

PAPER • OPEN ACCESS

Generic review on the potential of nuclear-renewable hybrid system for sustainable power production in Malaysia

To cite this article: Afiq Ariffin *et al* 2021 *J. Phys.: Conf. Ser.* **2053** 012021

View the [article online](#) for updates and enhancements.

You may also like

- [A stock-flow consistent input–output model with applications to energy price shocks, interest rates, and heat emissions](#)

Matthew Berg, Brian Hartley and Oliver Richters

- [Development direction and focus of new energy industry in Jilin Province](#)

Chunyan Qu, Jie Guan and Tao Wang

- [The energy industry in Russia: assessment of the state, problems and prospects](#)

Oksana B Sheveleva, Ekaterina V Slesarenko, Tatiana F Mamzina et al.



ECS Membership = Connection

ECS membership connects you to the electrochemical community:

- Facilitate your research and discovery through ECS meetings which convene scientists from around the world;
- Access professional support through your lifetime career;
- Open up mentorship opportunities across the stages of your career;
- Build relationships that nurture partnership, teamwork—and success!

Join ECS!

Visit electrochem.org/join



Generic review on the potential of nuclear-renewable hybrid system for sustainable power production in Malaysia

Afiq Ariffin¹, Nor Afifah Basri¹, Ahmad Termizi Ramli¹, Suhairul Hashim¹

¹Universiti Teknologi Malaysia, UTM, 81310 Johor Bahru, Malaysia

*Corresponding author's email : norafifah@utm.my

Abstract. Malaysia is diligently focusing its effort in developing renewable energy technology to diversify its energy sources and ensure security and sustainability in the energy sector. The development of renewable energy sector is expected to achieve 20 percent by the year 2025 to fulfil the aim of lowering greenhouse gases (GHG) produced by the energy industry. It is aligned with the commitment to the Paris Agreement signed in 2015 to reduce the emissions intensity to Gross Domestic Product (GDP) by 45% relative to 2005 levels by 2030. The rapid development of advance technology in the energy industry paved a new idea of integration of different energy resources for various industrial purposes, including power generation. The hybrid system between nuclear and renewable energy is an innovative application focusing to increase the efficiency and availability of electricity production, as well as providing additional services to industries from the energy generation process in the hybrid power plant. This paper presents the overview of the current scenario in the Malaysia energy industry, renewable energy status, the potential of nuclear-renewable hybrid system and the challenges of nuclear power development in Malaysia.

1. Introduction

Malaysia, energy sector is leading the other sectors (agriculture, waste, and industrial processes) for GHG emission record with 76% from total emission in 2011 [1]. Fossil fuel as the major contributor to GHG emission among energy sources are tremendously affecting global climate. Primary GHG consist of CO₂ and it has the most lethal effect on our environment [2]. According to Kiris and Kasap [3], CO₂ release for fossil fuel is 888 g/kW.h, 733 g/kW.h, and 499 g/kW.h for coal, oil, and natural gas, respectively.

Malaysia have signed and committed to Paris Agreement in response of mitigating the worldwide climate change threat. This Multilateral Environmental Agreement (MEA) was signed in 2015, and it requires Malaysia to reduce greenhouse gas emission by 45% by 2020 in relation to the 2015 GDP. Since the energy sector is identified as the main GHG emission contributors, the effort to reduce the national emission, along with decarbonisation strategy in the industry have been included in the National Development Plan such as Green Technology Master Plan (2017-2030) and Energy Efficiency Action Plan. Therefore, to be able to implement the SDGs and successfully comply with the Paris Agreement, Malaysia is expected to rely on renewable energy and other low carbon sources rather than fossil fuels.

Renewable energy (RE) development in Malaysia has been improving and contributing to a significant amount of energy in 2017 with 6947 ktoe which is triple the amount in year 2000 [4]. However, RE did not have the competency to replace the fossil fuel source as the main baseload in the energy mix. Hence, using RE alone to significantly reduce the GHG emission in the industry while



providing energy is not realistic. Another form of low carbon source like nuclear is proven as an alternative to assist RE in producing energy through hybrid technology [2]. This paper presents an overview of Malaysia energy scenario, the current development of RE, the potential of a hybrid system between nuclear and renewable energy and challenges for nuclear development in Malaysia. The aim is to stimulate further discussion and research on RE, nuclear energy and its hybrid technology.

2. Energy mix scenario in Malaysia

The primary energy production in Malaysia is contributed by 8 fuel types – gas, oil, hydropower, coal, biodiesel, biomass, solar and biogas. In 2018, the contribution of primary energy supply comes from natural gas (41%), crude oil and petroleum (30%), coal (22%) and hydropower and renewables (7%) with total amount of 99,873 ktoe [4]. From the primary energy supply, a total of 169,897 GWh electricity was generated from natural gas (39.1%), coal (43.4%) hydropower (15.6%), renewables (1.3%) and others (0.6%) as depicted in figure 1. The electricity generation capacity shows a steady increase from 156,000 GWh in 2016 and 162,184 GWh in 2017. The amount of generated electricity is within the installed capacity with the total amount of 33,991 MW [5].

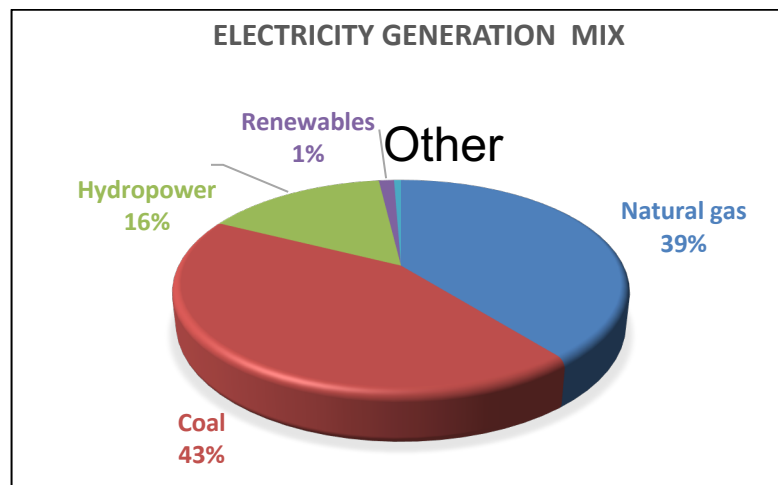


Figure 1. Electricity generation mix of 2018 [4].

There are 5 primary consumer sectors in the 2018 national energy consumption data – transportation, industry, non-energy use, residential and commercial, and agriculture. Transportation sector is leading the energy consumption with 38.5% followed by industry (28%), non-energy use (20%), residential and commercial (12.5%), and agriculture (1%). However, the electricity consumption by the same sector is monopolized by the industrial sector (49.8%), followed by commercial (29%), residential (20.5%), agriculture (0.4%) and transport (0.3%) sectors respectively with a total of 152,866 GWh. The electricity consumption is increasing from the 1990, in parallel with the development of economy and technology. The consumption data in 2018 has increased by 64.5% from 2008, which indicates large demand to the electricity sector.

Table 1 shows the available capacity, peak demand, and reserve margin for 3 regions in Malaysia in 2017 and 2018. Peak demand in 2018 stands at 18,338 MW in Peninsular Malaysia, 3,504 MW in Sarawak and 955 MW in Sabah [6]. This value increase by 3% from the previous year, 2017. The available capacity is higher than the peak demand with good reserve margin of more than 25% each year. However, the data shows major increase in demand but smaller increase in capacity, which caused the decreasing of reserve margin. Forecasted peak demand for Malaysia in 2030 will reach 22,815 MW, with projected growth of 1.8% per annum from 2020 [7]. On the other hand, researchers forecasted that reserve margin will decrease along with time because of retiring power plants and the increase in demand

[8]. Considering the existing and retiring power plants, the reserve margin will reach below 25% by 2030, which may lead to energy crisis if not planned properly.

Table 1. Malaysia's electricity generation capacity, demand and reserve margin in 2017 and 2018 [6].

Region	Available capacity (MW)		Peak demand (MW)		Reserve margin (%)	
	2017	2018	2017	2018	2017	2018
Peninsula Malaysia	23,711	24,227	17,790	18,338	35.5	32.1
Sabah	1,276	1,277	938	955	36.0	33.7
Sarawak	4,233	4,427	3,302	3,504	28.2	26.3

3. RE contribution in Malaysia energy mix

Renewable energy was first introduced in national energy policy on 1979. From then, several programs have been launched by the government in order to support the development of renewable energy in Malaysia. The initial target is to achieve 20% RE capacity mix by 2025, with a total of 3,758 MW new RE capacities should be installed starting 2020. In 2018, renewable energy (excluding hydropower) supplies only 1.3% from the total electricity generation. In 2019, there are 119 renewable energy power plant includes mini hydro, solar and biomass [9]. Upon completion of Malaysia's second Large Scale Solar (LSS) project in Bukit Selambau, Kedah, the RE capacity excluding large hydro plants will only stand at 403 MW, still miles away from the initial target. However, the national energy commission is confident to achieve the target with 11 new RE plants generation planned to operate from 2020 to 2030. If the new RE plants were operating according to the target, the projected capacity for RE will increase from 9% in 2020 to 23% in 2030, in tandem with reduction on fossil fuel capacity in the mix.

Among RE, hydropower contributed the highest percentage in RE mix with steady supply within 10% to 15% contribution in the energy mix. Contribution from solar power is increasing steadily with the completion of LSS project phase 1 and 2. However, research on biogas, geothermal and wind are continuously conducted to increase their contribution in the energy mix. From the current scenario, it can be concluded that only hydro and solar is able to be achieve commercialization in electricity industry in Malaysia and having the potential of hybrid with nuclear energy.

3.1. Solar

As an equatorial and tropical country, Malaysia is blessed with high solar radiation and have a promising future in solar energy development [10]. Several programs are introduced by government in encouraging solar PV (Photovoltaic) development. LSS is one of the recent programs that was introduced by Malaysia Energy Commission with cooperation of Tenaga Nasional Berhad (TNB). The purpose of LSS program is to develop large scale solar plant in Malaysia through a competitive bidding process. The first LSS project in Sepang, Selangor generates 50 MW with a system availability of over 99%. The second LSS project in Bukit Selambau, Kedah has started operating in September 2020, 114 days earlier than the initial target in December 2020 [11]. The third LSS project (LSS-3) was launched in June 2020 and scheduled to operate commercially by the end of 2021. LSS-3 with a capacity of 500 MW is expected to bring a significant effect in achieving the target of 20% contribution from RE by 2025 [12].

In the recent years, solar technology is rapidly developing, where many new technologies are introduced to increase solar competency in the energy industry. Chua et al. [13], in his research predicted that if solar energy remains competitive in Malaysia energy market, it will surpass other RE in electricity generation. However, solar energy has a very long way to achieve the same reputation as hydropower, especially in providing stable and sustainable amount of electricity.

3.2. Hydropower

Hydropower is the leading RE source in contributing electricity generation worldwide, including Malaysia. There are 10 large hydro power plant with combined capacity of 5534 MW in Malaysia [14]. Hydropower holds a share of 76% contribution among renewable energy in the electricity generation

capacity and contributes 10% to 15% % of overall electricity generation [15]. The installed capacity of hydropower reached 2,413 MW in 2016 with a generation of 5,072 GWh in 2018 [15].

Hydropower is considered green energy due to low GHG production. However, building large dam for hydro power plant cause negative effect to the environment. Hence, smaller scale hydropower is introduced several years ago in

Malaysia decrease the environmental impact compared to large hydropower plant [15,16]. Small scale hydropower produces power from 2 MW to 24 MW with 149 potential sites in Malaysia [15]. Small hydropower plants have low operating cost and the technology is suitable as decentralized power supply to meet the local small-scale electricity demand of remote areas, rural towns, or localized industries [17]. In 2014, there are 58 mini hydropower station around Malaysia, an increment of 65% compared in 2010 [18]. As one of the low cost RE, mini hydro has the prospect to reduce the environmental loading of Malaysia's energy usage in coming years [8,18]. Due to its advantages, such as clean, low environmental impact, low cost, and indigenous energy source, hydropower could play a vital role in the sustainable and green energy mix in Malaysia [19].

4. Small Modular Nuclear Reactor (SMR)

SMR is a reactor that have an output power less or equal 300 MWe and possess modularity concept. Baldwin et al. [20] describes the term modularity as building a complex product or process from smaller subsystem that can be designed independently and function together as a whole system. A module is the installation unit that is manufactured, assembled and tested in factory or workshop and transported to the SMR Nuclear power plant (NPP) site in such a state of readiness that no further significant processing is required to be done before installation. The SMR NPP is made of multiple such units of installation.

Globally, there are about 50 SMR designs with various power output at different stages of development [21]. A typical SMR consists of two sections: a power module and a power generation assembly. The power module houses the reactor core with the fuel rod assembly where nuclear fission generates heat. Most SMR designs available today are generation IV reactors that will be commercially deployed in several years [24,25].

SMR has many advantages for newcomer country in nuclear power programme because it provides investment flexibility and scalability. SMR is highlighted with its small footprint and compact design where it used less area compared to large NPP. It enables the government to find more suitable sites in development-limited areas or to redevelop unused area such as brownfields from retired fossil fuel plants. Due to its smaller scale and underground reactor core design, SMR may have lower visual impacts than large reactors located above surface. Thus, with less visual impact than conventional NPP, SMR can possibly located closer to the public settlements, where it can supply the intended electricity to the area.

The cost of SMR is a lot cheaper than the conventional NPP, depending on the reactor type and its capacity [22,23]. In the years coming, when more SMR design is commercialized and the licensing process is verified and endorsed, the capital costs will be more affordable hence making it accessible for a country that lack in financial support. Construction time for SMR take approximately 3 years compared to conventional NPP that would take approximately 8 years to complete [22]. Short construction time and short period of installation hastens the integration into the existing power grids [23]. Consequently, the capital cost can be reduced because 80% of the NPP life-cycle costs are incurred during the building phase [24].

5. Integration of Nuclear and RE: Nuclear – Hybrid System

Nuclear-renewable hybrid technology is the combination of nuclear and renewable resources in producing electricity and heat energy. Integration and coordination of multiple clean energy generation sources offers us the opportunity to maximize utilization of all clean energy technologies ensuring that our systems are both efficient in their operation and cost effective. This hybrid system is highly suitable for country that produce its electricity using both nuclear and renewable energy. Table 2 shows the

potential of nuclear-RE hybrid system and the possible outputs gained. Sabharwall et al. [25] compared three different type of cases which are nuclear only, nuclear-wind hybrid, nuclear-wind with hydrogen production hybrid and conclude that nuclear wind with hydrogen production is more attractive economically that the return on investment of the integration is faster than other model.

Table 2 Nuclear-renewable hybrid system [2].

Energy sources	Coupling method	Storage method	Possible outputs
Nuclear + Wind	Electrical	Hydrogen	Electricity, hydrogen
Nuclear + Solar	Thermal	Thermal	Electricity, heat
Nuclear + Biomass	Thermal	Chemical	Electricity, biofuels
Nuclear + Geothermal	Thermal	Thermal	Electricity, heat
Nuclear + Wind + Geothermal	Electrical and Thermal	Chemical	Electricity, chemical product, synfuel

According to Khalis and Bicer [26], SMR is the most suitable advanced reactor nowadays to be used for hybridization of nuclear and RE. Nuclear-renewable hybrid energy system (N-R HES) are synchronously controlled systems that dynamically apportion thermal and/or electrical energy to provide responsive generation to the power grid. N-R HES contains multiple subsystems [27]; nuclear heat generation source, a turbine that converts thermal energy to electricity, at least one renewable energy source, and industrial process that utilizes heat and/or power from the energy sources to produce a commodity-scale product.

There are three possible general categories introduced in 2016 for the integration system; tightly coupled HES, thermally coupled HES, and loosely coupled HES [27]. All thermal energies added together and all electric energies are combined together in tightly coupled system. Available thermal and electrical energy will be used in needed industry application suitable to this technology. For loosely coupled system, RE source and nuclear reactor generate electric separately and linked together at the electricity distribution level. The system may include electrical-to-thermal energy conversion equipment to provide thermal energy input to the industrial process. Lastly for the thermal coupled, nuclear and renewable subsystems are co-controlled to provide energy and ancillary services to the grid. These categories have more than one connection point to the grid and includes thermally integrated subsystems that are tightly coupled with the heat generation source [27].

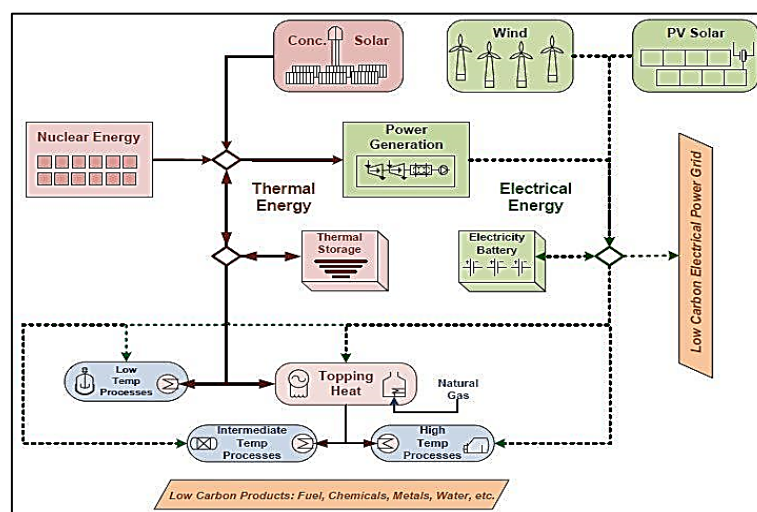


Figure 2. An example of hybrid energy system [2].

Figure 3 show recent patented hybrid nuclear-solar technology. It uses a nuclear reactor to heat a compressed working fluid that is expanded within turbines rotating compressors of both reactor plant

and air pressurising plant. Heat exchangers removes the low-grade heat from the working fluid and pass it to moisture removal equipment on the air compressing plant's downstream side. Inter cooler heat exchangers are used to further cool the working fluid until it enters the compressors, lowering compressor power requirements [28].

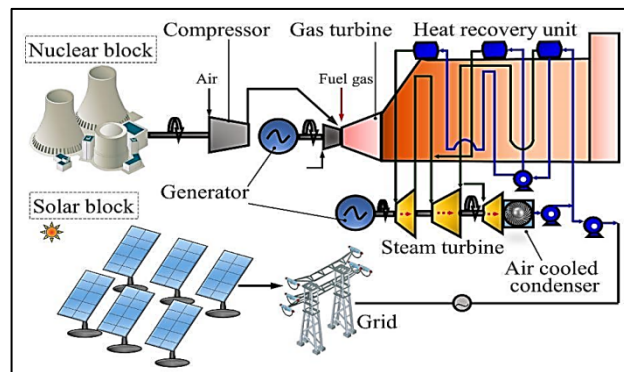


Figure 3. Hybrid nuclear solar energy system [28].

Integration of RE and nuclear energy comes with many advantages. Incorporation of the 2 technologies in 1 facility can improve their capability to become highly competitive in the energy sector, thus ensuring sustainable and green energy supply for future generation [2,23,29]. Coupling technology with nuclear allows the intermittent RE to have a higher grid penetration, thus increasing the overall efficiency to meet energy demand [2,29]. On the other hand, the positive image of RE helps to improve the negative sentiments on nuclear operating side by side, which will eventually subjugate the challenges faced with their independent use can be incorporated with the sustainability of nuclear power generation in the hybrid or integration system to subjugate challenges faces with their independent use. The capability of producing a useful product such as hydrogen also makes this new technology indispensable in the future. Hybridization of RE and nuclear would also encourages industrial symbiosis [29].

6. Challenges towards nuclear power development in Malaysia

Malaysia has once considered nuclear as an alternative resource to replace fossil fuels for baseload capacity. However, social and financial restrictions have decelerated the effort towards realizing nuclear power development in Malaysia.

Public acceptance has been the critical factor in implementing nuclear energy for a newcomer country. Public acceptance for nuclear is particularly low because it is majorly affected by nuclear accident that happened throughout the history, and further exaggerated by the mass media and movies [30]. In Southeast Asia, Indonesia has the higher public acceptance in nuclear power while Malaysia appears to be struggling to win over public support post-Fukushima accident [31]. For example, Lynas corporation, a mining company that open its plant in Gebeng caused a heated political argument and protest among public regarding the radioactive materials in the residue of rare earth material extraction process. According to Atomic Energy Licensing Board (AELB) Malaysia, radioactivity of these residue is low and not compromising to the environment and the public nearby the plant. However, the public is still concerned about the management of the radioactive residue and consistently urged the government to send it elsewhere outside the country.

The waste management issue from Lynas have led to bigger discussion about the nation's ability to manage nuclear waste from a nuclear power plant. Although the amount of waste generated by nuclear power is very small relative to other thermal electricity generation technologies, nuclear waste disposal has been the greatest challenge in nuclear power generation [32]. For over 6 decades, there is no long-term repository licenced by any nation even it is widely agreed that High Level Waste (HLW) and long-lived Intermediate Level Waste (ILW) were to be stored in deep geological disposal [2].

A country could not elude from financial risk in developing any type of power generation. The construction of NPP would cost billions of dollars and is increasing by year. According to Suman et al [2], the cost of constructing new NPP risen steeply compared to other low carbon alternatives. Adding to the problem, there is risk in the delay of construction and licensing that would escalate the capital cost of NPP [2]. Construction cost of nuclear power plant contribute majorly to the life cycle of the plant, while the fuel costs are a minor proportion of total generating costs. Hence, nuclear capital costs are greater than those for coal-fired plants and much greater than those for gas-fired plants [22].

Malaysia has taken its first step in producing green and sustainable energy by developing renewable energy such as solar, biomass, and hydropower. Due to many challenges hindering the development of nuclear in Malaysia, nuclear option is not prioritized for the time being. However, government has long accepted its capability to ensure national energy security and sustainability. With the increasing cost to import fossil fuel and limitation of power production from renewable sources, it is a matter of time when nuclear will be reconsidered as an energy source option in Malaysia.

7. Conclusion

Electricity consumption in Malaysia is projected to increase in parallel with population numbers that is expected to reach 41.5 million in 2040. There are only two options to decarbonise an ever-increasing demand in the electricity sector: nuclear power and renewable energy. Of these two options, only nuclear provides firmly dispatchable baseload electricity. On the other hand, decarbonising existing electricity system with 100% RE is unnecessarily expensive, and unsustainable for the long term. Even though Malaysia is expanding its RE production, more stable and larger amount of energy is needed to ensure the energy security for the future. With the emergence of nuclear renewable hybrid system, Malaysia should consider adopting this technology by combining small modular reactor with RE to generate electricity and other industrial purposes. There are certainly some technical and economic issues that needs deep consideration towards the implementation of the hybrid system. However, its potential to diversify the energy mix and to lower carbon emission in the future has been slowly proven, and certainly cannot be neglected.

8. References

- [1] Tang KHD. Climate change in Malaysia: Trends, contributors, impacts, mitigation and adaptations. *Sci Total Environ* 2019;650:1858–71. <https://doi.org/10.1016/j.scitotenv.2018.09.316>.
- [2] Suman S. Hybrid nuclear-renewable energy systems: A review. *J Clean Prod* 2018;181:166–77. <https://doi.org/10.1016/j.jclepro.2018.01.262>.
- [3] Kiris S, Kasap Y. Environmental Effects An analysis of the energy production efficiency of countries. *Energy Sources, Part A Recover Util Environ Eff* 2019;00:1–13. <https://doi.org/10.1080/15567036.2019.1696428>.
- [4] MEC. Peninsular Malaysia Electricity Industry Outlook 2019. 2019.
- [5] Malaysia Energy Commission. Industri Pembekalan Elektrik Malaysia Performance & Statistical Information. 2018.
- [6] Suruhanjaya Tenaga. Malaysia Energy Statistics Handbook 2018. Suruhanjaya Tenaga (Energy Comm 2019:1–86.
- [7] Malaysia Energy Commission. Report on Peninsular Generation Development Plan 2019. vol. 2019. 2020.
- [8] Basri NA, Ramli AT, Aliyu AS. Malaysia energy strategy towards sustainability: A panoramic overview of the benefits and challenges. *Renew Sustain Energy Rev* 2015;42:1094–105. <https://doi.org/10.1016/j.rser.2014.10.056>.
- [9] TNB. Integrated Annual Report 2019. 2019.
- [10] Khan R, Go YI. Assessment of Malaysia ' s Large-Scale Solar Projects : Power System Analysis for Solar PV Grid Integration 2019;1900060:1–17. <https://doi.org/10.1002/gch2.201900060>.
- [11] Sataloff RT, Johns MM, Kost KM. Integrated Annual Report 2019. 2019.

- [12] Tan CS, Maragatham K, Leong YP. Electricity energy outlook in Malaysia. *IOP Conf Ser Earth Environ Sci* 2013;16. <https://doi.org/10.1088/1755-1315/16/1/012126>.
- [13] Chua SC, Oh TH, Goh WW. Feed-in tariff outlook in Malaysia. *Renew Sustain Energy Rev* 2011;15:705–12. <https://doi.org/10.1016/j.rser.2010.09.009>.
- [14] Map Data in GEO - GEO Systems 2018. <http://globalenergyobservatory.org/constructNetworkIndex.php> (accessed April 19, 2021).
- [15] Yah NF, Oumer AN, Idris MS. Small scale hydro-power as a source of renewable energy in Malaysia: A review. *Renew Sustain Energy Rev* 2017;72:228–39. <https://doi.org/10.1016/j.rser.2017.01.068>.
- [16] Hossain M, Huda ASN, Mekhilef S, Seyedmahmoudian M, Horan B, Stojcevski A, et al. A state-of-the-art review of hydropower in Malaysia as renewable energy: Current status and future prospects. *Energy Strateg Rev* 2018;22:426–37. <https://doi.org/10.1016/j.esr.2018.11.001>.
- [17] Ho LW. Wind energy in Malaysia: Past, present and future. *Renew Sustain Energy Rev* 2016;53:279–95. <https://doi.org/10.1016/j.rser.2015.08.054>.
- [18] Abd Hamid MF, Ramli NA, Mat Napiah SNB. Factors Affecting Mini Hydro Power Production Efficiency : 2015:85–8.
- [19] Yuksel I. Dams and hydropower for sustainable development. *Energy Sources, Part B Econ Plan Policy* 2009;4:100–10. <https://doi.org/10.1080/15567240701425808>.
- [20] Upadhyay S, Sharma MP. A review on configurations, control and sizing methodologies of hybrid energy systems. *Renew Sustain Energy Rev* 2014;38:47–63. <https://doi.org/10.1016/j.rser.2014.05.057>.
- [21] IAEA. *Advances In Small Modular Reactor Technology Developments*. 2018th ed. Viena: Nuclear Power Technology Development Section, Division of Nuclear Power of the IAEA Department of Nuclear Energy; 2018.
- [22] Zohuri B. *Small Modular Reactors as Renewable Energy Sources*. 2018. <https://doi.org/10.1007/978-3-319-92594-3>.
- [23] Devanand A, Kraft M, Karimi IA. Optimal site selection for modular nuclear power plants. *Comput Chem Eng* 2019;125:339–50. <https://doi.org/10.1016/j.compchemeng.2019.03.024>.
- [24] Ho M, Obbard E, Burr PA, Yeoh G, Obbard E. A review on the development of nuclear power reactors. *Energy Procedia* 2019;160:459–66. <https://doi.org/10.1016/j.egypro.2019.02.193>.
- [25] Sabharwall P, Bragg-Sitton S, Boldon L, Blumsack S. *Nuclear Renewable Energy Integration: An Economic Case Study*. *Electr J* 2015;28:85–95. <https://doi.org/10.1016/j.tej.2015.09.003>.
- [26] Khalid F, Bicer Y. Energy and exergy analyses of a hybrid small modular reactor and wind turbine system for trigeneration. *Energy Sci Eng* 2019;7:2336–50. <https://doi.org/10.1002/ese3.327>.
- [27] Bragg-Sitton SM, Boardman R, Rabiti C, Kim JS, McKellar M, Sabharwall P, et al. *Nuclear-Renewable Hybrid Energy Systems: 2016 Technology Development Program Plan 2016*.
- [28] Keller MF. *Hybrid integrated energy production process*. 2005.
- [29] Sabharwall P, Bragg-sitton S, Boldon L, Blumsack S. *Integration : An Economic Case Study*. *Electr J* 2015;28:85–95. <https://doi.org/10.1016/j.tej.2015.09.003>.
- [30] Dahlan NY, Ibrahim A, Rajemi MF, Baharum F. Analysis of the Impact of Nuclear Power Plant on Malaysia ' s Power Systems : Costs , CO 2 Emission and System Reliability 2020:206–11.
- [31] Putra NA. The dynamics of nuclear energy among ASEAN member states. *Energy Procedia* 2017;143:585–90. <https://doi.org/10.1016/j.egypro.2017.12.731>.
- [32] IAEA. *Basic infrastructure for a nuclear power project*. IAEA Tecdoc 1513 2006.

Acknowledgements

This research is funded by Universiti Teknologi Malaysia under Research University Grant (GUP: Q.J130000.2651.16J77).