J. Res. Technol. Eng. 4 (2), 2023, 125-153

Journal Of Research Technology & Engineering

www.jrte.org

OVERVIEW OF SOLAR ELECTRICITY IN SRI LANKA AND RECYCLING PROCESSES

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Received:22 March 2023; Revised: 26 March 2023; Accepted: 28 March 2023; Available online: 10 April 2023

Abstract: Solar energy is a clean, renewable source with no emissions and low recurring costs. In recent years the technology of solar energy and its usage has experienced unprecedented change and rapid growth. Promotional and encouraging government policies about solar energy, technological improvements in less setup and maintenance cost, growing public awareness of environmental issues easy ways to cut down the users' electricity bills with assured power supply 24x7 are some of the facts that have facilitated and sustained this intense interest in the minds of users about solar technology worldwide, including in Sri Lanka.

In 2021, wind and Solar Energy accounted for more than one-tenth (10.3%) of Global electricity, and coal power generation experienced a significant rising of 9.0%. As an island country, Sri Lanka, there is a substantial rise in electricity generation in 2021 than previous years resulting 6.4% hike. But although the generation capacity is increased, Sri Lankans have faced a long time of power cuts and fuel shortages since the beginning of the pandemic season. As a result, that Sri Lankans are also moving into renewable energy sources.

The Sri Lankan Government and the Ministry of Power have launched some programs to promote this clean, renewable energy resource, solar, in collaboration with Sri Lankan sustainable energy authority.

Soorya Bala Sangramaya is one of the most popular programs the Sri Lankan government launched to promote solar energy in Sri Lanka. This program introduces three types of methods to capture solar energy and convert it into electricity: on-grid, off-grid, and hybrid systems. And also this project includes three payment schemes named net metering, net plus, and net accounting schemes.

In addition to a detailed overview of solar energy in Sri Lanka, this review paper is based on the proposals for solar energy promotions, implementation, and challenges of promoting solar as a significant energy resource in Sri Lanka. Finally, this includes the Photovoltaic waste generation in the world and the Design for recycling solar panels to give a brief idea of upcoming environmental issues and relevant solutions to solar panel implementation.

Index Terms — Energy Crisis, Payback Period, PV, Recycling, Renewable, Solar Energy, Solar Panel, Sri Lanka, Soorya Bala Sangramaya, Sustainable, Waste, World.

1 Introduction

Currently, countries worldwide are strongly prioritizing the attainment of the 17 Sustainable Development Goals (SDGs). Among these goals, the seventh goal is centered around "Affordable and Clean Energy." The United Nations intends to ensure that everyone has access to energy that is affordable, reliable, sustainable, and modern [1]. As per the definition of goal number 7, "Sustainable energy" refers to energy derived from sources that can be used repeatedly without the risk of depletion. This type of energy is obtained from natural resources that renew themselves at a faster rate than they are consumed [2]. This review concentrates on one of those natural sources - solar energy and provides a fundamental overview of its utilization in Sri Lanka.

1.1 Renewable vs. Non-Renewable

Nature provides various resources that can be used to derive energy, and these resources can be broadly categorized into three groups: primary and secondary energy resources, conventional and non-conventional energy resources, and renewable and non-renewable energy resources. Under the category of renewable and non-renewable energy resources, non-renewable sources consist of three main types of fossil fuels: coal, petroleum, and natural gas, while renewable sources include bioenergy, tidal energy, hydropower, geothermal energy, wind energy, and solar energy. Due to an unprecedented increase in population growth and economic development, the demand for energy is increasing exponentially worldwide. This has led to an increase in the number of energy sources used, which eventually leads to the depletion of non-renewable sources. Therefore, the world needs to focus on renewable sources since they are inexhaustible and replenish naturally over relatively short periods of time. Using renewable energy sources provides numerous advantages because they are dependable, inexpensive, eco-friendly, generate minimal byproducts, and promote sustainable growth. These sources can meet up to two-thirds of the global energy demand, which can significantly help reduce greenhouse gas emissions and ultimately combat global warming. Therefore, the importance of renewable sources cannot be underestimated [3].

1.2 An overview of energy usage in world.

Based on Fig.1, In 2021, wind and solar energy accounted for more than one-tenth (10.3%) of global electricity, an increase from 9.3% in 2020. This is over double their market share (4.6%) at the time the Paris agreement was signed in 2015. The growth rate of these sources has also increased, with wind generation up by 14% (the highest since 2017) and solar by 23% (the highest since 2018) in 2021. Taken together, they experienced a 17% rise. Despite this growth, it was slower than the previous decade, which had an average year-on-year growth of 20%. Overall, clean energy sources produced 38% of the world's electricity in 2021, with wind and solar being the fourth largest source of electricity globally. They were also the fastest-growing clean energy sources in 2021, while other zero-emission sources either declined (hydro) or remained stable (bioenergy and nuclear). Fossil fuels, primarily coal (36%) and gas (22%), still generated 62% of global electricity [4].

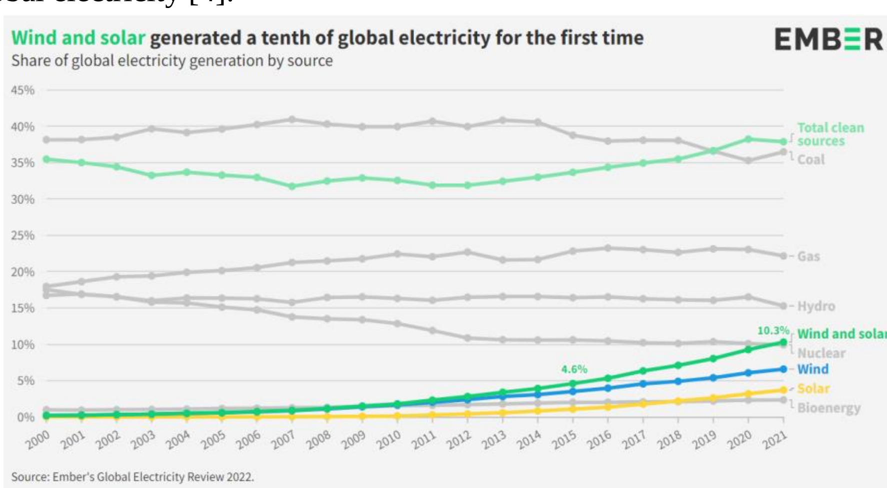

Fig.1. Share of global electricity generation by source

In 2021, fifty countries had more than one-tenth of their electricity generated by wind and solar, up from 43 in 2020 and 36 in 2019. Among these, seven countries (China, Japan, Mongolia, Vietnam, Argentina, Hungary, and El Salvador) achieved this milestone for the first time. The top five global economies (the United States, China, Japan, Germany, and the United Kingdom) have all exceeded the one-tenth benchmark. Europe leads with nine of the top ten countries, and three countries (Denmark, Luxembourg, and Uruguay) have even surpassed 40% of their electricity generated from wind and solar in 2021, showcasing their advanced technology for integrating renewable grids. However, the Middle East and Africa had the fewest countries that reached the one-tenth milestone, with Saudi Arabia's wind and solar generation less than 1%, and Egypt and the UAE, the next two hosts of the UN climate summit, producing only 3% [4].

According to Fig. 2, In 2021, clean energy generation growth, apart from wind and solar, experienced a setback. Drier conditions led to a 2% decrease in hydro generation, while nuclear generation rose by 4% due to reactors coming back online in France and Japan and new reactors starting in China and Russia. Bioenergy increased by 6%, although concerns have been raised about its actual emissions impact. Emerging technologies that are commonly included in Net Zero pathways, such as fossil fuels with carbon capture, hydrogen-based fuels, CSP, geothermal, and marine, still do not produce significant amounts of electricity [4].

Although wind and solar are the fastest-growing sources of clean electricity, the IEA Net Zero by 2050 report suggests that other technologies will contribute about a quarter of the growth in clean electricity. These technologies complement wind and solar and support the variability of these sources. Neglecting these complementary technologies will make it more challenging to achieve the required emissions reductions by 2030. Although an alternative IEA scenario suggests that it's possible to decarbonize without bioenergy and CCS, the IEA predicts that it would increase the cost of achieving zero-carbon power [4].

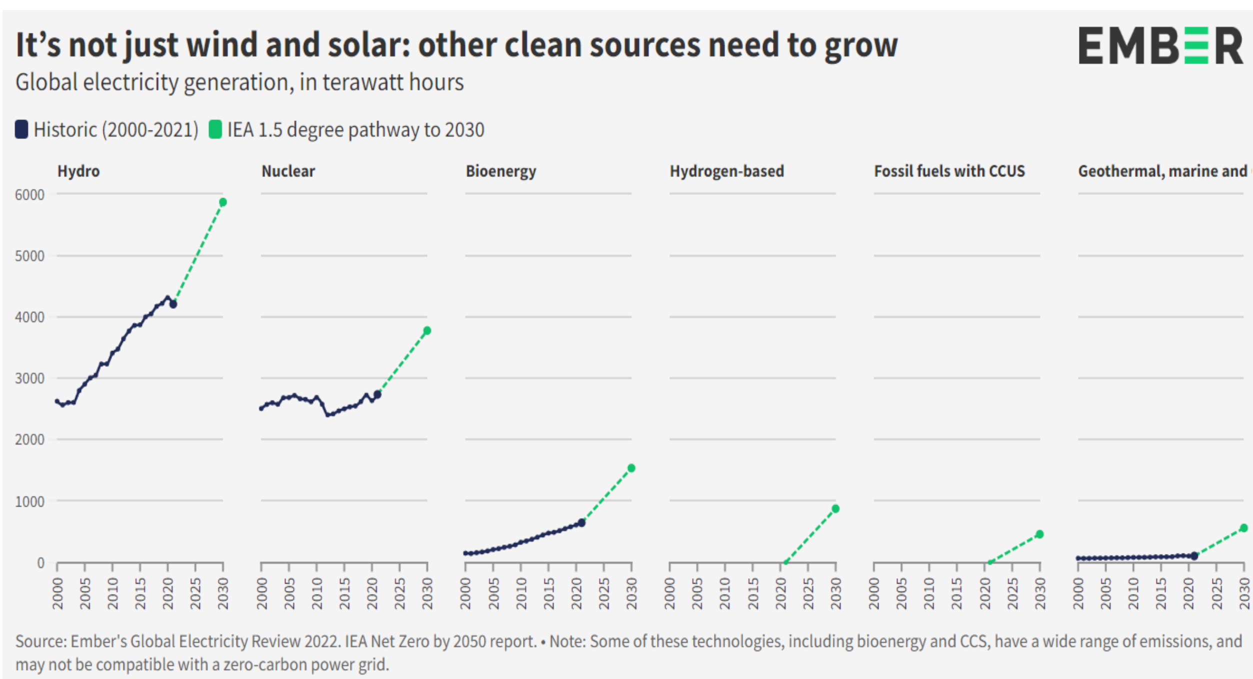

Fig. 2. Global electricity generation, in terawatts hours

In addition to wind and solar energy, coal power experienced a significant increase in 2021, rising by 9.0% to 10,042 TWh after falling by 4.2% in 2020. This is the largest percentage increase since at least 1985, and it broke the previous record for global power generation, which was set at 9,838 TWh in 2018, by 2%. Coal power accounted for 36.5% of global electricity, up from 35.3% in 2020, and China's share remained unchanged at 54% in 2021, after rising from 50% in 2019 to 54% in 2020. However, the IEA's 1.5-degree pathway requires a 73% reduction in unabated coal power generation globally from 2021 to 2030, highlighting how far the electricity transition is from meeting climate targets. This information is depicted in Fig. 3[4].

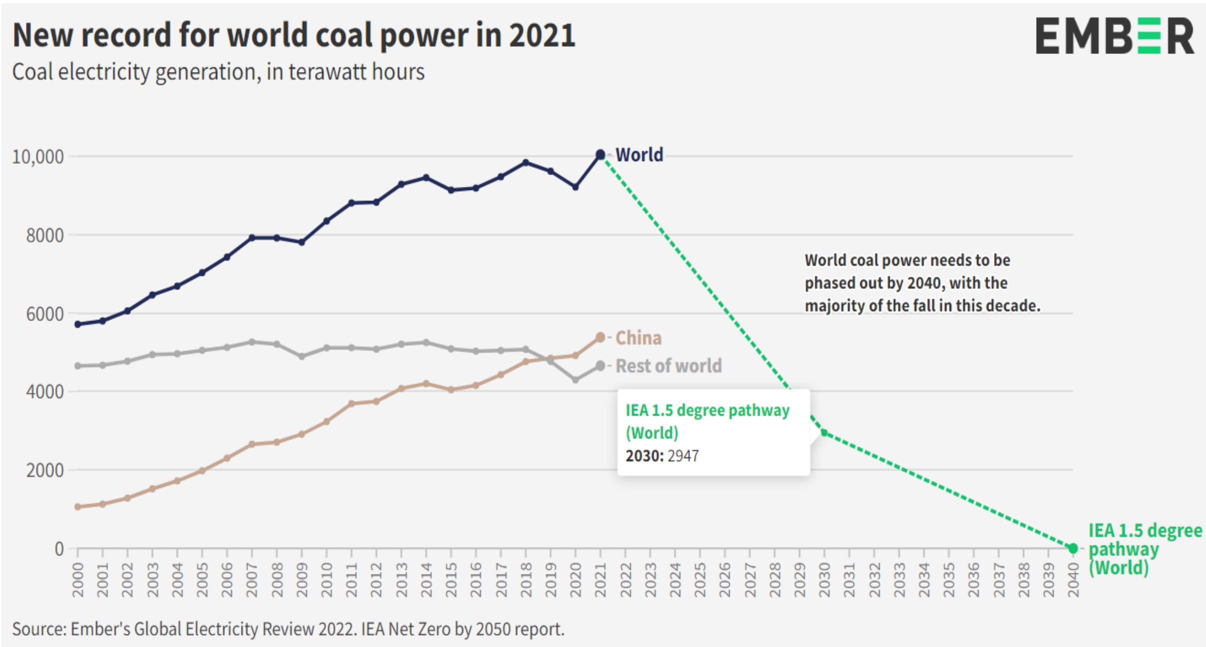

Fig. 3. - Coal electricity generation in terawatt hours

A Brief Introduction to Energy Sector in Sri Lanka

Sri Lanka fulfills its current energy requirements through a combination of different energy sources, including locally available non-fossil fuels and imported fossil fuels. Most the country's energy needs are met through biomass, which is an indigenous source of fuel, and imported fossil fuels like coal and petroleum. The remaining energy demand is satisfied by other indigenous sources, which include large hydro and renewable energy sources like small hydro, solar, and wind power. The total Installed Capacity (CEB & Private) at the end of year 2021 was recorded as 4,186 MW and the details are given below in the Table 1[5].

Table 1. Total installed capacity in Sri Lanka by 2021

Installed Capacity (MW)			
		2021	**Percentage of Total**
CEB –	Hydro	1383	33%
	Thermal – Oil	654	16%
	Thermal – Coal	900	22%
	NCRE – Wind	104	2%
	Total – CEB	**3040**	**73%**

PPP –	Thermal NCRE – Mini Hydro NCRE – Wind NCRE – Other **Total – PPP**	433 414 148 150 **1146**	10% 10% 3% 4% **27%**
	Total	**4186**	**100%**

Source - CEB SALES & GENERATION DATA BOOK - 2021

1.3.1 Electricity Generation

The net electricity generation from both CEB and IPP sources in 2021 was 16,716 GWh, showing a 6.4% increase from the previous year. CEB power stations produced 12,711 GWh of electricity, making up 76% of the total electricity generation. The remaining 24% of electricity came from private sector power stations. Among the CEB power stations, hydro power plants were responsible for 5,640 GWh of electricity, which is 33.7% of the total generated during the year. The CEB hydro power plants showed a significant increase of 44.2% in electricity generation compared to the previous year. Meanwhile, coal power plants contributed 33% of the total electricity generated in 2021. CEB thermal generation, consisting of both oil and coal, decreased from 7,219 GWh in 2020 to 6,753 GWh in 2021, representing 40% of the total electricity generation. Apart from these details, the total gross electricity generation of Sri Lanka from 2011 to 2021 is shown in Fig. 4 below [5].

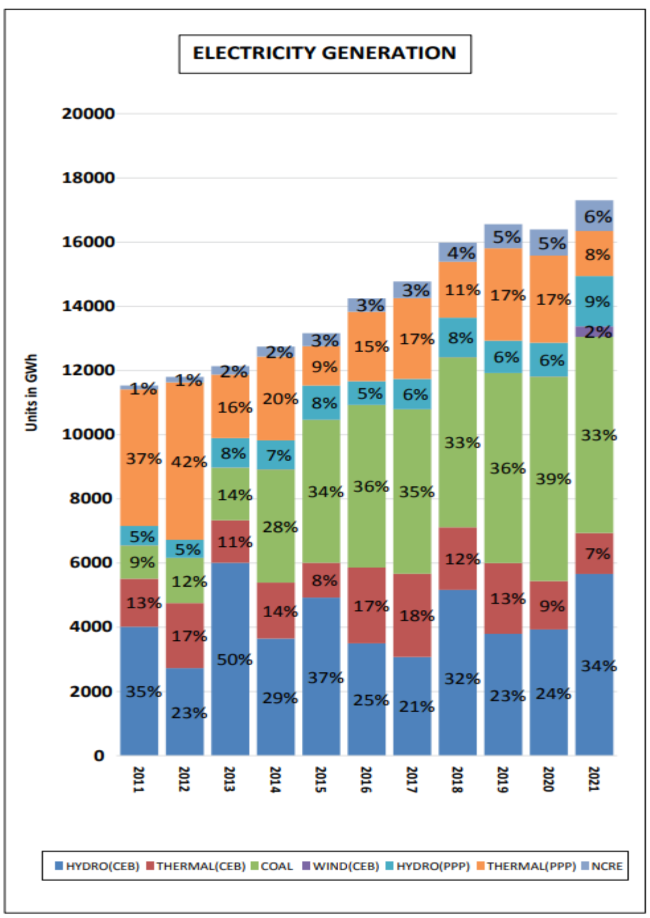

Fig. 4. Total gross electricity generation of Sri Lanka from 2011 to 2021

Although the statistics indicate like this, the people of Sri Lanka have been facing daily power cuts lasting for as long as 12-13 hours and a fuel shortage since March 2022. Consequently, tens of thousands of individuals have been compelled to queue outside petrol stations for hours [6]. Therefore, it is imperative that significant attention is given to understanding the reasons behind this energy crisis that has impacted the entire nation.

1.3 Energy Crisis in Sri Lanka

The global energy crisis is a significant issue facing the world today. The energy crisis can be defined as the rapid exhaustion of non-renewable, concentrated energy sources. Additionally, any substantial disruption in the supply of energy resources to an economy is also regarded as an energy crisis.

The world is currently facing an energy crisis due to a combination of some factors, including the increasing global population, rapid industrialization, and urbanization. Furthermore, fossil fuels, such as coal, oil, and natural gas, have traditionally been the primary sources of energy for the world, but they are finite resources that are being rapidly depleted. Most of countries in the world depend on these non-renewable energy sources. Therefore, the energy crisis becomes the global issue in current world.

As a country like Sri Lanka, the matter of energy has consistently been of utmost significance. The crisis has had a significant impact on the economy and society, and it is still ongoing. Several factors have contributed to the energy crisis in Sri Lanka, such as climate change, the exhaustion of non-renewable resources, and the expense of energy. There are several actions that can be taken to tackle the energy crisis. For instance, governments can allocate funds towards renewable energy sources like wind and solar power to decrease reliance on non-renewable resources and combat climate change [7]. Furthermore, consumers can reduce their energy usage and save money by adopting more energy-efficient appliances. As well as below are some of solution which are taken by some developed countries to mitigate the energy crisis. The first one is the Renewable energy. This is one of the most important solutions because these energies are renewable, sustainable, and efficient. Renewable energy sources include solar, wind, geothermal, hydroelectric, and ethanol. These energy sources hold significance because they are eco-friendly and renewable, which implies they can be utilized repeatedly without harm to the environment. Furthermore, these sources offer clean energy, which is crucial in reducing carbon emissions. Energy conservation presents an alternative method of alleviating the energy crisis and it is one of the most critical solutions. It includes reducing our energy consumption and identifying ways to generate energy while using fewer resources. This can be achieved by adopting more efficient devices, lowering energy usage in workplaces, and ensuring that we use energy prudently while traveling [8].

The issue of energy scarcity is a worldwide concern that is anticipated to worsen in the upcoming years. Addressing this issue entails not only discovering means to generate additional energy but also discovering means to utilize energy more effectively. The aim of this review is to demonstrate that solar energy is the most suitable renewable energy source for Sri Lanka to mitigate its energy crisis and shift towards sustainable development. With abundant sunlight, solar energy can be harnessed efficiently to power homes, businesses, and industries, while reducing carbon emissions and dependence on fossil fuels. Consequently, this study proposes that Sri Lanka should prioritize the development of solar energy infrastructure to achieve its sustainable development goals.

2. WHAT IS SOLAR ENERGY

Most of the world's energy supply, including solar, hydro, wind, wave, and biomass energy, is derived from the sun, which also created the fossil fuels we use today. The sun generates energy through fusion reactions in its core, which have been ongoing for 4.5 billion years and are projected to continue for another 6.5 billion years. The sun radiates a total power of about 3.86 × 1026 W into space, but only a tiny fraction of that power, approximately 0.000000045%, is intercepted by the earth due to its small radius compared to the distance from the sun. Nonetheless, this still amounts to an enormous 1.75 × 1017 W. The sun emits mostly visible and infrared radiation, with a very small percentage in the radio, UV, and X-ray ranges. Its electromagnetic radiation has a temperature similar to that of a black body, around 5778 K with a peak in the yellow range of the visible spectrum, which is sometimes approximated as 6000 K for simplicity [9].

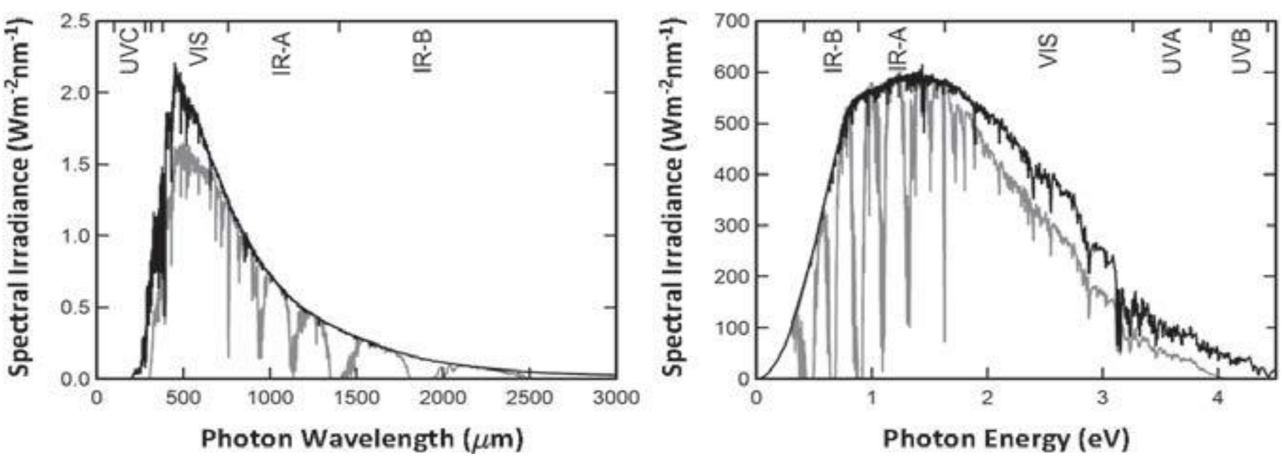

Fig. 5. The AM0 spectrum of solar radiation, as would be observed at the top of the earth's atmosphere. The spectral irradiance is shown as a function of photon wavelength (left) and photon energy (right). The spectral regions are indicated. Image credit

Fig. 5. displays the spectrum of radiation from ultraviolet to infrared that is observed outside of Earth's surface. This particular spectrum, known as the "AM0" spectrum, is commonly used to model and assess the effectiveness of solar cells in space applications. The "AM" refers to the "air mass," which represents the thickness of Earth's atmosphere that the radiation passes through before being observed. In this case, the air mass is zero. However, when solar radiation reaches the Earth's surface, it is altered by absorption and scattering, as well as reflection from the surface. This results in a reduction in intensity and changes to the spectrum. The scattering of radiation means that the receiver will not only receive radiation directly from the visible solar disk, but also from other parts of the sky. Standard models and spectra have been developed to facilitate simulations and estimations. ASTM Standard G1738 provides tables that are widely used to represent solar radiation on Earth in two different forms, as shown in Fig. 6. The first form is AM1.5D, which refers to Direct Normal Incidence radiation that is received on Earth directly from the solar disk. This is the type of radiation that would be received by a concentrating collector. The standard direct spectrum has a total integrated irradiance of 900.1 Wm^{-2}.

The second form is AM1.5G, which represents Hemispherical on 37° Tilted Surface radiation. This adds the direct radiation and the scattered diffuse radiation to yield the hemispherical or global radiation that impinges on a sun-facing, 37◦-tilted surface. This form is useful for modeling flat plate (non-concentrating) collectors. The total integrated irradiance for the standard hemispherical tilted spectrum is 1000.4 Wm^{-2}[9].

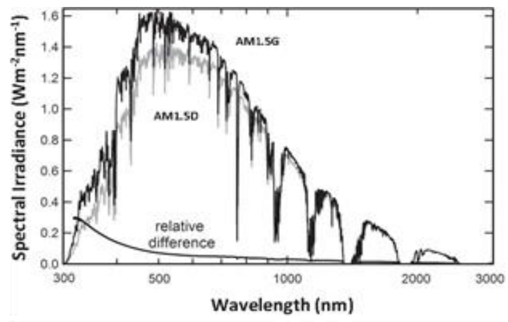

Fig. 6. AM1.5 global (AM1.5G) and direct normal (AM1.5D) standard terrestrial solar and their relative difference as a function of wavelength

The solar radiation spectrum has many narrow and broad notches caused by absorption by atmospheric gas and vapor molecules. The atmosphere is opaque to ultraviolet radiation with wavelengths below about 300 nm due to absorption by molecules such as H_2, O_2, and N_2. Ozone is the main absorber in the near-UV spectral range, which also affects the visible range. NO_2 and water vapor also impact the visible range, while water vapor introduces several broad absorption bands in the infrared range. Carbon dioxide and oxygen also have an effect.

The solar constant is the long-term average of the total solar irradiance at the average distance of the Earth's orbit, which is called one Astronomical Unit. Its reference value is 1366.1 Wm−2. However, the solar constant is not constant and varies by ±3% due to the Earth's elliptical orbit. Additionally, there is a variation of about ±0.1% in the solar constant due to a variation in the total luminosity of the sun itself over the 11-year solar cycle. Researchers have attempted to model this variation over the last 400 years by correlating it with recorded sunspot numbers, suggesting that the sun's power output may have varied by up to 1%.

Solar radiation reaching the earth's surface varies due to diurnal and seasonal changes. On average, around 342 W is available per square meter of the earth's surface, amounting to an annual energy input of 5.46×1024 J. However, approximately 29% is reflected back to space, and 23% is absorbed in the atmosphere, with the remaining 48% passing through and being absorbed by the surface. The distribution of solar radiation reaching the earth's surface is studied and monitored extensively, with satellite-derived estimates available globally. The highest insolation is found in the high tropical and low temperate latitudes, and measurements of solar radiation are made at many sites globally with calibrated pyrheliometers. Historical data and long-term averages are available through various databases, including the World Radiation Data Centre and the Baseline Surface Radiation Network. Engineers use this data to design solar energy collection systems. Solar radiation is also estimated from satellite-based instruments, with NASA providing long-term estimates of surface solar energy flux for the entire globe. This data is accessible via the RET Screen Clean Energy Management Software system [9].

2.1 Modern Applications of Solar Energy

There are various methods to capture solar energy and convert it into useful forms, ranging from traditional and simple to advanced and complex technologies. The outputs of these methods can include low grade heat, high temperature industrial process heat, hydrogen, synthesis gas, synthetic hydrocarbons, other chemical energy carriers such as ammonia and metals, as well as intermittent or dispatchable electricity. These technologies are currently at different stages of development and have varying costs of energy. This section provides an overview of these methods, which will be discussed in detail in the following chapters [9].

2.1.1 Off-grid systems.

An off-grid system is a term used to describe a system that is not connected to the main electrical grid. In Fig.3 shows the structure of off-grid. The primary example of an off-grid system is a standalone photovoltaic (PV) system, which can generate power and operate appliances without relying on the main grid. These systems are often used to provide electricity to small communities in remote areas that lack access to traditional power sources.

Off-grid systems are also known as mini-grids or standalone systems. The key feature of an off-grid system is its ability to function independently of the main grid or other systems. To generate electrical energy, off-grid systems typically use solar panels, which require the energy to be stored in a battery bank to accommodate fluctuations in demand. The purpose of this project is to evaluate the feasibility of installing a PV system that operates off-grid to power a bus shelter. This concept could be applied on a larger scale to provide electricity to homes in remote areas where it is costly to connect to the main grid infrastructure [10].

2.1.2 Grid-Tied System

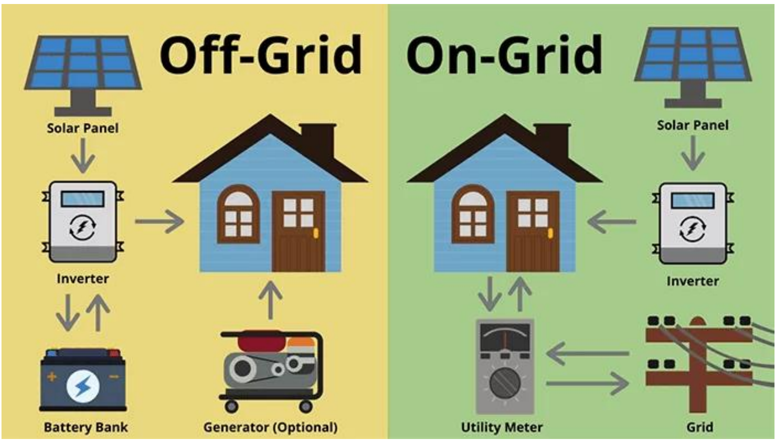

Fig. 7. Off-grid and On-grid [3].

A grid connected photovoltaic power system is an electricity generation system that is connected to the main utility grid. In the Fig.7 shows the structure of on-grid. It includes solar panels, an inverter, and equipment necessary for grid connection. Grid connected systems are suitable for residential, commercial, and larger scale applications, and differ from off-grid solar power systems. Typically, grid connected systems do not require battery backup because excess energy generated by the system is automatically transferred to the utility grid when the demand is low. For residential setups, grid connected rooftop systems typically have a capacity of 10 kilowatts, which is usually sufficient to meet the energy needs of the household. Any excess power generated by the system is fed back to the main grid and can be used by other consumers. The amount of excess power transferred to the grid is tracked by a metering system. In some cases, the wattage of the PV system may be less than the household's normal energy consumption due to various factors, in which case the household will use electricity from the main grid to meet their energy needs [10].

2.1.3 Hybrid Solar Power System.

A hybrid solar power system is a type of solar power system that incorporates energy storage in the form of a battery backup. This type of system is similar to a grid-tied solar power system, but with the added benefit of energy storage. In the Fig.8. shows the structure of hybrid solar power system. In a hybrid system, excess solar power is stored in batteries for later use, and when demand exceeds solar production, the stored energy is used to meet the shortfall. While hybrid solar power systems are more expensive, they provide the dual benefit of reducing electricity bills and providing backup power during outages. These systems typically consist of a PV array, a charge controller, a battery bank, and an inverter, and may also include a secondary power source like a wind turbine or a gas generator in some cases [11].

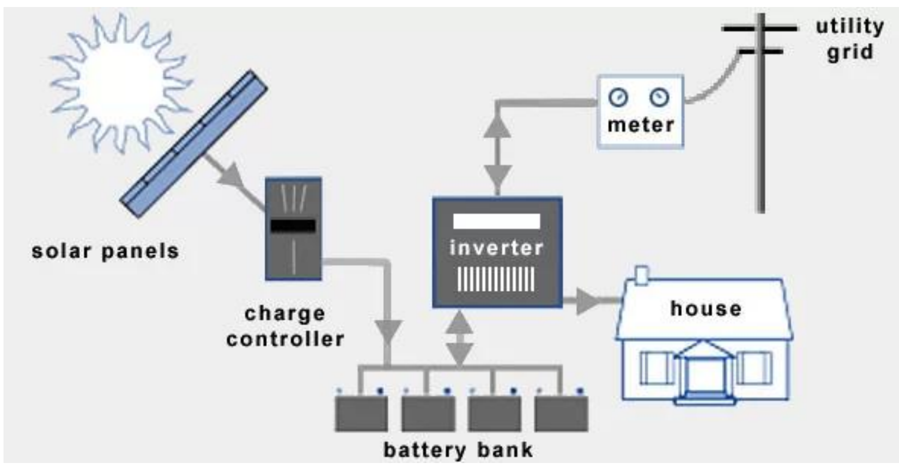

Fig.8 . Hybrid Solar Power System [11].

Advantages:

- Energy Storage: Hybrid solar power systems allow for energy storage in batteries, providing power even when there is no sunlight. This is particularly useful during power outages.
- Cost Savings: Energy storage systems can help save money by ensuring that stored power is used instead of power from the grid.

Disadvantages:

- Cost: The cost of a hybrid solar power system is higher due to the need for battery replacements. Although battery costs have decreased in recent years, they will still need to be replaced at some point.
- Expertise: Hybrid solar power systems are more complex and may require a solar installer with a higher level of expertise to design and install. It's important to find out if your solar power company offers installation of this type of system [3].

3. **Why solar power in Sri Lanka**

Sri Lanka is situated close to the equator, making it an ideal location for solar power generation as it receives a consistent and plentiful supply of solar radiation throughout the year. In the Fig.9. shows the solar radiation over the island. The solar radiation over the island does not show any significant seasonal variation [12]. According to the solar resource map created by NREL of the USA, the flat dry zone in Sri Lanka, which accounts for two-thirds of the land area, experiences solar radiation ranging from 4.0 to 4.5 $kWh/m^2/day$. However, there are several factors that can influence the amount of electricity generated from solar panels installed in any given location.

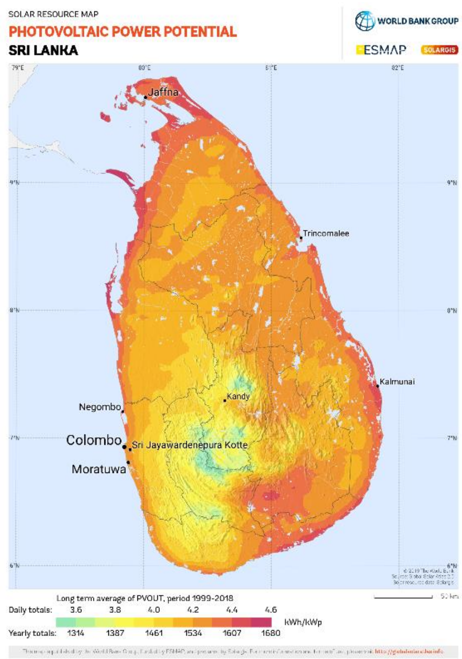

Fig. 9. solar radiation over the island [4].

Table 2: Generation Cost- 2015 January to June Source: Generation Performance in Sri Lanka – 2015

Generation Average	Type Generation in 2015 First Half – GWh	unit cost (Rs./kWh)
Hydro Power - CEB	2361	3.37
Thermal Plants – CEB	3029	11.47
Thermal – Hired / Private	403	34.69
Renewable / Solar	607	16.97

Table 2 presents a comparison of generation costs during the first half of 2015. For renewable energy to be effectively integrated into Sri Lanka's electricity generation mix, it is crucial to address the challenges that may arise and implement measures to mitigate them as much as possible [12].

3.1 Battle for Solar Energy (Soorya Bala Sangramaya).

The "Battle for Solar Energy" project is a community-based program that aims to integrate solar electricity generated through rooftop panels into the national grid. This program allows buildings of all types to install PV panels on their roofs and generate solar power. The maximum installed capacity is determined by the customer's contract demand. The Ceylon Electricity Board will sign a 20-year contract with customers who join the program. Studies have shown that small rooftop solar power plants offer significant economic, environmental, and social benefits. The following are some key benefits aimed by the "Battle for Solar Energy" mission:

- Rooftop solar power plants can make a tremendous contribution to balancing the electricity system throughout the island, as they are scattered all over.
- Transmission and distribution losses are minimal since the consumer and generator are close to each other.
- Small-scale entrepreneurs, as well as multi-million companies, can participate in electricity production.
- When electricity customers become producers, it can boost their economy.
- Small-scale rooftop solar power generation scattered throughout the island can have a positive impact on the security of the electricity supply.
- Using this free source of solar energy can reduce the foreign exchange spend on fossil fuels.
- The generators will receive an additional income.
- The plan is to add 200 MW to the grid by 2020 and increase it to 1000 MW by 2025.
- Customers who join this scheme can receive a monthly income of approximately Rs.300/= for the first 7 years after paying their bill and interest, and Rs.2500/= monthly from the 8th to 20th year.
- The industry has created many direct and indirect jobs. Additionally, there has been a significant increase in interest in this field.
- The ability to reduce CO2 emissions from thermal power plants to 1,50,000 MT [12].

The "Battle for Solar Energy" mission proposes that customers who invest in solar panels for their rooftops should pay back their loan within the first 7 years after the initial investment, and during this time, they would pay a higher rate for a unit of electricity to cover their investment capital and bank interest. For the next 8-20 years, the generating electricity would be purchased at a price that offers a reasonable benefit for the customer's investment.

If a customer has installed a 1kW solar panel on their rooftop in Sri Lankan climate conditions, they can generate approximately 115-125 units per month. Based on the proposed rate of payment, they would receive an income of about Rs. 2500-2700 per month. If the customer had taken a bank loan facility for fixing the solar panels and the loan period is 7 years with an interest rate of 8% to 13%, they would have to pay about Rs. 2200 per month.

After paying off the loan instalments, interest, and the cost of electricity consumption, the consumers would be able to retain about Rs. 300 per month. If the loan scheme is more concessionary, the income level of the customer would be increased. Once the loan instalments are paid off in 7 years, the customer can expect to receive a net income of about Rs. 2500-2700 per month for a further period of up to 20 years [12].

The Ministry of Power and Renewable Energy has launched a national program to install 100,000 solar rooftops over the next ten years to meet the country's electricity needs with green energy sources. This program aims to have at least 18% of electricity produced by domestic customers in Sri Lanka. However, presently, solar power generation at the domestic level is mostly restricted to high-income and upper-middle-class people due to the non-payment for excess electricity fed to the network. To attract low-income electricity consumers to participate in the solar energy mission, the ministry has introduced promotional schemes. The aim is to have another 20,000 low-income families become producers of electricity. The ministry expects to produce 200 MW by the year 2020 from this project and increase it to 1000 MW by the year 2025. The government has proposed to set up rooftop power plants on government buildings, and state-owned banks and related organizations are offering their maximum cooperation to the program's success. Private sector investment is also setting up large-scale solar power plants. The first commercial-scale solar power station, Buruthakanda Solar Park, was set up in Hambantota and has a total generation capacity of 1.237 MW. LAUGFS Gas PLC has set up a 20 MW plant in Hambantota district. Hatton National Bank's head office branch generates 1.3 MW of solar power, while MAS Holdings has unveiled Sri Lanka's another large rooftop solar plant with a capacity of 1 MW. Expolanka Holdings PLC Group has set up another large commercial plant with 2326 solar panels and an energy production capacity of 651 kW in Wellampitiya [12].

4. Sri Lankan Implementation

As a way to lessen its dependence on non-renewable energy sources, Sri Lanka has been gradually introducing solar energy. Due to the nation's rapid industrialization and urbanization, energy demand has increased, and the government has taken measures to satisfy this demand sustainably. The Sri Lankan government has set a goal of achieving 80% renewable energy generation by 2030 by utilizing solar panels and other renewable energy sources [1]. Sri Lanka has put in place a net metering scheme that allows people to install solar panels and sell any extra electricity they produce back to the national grid in order to encourage the use of solar energy. This method promotes the use of green energy, reduces electricity costs, and adds to the nation's energy supply.

4.1 Advantages

Sri Lanka's proximity to the equator means that there is a high amount of solar radiation all year round, resulting in minimal fluctuations in solar radiation across the island throughout different seasons [12]. Sri Lanka is hence a good site to produce solar energy. Electricity or heat may be produced using solar energy, which is acquired from solar radiation. Using such energy allows us to utilize ongoing solar energy while also utilizing technological advancements. Renewable energy may so serve society in a variety of ways.

The International Energy Agency (IEA), a major energy organization, claims in its Global Energy Outlook 2020 report that the finest solar energy systems in the world can deliver the cheapest power in recorded history. In most developed nations, the technique is less expensive than coal and gas. The paper claims that solar power can currently generate energy at US$20 "or lower" per megawatt hour (MWh), far cheaper than coal or gas, in ideal sites with favorable renewable policy support and strong access to funding. The analysis also predicts that solar energy costs will continue to decline and will do so by 65%

during the following two decades [16]. As a result, utilizing solar power would be less expensive than using other types of energy. Also, solar energy has no environmental impact at all when compared to the other energy sources we utilize. Additionally, it does not contribute to the emission of greenhouse gases or the obstruction of waterways. This has the additional benefit of not generating any noise pollution when solar energy is being produced. As a result, urban residents won't have the same issue. Yet a significant advantage of solar energy is its ability to deliver electricity to locations where the national grid cannot. Also, the power plants that may be constructed using these solar panels can be installed on the roof, offering urban residents still additional convenience. Benefits may be obtained in terms of the economy, ecology, and society, particularly with rooftop solar power plants. Also, it can result in immediate cost savings on your power bill. It is also conceivable to utilize this technology to generate income by returning any unused power to the national grid.

Moreover, small rooftop solar power systems also have the potential to make a significant contribution to the stability of the island's overall electrical infrastructure. When it comes to it,

- Due to the proximity of the customer and the generator, transmission and distribution losses are reduced.
- The potential for electricity generation extends beyond the millions of businesses to small business owners.
- As a result, power users may grow their economy by turning into producers.
- These small-scale power generators are erected on roof tops and dispersed over the island, improving the security of the electrical supply.
- We can spend less money on fossil fuels thanks to this free solar energy source.
- As a result, thermal power plants may be able to cut their carbon dioxide (CO_2) emissions by as much as 1,50,000 metric tons.
- Moreover, this industry also generates a significant amount of direct and indirect employment [13].

When considering other energies, solar energy is an energy method that has a very low environmental impact as mentioned above. It does not deplete natural resources, emit CO_2 or other gases into the air, or produce liquid or solid waste. Due to this, many major direct or indirect derivative advantages of solar energy can be obtained in terms of sustainable development. By the time,

- No greenhouse (mainly CO_2, NO_x) or toxic gas emissions (SO_2, particles).
- Reclamation of degraded land.
- Reduction of transmission lines from power grids.
- Improving the quality of water resources.
- Increasing regional/national energy independence.
- Diversification and security of energy supply.
- Accelerating rural electrification in developing countries. Advantages such as can be identified [15]. Due to the advantages of these solar power plants, a 1.7 GW solar power plant has been built in Hambantota Baruthakanda area of Sri Lanka on 45 acres of land [18].

4.2 Disadvantages

When talking about the production of energy by solar panels, it is necessary to consider not only the advantages but also the disadvantages. The disadvantages of energy produced by solar panels are much less when considering other energies. The main thing to consider here is the solar panels that have expired as well as the impact of damaged solar panels. This problem is not only affecting Sri Lanka, but the whole world has to face this problem. The data that is currently available estimates that there were between 43,000 and 250,000 tons of solar PV (photovoltaic) waste globally as of the end of 2016. Compared to the tiny number now generated, recycling does not appear to be a financially feasible option given the expected rise of waste PV panels until the year 2050. A plan for recycling and recovering EOL (end of life) boards must be implemented in the present decade. According to Fig. 10, this quantity of solar panel trash is anticipated to rise sharply over time. By 2030, it will account for between 4 and 14 percent of all generating capacity, and by 2050, it will account for more than 80 percent [14].

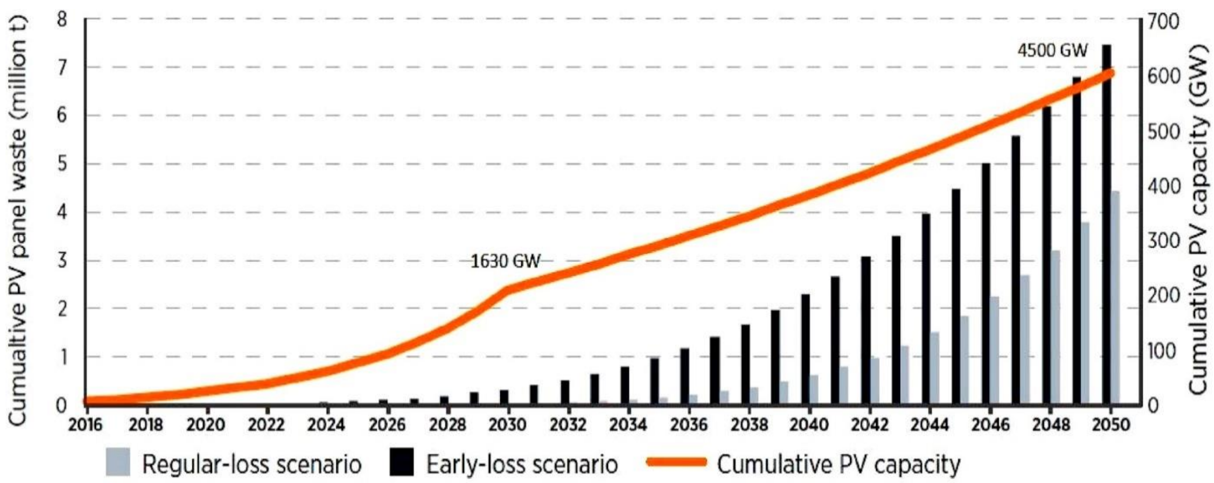

Fig. 10. The estimated cumulative worldwide solar PV module waste (tons) 2016–2050 [3]

The other important environmental impact associated with photovoltaic modules is the damage to the environment caused by the manufacturing and destruction of solar panels. Fundamentally, the use of hazardous chemicals as raw materials in the manufacture of solar panels. Because of the harm they do, these dangerous compounds may end up in the environment. Due to solar panel breakage, the silicon, copper, aluminum, and glass utilized here might end up in the environment. Its environmental effect can thus be reduced by recycling old modules. While recycling glass and copper can also result in these advantages, recycling silicon and aluminum will have the biggest positive effects on the environment. Also, correct module disposal can lower emissions of dangerous metals or hazardous and cancer-causing chemicals and using recycled aluminum lowers CO_2 emissions [17].

5. Government support for Solar systems.

Sri Lankan government has already taken some good steps to promote solar energy within the country. Among those steps, the biggest project was organized by the ministry of power, in collaboration with Sri Lankan Sustainable Energy Authority.

5.1 Soorya Bala Sangramaya

The Ceylon Electricity Board (CEB) and Lanka Electricity Company (Private) Limited (LECO) have launched a program to encourage the installation of small solar power plants on rooftops of households, religious places, hotels, commercial establishments, and industries. The program aims to add 1000 MW of solar electricity to the national grid by 2025 and 1500 MW by 2030 [20]. Consumers have the option to generate and use electricity on their premises, and excess electricity can be sold to the national grid or banked for later use. The program offers three schemes, Net Metering, Net Accounting, and Micro Solar Power Producer, based on the electricity usage of the customer. The installation service must be obtained from a registered solar service provider. This initiative promotes renewable energy sources, reduces dependence on non-renewable sources of energy, and provides an opportunity for consumers to generate their own electricity and contribute to the national grid while reducing their electricity bills.

Scheme 01 - Net Metering: This scheme allows any electricity consumer to install a renewable energy-based electricity generating facility and connect it to the LECO's electricity network. The connection will be metered by an export/import energy meter, and at the end of each billing period, LECO will read the consumer's export and import meter readings to prepare the electricity bill. The key feature is that there will be no financial compensation for excess energy exported by the consumer, and all exports will be set-off against the consumer's own consumption. The generating facility's installed capacity should not exceed the customer's contract demand, and the scheme is open to all renewable energy forms, including solar.

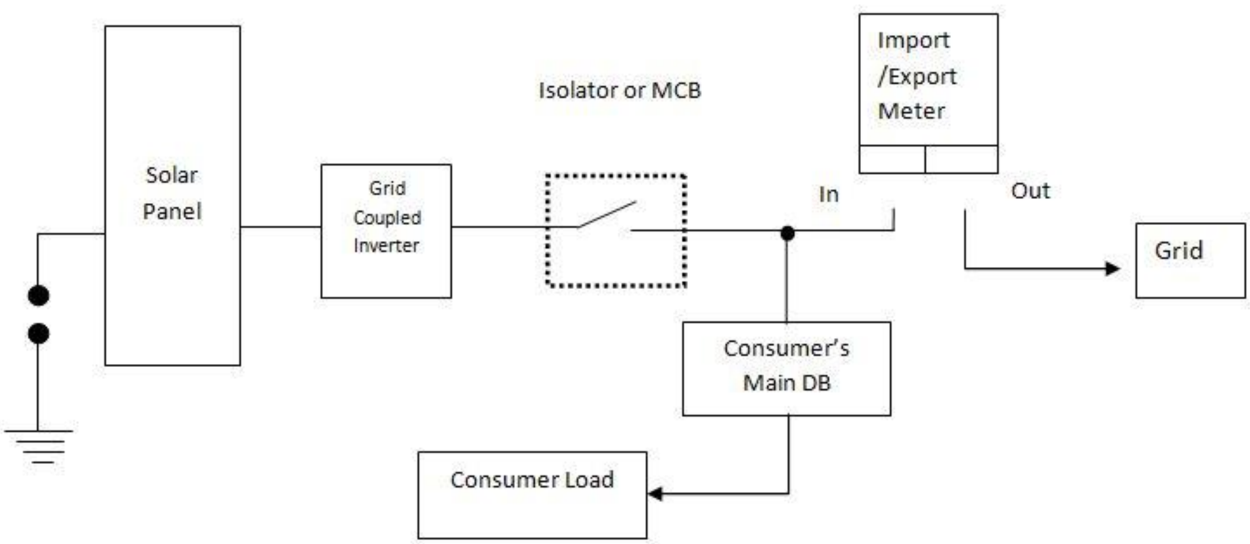

Fig. 11. Typical connection arrangement for the Scheme 1

Scheme 02 - Net Accounting: This scheme is similar to Scheme 01 but with an additional element where the export energy will be paid at an export tariff. The customer will be paid Rs 22.00 per exported unit during the first 7 years and Rs 15.50 per exported unit from the 8th year to the 20th year. If the consumption is greater than the energy generated from the solar panels, the customer will be billed using the existing electricity tariff for the import. This scheme is limited to rooftop solar power generation and the installed capacity of the customer, and the contract period is 20 years [20].

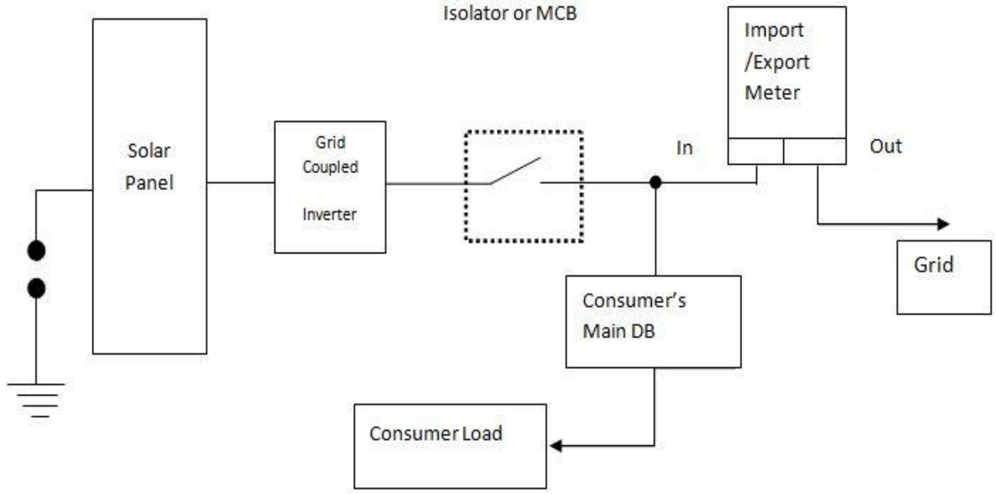

Fig. 12. Typical connection arrangement for the Scheme 2

Scheme 03 - Net Plus: This scheme meters the total generation of electricity from the solar PV power plant separately using a dedicated export energy meter, for which the customer will be paid at the export tariff. The energy import will be measured through a separate import energy meter, and the generating facility's installed capacity should not exceed the customer's contract demand. The customer will be paid for their energy registered in the export meter at the export tariff and charged for import using the normal customer tariff. The solar PV inverter output should be brought to the metering point, where both import and export energy meters are in a separate meter cubicle. The meter cubicle should be properly sealed to avoid tampering, and any associated costs for shifting the meter to a new location will be charged at the prevailing rate from the consumer in addition to their Net + plus connection charge. The contract period is 20 years.

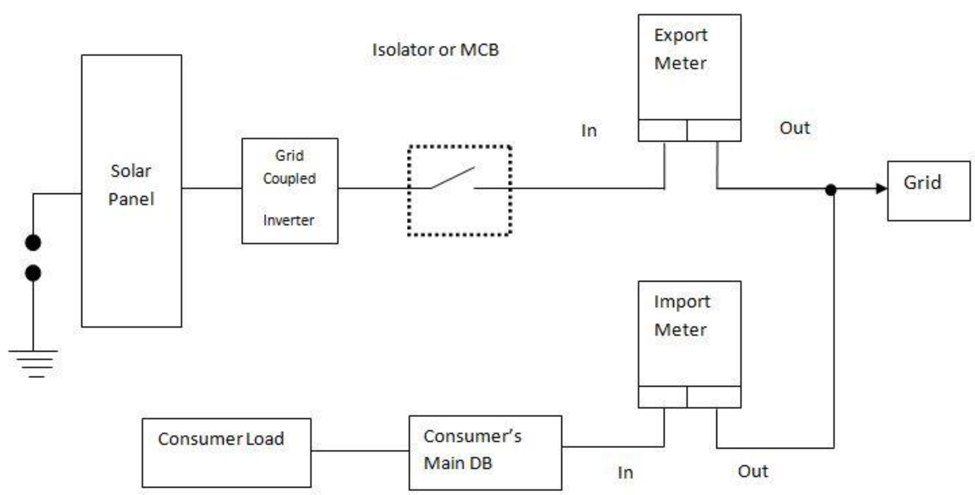

Fig. 13. Typical connection arrangement for the Scheme 3

6. Installation of Roof Top Solar Power Plant

Considerations for installing a solar power panel at home.

1. Strength of the roof

Solar power panels with different capacities are available in the market, and a Solar Panel of 420 Watts on average weighs 24 kilograms. If that plan to establish a Solar Power plant of 2 kilowatts, which requires installing 5 solar power panels, the weight will be approximately 120 Kg. The load on the roof will increase in line with the capacity. Therefore, the strength of the roof should be carefully assessed considering the 20-year life span of the plant [19].

2. Amount of light received by the roof.

The amount of light received by the rooftop may reduce due to the presence of trees and buildings surrounding the house. Obstacles such as these should be considered while estimating the 20-year life span.

3. Selection of a service provider for solar power plant installation

Many service providers exist in Sri Lanka for contracting the installation of Rooftop Solar. They must register with the Sri Lanka Sustainable Energy Authority (SLSEA). Therefore, it is essential to select an institution registered with SLSEA, as they publish a list of registered service providers on the SLEA website [19]. Otherwise, issues may arise when connecting your solar panel to the national grid if installed by an unregistered company. The registered solar panel installation company will install the solar panels, inverter and other necessary protection equipment for the capacity you request.

4. A Solar Panel

There are various solar power panels available in the market. Therefore, the focus should be on the efficiency and durability of solar panels while selecting a solar panel.

The most efficient and durable solar panels are recognized as Tier one solar panel brands.

7. Payback Period of Solar Panels

The payback period refers to the duration required to recoup the initial investment expenses. In more straightforward language, it is the time needed for an investment to reach the point of breaking even. The sooner you can recover your investment costs, the more advantageous it is for profitability. Therefore, the payback period indicates the period necessary to recover the project's costs.

Here are the steps to calculate the payback period:

1. Determine the initial cost of the solar panel system. This includes the cost of the panels, installation, and any necessary equipment such as batteries or inverters.
2. Determine the amount of energy the solar panels will produce each year. This can be calculated based on the size of the panels and the amount of sunlight they will receive in your location.
3. Determine the cost of electricity from the grid. This is the cost per kilowatt-hour (kWh) that you currently pay for electricity.
4. Calculate the annual energy savings from the solar panels by multiplying the energy production (in kWh) by the cost of electricity from the grid.
5. Annual energy savings = Energy production (kWh/year) x Cost of electricity from grid (Rs/kWh)

6. Divide the initial cost of the solar panel system by the annual energy savings to determine the payback period.

   Payback period = Initial cost of solar panel system / Annual energy savings

For example, if the initial cost of the solar panel system is Rs 20,000 and it produces 10,000 kWh of energy each year, and the cost of electricity from the grid is Rs 0.15/kWh, the annual energy savings would be:

Annual energy savings = 10,000 kWh/year x Rs 0.15/kWh = Rs 1,500/year

The payback period would be:

Payback period = Rs 20,000 / Rs 1,500/year = 13.3 years

Therefore, it would take approximately 13.3 years to recover the initial cost of the solar panel system through energy savings.

During the "Net Plus" program of the government, this system was installed. Below is a breakdown of how well the solar roof performed during the day. Two charts are provided to compare the performance on sunny and cloudy/rainy days. The system generates electricity from seven in the morning until four in the afternoon, and the entire amount is supplied into the national grid. The system generates 94.5 kWh (units) on a sunny day and 65.3 kWh on a cloudy or wet day. The following charts show the performance over the course of a month. Once more, for comparison, the data for a regular good month and a monsoon month are displayed. Both a good month (March) and a rainy month (November) yield 2,744 and 1,773 units, respectively [21].

7.1 Income and time till repayment

According to the "Net Plus" system, the grid connection agreement is valid for 20 years. For the first 7 years, the Ceylon Electricity Board (CEB) will pay Rs 22 per kWh, and for the following 13 years, Rs 15. Solar panels can last up to 30 years, and after 20 years the system can be used as long as it complies with all applicable rules and regulations.

Throughout the first seven years, annual generation totaled 23,582 kWh.

Total annual income during the first seven years: 23,582 x 22 = Rs 518,804

The system will cost Rs 2,600,000 in total.

The simple payback period is 5.01 years as a result.

For the first seven years, the annual income totaled Rs. 23,582 multiplied by 15 to reach Rs. 353,730.

The owner would be paid an annual income of Rs 3.53 lakh for the following 13 years and Rs 5.18 lakh for the following two years [21].

These data demonstrate the financial advantages to the owner of this system, albeit there may be modest adjustments as the system ages. By investing Rs 26 Lakhs over the course of the 20-year contract, the owner will obtain a total return of Rs 82.3 Lakhs. If the system is still operational after 20 years and the solar panels are still in use, the owner will continue to get free electricity for a further 10 years, allowing them to utilize it at home and export any excess to the grid while they are retired.

8. Recommendation /Proposal of improve solar panel in Sri Lanka

Sri Lanka is a tropical country blessed with abundant sunlight, making it an ideal location for solar energy generation. However, the country's dependency on non-renewable energy sources is still high. As a result, it is essential to explore ways to increase the use of solar energy to meet the country's growing energy demand. This research paper proposes several measures to promote and improve the service of solar panels in Sri Lanka.

1. The government should only approve new buildings if they are solar powered. This step will ensure that all new buildings in the country have solar panels installed, contributing significantly to the country's solar energy production.
2. The government can directly involve in installing rooftop solar systems. In that case, it will benefit the people as they can create their own off-grid and on-grid systems within their budget.
3. New industries should be required to power up on-grid solar systems as a part of their approval process. This will encourage the initiatives to shift towards renewable energy sources and decrease their dependence on non-renewable energy sources.
4. Many industries operate only during the daytime, so they can switch to solar-powered systems, which will decrease their electricity bills and promote the use of solar energy.
5. The government can power up schools, universities, and temples with solar panels. These places are ideal for solar power because of their large rooftops and daytime energy consumption.
6. Promoting more solar system awareness programs will encourage people to shift towards solar energy and educate them on the benefits of solar energy.
7. Continuing the government loan system, such as "Soorya Bala Sangramaya", will help people obtain financial assistance to install solar panels, especially those who cannot afford solar panels.
8. Providing solar panel-related materials such as solar panels, inverters, charge controllers, batteries, BMS, and DC wire at subsidized prices will help people to purchase these materials at an affordable rate.

These measures, if implemented correctly, can significantly increase the use of solar panels in Sri Lanka, which will benefit the country's economy, environment, and people.

8.1 Barriers and Challengers for Solar PV penetration in Sri Lanka

01. Grid Integration Barrier

The Sri Lanka Power System faces challenges integrating renewable energy sources due to its size and the intermittency of wind and solar power. Other islands, such as Hawaii, the Canary Islands, Tasmania, and Ireland, have been prosperous in incorporating renewable energy sources [22]. The connection of the Sri Lanka power grid to the Indian power grid may also increase the potential for renewable energy absorption. The Ministry of Power and Energy should establish a limit for renewable power absorption, which will be affected by the total penetration of intermittent renewable energy sources and unit/park size.

Most renewable energy generation must be must-run to avoid wasting resources, and only biomass-based age may be considered dispatchable. Developers perceive the lack of provisions for wind or solar spilling in current SPPAs as a potential risk, and a compensation mechanism is required. Improvements to overcome transmission/distribution constraints must be met by project developers at CEB standard rates or work estimates, with delays in construction being an issue. The technical requirements for SPPA have been controversial, but in 2008, rules were amended with grid interconnection requirements for wind facilities [23].

01) Intuitional Barrier

The lack of clear institutional responsibility and stakeholder agreement can impede the promotion of solar energy in Sri Lanka. One attempt to address this issue is by making representatives of stakeholders' members of the Board of SLSEA [24]. However, the dispute about whether PUCSL has the right to approve the FITs is a significant institutional barrier.

The management of renewable energy sources in Sri Lanka involves many institutions, both government and provincial councils. Local Authorities have jurisdiction over the power sector and are eligible for generation licenses over 25 MW capacities [23]. The Mahaweli Authority controls conventional hydropower generation through its Water Management Secretariat. Research can benefit the use of renewable energy, especially with net-metering technology. The National Engineering and Research & Development Centre and Sri Lankan universities can carry out this research. Sri Lanka, Sustainable Energy Authority, should collaborate with these institutions to foster research into renewable energy sources.

02) Financial barriers

The power sector is facing a significant financial deficit, expected to be funded by the government's Treasury. The current retail tariffs do not fully cover the costs, meaning that the government has to pay for electricity generation in addition to consumers. This situation could be improved by implementing full cost-reflective tariffs or providing transparent subsidies through the Bulk Supply Account. However, the Bulk Supply Account still needs to be implemented, and the government needs a financing mechanism. Renewable energy costs have yet to reach grid parity, and Sri Lanka, Sustainable Energy Authority, is required by law to have a renewable energy fund. However, this fund is not operational, so consumers are paying the total cost of renewable energy. This could lead to legal challenges in the future. There are also concerns about the level of Feed-in Tariffs, particularly for wind power projects. A more sophisticated mechanism for price discovery, such as tenders, may be needed to address this issue.

03) Informative barriers

In Sri Lanka, there still needs to be more awareness among decision-makers and inexperienced stakeholders regarding renewable energy's economic, social, and environmental benefits [24]. Some government stakeholders view renewable energy as an expensive investment without considering its short and long-term benefits. There needs to be more understanding of the advantages of energy swaps in small, fuel-dependent countries. Subsidized electricity prices to specific consumers also make renewable energy appear more expensive than it is. Additionally, PUCSL previously published the cost of the renewable energy pool but has since limited this information, failing to identify the price in the final Bulk Supply Tariff summary [26]. Proposals to break down the cost of generation, transmission, distribution, levies, surcharges, and subsidies in the consumer bill have yet to be implemented. Civil opposition to renewable energy, often due to competing land-use interests, is also a significant barrier, particularly for larger wind power projects. Effective land-use management is critical to the success of these projects.

04) Regulatory barriers

The safety measures may prevent net-metering consumers from connecting to the power system. Traditionally, users were required to disconnect their system when using captive generation for safety reasons. However, net metering was allowed in 2010, and PUCSL must enact compatible regulations. FIT is only permitted for facilities less than 10 MW, which restricts economies of scale, particularly for wind power [27,24].

The 10 MW threshold is related to technical issues, and PUCSL should establish the necessary technical regulations in the existing draft Grid Code. The lack of a clear grid code has resulted in a limit of 10 MW per facility for renewable power. PUCSL should also clarify the promotion mechanism for facilities more significant than 10 MW.

Inter-licensee agreements between CEB-owned Generation License/Transmission License and Transmission License/Distribution Licenses still need to be implemented. Private investment in the power sector should be encouraged by increasing transparency.

The current law requires public sector participation to develop RES-E facilities beyond 25 MW, and PPP was chosen as the primary mechanism to comply with this condition [27]. The following sections discuss PPPs' current and foreseeable future in the power sector and RES-E under this scheme.

9. World Large-scale PV installation

The market for solar PV cells is diverse, but c-Si cells dominate 80% of it globally[28,29,30]. Thin film solar cells are also made from materials like Cd Te and CIGS. In 2017, the newly installed capacity was around 99.1 GW, similar to the total capacity installed by the end of 2012[31]. By the end of 2017, the full installed capacity was over 400 GW, with a significant increase between 2015-2016 from around 200 GW to 300 GW [31].

Fig. 14 shows that the cumulative installed solar power capacity grew by 32% from 206.5 GW in 2016 to 404.5 GW in 2017.

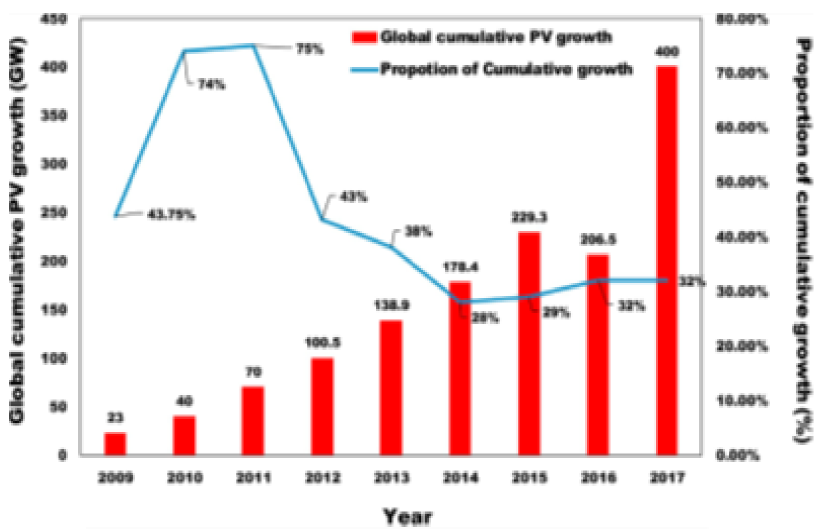

Fig. 14. Global growth solar PV capacity

In 2007, Germany introduced a tariff scheme and became the first country to allow the commercial connection of solar power to their national grid [32]. The global installed capacity was 9.2 GW that year, and by the end of 2017, the cumulative installed capacity had increased by approximately 43% [31].

In 2017, the Asia-Pacific region became the leading area for solar power, with a total installed capacity of 221.3 GW after an increase of 73.7 GW[32,33]. They represented a 55% global capacity share, as shown in Fig. 15[31].

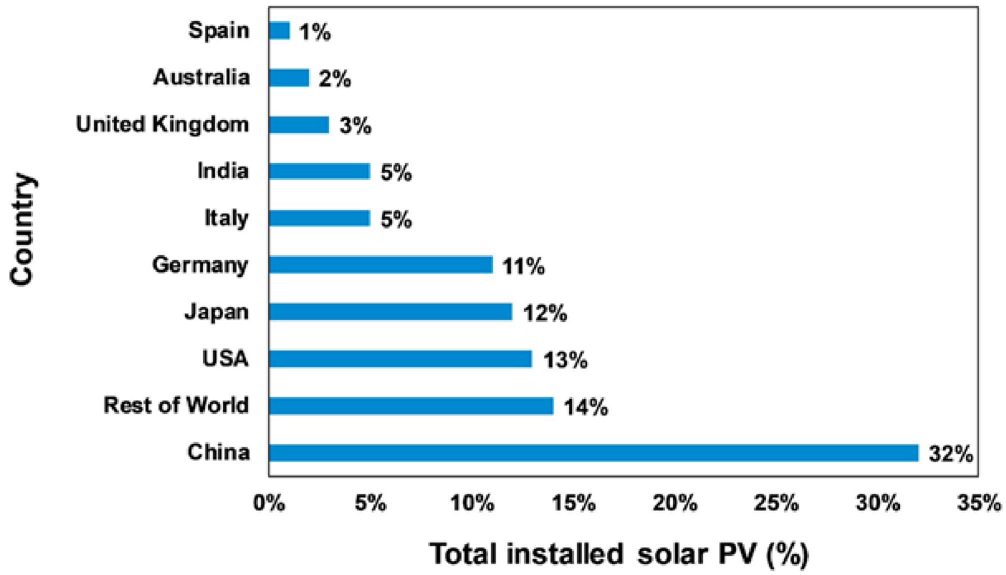

Fig. 15. The top 10 countries worldwide by total installed solar PV capacity at the end of 2017

European nations were pioneers in solar power and still hold the second position globally with a cumulative PV capacity of 114 GW. However, their share has declined to 28%. The United States is in third place with a total installed capacity of 59.2 GW, representing around 15% [31]. In 2017, Africa and the Middle East's global capacity share was only 1.7%, despite adding 2.1 GW to their total solar capacity [31]. China operated almost one-third (32.3%) of the world's solar power generation capacity in 2017, surpassing the USA to become the largest solar power generating nation [33]. The USA overtook Japan that same year, although both countries' total world capacity share had declined [34].

In 2017, Japan's solar power capacity of 49.3 GW accounted for 12.2% of the global total, down from 13.8% in 2016 [32]. None of the European nations ranked among the top three solar power-generating countries, and only Germany was in fourth place with a double-digit global share. However, Germany's global share declined from 13.4% in 2016 to 10.6% in 2017 due to a low new installation of 1.8 GW [32]. In 2017, India became one of the top five countries for the first time by doubling its total PV capacity to 19 GW and increasing its share of global installed capacity by 4.7% after adding more than 10 GW of solar generation capacity. As of the end of 2017, only Italy and the United Kingdom had more than 10 GW of installed solar capacity, with Italy at 19.4 GW and the United Kingdom at 12.7 GW [33]. Based on current estimates, it is unlikely that any other country will increase their installed capacity to 10 GW in 2018, as Australia, France, and Spain were all below that level in 2017[32].

10. Photovoltaic panel waste Generation

The estimated lifetime of PV modules is 25 years, after which the installed PV power (MW) is considered waste. To determine the time shift, the years of installation and waste generation can be represented by x and y, respectively, where y=x+25 [28]. Currently, there are two commercially available PV recycling technologies, with other technologies being researched. The c-Si technology dominates the market, followed by thin-film technology using Cd Te or CIGS technology [35,36,37]. Recycling processes for c-Si and thin-film PV panels are different because of their other module structures [31]. Recycling c-Si modules aims to recover the quilted glass and substrate glass containing the semiconductor layer, which requires separating the layers and recovering the Si cells and other metals [36,37]. Methods for removing the encapsulant from the laminated structure include thermal, mechanical, and chemical processes such as etching to recapture metals from Si cells.

According to the content, the semiconductors and substrate glass metals are separated and recovered using different methods. The waste generated during a PV panel's four primary life cycle phases, which include panel production, transportation, installation, and end-of-life (EOL) disposal, is significant. However, the waste forecast model presented in the content covers all life cycle stages except production. It is assumed that waste generated during production is easily managed and treated by waste treatment contractors or manufacturers and is not a societal waste management issue.

Design for Recycling PV Panel.

The International Energy Agency (IEA) stresses the importance of designing PV panels that can either recover the raw materials or offer secondary raw materials that can be used for other purposes. The critical requirements evaluated by the Photovoltaic Power Systems Programme (PVPS) are functionality, longevity, durability, reliability, and cost, and Design for Recycling (DFR) must improve and support these aspects.

Two primary types of PV panels, silicon-based and thin-film panels, require different recycling methods and can be recycled using separate industrial processes. Currently, silicon-based panels are more commonly used and comprise mainly glass, plastic, and aluminum, all recycled in large amounts [38]. However, amorphous silicon PV panels are easily recyclable and do not require any processing.

Recycling silicon-based PV panels starts with disassembling the product to separate the glass and aluminum parts, which are reused to make new panels. The remaining materials are then treated in a heat treatment unit at 500 C, where the plastic evaporates, leaving the silicon cells ready for further processing. The plastic is not wasted and is reused as a heat source for thermal processing. After the heat treatment, the hardware is physically separated, with 95% being easily reusable and the rest being refined. Silicon particles known as "wafers" are removed with acid, and broken wafers are melted to create new silicon modules, with a recycling rate of 98% for the silicon material.

The authors present a schematic representation of the recycling process of PV modules in Fig. 16. The diagram illustrates the mechanical, thermal, and chemical processes used to recover all the components at the modules' end of life (EOL) [39, 40]. The thermal and chemical processes are the two main phases of the recycling process. The thermal process must occur at low temperatures ($\leq$ 60°C) to minimize energy expenditure and environmental impact while enabling the recovery of polymeric materials without degrading the plastic. This process also helps to contain emissions and obtain authorization to build treatment plants.

The recycling process of PV modules involves mechanical, thermal, and chemical processes to recover all components. The chemical process is crucial as it requires precise conditions to obtain pure silicon with the necessary purity level for producing new PV cells and modules. Quality control is needed to ensure the purity of the silicon powder.

Recycling PV modules involves several steps, beginning with mechanical disassembly to separate the frame, tempered glass, and PV module. Next, a thermal process isolates the photovoltaic cells by softening the polymer layers in EVA. The materials inside each cell, namely silicon and copper, are then recovered through a chemical process. However, recovering silicon can be challenging since it is embedded in copper circuits in the PV cell and doped with chemical additives. Hydrometallurgy processes are necessary to recover silicon, which involves extracting metals from minerals by dissolving minerals in an aqueous phase and then recovering the metal. Although hydrometallurgy is selective, economical, and has a low environmental impact, it is still relatively expensive. Nevertheless, the complete recyclability of the PV module is crucial, and silicon recovery is an essential component of the process [41].

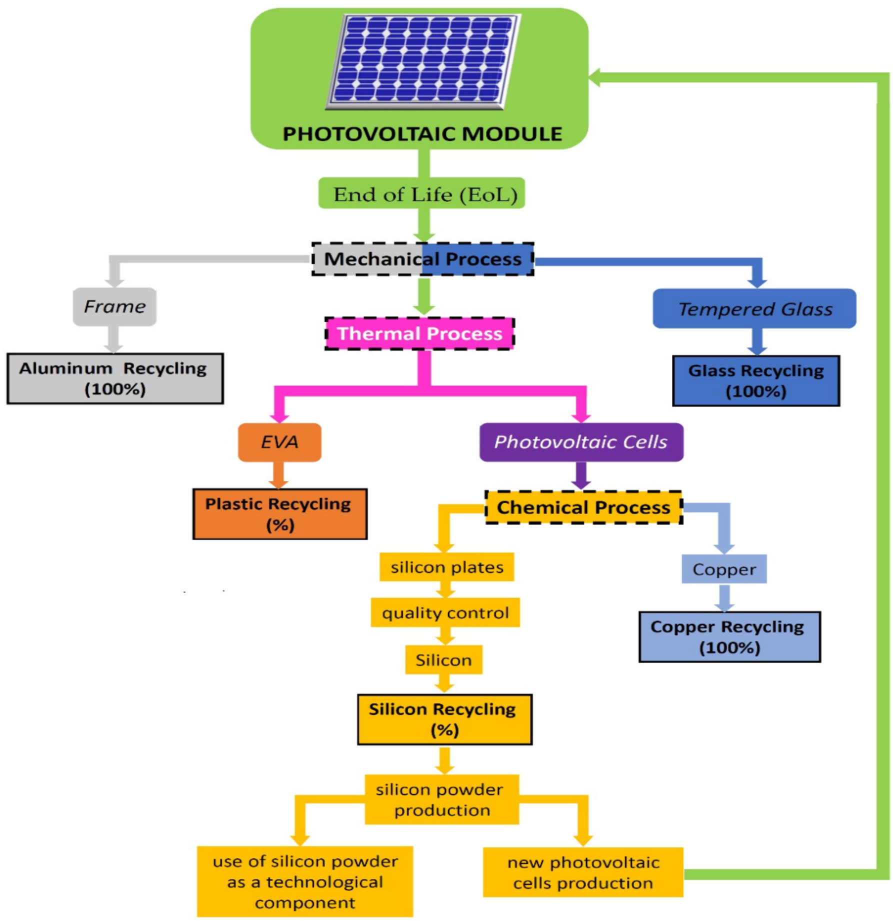

Fig. 16. Logical scheme for silicon-based PV module total

Adopting the logical scheme above for a very common standard PV module of 21 kg, we can obtain: 15 kg of glass; 2.8 kg of plastic material; 2 kg of aluminum; 1 kg of silicon powder: and 0.14 kg of copper, as shown in Fig. 17.

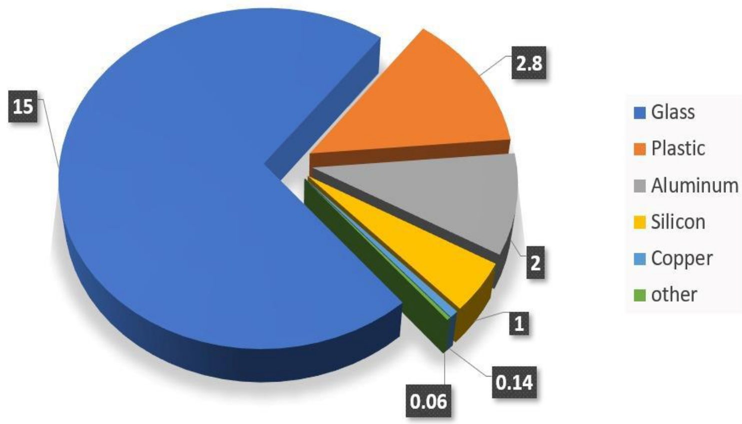

Fig. 17. Recycling material from a 21 kg commercial PV panel.

The importance of PV technology cannot be overstated when promoting a clean environment. However, it is also true that PV panels produce a significant amount of waste per unit of energy compared to other sustainable power generation and electricity technologies. This led to a growing concern among researchers about recycling PV panels to reduce the environmental impact of end-of-life treatments. Promoting the recycling of PV panels can increase economic and social development opportunities while simultaneously reducing greenhouse gas emissions through electricity generation. As such, recycling PV panels is an essential aspect of promoting sustainable development and mitigating the negative environmental impacts of the energy sector.

11 Conclusion

This review paper focuses on solar power and its implementation in Sri Lanka. This review highlighted the importance of solar power for Sri Lanka and how it can help to address the country's energy crisis. We explored the different types of solar power systems, such as on-grid, off-grid, and hybrid systems, along with their advantages and disadvantages.

We proposed several recommendations to promote the installation of solar panels in Sri Lanka. These recommendations included new government building approvals, direct involvement from the government, the starting of new industries, etc.

However, implementing solar panels in Sri Lanka faces several barriers and challenges, such as high initial costs, payback period time, and more government support. To overcome these challenges, we recommended that the government reduce taxes, provide solar panel installation loans, and continue supporting initiatives such as the Soorya Bala Sangramaya.

Moreover, we also emphasized the need to recycle PV panels to prevent environmental pollution.

In conclusion, this review paper demonstrated that solar power has the potential to play a significant role in Sri Lanka's energy future.

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