

Review

Solar Photovoltaic Home Systems in Malaysia: A Comprehensive Review and Analysis

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Abstract: This paper presents a thorough review and analysis of solar photovoltaic (PV) home systems in Malaysia, offering a comprehensive exploration of their implementation, challenges, benefits, and future potential. As a nation striving to embrace sustainable and renewable energy solutions, Malaysia's adoption of solar PV systems at the residential level is of paramount importance. The study delves into the current state of solar PV deployment, government initiatives, and policy frameworks that influence adoption trends. It examines the economic, environmental, and societal advantages of solar PV home systems, outlining their contribution to reducing electricity costs, carbon emissions, and energy dependence. Addressing barriers to wider acceptance, the paper scrutinizes challenges encompassing cost, awareness, intermittency, and regulatory constraints. Furthermore, the study evaluates the socio-economic implications of solar PV home systems, including potential job creation and energy independence. Technological advancements, such as enhanced efficiency and smart grid integration, are also explored for their role in surmounting obstacles. Drawing insights from practical case studies, the paper underscores successful installations and the lessons they offer. In examining policy and regulatory frameworks, it analyzes existing incentives while suggesting improvements to accelerate adoption. Finally, the paper offers a visionary perspective on the future trajectory of solar PV home systems in Malaysia, envisioning increased affordability, advanced energy storage solutions, and seamless integration with emerging technologies. This holistic analysis contributes valuable insights to propel Malaysia's sustainable energy transition and inform strategic decision making for stakeholders across sectors.

Keywords: solar; photovoltaic (PV); home system; renewable energy; carbon emissions; greenhouse gas; energy sector and Malaysia



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1. Introduction

The global energy landscape has seen a revolutionary transition in recent years toward sustainable and renewable sources, and Malaysia is no exception [1]. Malaysia, as a country with strong economic expansion and a growing need for energy, confronts the combined problem of providing its energy demands while decreasing its carbon imprint [2]. Solar photovoltaic (PV) household systems have emerged as an important and promising component of Malaysia's energy policy in this setting. These systems not only allow households to harvest clean, renewable energy straight from the sun but they also have the ability to transform the nation's energy landscape by diversifying the energy mix and improving energy security.

Malaysia's tropical environment, with plentiful sunlight all year, provides a natural advantage for the mass adoption of solar PV home systems [3]. With a commitment to sustainability and environmental responsibility, the country aspires to use its solar potential

in order to cut greenhouse gas emissions, minimize the effects of climate change, and relieve strain on traditional energy sources. Furthermore, solar PV household systems are consistent with Malaysia's overarching aims of increasing energy self-sufficiency, lowering energy import reliance, and fostering long-term economic growth. The significance of solar PV home systems extends beyond environmental considerations. In a nation where energy costs have been on the rise, these systems hold the promise of reducing electricity bills for homeowners while creating avenues for generating income through excess power generation fed back into the grid [4]. This economic empowerment at the individual level contributes to community resilience and alleviates financial burdens, ultimately enhancing the quality of life.

Southeast Asia has been captivated by solar photovoltaic (PV) home systems, which provide a ray of hope in the pursuit of clean, affordable, and sustainable energy solutions. This dynamic region, which includes diverse countries like the Philippines, Vietnam, Thailand, Malaysia, and Indonesia, faces particular energy challenges due to rapidly increasing urbanization, population growth, and the growing demand for electricity [5]. The main ways to meet this demand have been through traditional energy sources like coal and oil, which have led to environmental degradation and a heavy reliance on fossil fuels. In addition to exacerbating pollution and contributing to climate change, this reliance on non-renewable energy sources has created difficulties for energy security and affordability. With both the commercial and residential sectors embracing solar energy, Thailand has a more developed solar photovoltaic market. The nation's feed-in tariff program has boosted the use of solar energy. Singapore concentrates on rooftop solar due to its lack of land for large-scale solar projects. For home solar installations, the government provides rebates and incentives in Singapore. Connecting Indonesia's vast archipelago's isolated islands to the grid presents special difficulties. Net metering was instituted by the government to encourage the use of solar PV. When it comes to residential solar PV installations, Germany leads the world. Strong public support for renewable energy and advantageous feed-in tariffs are credited with the nation's success [6]. The solar landscape in the United States of America (USA) is varied. Encouraged by incentives, states like California have seen a significant uptake of residential solar power, while other states are still developing their solar markets [7]. In terms of solar installation and manufacturing, China leads the world. The widespread adoption of solar power in homes can be attributed to the government's aggressive policies and subsidies. When compared to other countries, Malaysia has significant solar potential and government initiatives in place, but residential solar PV adoption is still in its early stages.

Energy security has been the focus of Malaysia's energy policies, which include progressive fuel diversification and the development of renewable energy sources under the Fifth Fuel Policy [8]. However, the majority of Malaysia's primary energy source still comes from hydrocarbons. The major energy supply totaled 100 Mtoe in 2018, with natural gas accounting for 41% of that amount, followed by crude oil (26%), coal and coke (22%), and petroleum products (4%) [9]. In 2018, renewables made up around 7% of the primary energy supply. Compared to the worldwide average, Malaysia uses petroleum products to meet a larger percentage of its energy needs (48%), driven by the country's transportation and industrial sectors [9]. In contrast, Malaysia uses 20% less power than the world average (24%), which reflects the country's comparatively low residential and business usage [10]. In Malaysia, the yearly increase in electricity consumption has been somewhat slower in terms of its compound annual growth rate (CAGR) of 5.5% between 2010 and 2018 than the annual growth in the GDP of 5.2% CAGR in the same period [9]. While other regions (Peninsular Malaysia and Sabah) have seen a plateau in the demand for industrial power, the Sarawak Corridor of Renewable Energy (SCORE) has attracted energy-intensive enterprises consuming electricity in the past twelve years. In Peninsular Malaysia, coal gradually replaced gas in 2010 as the primary fuel for power generation. To accommodate the increased demand, massive hydro plants were constructed in Sarawak. Gas accounted for 39% of all installed capacity in 2020, while coal accounted for 34% of all

installed capacity. In the mix of the country's installed capacity, renewables account for 23% [10]. Malaysia is gradually moving toward being a net importer of fuels for power generation as a result of the growing dependence on imported coal, diminishing domestic gas supplies, and limited progress in utilizing renewable resources. When the proposal to restructure the energy market is adopted in the future, it will increase pricing competition, expand consumer options, and stimulate the economy of the sector.

Furthermore, solar PV home systems play a pivotal role in advancing technological innovation and job creation. The deployment of these systems fosters a burgeoning solar industry, stimulating research and development in renewable energy technologies, energy storage solutions, and smart grid integration. The subsequent growth in the solar sector also translates into new employment opportunities, contributing to Malaysia's economic diversification and competitiveness in the global green technology market [11–13]. In this dynamic landscape, it becomes imperative to comprehensively explore the implementation, challenges, benefits, and future potential of solar PV home systems in Malaysia. This paper delves into these aspects, providing a holistic understanding of how solar PV systems are poised to shape the energy trajectory of Malaysia and lay the foundation for a sustainable and resilient energy future.

The remaining portion of the paper is structured as follows, In Section 2 titled solar PV landscape in Malaysia, the current status of solar PV deployment in Malaysia is assessed, including installed capacity, growth trends, and regional distribution. Sections 3 and 4 provide an overview of the government's initiatives and policies promoting renewable energy adoption and solar photovoltaic (PV) efficiency in comparison with other types of renewable energy (RE), respectively. The benefits of solar PV home systems and challenges hindering the widespread adoption of solar PV home systems, such as high upfront costs, lack of consumer awareness, regulatory barriers, and intermittency, are discussed in Sections 5 and 6, respectively. Section 7 describes the socio-economic implications, including job creation potential in the solar PV industry and contribution to energy independence and reduced imports. The technological innovations, such as advancements in solar PV technology, and ways to address challenges and enhance viability are described in Section 8. Real-world case studies of solar PV home system installations in Malaysia and the future trajectory of solar PV home systems in Malaysia are shown in Sections 9 and 10, respectively. We summarize the key findings, insights, and recommendations from the comprehensive review and analysis in Section 11.

2. Solar PV Landscape in Malaysia

The solar photovoltaic (PV) landscape in Malaysia has undergone significant transformation in recent years, reflecting the nation's commitment to adopting sustainable and renewable energy sources. Malaysia's abundant sunlight and growing emphasis on clean energy have positioned solar PV as a crucial contributor to the country's energy mix. The solar PV landscape encompasses various aspects, including policies, capacity growth, technological advancements, and industry developments.

The current status of solar PV deployment in Malaysia highlights significant progress and continued momentum in adopting renewable energy sources, particularly solar photovoltaic systems. The following points provide an overview of the current state of solar PV deployment.

2.1. Installed Capacity and Growth Trends

Malaysia is located close to the equator. The large-scale solar project might be implemented in Malaysia due to the country's average monthly solar radiation of 400 to 600 MJ/m² [9]. The solar power potential in Malaysia is depicted in Figure 1. When compared to other Malaysian towns, Kota Kinabalu (1900 kWh/m²), Bayan Lepas (1809 kWh/m²), George Town (1785 kWh/m²), and Taiing (1768 kWh/m²) have the greatest sun radiation levels. The development of solar energy has been supported by a number of organizations, including the Malaysia Energy Centre, Tenaga Nasional Berhad (TNB), and Sustainable

Energy Development Authority Malaysia (SEDA) [10]. According to Figure 2, the installed capacity of solar energy has expanded from 205 MW in 2014 to 2165 MW in 2023, showing that favorable government policies and actions in different end-user sectors have led to a large growth in the solar industry [14]. However, local and international photovoltaic producers are equally crucial to the advancement of solar energy. Malaysia ranked as the world's third-largest producer of photovoltaic technology in 2021 [15].

SOLAR RESOURCE MAP

PHOTOVOLTAIC POWER POTENTIAL MALAYSIA

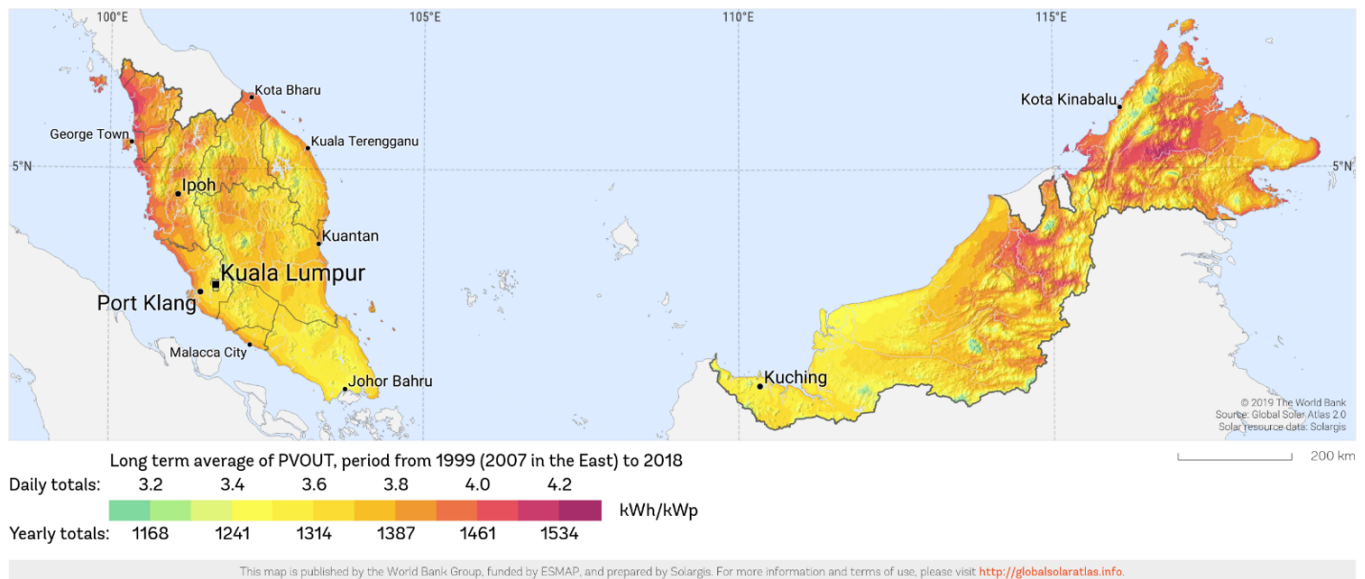


Figure 1. Photovoltaic power potential in Malaysia [16].

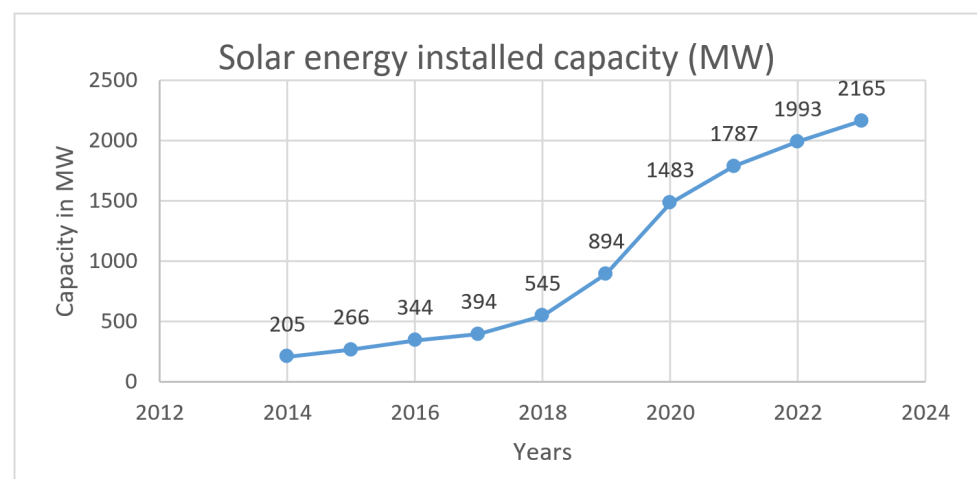


Figure 2. Solar energy installed capacity.

According to Malaysian solar panel orientation guidelines, facing southward toward the equator is the best orientation. In particular, during peak hours, this enables the panels to receive the maximum amount of sunlight possible throughout the day [17]. The most effective material for turning sunlight into electricity is found in monocrystalline solar panels, making them the best option for the cloudy weather of Malaysia [18]. Polycrystalline semiconductor performance is dependent on solar radiation levels. The temperature of polycrystalline modules is marginally higher than that of amorphous modules but

lower than that of monocrystalline modules. However, compared to polycrystalline and monocrystalline solar cells, amorphous solar cells produce less energy at high solar radiation intensities [19].

2.2. Regional Distribution

Solar PV deployment is not uniform across Malaysia, with certain regions exhibiting higher adoption rates. The central and northern regions, including urban centers like Kuala Lumpur and Penang, have witnessed significant solar PV installations due to higher population densities and greater awareness. The total of 269 GW solar PV deployments showcases a diverse distribution across different regions of Malaysia [14]. Solar PV deployment spans various sectors, with residential, commercial, and industrial entities embracing the technology. Residential solar PV installations contribute approximately 22.7 GW (8.5%) of the total installed capacity, showcasing increasing homeowner interest [14]. Homeowners are increasingly recognizing the economic benefits of generating their electricity. The net metering program has facilitated grid integration, allowing them to export surplus energy and offset their electricity bills. The commercial and industrial sectors combine to contribute 15.1 GW (5.6%), indicating a growing commitment to sustainable practices of businesses [14]. Businesses and industries are leveraging solar PV to reduce operational costs and environmental impact. Rooftop solar installations and ground-mounted arrays contribute significantly to the country's solar capacity. The summary of renewable energy resource potential is shown in Figure 3. The regional distribution is given below:

- i. Peninsular Malaysia: Peninsular Malaysia, including Kuala Lumpur, Selangor, Johor and Melaka, Penang, Kedah, Pahang, Terengganu, and neighboring provinces, leads in installed solar capacity, contributing approximately 137.5 GW of 51.11% [20]. Based on a study by SEDA, the north-western part of Peninsular Malaysia receives the highest solar irradiation.
- ii. Sabah Region: Sabah also has good conditions for solar PV power generation. Sabah and the surrounding areas account for 99.4 GW of 36.95%, demonstrating active solar adoption in the Sabah region [21].
- iii. Sarawak Region: Sarawak and the neighboring provinces collectively contribute 32.1 GW of 11.93%, reflecting growing regional engagement [14].

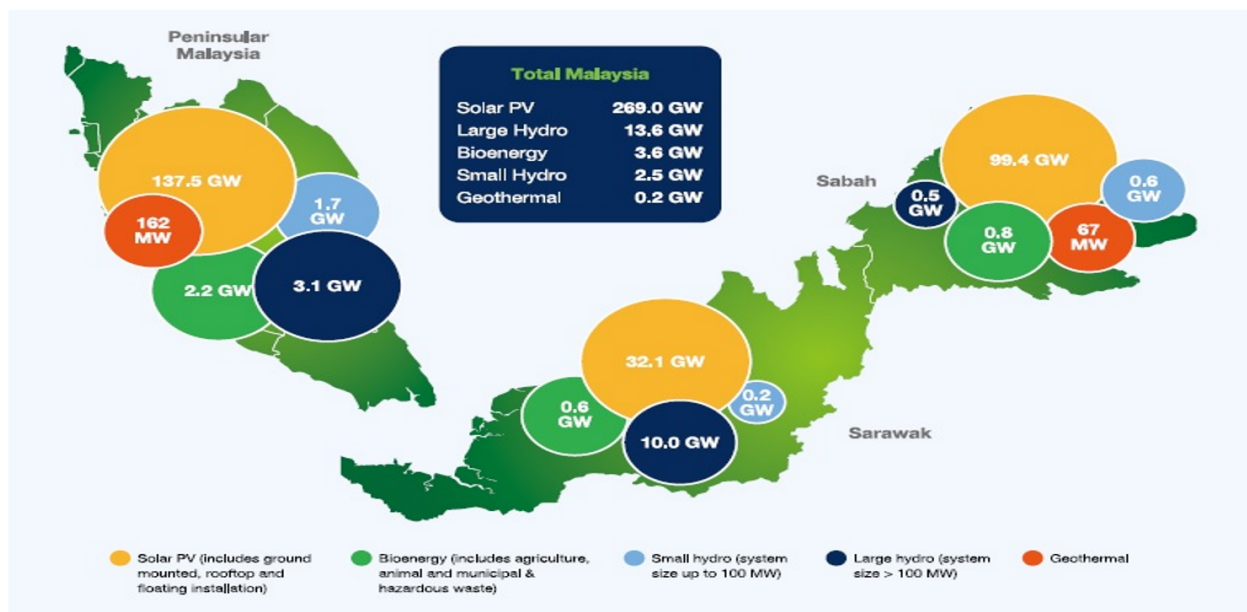


Figure 3. Summary of renewable energy resource potential.

2.3. Technological Advancements

Advancements in solar PV technology have improved efficiency and affordability, contributing to wider adoption. Research and development efforts have led to increased solar panel efficiency, allowing for greater electricity generation from limited roof space. Energy storage solutions are becoming more accessible, addressing the challenge of intermittency and enabling solar energy consumption during non-sunlight hours [22]. Malaysia has made substantial strides in solar PV deployment, with its installed capacity experiencing continuous growth over the years [23]. According to the Malaysia Renewable Energy Roadmap (MyRER), the government wants to have 31% (13 gigawatts) of the country's energy demands met by renewable energy by 2025 and 40% (18 gigawatts) by 2035 [10]. The trajectory of solar PV deployment in Malaysia remains positive. Continued technological advancements, decreasing costs, and heightened public awareness are poised to drive the installed capacity beyond 70% by 2050. According to statistics from Berlin-based consulting firm Apricum, there are plans to install solar power for another 1098 MW by 2025 and another 2414 MW by 2035 [24]. These statistics provide a comprehensive picture of Malaysia's dynamic solar PV deployment landscape. The nation's proactive strategy to shift to cleaner and more sustainable energy sources is reflected in the nation's expanding installed capacity, regional diversity, and strategic government assistance. Finally, the present state of solar PV deployment in Malaysia highlights the country's attempts to shift to a cleaner and more sustainable energy future. The combination of regulatory backing, technology advances, and rising public interest in solar energy bodes well for Malaysia's sustained increase in solar PV capacity and contribution to the country's total energy landscape.

3. Government's Initiatives and Policies Promoting Renewable Energy Adoption

Malaysia's government has shown a strong commitment to boosting renewable energy adoption as a cornerstone of the country's long-term growth. Malaysia intends to diversify its energy mix, reduce greenhouse gas emissions, and improve energy security through a variety of projects and regulations [25]. Here are some important government-led initiatives that demonstrate Malaysia's commitment to renewable energy adoption.

3.1. Feed-In Tariff (FiT) Scheme

The FiT scheme, introduced in 2011, incentivizes the adoption of renewable energy sources, including solar PV [26]. Under the FiT scheme, producers of renewable energy, including solar energy, are offered long-term contracts with guaranteed prices for the electricity they generate. This predictable revenue stream encourages investments in renewable energy projects. With the help of the FiT program, an individual may produce their own power to sell to the grid. They receive their payment as a FiT subscriber from the renewable energy fund, also known as Dana Kumpulan Wang Tenaga Boleh Baharu (KWTBB), which is derived from energy users who use more than 300 kWh of power each month. The contract one enters into with TNB specifies a time period during which the tariff rate is set. This plan uses sustainable energy sources including solar, biomass, biogas, and small hydro.

3.2. Net Energy Metering (NEM) Program

The NEM program was introduced to encourage consumers to install solar PV systems on their premises. Through NEM, consumers with solar PV installations can offset their electricity bills by exporting surplus energy to the grid. This program enhances the economic viability of solar PV systems and encourages consumers to become prosumers, generating and consuming their electricity. In accordance with the user's tariff, the net energy metering (NEM) scheme enables self-consumption of the power produced by the user's solar PV system while also selling any excess energy to the distribution licensee (TNB) at a 1 to 1 offset. The NEM allotment is 500 MW, of which 120 MW will be used by residential customers, 195 MW by businesses, and 185 MW by industries [27].

3.3. Renewable Energy Act 2011

The Renewable Energy Act of 2011 provides the legal framework for the promotion of renewable energy in Malaysia. The Act establishes the regulatory mechanisms and guidelines for the implementation of renewable energy projects, including solar PV, while setting targets for renewable energy capacity [28]. The Malaysian government's Sustainable Energy Development Authority (SEDA) is in charge of promoting and putting sustainable energy into practice. The fundamental goal of this Act is to utilize or create energy to meet present demands without compromising those of future generations. This goal includes using renewable energy sources. In addition, Malaysia wants to have advanced sustainable development by 2025. Therefore, using green technology as a catalyst for economic growth in the future might assist in advancing the sustainable development and green growth of the nation. The National Green Technology Policy (NGTP) also emphasizes a variety of industries, including waste management, construction, energy, and transportation. The entire amount of energy used by each sector was tallied, and among all of the sectors, residential and industrial use 33% more energy than commercial (23%) and transportation (15%) [29].

3.4. Green Technology Master Plan (GTMP)

The GTMP outlines Malaysia's green technology development strategy, emphasizing renewable energy adoption as a key component. The plan sets ambitious targets for renewable energy capacity and outlines strategies for enhancing research and development, investment, and human capital development in the green technology sector. Compared to 18.9% in 2016, the aspirational objectives for installed RE capacity are set at 20% by 2020, 23% by 2025, and 30% by 2030 [30]. The overall cost of any renewable energy source must, however, be comparable to that of conventional resources, and no new, large-scale coal-fired power plants must be built beyond 2020 [29]. Malaysia will have 1200 MW of extra installed large-scale solar (LSS) farm capacity, with 200 MW in Sabah and 1000 MW in Peninsular Malaysia [31]. Rooftop solar PV power generation will be able to use NEM. With an annual quota of 100 MW, it seeks to reach a total solar capacity of 1050 MW by 2023 [26]. The NEM is available to all power users and has the following goal capacities: industry (45%), commercial (45%), and residential (10%) [30].

3.5. Green Investment Tax Allowance (GITA) and Green Income Tax Exemption (GITE) Schemes

These schemes provide tax incentives to entities investing in green technology and renewable energy projects, including solar PV. Figure 4 shows the scope of the green technology tax incentive.

The GITA offers tax allowances on qualifying capital expenditure, while the GITE provides income tax exemptions for a specified period to entities engaged in green technology activities [32]. The green technology tax incentive was created in 2014 in line with the Malaysian government's goals to promote the expansion of Malaysia's green economy. The initiative intends to provide the business a choice between two potential rewards. Companies may apply for the GITA if they wish to purchase qualifying green technology assets listed in Malaysia's green recognition scheme (MyHIJAU) directory or if they wish to implement qualifying green technology projects for their personal use or for commercial purposes. Companies that qualify as green technology service providers and are included in the MyHIJAU directory are eligible for the GITE.

3.6. Low Carbon Cities Framework

The low-carbon cities framework aims to transform urban areas into low-carbon, sustainable communities. The framework encourages the adoption of renewable energy technologies, including solar PV, within urban planning and development processes.

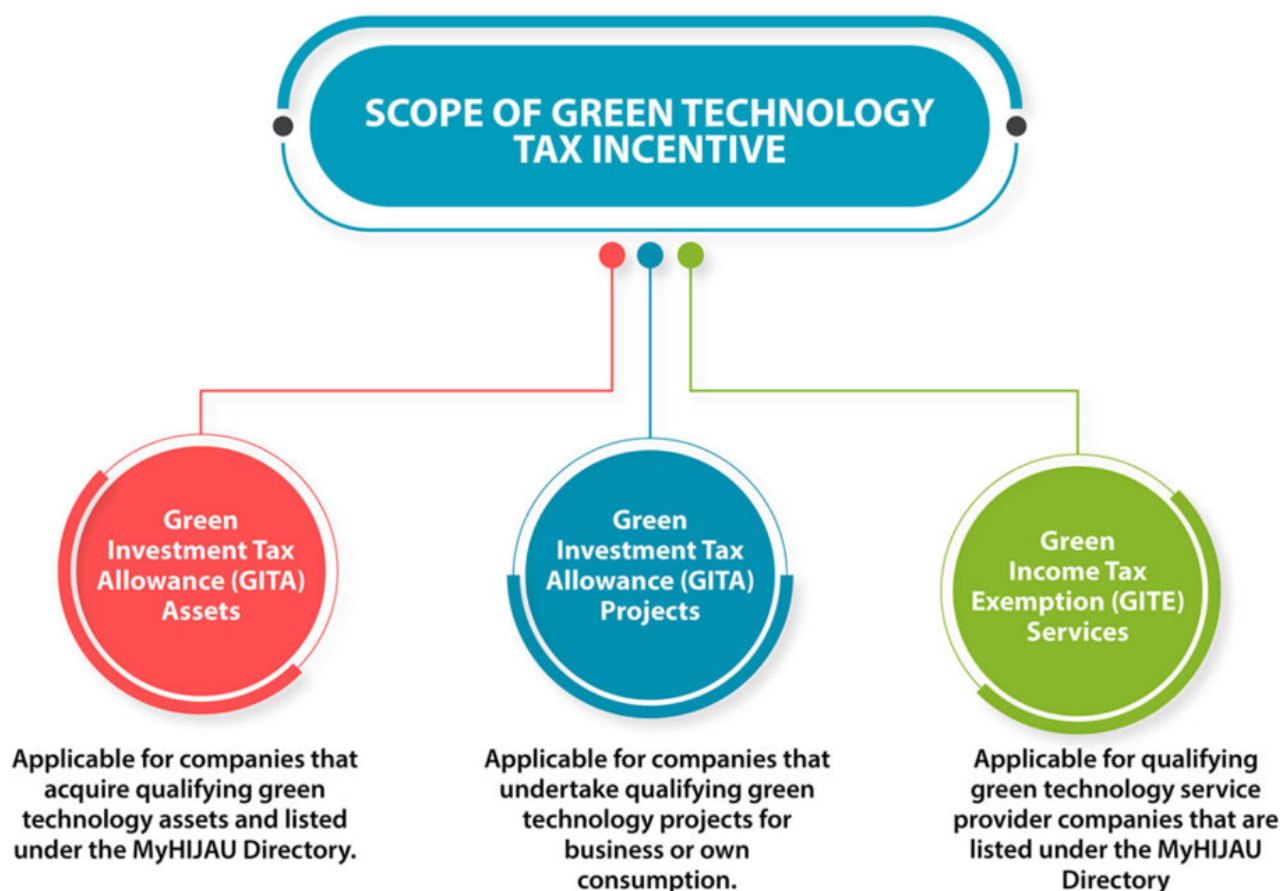


Figure 4. Scope of green technology tax incentive.

The Kuala Lumpur Climate Action Plan 2050 (2021) estimates that the city's yearly carbon footprint in 2017 was 25 Mtoe [33]. The largest source of emissions in the city, accounting for 56% of all emissions, was transportation. The greenhouse gases (GHGs) emissions inventory is an essential instrument for tracking, reporting, and assessing a city's progress on climate action as well as quantifying and estimating carbon emissions [34]. An updated inventory can inform Kuala Lumpur City Hall (DBKL), Malaysia, regarding the degree to which efforts to mitigate climate change have really reduced GHG emissions or their equivalent over time in reduced carbon emissions [33]. Meanwhile, it is anticipated that Kuala Lumpur's carbon emissions will more than treble without considerable action by DBKL. The CO₂ emissions forecast of Malaysia from 2017 to 2050 is shown in Figure 5.

Global CO₂ emissions are predicted to rise from 35.3 billion metric tonnes in 2018 to approximately 43.08 billion metric tonnes in 2050 based on a business-as-usual trend. According to US Environmental Protection Agency (EPA) projections, economy-wide CO₂ emissions in the US, including electricity generation and use, are expected to be 35% to 43% lower in 2030 as a result of the Inflation Reduction Act (IRA) [35]. A minimum of a 55% reduction in greenhouse gas emissions by 2030 necessitates increased renewable energy and energy efficiency. The CO₂ emissions forecast worldwide from 2030 to 2050 is depicted in Figure 6.

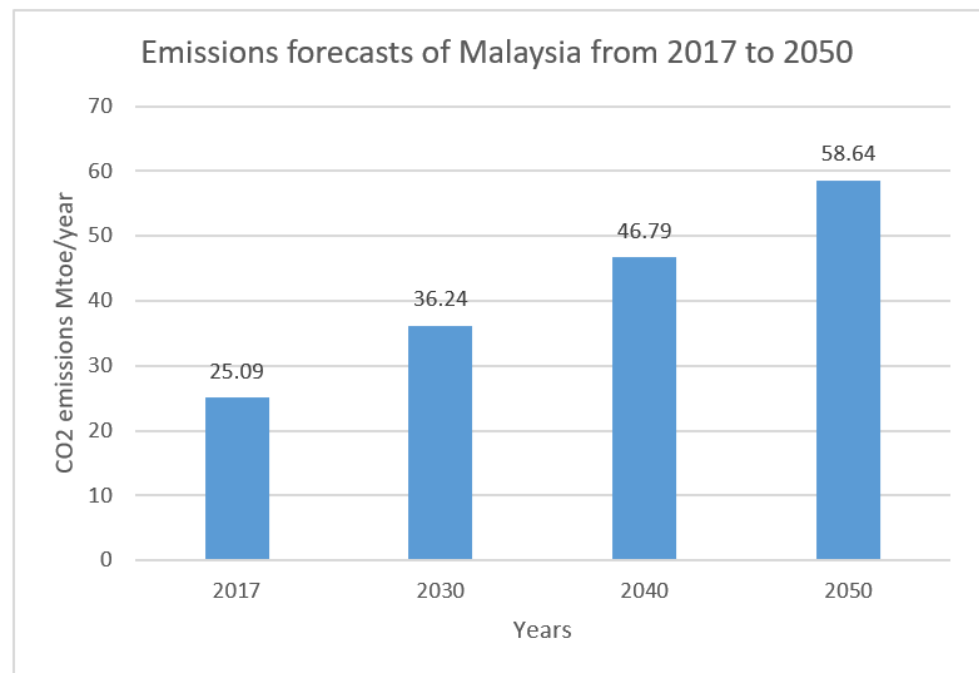


Figure 5. CO₂ emissions forecast of Malaysia from 2017 to 2050.

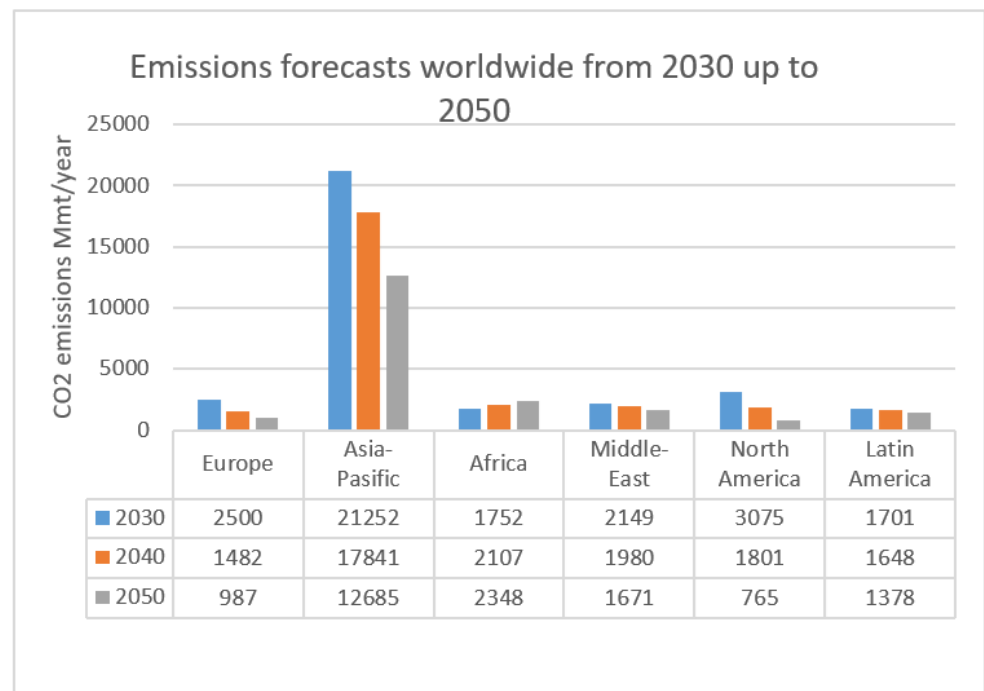


Figure 6. CO₂ emissions forecast worldwide from 2030 to 2050.

3.7. National Renewable Energy Policy and Action Plan (NREPAP)

The NREPAP outlines a comprehensive strategy to accelerate renewable energy development in Malaysia. It sets clear targets for renewable energy capacity, outlines supportive regulatory frameworks, and highlights the importance of technology transfer and capacity building. To support and stimulate the expansion of a variety of renewable energy resources in Malaysia, new technologies and regulations are needed. Greentech Malaysia was founded in 2010 to connect the programs, strategies, and plans that include financial aid for power generation in the form of loans, grants, and feed-in tariffs [36]. Additionally,

the Pakatan Harapan (PH) platform made a promise to increase the supply of renewable energy by 20% by 2025 [34]. Additionally, the Energy Commission supports the Ministry of Energy, Science, Technology, Environment, and Climate Change (MESTECC) in developing government programs and policies to reduce the fuel credit, which increases the percentage of renewable energy (RE) in the generating mix. As shown in Table 1, a number of foreign corporations choose to establish bases in Malaysia owing to factors such as favorable banking loans, reasonable regulations, favorable tax breaks, competitive labor prices, and first-rate infrastructure and amenities.

Table 1. The photovoltaics companies in Malaysia [37].

Company Name	Description
Malaysian companies	
TS Solartech	TS Solartech was established in 2010 and is based in Malaysia's Penang Science Park. The company is committed to the development, design, and manufacture of premium solar cells, modules, and PV systems. This business produces solar cells on 7 production lines with a total capacity of 640 MW.
Foreign companies	
First Solar	First Solar, an industry pioneer in American solar technology and a prominent global supplier of ethically made eco-efficient solar modules that advance the battle against climate change, was founded in 1999. It is situated in the Kulim Hi-Tech Park area. This business has 24 manufacturing lines and a capacity of roughly 2200 MW (solar cells).
JA Solar	The opening of a 400 MW high-performance photovoltaic (PV) solar cell manufacturing plant in Penang, Malaysia, was announced by JA Solar Holdings Co., Ltd. The factory, which is JA Solar's first production facility outside of China, is set up to make multi-crystalline solar cells with a high conversion efficiency for use in PV power generation.
Jinko Solar	A solar technology leader with a solid reputation for innovation is Jinko Solar Co., Ltd. The firm adopts the objective of "changing the energy portfolio and taking responsibility for enabling a sustainable future", positioning itself strategically in the key sectors of the solar industrial chain. With an emphasis on integrated photovoltaic product research, development, and manufacturing as well as comprehensive clean energy solutions, it dominates the worldwide mainstream photovoltaic market in terms of sales. It is situated in the Penang industrial area. This company has 7 production lines, and its capacity is about 550 MW (solar cells).
Panasonic Energy Malaysia	Ditrolc Solar and the Panasonic Group have worked together on various projects in the Asian area over a long period of time. In order to smoothly integrate the system on the rooftop of PECMY, it is required to design a solar rooftop system for the factory during construction and to collaborate closely with its Japanese counterpart. It is positioned in Kulim Hi-Tech Park. Its capacity is about 350 MW.
Q-cells Malaysia	The headquarters of the Malaysian company Q Cells Malaysia Sdn. Bhd. are in Cyberjaya. The business is a manufacturer of semiconductors and related devices. The business was founded on 21 March 2008. About 1300 MW (solar cells) of capacity and 4 production lines are present.
SunPower	While their new business, Maxeon Solar Technologies (Maxeon Solar), will concentrate on making solar panels, SunPower will still provide distributed generation energy services. It is situated in Malacca. There are 28 production lines visible, with a 1450 MW (solar cells) capacity.
LONGi Solar	The technological and production leadership of LONGi in solar wafers, cells, and modules demonstrates their dedication to accelerating the switch to sustainable energy. They offer comprehensive solutions for the solar and renewable energy industries by providing high-quality, dependable goods and systems. It is positioned in the Kuching, Sarawak, area. Its capacity is about 620 MW.

These government initiatives and policies collectively underscore Malaysia's commitment to transitioning toward a more sustainable and greener energy future. By fostering a conducive environment for renewable energy adoption, Malaysia seeks to reduce its carbon footprint, enhance energy security, and contribute to global efforts to combat climate change.

4. Comparison of Solar Photovoltaic (PV) Efficiency with Other Renewable Energy (RE)

Solar energy sources are among the most sustainable and ecologically friendly renewable energy sources accessible right now [38,39]. The best potential substitute for energy produced from fossil fuels is RE. This energy is clean and has little effect on the environment. It has shown to be a competitive alternative to major transformative technologies in addition to being an RE source. Its growth contributes to a decrease in GHG emissions and global warming. By using photovoltaic (PV) cells to produce direct power or by extracting the thermal energy contained in solar energy, direct electricity may also be produced [39]. As a result of its accessibility, solar energy has emerged as one of the most widely used RE sources.

In order to decrease their reliance on fossil fuels and enhance domestic solar energy consumption, many nations have established solar energy policies [38]. Additionally, in order to meet the growing need for energy while avoiding the negative effects that fossil fuels have on the environment and other problems, some nations have been pressured to research and transition to ecologically favorable RE sources [39]. Solar energy, like other renewable energy sources, is a promising and easily accessible source of energy for alleviating the long-term energy dilemma [40]. Due to the population increase and technological improvements, the world's energy consumption is rising quickly. Therefore, it is crucial to pick a reliable, affordable, and lasting RE source to meet future energy demand. Nevertheless, despite the fact that the principal energy source, fossil fuel, is finite and alternative energy sources are prohibitively expensive, the solar sector is constantly expanding around the world due to the massive need for energy [40].

Renewable energy sources are seen as a clean and sustainable alternative to fossil fuels in the face of urgent concerns like climate change and fossil fuel depletion. Through a vast number of scientific articles and patents, photovoltaic technologies have developed into a prominent subject of study and development [41]. Photovoltaic systems' core building block and main component are solar cells. A solar cell is an electrical device that uses the photovoltaic effect, a chemical or physical mechanism, to convert the energy in photons directly into direct current (DC) power. When photons with energies larger than the band gap of the cell's material are absorbed, charge carriers are excited, which leads to the production of current and voltage. The percentage of incident light output that is converted to electrical energy under normal circumstances is the definition of a photovoltaic cell's conversion efficiency [41]. The solar cell of photovoltaic (c-Si) technology has been acknowledged as the sole long-term sustainable, environmentally benign, and economically feasible renewable energy source to replace fossil fuels ever since it was developed [42]. Cost reduction to compete with fossil fuels has been the main engine of growth for the Si photovoltaic sector. The crystalline Si photovoltaic sector continues to be rich in innovative device designs and optical enhancement approaches despite its quick maturity.

Government energy strategies must include domestic and local renewable energy sources, such as domestic and local natural resources. The Malaysian government sets the parameters for energy production, supply, and consumption in the country. Malaysia's government is now making an effort to boost RE output [43]. The Department of Electricity and Gas Supply oversees the regulation of the energy industry. Other stakeholders include clients, service industries, research and development (R&D) organizations, and energy providers. Government-owned businesses Tenaga Nasional Berhad (TNB) and Petroliaam Nasional Berhad (PETRONAS) control the majority of the energy sector in Malaysia. In conclusion, these energy metrics are meant to support sustainable development in relation to Malaysian energy policies [44].

Hotspots typically occur in a PV array due to high temperatures and inconsistencies in individual panel outputs, which reduce the efficiency of the solar PV plant. Over time, these hotspots seriously impair the PV panel, increasing the cost of maintenance and repairs. To prevent the creation of hotspots, PV module manufacturers must perform quality inspections. Standards must be set up in order for the maker to improve the quality

and lifespan of the PV modules [45]. The National PV Monitoring & Performance Database is used by the PV Monitoring System (PVMS), according to SEDA (2020), to track the efficiency and dependability of a few grid-connected solar photovoltaic (PV) installations.

Wind turbine capacity factors (measures of efficiency) generally range from 25% to 50% depending on wind resources and turbine technology [46]. Although solar PV efficiency is better than that of individual wind turbines, wind energy can be more constant in windy areas. Hydropower plants are highly efficient, frequently surpassing 90%. Solar PV is less efficient than hydroelectric electricity in general, but it is more adaptable since it may be put in a variety of sites. The efficiency of biomass energy varies based on the technology and feedstock employed. It can range between 25% and 50%. Solar PV is often more efficient than many biomass energy systems; however, the two serve distinct functions (electricity generation vs. heat or biofuels). Thermal efficiency in geothermal power plants may be great, frequently surpassing 90%. In terms of turning energy into electricity, solar PV is less efficient than geothermal. The efficiency of tidal and wave energy conversion devices varies; however, capacity factors are frequently less than 50% [46]. Although solar PV is more efficient than many tidal and wave energy systems, these sources may offer steady electricity in appropriate areas. Although ocean thermal energy conversion systems may attain great thermal efficiency, they confront technological and economic constraints. Fuel cells use electrochemical reactions to produce energy, where hydrogen is usually used as the fuel. Growing interest has been shown in hydrogen energy as a perfect green energy substitute and renewable resource [47]. If hydrogen is created in an environmentally friendly manner, it generates power with impressive efficiency and no emissions [48]. However, there are difficulties in producing hydrogen, inadequate infrastructure, and expensive prices. Small-scale hydropower plants can be installed in rivers and streams to provide off-grid or nearby populations with electricity. Although it is contentious, nuclear power is thought to be a low-carbon energy source that can generate a sizable amount of electricity. It raises questions, nevertheless, regarding radioactive waste handling and safety. Carbon capture and storage (CCS) technology reduces greenhouse gas emissions by capturing carbon dioxide emissions from power plants and industrial operations [49]. However, high expenses, energy-intensive procedures, risks associated with leaks, and long-term storage are the issues. Lithium-ion batteries and other energy storage technologies are essential for increasing energy efficiency and integrating intermittent renewable energy sources into the grid [50]. They have limitations, which include cost, the battery's limited energy capacity, and the production's environmental impact.

Solar PV is becoming increasingly popular and has a greater range of uses. Concentrated solar power (CSP) systems may reach great efficiency, with some designs topping 40% thermal efficiency. In some cases, solar PV efficiency might be lower than CSP efficiency, especially when energy storage is included. For commercially accessible solar PV systems, the energy conversion efficiency generally ranges from 15% to 22% [51]. Depending on the panel quality and regional environmental factors, this efficiency may change. Solar PV is a dependable source of renewable energy in Malaysia due to the year-round abundance of sunshine. The manufacturing process and panel removal at the end of their useful lives are the main environmental impacts of solar PV systems while they are in use. Solar PV is frequently seen as a cost-effective choice in Malaysia for residential, commercial, and utility-scale applications because of its continually falling price.

5. Benefits of Solar PV Home Systems

The advantages of solar photovoltaic (PV) home systems for people, families, and communities are numerous. These systems use solar energy to create electricity, making them a clean, sustainable, and renewable source of energy. Some of the main advantages of solar PV home systems are as follows.

5.1. Economic Advantages for Homeowners

One of the primary economic incentives for homeowners to invest in solar PV systems is the substantial reduction in electricity bills. By generating their electricity, homeowners can significantly decrease their reliance on grid-supplied power [52]. Solar energy systems convert sunlight into electricity, offsetting the need to purchase electricity from utility companies. This translates into direct cost savings over the system's operational lifespan, which can extend for decades. Homeowners who generate excess electricity from their solar PV systems can take advantage of FiTs or net metering programs. Under FiTs, excess energy exported to the grid is purchased by utility companies at a favorable rate, effectively turning homeowners into energy producers and income earners [53]. This additional income stream contributes to shortening the system's payback period and enhancing its overall financial viability. In regions with net metering policies, homeowners can offset their electricity bills by exporting surplus energy to the grid. When the solar PV system generates more electricity than is being used on-site, the excess energy is fed back into the grid, effectively "banking" it for later use. During periods of lower solar generation, homeowners can draw on these credits, further reducing their electricity bills. Solar PV home systems lessen a homeowner's dependency on the grid by offering a renewable electricity source. This benefit is not unique to Malaysia; it is also widely recognized in nations like the US, Germany, and Australia, where solar energy is rapidly becoming a more cost-effective and efficient way to reduce electricity costs.

5.2. Environmental Benefits

As the economy and industrialization grow more quickly, environmental pollution and energy scarcity are becoming bigger problems for human society [54]. Solar PV systems provide power without polluting the environment or releasing greenhouse gases [55]. A total of 1 kWh of solar power can reduce 0.8 kg of CO₂ [56]. Recycling of the solar system for the generation of energy results in zero GHG emissions and zero environmental impact. Less material is used overall in the production of thin-film solar panels because semiconductor materials are layered thinner. Reducing the environmental impact of mining and manufacturing can help conserve natural resources. The time it takes for a thin-film solar panel to produce as much energy as was used in its manufacture is known as the energy payback time, and thin-film solar panels often have this time reduced. Compared to some other panel types, they begin offsetting their carbon footprint faster [57]. Solar PV systems contribute to a decrease in pollution and greenhouse gas emissions. They generate renewable, clean energy, which is crucial in nations with high carbon emissions. For example, solar PV systems can help lessen the reliance on coal-fired power plants in nations like the US, China, and India.

Homeowners may dramatically reduce their carbon footprint by switching to solar energy from conventional fossil fuel-based power sources. This helps to slow down global warming and protect the environment for the next generations. Solar PV systems enable homes to generate their own electricity, minimizing reliance on volatile and finite fossil resources. As a result, households are protected from fuel price swings and have a more reliable and consistent supply of energy. Burning fossil fuels to produce energy traditionally contributes to pollution of the air and water [58]. Solar energy users contribute to the improvement of the health and quality of life of the environment by ensuring that the air and water in their communities are cleaner. Homeowners who make the investment in solar PV systems become sustainability activists, influencing their friends and encouraging a greener way of living. This widespread use of renewable energy sources has the potential to affect society more broadly and inspire government support for clean energy programs.

In conclusion, solar PV systems are a desirable alternative for households due to the financial benefits of lower power bills and possible revenue from FiTs, as well as the environmental advantages of lower carbon emissions and increased energy independence. By adopting renewable energy and minimizing its environmental effect, homeowners contribute to a more sustainable future beyond just personal financial rewards.

6. Challenges and Barriers to Solar PV Systems

Solar photovoltaic (PV) systems have a lot to offer, but they also face several challenges that might limit widespread adoption and commercial success. Depending on the setting and circumstance, these challenges might vary, but common difficulties include the following.

6.1. Challenges Hindering Widespread Adoption

The high initial costs of acquiring and installing solar PV systems continue to be a major obstacle to their wider adoption [59]. Despite the potential long-term benefits, many homeowners find the upfront outlay to be intimidating. Incentives and financing choices are crucial to resolving this issue. Adoption is frequently hampered by low customer understanding of the advantages of solar PV systems and the numerous financial incentives offered [60]. Many homes can be reluctant to adopt the technology because they do not completely comprehend the possibilities for lower power costs, money production, and environmental advantages. Homeowners may be discouraged from installing solar PV systems by complicated regulatory procedures, permitting requirements, and administrative obstacles. Uncertainty brought on by ambiguous or shifting legislation may make it challenging for homeowners to understand the installation process and interact with local authorities.

6.2. Intermittency of Solar Power and System Reliability

Solar energy production is by its very nature sporadic since it depends on the presence of sunshine. Meeting the steady demand for energy becomes difficult because of this intermittency, especially when there is little or no sunshine [61]. During these periods, homeowners might have to rely on the grid or energy storage options. System dependability and stability may be impacted by the intermittent nature of solar electricity. Solar PV systems cannot produce electricity when sunshine is not available without suitable energy storage technologies, thereby causing interruptions in the power grid [62]. This may be a problem for homeowners who value constant access to energy. By storing extra solar energy for usage when there is not enough sunshine, energy storage technologies like batteries reduce the effect of intermittency. Energy storage methods, however, raise the total cost of the system and necessitate maintenance. Advances in battery technology are addressing these concerns, making storage more efficient and cost-effective [63]. The second life of electric vehicle batteries has been the prime choice for a better energy storage system with a small amount of investment. To enhance system reliability, solar PV systems can be integrated with the grid and smart technologies. Grid-connected systems allow homeowners to export excess energy to the grid and import power when needed. Smart technologies, like predictive analytics and demand response, optimize energy usage and reduce reliance on grid power during low-sunlight periods.

In conclusion, challenges such as high upfront costs, limited awareness, and regulatory barriers hinder the widespread adoption of solar PV systems among homeowners. The intermittency of solar power presents reliability concerns, particularly without energy storage solutions. However, advances in technology, supportive policies, and innovative solutions like energy storage and grid integration are gradually mitigating these challenges, making solar PV systems more viable and appealing options for homeowners seeking sustainable energy solutions.

6.3. Challenges and Potential Improvements

Simplifying and expediting the permitting and approval processes for solar PV installations can reduce administrative barriers, enabling quicker deployment. Clear guidelines and standardized procedures would help homeowners and businesses navigate these processes more easily. Expanding the net metering program to accommodate larger systems and higher generation capacities could encourage more significant solar PV installations, both residential and commercial. Adjusting net metering regulations to match varying

energy demand profiles would also optimize self-consumption. Introducing low-interest loans, grants, or rebates for solar PV installations could mitigate upfront costs, making solar adoption more financially viable for homeowners and businesses [64]. Implementing community solar models would allow multiple participants to invest in a shared solar PV system, enabling those who cannot install systems on their properties to access solar energy benefits. Government-led awareness campaigns highlighting the economic and environmental advantages of solar PV adoption could increase consumer knowledge and interest [65]. Offering incentives for energy storage solutions alongside solar PV installations could address intermittency concerns and improve system reliability. Continued adjustments to FiT rates that reflect changing technology costs and market conditions could maintain investor interest and foster large-scale solar projects.

7. Socio-Economic Implications

The adoption of solar photovoltaic (PV) home systems can have significant socio-economic implications for individuals, communities, and societies as a whole. These implications can vary depending on the scale of adoption, government policies, and the local context. Here are some of the key socio-economic implications of solar PV home systems.

7.1. Job Creation Potential in the Solar PV Industry

The solar PV industry has the potential to create jobs throughout the manufacturing and supply chain process. From producing solar panels, inverters, and other components to assembling and distributing these products, a thriving solar industry can stimulate employment opportunities in these sectors. The installation and maintenance of solar PV systems require skilled professionals, including solar technicians, electricians, engineers, and project managers [66]. As solar adoption increases, demand for these specialized roles grows, creating a steady stream of employment opportunities. The pursuit of increased efficiency, innovative materials, and new technologies in solar PV systems drives the need for research and development. Scientists, engineers, and researchers are essential for advancing solar technology, leading to job opportunities in the research and innovation sector [67]. As consumer awareness of solar PV benefits increases, the demand for sales and marketing professionals in the solar industry rises. These individuals play a pivotal role in educating consumers, promoting solar products and services, and driving adoption. Solar PV adoption often requires consulting services for system design, energy analysis, and financial planning. Professionals in energy consultancy and financing can guide homeowners and businesses through the process, contributing to the industry's growth. The expansion of the solar PV industry necessitates skilled workforce development. Training centers, educational institutions, and vocational schools can play a critical role in preparing individuals for careers in the solar sector.

7.2. Contribution to Energy Independence and Reduced Imports

Solar PV adoption contributes to a diversified energy mix, reducing reliance on a single energy source [68]. The impact of disruptions in the supply networks of fossil fuels is reduced by this diversity, which improves energy security. Malaysia is one of the nations that imports energy to suit its needs for power. Countries may utilize their indigenous solar resources and create power locally by adopting solar PV systems, hence lowering the demand for energy imports. When there is a significant demand for power, solar PV systems frequently produce electricity during these times. This improves energy independence by easing the burden on the grid and eliminating the need to import electricity during periods of high demand. Prices for fossil fuels might fluctuate because of dynamics in the world market. Solar photovoltaic systems offer users a reliable and predictable supply of energy, protecting them from changes in the cost of fossil fuels and potential energy price shocks [69]. The decrease in fossil fuel-based energy imports helps to minimize carbon emissions and environmental effects, which is in line with the aims for the global climate.

In conclusion, there is a lot of room for job growth in the solar PV sector, from manufacturing and installation to consulting and research. The adoption of solar PV increases energy security, diversifies the energy mix, and promotes energy independence by lowering imports. Countries may promote economic development, employment opportunities, and sustainable energy practices while minimizing their dependency on foreign energy sources by adopting solar energy.

8. Technological Innovations

Technological innovations in solar photovoltaic (PV) systems have been instrumental in advancing the efficiency, reliability, and cost-effectiveness of solar energy generation.

8.1. Advancements in Solar PV Technology

Technological advancements have led to higher-efficiency solar panels, enabling them to convert a larger portion of sunlight into electricity. Innovations in materials, such as monocrystalline and polycrystalline silicon, have contributed to increased energy yield from smaller surface areas. Perovskite solar cells (PSCs) are a promising alternative to cutting-edge silicon (Si)-based solar cells due to their high performance, ease of synthesis, and low fabrication costs [70]. Energy storage technologies, such as lithium-ion batteries, have advanced significantly, allowing homeowners to store excess solar energy for use during periods of low sunlight [71]. Battery systems enhance system reliability, enable the self-consumption of generated energy, and provide backup power during grid outages. Smart grid technologies facilitate the seamless integration of solar PV systems with the electrical grid [72]. These systems allow bidirectional communication between the grid and solar installations, enabling the dynamic management of energy flows, load balancing, and demand response. Microinverters and power optimizers have improved the efficiency and performance of solar PV systems by optimizing the output of each individual solar panel. These technologies mitigate losses caused by shading, panel mismatch, and other factors. Bifacial solar panels capture sunlight on both sides, increasing energy yield by reflecting light off surfaces beneath the panels. This innovation enhances energy generation in various installation environments. Solar panels installed on water bodies, known as floating solar arrays or “photovoltaics”, utilize underutilized spaces and benefit from cooling effects, enhancing panel efficiency. These installations are particularly beneficial in regions with limited land availability. Combining wind turbines and solar panels allows for the utilization of the complementary qualities of these two renewable energy sources. When the sun is shining, solar panels provide electricity during the day, but wind turbines can generate power night or day depending on the wind speed and direction. Energy production reliability can be increased by utilizing solar and wind both sources of energy. Combining wind turbines and solar panels allows for the utilization of the complementary qualities of these two renewable energy sources [73]. When the sun is shining, solar panels provide electricity during the day, but wind turbines can generate power night or day depending on the wind speed and direction. Since Malaysia has access to water resources, generating consistent and dependable energy can be achieved by integrating solar panels with hydroelectric or hydropower systems. Hydroelectric energy can be produced continuously, while solar energy can only be used to generate power during the day [74]. Biogas or biomass generators can be combined with solar panels. While solar power generates electricity during sunny days, biomass or biogas generators use organic materials to generate electricity, providing a steady supply of energy [75]. Advancements extend beyond technology to include financing models. Leasing, power purchase agreements, and community solar initiatives make solar PV systems more accessible to a broader range of homeowners.

8.2. Addressing Challenges and Enhancing Viability

The intermittency problem is addressed by energy storage devices, which store excess energy for use when there is less sunshine. This guarantees a steady supply of electricity,

decreasing dependency on the grid and increasing system dependability. Homeowners may use more of the energy they produce thanks to increased efficiency, smart grid integration, and energy storage, which minimizes reliance on grid power and increases cost savings. Fewer panels are required to produce the same quantity of energy with increased efficiency, which lowers the initial installation costs [76]. Additionally, improvements in financing strategies give households more affordable alternatives for solar PV system purchases. Integration of the smart grid enables communication between solar PV systems and other smart household appliances, maximizing energy efficiency [77]. Home management that is both economical and energy-efficient is made possible by this combination. Solar PV systems integrated into smart grids can provide ancillary services, such as frequency regulation and voltage support, enhancing overall grid stability and performance. Higher efficiency and reduced reliance on grid power translate to lower carbon emissions and decreased environmental impact, aligning with sustainability goals.

In summary, advancements in solar PV technology, spanning improved efficiency, energy storage, smart grid integration, and innovative financing models, address challenges and significantly enhance the viability of solar PV home systems. These innovations empower homeowners to maximize energy self-consumption, reduce costs, and contribute to a greener and more sustainable energy future.

9. Real-World Case Studies of Solar PV Home System Installations in Malaysia

The case studies demonstrate how solar PV home system installations have been implemented in various residential settings in Malaysia, promoting renewable energy adoption and sustainability.

- i. **Residential Rooftop System in Kuala Lumpur:** A residential homeowner in Kuala Lumpur installed a 5 kW rooftop solar PV system on their bungalow. The system consisted of monocrystalline solar panels, microinverters, and a lithium-ion battery for energy storage. The homeowner encountered challenges related to obtaining necessary permits and approvals from local authorities. Additionally, the initial investment was a concern due to the high upfront costs. Through persistence and collaboration with local authorities, the homeowner successfully navigated the permitting process. The incorporation of energy storage allowed for better utilization of generated energy, even during nighttime hours.
- ii. **Off-Grid Solar System in Rural Perak:** A village in rural Perak developed an off-grid solar PV system capacity of 44 MW to power their residences. The system has charge controllers, inverters, a battery bank, and solar panels. The area's lack of grid connectivity was a problem. Another consideration was making sure the system's design could satisfy the neighborhood's energy requirements all day long, including at night. For the system to meet the community's energy needs, proper system design and battery sizing were essential. The research brought attention to how crucial it is to comprehend load patterns and maximize energy storage for off-grid applications.
- iii. **Net Metered System in Penang:** On their personal rooftop, a homeowner in Penang constructed a 3 kW solar PV system. The system had a grid connection, enabling net metering. The first metering process and net metering billing structure presented difficulties for the homeowner. The system payback period and return on investment raised questions. The energy company's assistance helped the homeowner comprehend the advantages of the net metering program. The homeowner's investment became more financially feasible when power prices rose, resulting in lower electricity bills and the possibility of earning money from exporting excess energy.
- iv. **Hybrid System with Energy Management in Selangor:** The first LSS project in Sepang, Selangor, generated 50 MW with a system availability of over 99%. The system featured sophisticated energy management technology, battery storage, and solar panels. Careful system setup was necessary to balance energy use, storage, and grid interaction. Initial difficulties were integrating with already-existing

electrical infrastructure and improving load patterns. With the hybrid system, the homeowner enjoyed the advantages of energy independence and flexibility. There were significant cost savings and a decreased dependency on grid power as a result of the capacity to control energy flows, charge batteries during off-peak hours, and utilize stored energy during peak hours.

In summary, these case studies illustrate the diversity of solar PV home system installations in Malaysia. Each installation addressed unique challenges, such as permitting, system design, grid connectivity, and energy management. Through these experiences, homeowners and communities gained valuable insights, emphasizing the importance of proper system design, regulatory understanding, and collaboration with local authorities. These successful case studies showcase the feasibility and benefits of solar PV adoption, encouraging more homeowners to explore this sustainable energy option.

10. Future Trajectory of Solar PV Home Systems in Malaysia

The future trajectory of solar PV home systems in Malaysia is poised for significant growth and transformation. Technological advancements, economies of scale, and improved manufacturing processes are expected to drive down the costs of solar PV components. As a result, the upfront costs of installing solar PV systems will become more affordable, encouraging a broader range of homeowners to invest in solar energy. Continued government support through policies, incentives, and regulatory frameworks will play a crucial role in fostering solar PV adoption. Refinements to existing policies and the introduction of new incentives could further incentivize homeowners to embrace solar energy solutions. Escalating electricity prices and the volatility of fossil fuel markets will make solar PV systems more attractive as a means of hedging against future energy cost increases. Homeowners will recognize the financial benefits of generating their electricity, especially in the context of fluctuating conventional energy prices. Advances in energy storage technologies, such as battery systems, will address the intermittency challenge of solar PV systems. More efficient and cost-effective batteries will enable homeowners to store surplus energy during peak sunlight hours and utilize it during the evening or cloudy days, enhancing system reliability. Smart grid integration, energy management systems, and home automation will become integral components of solar PV home systems [78]. Homeowners will be able to optimize their energy usage by aligning solar generation with consumption patterns, enabling better control and efficiency. As urbanization continues, space constraints will drive the adoption of smaller-scale solar PV installations, such as rooftop systems. Innovative solutions like floating solar arrays and integration into urban infrastructure will emerge to maximize solar potential within limited spaces. Increasing educational efforts and awareness campaigns about the benefits of solar energy will empower homeowners with information to make informed decisions about adopting solar PV systems. A more knowledgeable consumer base will drive higher adoption rates. Growing environmental consciousness and a desire to reduce carbon footprints will prompt more homeowners to embrace sustainable energy sources like solar power, aligning with global efforts to combat climate change.

The future trajectory of solar PV home systems in Malaysia is optimistic, with increased affordability, improved energy storage, and integration with smart technologies driving widespread adoption. As these trends converge with supportive policies, rising energy costs, and heightened environmental awareness, Malaysia is likely to experience substantial growth in solar PV installations. This trajectory will contribute not only to homeowners' financial savings but also to the nation's energy security, environmental sustainability, and overall transition to a greener energy landscape.

11. Conclusions

While Malaysia has made significant strides in promoting solar PV adoption through policies, regulations, and incentives, further improvements can accelerate wider deployment. Streamlined permitting, expanded net metering, financial support, and community

initiatives are some areas to focus on. By enhancing these policies and incentivizing solar PV adoption, Malaysia can continue to drive sustainable energy growth, contribute to energy security, and reduce carbon emissions. Malaysia's solar PV adoption has shown steady growth, with installed capacity increasing from 205 MW to 2165 MW in 2023 years, reflecting an annual growth rate of 3.78%. This growth has been supported by government initiatives, policies, and incentives. Solar PV installations are geographically distributed across regions in Malaysia. The central region leads in installed capacity, followed by the northern, eastern, and southern regions. This balanced distribution underscores the widespread interest in solar energy adoption. Residential installations contribute 8.5%, with homeowners increasingly recognizing the economic benefits. Commercial and industrial sectors contribute 5.6%, showcasing businesses' commitment to sustainability and energy cost savings. The feed-in tariff (FiT) scheme and net energy metering (NEM) program have been pivotal in driving solar PV adoption. FiT has facilitated utility-scale projects, while NEM has empowered individuals to become energy prosumers. Technological advancements have led to improved solar panel efficiency, energy storage solutions, smart grid integration, and innovative financing models. These advancements have addressed challenges such as intermittency and affordability.

The importance of green technology is global and cuts across national boundaries. All around the world, nations are realizing how urgently they must switch to green technology solutions. Nations are adopting sustainable practices due to the urgency of mitigating climate change, lowering greenhouse gas emissions, and protecting our natural resources. These actions have significant positive effects on the environment as well as on the economy, society, and geopolitics. Green technology adoption is now a crucial part of national policies in developed nations. Significant investments have been made in sustainable transport, green urban planning, and renewable energy by nations like Sweden, Denmark, and Germany. Their experiences show how integrating green technology can result in increased economic growth, the creation of jobs, and a reduction in environmental impact, and they are an inspiration to the rest of the world. Green technology offers developing countries a chance to forgo traditional industrialization and adopt sustainable development from the start. Several countries in Asia and Africa are utilizing renewable energy sources, such as wind and solar energy, to supply off-grid communities with electricity. By doing this, they are lessening their carbon footprint and minimizing their dependency on fossil fuels in addition to addressing energy poverty. In addition, the world community understands how critical international collaboration is to the advancement of green technology. The Paris Agreement and other initiatives like it demonstrate our shared commitment to halting climate change and accelerating the shift to a more sustainable future. The global adoption of green solutions is accelerated in large part by international exchanges of resources, technology, and knowledge. In summary, the significance of green technology transcends national boundaries and applies to all countries, including Malaysia. We can all be impacted by this global imperative, and by drawing attention to it globally, we can work together to create a future that is more environmentally conscious and sustainable for future generations.

Challenges hindering wider adoption include high upfront costs, lack of consumer awareness, regulatory barriers, and intermittency. These challenges have the potential to slow down the adoption rate and hinder the full realization of solar PV's benefits. In conclusion, the review underscores the substantial progress of solar PV adoption in Malaysia while highlighting challenges that need to be addressed for the sector's continued growth. Overcoming these challenges is imperative to fully realizing the economic, environmental, and societal benefits of solar PV home systems, contributing to Malaysia's sustainable energy future.

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References

- Beton Kalmaz, D.; Awosusi, A.A. Investigation of the driving factors of ecological footprint in Malaysia. *Environ. Sci. Pollut. Res.* **2022**, *29*, 56814–56827. [CrossRef] [PubMed]
- Bakirtas, T.; Akpolat, A.G. The relationship between energy consumption, urbanization, and economic growth in new emerging-market countries. *Energy* **2018**, *147*, 110–121. [CrossRef]
- Ong, H.C.; Mahlia TM, I.; Masjuki, H.H. A review on energy scenario and sustainable energy in Malaysia. *Renew. Sustain. Energy Rev.* **2011**, *15*, 639–647. [CrossRef]
- Husain, A.A.; Phesal MH, A.; Ab Kadir MZ, A.; Ungku Amirulddin, U.A. Techno-economic analysis of commercial size grid-connected rooftop solar pv systems in malaysia under the nem 3.0 scheme. *Appl. Sci.* **2021**, *11*, 10118. [CrossRef]
- Southeast Asia Energy Outlook. 2019. Available online: <https://www.iea.org/reports/southeast-asia-energy-outlook-2019> (accessed on 28 October 2023).
- Wand, R.; Leuthold, F. Feed-in tariffs for photovoltaics: Learning by doing in Germany? *Appl. Energy* **2011**, *88*, 4387–4399. [CrossRef]
- Preston, B.L.; Curtright, A.E.; Wong, B.; Regan, L. Incentivizing Solar: Catalyzing Solar Energy Technology Adoption to Address the Challenge of Climate Change. 2021. Available online: <https://policycommons.net/artifacts/4828920/incentivizing-solar/5665651/> (accessed on 28 October 2023).
- Solangi, K.H.; Islam, M.R.; Saidur, R.; Rahim, N.A.; Fayaz, H. A review on global solar energy policy. *Renew. Sustain. Energy Rev.* **2011**, *15*, 2149–2163. [CrossRef]
- National Energy Balance. 2018. Available online: https://www.st.gov.my/ms/contents/files/download/111/National_Energy_Balance_2018.pdf (accessed on 30 September 2023).
- Malaysia Renewable Energy Roadmap. 2021. Available online: https://www.seda.gov.my/reportal/wp-content/uploads/2021/12/MyRER_webVer-1.pdf (accessed on 30 September 2023).
- Raihan, A.; Muhtasim, D.A.; Farhana, S.; Pavel, M.I.; Faruk, O.; Rahman, M.; Mahmood, A. Nexus between carbon emissions, economic growth, renewable energy use, urbanization, industrialization, technological innovation, and forest area towards achieving environmental sustainability in Bangladesh. *Energy Clim. Chang.* **2022**, *3*, 100080. [CrossRef]
- Ho, S.M.; Lomi, A.; Okoroigwe, E.C.; Urrego, L.R. Investigation of solar energy: The case study in Malaysia, Indonesia, Colombia and Nigeria. *Int. J. Renew. Energy Res.* **2019**, *9*, 1–10.
- Ho, S.M.; Edmund, C.; Adewale, G.; Hammed, B.; Ahmed, Y. Advanced research in solar energy: Malaysia, UAE and Nigeria. *Eurasian J. Anal. Chem* **2018**, *13*, 312–331.
- SEDA Malaysia. 2023. Available online: <https://www.seda.gov.my> (accessed on 30 September 2023).
- Vakulchuk, R.; Overland, I.; Suryadi, B. ASEAN's energy transition: How to attract more investment in renewable energy. *Energy Ecol. Environ.* **2023**, *8*, 1–16. [CrossRef]
- Solargis. Global Solar Atlas. 2022. Available online: <https://globalsolaratlas.info/download/malaysia> (accessed on 30 October 2023).
- Mousazadeh, H.; Keyhani, A.; Javadi, A.; Mobli, H.; Abrinia, K.; Sharifi, A. A review of principle and sun-tracking methods for maximizing solar systems output. *Renew. Sustain. Energy Rev.* **2009**, *13*, 1800–1818. [CrossRef]
- Ab Kadir MZ, A.; Rafeeu, Y.; Adam, N.M. Prospective scenarios for the full solar energy development in Malaysia. *Renew. Sustain. Energy Rev.* **2010**, *14*, 3023–3031. [CrossRef]
- Ghazali, A.M.; Rahman, A.M.A. The performance of three different solar panels for solar electricity applying solar tracking device under the Malaysian climate condition. *Energy Environ. Res.* **2012**, *2*, 235. [CrossRef]
- Aldhshan, S.R.; Abdul Maulud, K.N.; Wan Mohd Jaafar, W.S.; Karim, O.A.; Pradhan, B. Energy consumption and spatial assessment of renewable energy penetration and building energy efficiency in Malaysia: A review. *Sustainability* **2021**, *13*, 9244. [CrossRef]
- Markos, F.M.; Sentian, J. Potential of solar energy in Kota Kinabalu, Sabah: An estimate using a photovoltaic system model. *J. Phys. Conf. Ser.* **2016**, *710*, 012032. [CrossRef]

22. Sánchez, A.; Zhang, Q.; Martín, M.; Vega, P. Towards a new renewable power system using energy storage: An economic and social analysis. *Energy Convers. Manag.* **2022**, *252*, 115056. [CrossRef]
23. Hosenuzzaman, M.; Rahim, N.A.; Selvaraj, J.; Hasanuzzaman, M.; Malek, A.A.; Nahar, A. Global prospects, progress, policies, and environmental impact of solar photovoltaic power generation. *Renew. Sustain. Energy Rev.* **2015**, *41*, 284–297. [CrossRef]
24. Mail, M. More Malaysians Transitioning to Solar Power to Reduce Electricity Bills. 6 July 2023. Available online: <https://www.malaymail.com/news/malaysia/2023/07/06/more-malaysians-transitioning-to-solar-power-to-reduce-electricity-bills/78144> (accessed on 20 September 2023).
25. National Energy Policy, 2022–2040. 2022. Available online: https://www.ekonomi.gov.my/sites/default/files/2022-09/National%20Energy%20Policy_2022_2040.pdf (accessed on 1 October 2023).
26. Abdullah WS, W.; Osman, M.; Ab Kadir, M.Z.A.; Verayiah, R. The potential and status of renewable energy development in Malaysia. *Energies* **2019**, *12*, 2437. [CrossRef]
27. Rooftop Solar. 9 April 2020. Available online: <https://solarvest.my/about-us/rooftop-solar-residential/> (accessed on 1 October 2023).
28. Vaka, M.; Walvekar, R.; Rasheed, A.K.; Khalid, M. A review on Malaysia’s solar energy pathway towards carbon-neutral Malaysia beyond Covid’19 pandemic. *J. Clean. Prod.* **2020**, *273*, 122834. [CrossRef]
29. Renewable Capacity Statistics. 2019. Available online: <https://www.irena.org/publications/2019/Mar/Renewable-Capacity-Statistics-2019> (accessed on 1 October 2023).
30. Green Technology Master Plan 2017–2030. 2019. Available online: <https://policy.asiapacificenergy.org/node/343> (accessed on 1 October 2023).
31. Zainal Ariffin, Z.; Isa, N.; Lokman, M.Q.; Ahmad Ludin, N.; Jusoh, S.; Ibrahim, M.A. Consumer Acceptance of Renewable Energy in Peninsular Malaysia. *Sustainability* **2022**, *14*, 14627. [CrossRef]
32. NEM 3.0—Renewable Energy Malaysia. 2023. Available online: <https://www.seda.gov.my/reportal/nem/> (accessed on 1 October 2023).
33. Green Investment Tax Allowance (GITA) & Green Income Tax Exemption (GITE). 2023. Available online: <https://www.mgtc.gov.my/what-we-do/green-incentives/green-investment-tax-incentives-gita-gite/> (accessed on 1 October 2023).
34. Kuala Lumpur Climate Action Plan 2050. 2021. Available online: https://www.dbkl.gov.my/wp-content/uploads/2021/07/C4_0_KLCAP2050_viewing-only-MR-single_compressed.pdf (accessed on 1 October 2023).
35. Orvis, R.; Gopal, A.; Rissman, J.; O’boyle, M.; Baldwin, S.; Busch, C. Closing the Emissions Gap between the IRA and 2030 US NDC: Policies to Meet the Moment. Energy Innovation. 2022. Available online: <https://energyinnovation.org/wp-content/uploads/2022/12/Closing-The-Emissions-Gap-Between-IRA-And-NDC-Policies-To-Meet-The-Moment.pdf> (accessed on 1 October 2023).
36. Kongboon, R.; Gheewala, S.H.; Sampattagul, S. Greenhouse gas emissions inventory data acquisition and analytics for low carbon cities. *J. Clean. Prod.* **2022**, *343*, 130711. [CrossRef]
37. Soonmin, H.; Taghavi, M. Solar energy development: Study cases in Iran and Malaysia. *Int. J. Eng. Trends Technol.* **2022**, *70*, 408–422. [CrossRef]
38. Timilsina, G.R.; Kurdgelashvili, L.; Narbel, P.A. Solar energy: Markets, economics and policies. *Renew. Sustain. Energy Rev.* **2012**, *16*, 449–465. [CrossRef]
39. Dehghani Madvar, M.; Alhuyi Nazari, M.; Tabe Arjmand, J.; Aslani, A.; Ghasempour, R.; Ahmadi, M.H. Analysis of stakeholder roles and the challenges of solar energy utilization in Iran. *Int. J. Low-Carbon Technol.* **2018**, *13*, 438–451. [CrossRef]
40. Kannan, N.; Vakeesan, D. Solar energy for future world—A review. *Renew. Sustain. Energy Rev.* **2016**, *62*, 1092–1105. [CrossRef]
41. Shubbak, M.H. Advances in solar photovoltaics: Technology review and patent trends. *Renew. Sustain. Energy Rev.* **2019**, *115*, 109383. [CrossRef]
42. Chowdhury, M.S.; Rahman, K.S.; Chowdhury, T.; Nuthammachot, N.; Techato, K.; Akhtaruzzaman, M.; Tiong, S.K.; Sopian, K.; Amin, N. An overview of solar photovoltaic panels’ end-of-life material recycling. *Energy Strategy Rev.* **2020**, *27*, 100431. [CrossRef]
43. Izam, N.S.M.N.; Itam, Z.; Sing, W.L.; Syamsir, A. Sustainable development perspectives of solar energy technologies with focus on solar Photovoltaic—A review. *Energies* **2022**, *15*, 2790. [CrossRef]
44. Hannan, M.A.; Begum, R.A.; Abdolrasol, M.G.; Lipu, M.H.; Mohamed, A.; Rashid, M.M. Review of baseline studies on energy policies and indicators in Malaysia for future sustainable energy development. *Renew. Sustain. Energy Rev.* **2018**, *94*, 551–564. [CrossRef]
45. Denholm, P.; Kulcinski, G.L.; Holloway, T. Emissions and energy efficiency assessment of baseload wind energy systems. *Environ. Sci. Technol.* **2005**, *39*, 1903–1911. [CrossRef]
46. Bilgili, M.; Ozbek, A.; Sahin, B.; Kahraman, A. An overview of renewable electric power capacity and progress in new technologies in the world. *Renew. Sustain. Energy Rev.* **2015**, *49*, 323–334. [CrossRef]
47. Wan, C.; Zhou, L.; Xu, S.; Jin, B.; Ge, X.; Qian, X.; Xu, L.; Chen, F.; Zhan, X.; Yang, Y.; et al. Defect engineered mesoporous graphitic carbon nitride modified with AgPd nanoparticles for enhanced photocatalytic hydrogen evolution from formic acid. *Chem. Eng. J.* **2022**, *429*, 132388. [CrossRef]

48. Stambouli, A.B. Fuel cells: The expectations for an environmental-friendly and sustainable source of energy. *Renew. Sustain. Energy Rev.* **2011**, *15*, 4507–4520. [[CrossRef](#)]
49. Zahedi, R.; Aslani, A.; Seraji, M.A.N.; Zolfaghari, Z. Advanced bibliometric analysis on the coupling of energetic dark greenhouse with natural gas combined cycle power plant for CO₂ capture. *Korean J. Chem. Eng.* **2022**, *39*, 3021–3031. [[CrossRef](#)]
50. Behabtu, H.A.; Messagie, M.; Coosemans, T.; Berecibar, M.; Anlay Fante, K.; Kebede, A.A.; Mierlo, J.V. A review of energy storage technologies' application potentials in renewable energy sources grid integration. *Sustainability* **2020**, *12*, 10511. [[CrossRef](#)]
51. KhareSaxena, A.; Saxena, S.; Sudhakar, K. Energy performance and loss analysis of 100 kWp grid-connected rooftop solar photovoltaic system. *Build. Serv. Eng. Res. Technol.* **2021**, *42*, 485–500. [[CrossRef](#)]
52. Hanser, P.; Lueken, R.; Gorman, W.; Mashal, J.; Group, T.B. The practicality of distributed PV-battery systems to reduce household grid reliance. *Util. Policy* **2017**, *46*, 22–32. [[CrossRef](#)]
53. Cui, Y.; Zhu, J.; Meng, F.; Zoras, S.; McKechnie, J.; Chu, J. Energy assessment and economic sensitivity analysis of a grid-connected photovoltaic system. *Renew. Energy* **2020**, *150*, 101–115. [[CrossRef](#)]
54. Fucheng, Y.; Yuanmeng, L.; Liu Zhengyan, C.; Junpeng, Z. Synthesis and Photocatalytic Properties of Na Doped g-C₃N₄ Nanotubes. *Chin. J. Rare Met.* **2022**, *2022*, 889–895.
55. Shahsavari, A.; Akbari, M. Potential of solar energy in developing countries for reducing energy-related emissions. *Renew. Sustain. Energy Rev.* **2018**, *90*, 275–291. [[CrossRef](#)]
56. Alsema, E. Energy payback time and CO₂ emissions of PV systems. In *Practical Handbook of Photovoltaics*; Academic Press: Cambridge, MA, USA, 2012; pp. 1097–1117.
57. Shukla, A.K.; Sudhakar, K.; Baredar, P. A comprehensive review on design of building integrated photovoltaic system. *Energy Build.* **2016**, *128*, 99–110. [[CrossRef](#)]
58. Omer, A.M. Energy, environment and sustainable development. *Renew. Sustain. Energy Rev.* **2008**, *12*, 2265–2300. [[CrossRef](#)]
59. Palm, J. Household installation of solar panels—Motives and barriers in a 10-year perspective. *Energy Policy* **2018**, *113*, 1–8. [[CrossRef](#)]
60. Rai, V.; Reeves, D.C.; Margolis, R. Overcoming barriers and uncertainties in the adoption of residential solar PV. *Renew. Energy* **2016**, *89*, 498–505. [[CrossRef](#)]
61. Armaroli, N.; Balzani, V. The future of energy supply: Challenges and opportunities. *Angew. Chem. Int. Ed.* **2007**, *46*, 52–66. [[CrossRef](#)]
62. Zahedi, A. Maximizing solar PV energy penetration using energy storage technology. *Renew. Sustain. Energy Rev.* **2011**, *15*, 866–870. [[CrossRef](#)]
63. Ribeiro, P.F.; Johnson, B.K.; Crow, M.L.; Arsoy, A.; Liu, Y. Energy storage systems for advanced power applications. *Proc. IEEE* **2001**, *89*, 1744–1756. [[CrossRef](#)]
64. Van Opstal, W.; Smeets, A. Circular economy strategies as enablers for solar PV adoption in organizational market segments. *Sustain. Prod. Consum.* **2023**, *35*, 40–54. [[CrossRef](#)]
65. Huang, H.L.; Cheng, L.K. Predicting intention of residential solar installation: The role of ecological lifestyle, consumer innovativeness, perceived benefit, government incentives, and solar product knowledge. *Energy Environ.* **2022**, *34*, 0958305X221100525. [[CrossRef](#)]
66. Hamilton, J. *Careers in Solar Power*; US Bureau of Labor Statistics: Washington, DC, USA, 2011.
67. Sarewitz, D. Advancing the science of science and innovation policy. In *Testimony before the US House of Representatives Committee on Science and Technology*; CSPO Report, 10-04; Arizona State University: Phoenix, AZ, USA, 2010.
68. Solaymani, S. A review on energy and renewable energy policies in Iran. *Sustainability* **2021**, *13*, 7328. [[CrossRef](#)]
69. Herzog, A.V.; Lipman, T.E.; Edwards, J.L.; Kammen, D.M. Renewable energy: A viable choice. *Environ. Sci. Policy Sustain. Dev.* **2001**, *43*, 8–20. [[CrossRef](#)]
70. Shah, S.A.A.; Sayyad, M.H.; Sun, J.; Guo, Z. Recent advances and emerging trends of rare-earth-ion doped spectral conversion nanomaterials in perovskite solar cells. *J. Rare Earths* **2022**, *40*, 1651–1667. [[CrossRef](#)]
71. Speidel, S.; Bräunl, T. Leaving the grid—The effect of combining home energy storage with renewable energy generation. *Renew. Sustain. Energy Rev.* **2016**, *60*, 1213–1224. [[CrossRef](#)]
72. Shafiullah, G.M.; Maung Than Oo, A.; Ali, A.B.M.S.; Wolfs, P. Smart grid for a sustainable future. *Smart Grid Renew. Energy* **2013**, *4*, 23–34. [[CrossRef](#)]
73. Kabalci, E. Design and analysis of a hybrid renewable energy plant with solar and wind power. *Energy Convers. Manag.* **2013**, *72*, 51–59. [[CrossRef](#)]
74. De Jong, P.; Sánchez, A.S.; Esquerre, K.; Kalid, R.D.A.; Torres, E.A. Solar and wind energy production in relation to the electricity load curve and hydroelectricity in the northeast region of Brazil. *Renew. Sustain. Energy Rev.* **2013**, *23*, 526–535. [[CrossRef](#)]
75. Giwa, A.; Alabi, A.; Yusuf, A.; Olukan, T. A comprehensive review on biomass and solar energy for sustainable energy generation in Nigeria. *Renew. Sustain. Energy Rev.* **2017**, *69*, 620–641. [[CrossRef](#)]
76. Sampaio, P.G.V.; González, M.O.A. Photovoltaic solar energy: Conceptual framework. *Renew. Sustain. Energy Rev.* **2017**, *74*, 590–601. [[CrossRef](#)]

-
77. Anda, M.; Temmen, J. Smart metering for residential energy efficiency: The use of community based social marketing for behavioural change and smart grid introduction. *Renew. Energy* **2014**, *67*, 119–127. [[CrossRef](#)]
 78. Sarker, M.T.; Alam, M.J.; Uddin, M.N. Auto Intensity Control Technology for Solar Street Lights and Feasibility Study with Traditional System in Bangladesh. *Int. J. Eng. Tech.* **2023**, *9*, 36–44.

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