130 and 200% above existing levels due to an expected population growth of 25% by 2030 [5]. Consequently, water treatment industries would have a significant carbon impact, posing a serious threat to the environmental sustainability.

Environmental sustainability encompasses all aspects of life. It is intimately related to humanity's future, defining how we should conserve and manage natural resources, air quality, water quality, and the ecosystems. It also aids in the prevention of environmental damage caused by technological advancement. Among the way to achieve environmental sustainability is to have effective wastewater treatment. Globally, around 80% of wastewater is being released back into the environment [6] without being treated or reused. This indicates that over 1.8 billion people in the world are consuming contaminated water, a potential health hazard. Hence, wastewater treatment is pivotal in fulfilling the growing demand for clean water in rapidly expanding cities, enhancing energy production and industrial development, and promoting sustainable agriculture.

Societal and environmental pressures over recent years have led to a growing movement for the industry to reduce its wastewater and treat it before discharge. Wastewater is now seen as a potential resource and its use, or recycling after suitable treatment, can provide economic and financial benefits. Societal and environmental pressures over recent years have led to a growing movement for the industry to reduce its wastewater and treat it before discharge. Wastewater is now seen as a potential resource and its use, or recycling after suitable treatment, can provide economic and financial benefits.

In Malaysia, there are 8147 sewage treatment plants and network pumping stations nationwide which are managed by the Indah Water Konsortium Sdn Bhd (IWK). Owned by the Minister of Finance Incorporated, IWK is Malaysia's national sewerage company which has been entrusted with the task of developing and maintaining a modern and efficient sewerage system for all Malaysians. The national operator of sewerage services operates and maintains more than 6800 sewage treatment plants across more than 19,400 km of sewer pipelines. Currently, IWK provides sewerage services to approximately 26 million population. IWK has been practicing the reuse of sewage by-products at 13 of their regional plants as an initial effort to conserve water, energy, and the environment. The reuse of the treated effluent is currently confined to internal housekeeping or non-potable use, such as sewage treatment plants compound cleaning, vehicle cleaning, and watering of plants for landscaping purposes.

Sewage treatment is the process of removing contaminants from wastewater, primarily from household sewage. It includes physical, chemical, and biological processes to remove these contaminants and produce environmentally safer treated wastewater. A by-product of sewage treatment is usually a semi-solid waste or slurry, called sewage sludge that has to undergo further treatment before being suitable for disposal or land application [3]. Overall, the processes of wastewater treatment consume a substantial portion of energy. Nevertheless, the wastewater influent contains a large amount of energy contents in the form of organics. Therefore, to maintain a sustainable society, it is clearly beneficial to efficiently extract energy from wastewater to compensate energy use of the treatment process which can be realised by anaerobic processes to produce methane, hydrogen, or bioelectricity.

Recently, a bioelectricity processing method known as microbial fuel cells (MFCs) has gained increased interest for their promising and potentially alternative renewable energy source. Initially, MFC emerged as an alternative energy-added wastewater treatment technology which can produce electricity during wastewater treatment. The recent advancement in the field of MFC provides promising technology not only to obtain energy but also to treat organic content wastewater at the same time. Moreover, the use of MFC as an alternative source for power generation is considered a reliable, clean, efficient process, which utilises renewable methods and does not generate any toxic by-product. MFC is also considered an environmentally friendly conversion technology due to its capability of converting the chemical energy stored in the organic matter to electricity assisted by microorganisms. Figure 3 shows the graphical application of MFC.

MFC is a process where microbes convert chemical energy generated by the oxidation of organic/inorganic molecules into adenosine triphosphate through sequential reactions. In this process, electrons are transported to a terminal electron acceptor to generate an electrical current. The MFC system consists of an anode and a cathode and an external load connecting the two electrodes. During MFC operation, the bacteria switch their electron-donating direction from the natural electron acceptor

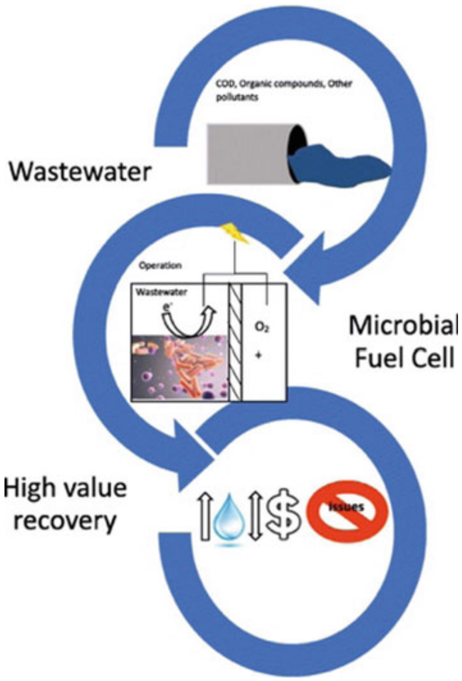

Fig. 3 Graphical application of MFC. Reprinted from Sci Total Environ, Munoz-Cupa C, Hu Y, Xu C, Bassi A., An overview of microbial fuel cell usage in wastewater treatment, resource recovery and energy production, Copyright (2021), with permission from Elsevier

in the bulk wastewater, mainly oxygen or nitrate, directly to the anode via a redox reaction of electron mediators on the anode surface. Figure 4 shows the concept of MFC towards the production of renewable energy.

MFC offers several advantages over other renewable energy. Mainly, its direct conversion of chemical energy within the substrate to electricity allows a higher energy conversion efficiency without any combustion process [7]. It uses low energy consumption while offering significant cost savings since the process of MFC does not require any energy input to drive the system for its operation. The system can be operated at ambient temperature, thus avoiding huge energy consumption to stabilise the temperature of the system. Additionally, the use of microorganisms in MFC for electricity generation eliminates the high cost of constructing the MFC compared to the cost of using a metal catalyst or extracted enzymes. Prior empirical studies have shown that energy from MFC is able to power up small devices like sensors, low-voltage capacitors, and small direct current (DC) motors.

Figure 5 depicts a comparison of the findings of the studies by Ge and He [8] and Li, Yu [9]. In the first part (section a), it shows that from Ge and He [8] findings, the input energy is 0.15 mW/m3 and the energy generated by MFC is 0.081 mW/m3. Meanwhile in the second part (section b), in the findings of Li, Yu [9], the energy required for the process is 0.076 mW/kg COD and a power of 0.026 mW/kg COD is produced. In comparison, there was an energy consumption of anaerobic sludge of 0.6 kW/kg COD indicating that MFC application for renewable energy is sustainable.

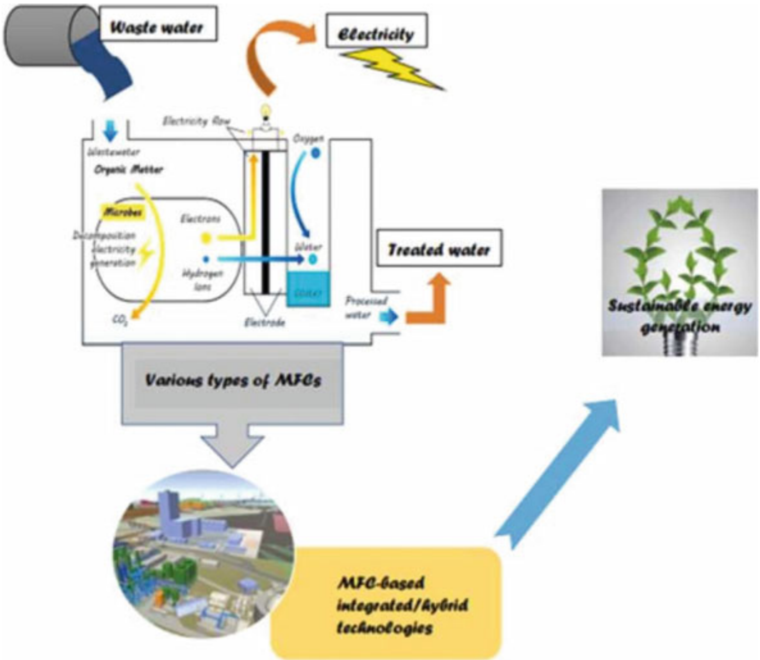

Fig. 4 The concept of MFC towards the production of renewable energy. Reprinted from Process Safety and Environmental Protection, A. Nawaz, Ikram ul Haq, K. Qaisar, B. Gunes, S.I. Raja, K. Mohyuddin, H. Amin., Microbial fuel cells: Insight into simultaneous wastewater treatment and bioelectricity generation., 357–373, Copyright (2022), with permission from Elsevier

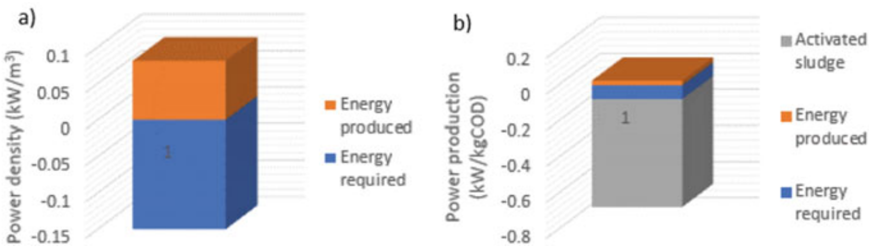

Fig. 5 Comparison of Energy Balance of MFC (a) Municipal wastewater with dual MFC (redrawn from Ge and He [8]; (b) municipal wastewater with single MFC and conventional activated sludge. Reprinted with permission from Li, Yu [9]

Furthermore, several studies have examined its application in wastewater treatment in terms of energy consumption and operational costs. The ability of the electroactive microbial communities to harvest and extract clean energy from waste organic sources rather than filtering the contaminants has allowed MFC to utilise many different types of wastewaters, ranging from domestic wastes, industrial wastes, agricultural waste, and animal waste. Furthermore, the fuels for MFCs are flexible in that they can be different kinds of biodegradable waste, reduced carbohydrates, glucose, sucrose, acetate, lactate, starch, and some other complex substrates in municipal or industrial wastewater, and in the form of liquid or sludge. In comparison with other wastewater treatment systems such as anaerobic digestion [10] or activated sludge [11], MFC offers a much lower cost to manage and dispose of sludge. Therefore, MFC is seen as an ideal and potential green technology that can generate clean and renewable electricity from the treatment of wastewater.

However, MFC technology is still in its infancy and has yet to be scaled up for mass operations due to several limitations and challenges. High internal resistance, high energy losses, high costs for construction and operation, and difficulty of scaling up are among the issues that need to be further addressed to facilitate an economically feasible operation of MFC. To overcome some of the present limitations, the combination of separation methods and new configurations for MFC needs to be investigated for further application in wastewater treatment for continued improvements in fuel cell design and efficiency as well scale-up with economically practical applications tailored to local needs. Future studies are needed to increase the power output to decrease the operational cost and have a better renewal value because of the high capital cost. Further investigation also should consider recovery or other high-value products such as nutrients or pharmaceutical products by MFC.

4 The Public Perceptions and Attitudes Towards Sustainable and Renewable Energy

Advances in new technologies and the desire to achieve a sustainable and safe energy supply, enable communities to transition from conventional to renewable resources. Although the transition to renewable energy is gaining popularity globally, its development is constrained by several challenges, most notably social resistance. Public perception of alternative energy sources is considered one of the most important factors influencing the development of renewable energy facilities and technologies. Other significant challenges include low acceptance in different social sectors, lack of knowledge, and negative public perceptions.

It is critical to understand the interdependence of technology, society, and government, as every change in one is likely to influence the others. As such, their interdependence affects the acceptance of the society in terms of change and technology, an aspect that plays a significant role in the evolution of renewable energy developments. According to Jasanoff [12], the relationship between science and technology is mutually beneficial, in that science has an effect on society and society has an effect on science. Therefore, entrepreneurs, scientists, and policymakers working on sustainable and renewable energy technology should continuously look for new ways to engage the public in innovation [13]. Research in sustainable and renewable energy should prioritise problem-solving, interdisciplinarity, and social inclusive studies [14, 15].

Renewable energy acceptance is shaped by three dimensions: market, socio-political, and community, thereby distinguishing a universal and homogenising sense of acceptance (often reflected in 'positive' national opinion polls) from its representation in policies and the varied reactions of local communities [16]. Public acceptance and perception can help to prevent, or at least anticipate, possible future controversies, to provide ideas for new and better products and services, and to increase the openness and transparency of scientific and technological developments, which is a prerequisite for a trust relationship between different actors [17]. Public involvement has also demonstrated that they can be proactive and come up with interesting suggestions, such as including energy and environmental issues in educational programmes, from elementary school to universities [18]. One tool that enables the connection between different actors involved in the development of a project is the communication of the environmental issues and energy technologies that shape public opinion, change policies, and affect our world [19].

Adequate communication techniques for renewable energy transition initiatives would transpire a positive or negative effect, depending on how those projects are being understood and accepted. Hence, it is critical to effectively communicate technical and scientific knowledge, keeping the pertinent information as simple to understand as feasible. Additionally, the timing of communication is also important, communication strategies should be implemented prior to initiating any project development. Volken, Xexakis [20] found that public acceptance can increase or decrease during the communication process for new technologies depending on the information load received. For example, in Switzerland, the acceptance of geothermal energy decreased with increasing knowledge, most likely as a result of learning about past accidental impacts, such as induced seismicity [21]. In another study, Pellizzone, Allansdottir [22] found that while the public's perception of renewable energies is positive and optimistic at the beginning, the public's favourable perception may decrease when the project is considered in the immediate environment, resulting in the phenomenon known as 'not in my backyard.'

Additionally, the media play a critical part in creating awareness and providing microbial fuel cell technology information to the public, as analysed by Stauffacher, Muggli [23], who highlighted the requirement of transparency and diligent monitoring of communication and public engagement. Numerous factors influence public opinion about microbial fuel cells as a sustainable and renewable energy, including the ability of the technology to solve the groundwater contamination, water resource sustainability, uncertainty regarding reversibility, seismic activity, cost–benefit ratio, level of knowledge about the technologies, dissemination channels, and the integration of various actors in project planning and public consultation exercises [24]. Renewable energy projects in the microbial fuel cell are generally discussed in different social sectors in terms of their environmental, economic, and political implications [17]. Therefore, creating awareness and providing adequate information of microbial fuel cell at the right time is crucial to ensure a continuous public support on the agenda of sustainable and renewable energy movement in Malaysia especially in this promising green technology.

As per sustainable development goal number seven on affordable and clean energy and 7(a) on enhancing international cooperation to facilitate access to clean energy research and technology by 2030, renewable energy development and improvement are critical for MFC to move forward. Investment from interested investors such as angle investors, government, society, NGO, and the public is most welcome to achieve this spirit. Cooperation and collaboration among those parties will swift the process tremendously.

Nevertheless, there is a need to understand public attitudes towards global issues and multiple energy technologies. Indeed, public acceptance is necessary for the successful implementation of an energy transition towards renewable energy sources. Although the global benefit of renewable energy is well known, some concerns still exist on their impact on local environment. Hence, the role of the government and media on rising the public awareness of sustainable and renewable energy is crucial. Supportive government policies and financial incentives such as subsidies, competitive pricing of energy technologies, and tax rebate would also improve public acceptance and perception of renewable energy adoption. Moving forward, it is reasoned that the policymaker should observe the development of a sustainable and renewable energy policies based on an effective coordination and collaboration with key stakeholders to ensure that the change towards sustainable and renewable energy is successful.

5 Conclusions

This chapter demonstrates that the transition from conventional ways of energy sources producers had slowly moved to renewable energy due to its scarcity. However, the transition from fossil fuels to renewable energy sources (microbial fuel cells) provides significant challenges and opportunities for various energy sectors. Although various efforts and strategies have been created to increase the adoption of renewables and other efficient technologies, including but not limited to information programmes and financial incentives, the concept of renewable energy in Malaysia is still in its infancy.

Continuous exploitation of non-renewable resources of energy would significantly impact the climate change and create vulnerabilities in future global energy security and sustainability, due to the fact that these resources will eventually decrease. Malaysia has a great potential to venture for sustainable and renewable energy as it is blessed with a vast supply of solar, wind, hydro, biogas, and biomass. Although these natural resources are readily available substantially, a dive towards the era of sustainable of renewable energy development is unavoidable.

A potential technology of sustainable and renewable energy that can be exploited is the MFC technology. While MFC promises a clean, zero-emission energy technology for a sustainable source of energy, it is constrained by costs, durability, complexity, as well as operational safety. Despite these limitations, MFC technology is gaining traction globally as one of the most sustainable ways to treat wastewater, alternative source of renewable energy, and by extension, reducing carbon intensity. Numerous large-scale research and development programmes are being funded globally to overcome these difficulties and to establish an industrial scale for MFC.

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