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Solar Power as a Sustainable Energy Source and Readiness Level in Sri Lanka: A Review

Lasny Manjitha (1st Author)
University of Kelaniya
Kelaniya, Sri Lanka
lasni91@yahoo.com

Amila Munasinghe (2nd Author)
University of Kelaniya
Kelaniya, Sri Lanka
amila@kln.ac.lk

***Abstract* — Rapid demand for energy has influenced engineers and scientists' investigation on renewable sustainable energy solutions. Although a wide variety of sustainable natural energy resources are available, usableness depends on technical feasibility and government intervention. Solar energy is a widely accepted solution for electricity generation due to its unique availability. With promotion of the solar power as a means for Sustainable Development Goal (SDG7) of the United Nations, this study is motivated to review information on solar power as a renewable energy source and to examine how Sri Lanka is ready for such move to relieve the economic burden from imported energy. The paper reveals government interventions in solar power initiatives and challenges towards energy sustainability and provides a future outlook.**

Keywords* — *sustainability, solar power, Sri Lanka, energy

I. INTRODUCTION

With the complex lifestyles of humans and the development of economies, the energy demand is rapidly increasing globally. As the World Energy Council predicts [1], global electricity demand will peak in 2030. Increased use of conventional energy sources like fossil fuel over the years has caused several hazards such as water and air pollution, global warming, acid rain, land degradation, and all of these hazards transforming towards a burning global issue- Climate change. Fossil fuel is only one of the three main categories of global energy resources (oil, gas, coal) and global attention is focused on two other categories of energy resources; nuclear energy and renewable energy (wind, solar, geothermal, airpower, biomass, hydrogen, ocean) [2]. With the United Nations focus on Climate change through Framework Convention on Climate Change (UNFCCC), leading international bodies such as International Renewable Energy Agency (IRENA) promote the widespread adoption and sustainable use of renewable energy sources that includes bioenergy, geothermal, hydropower, ocean, solar and wind energy as sustainable & clean energy sources. United Nations Sustainable Development Goals (SDGs) set in 2015 “Ensure access to affordable, reliable, sustainable and modern energy for all” as the seventh goal (SDG7), has emphasized the sustainability in energy usage to achieve by 2030 [4].

Advancement in technology, proper regulation of policies [5] and enhancement of efficiency through research and development (R&D) [6] are some of the options to conserve the existing energy sources while the innovation of environment-friendly renewable resources. The sustainability concept concerns preserving natural resources for future generations to meet their own needs while fulfilling the present needs [7]. Among different renewable energy sources, solar power has become significant as it uses the energy of the sun which is giving a large amount of energy due to the fusion of hydrogen nuclei in the form of solar radiations.

This article focuses on answering the research question of "What do we know about solar power and how the government of Sri Lanka supports its adoption”. This study was motivated due to the scant literature that reveals the readiness and levels of adoption of sustainable energy sources by Sri Lanka. Accordingly, this paper aims to produce an overview of solar power as a means for reaching the Sustainable Development Goal (SDG7) of the United Nations and provide information on its readiness and adoption in Sri Lanka.

II. SOLAR POWER AS A SUSTAINABLE ENERGY SOURCE

The Joint Sustainable Development Goals (SDG) Fund is one of the initiatives that transform policies and stimulate strategic investments that require meeting SDGs' needs [8]. Among 17 goals, the world is progressing towards Goal 7 with encouraging signs that energy is becoming more sustainable and widely available. As improvement proofs, access to electricity in poorer countries shows making impressive gains in energy efficiency in the electricity sector. As the name implies, it should have more focused attention to improve access to clean and safe energy sources. Its Energy Progress Report provides a global dashboard to register progress on energy access, energy efficiency and renewable energy. This assesses the progress of each country using these three main aspects how far they stand ahead for SDG. As at the website of United Nations, Department of Economic and Social Affairs, Sustainable

Development [9] still 13% of the global population lacks their access to modern electricity while 3 billion people are relying on wood, coal, charcoal or animal waste for cooking and heating. Usage of these conventional energy sources has become the dominant contributor to climate change with 60% of total global greenhouse gas emissions. According to the data found in 2016, the share of renewable energy sources has increased at its fastest rate since 2012 by the application of hydropower, wind, and solar [10].

Sustainability is not a new concept to the scientific community and it has become the main component of recent national policies, strategies and development plans of many countries [11].

Applications of renewable energy sources have shown not only environmental benefits but also economic development as well. Especially renewable energy development has become a trend globally to meet the need for electricity due to the rapid decrease of stored sources and negative environmental impacts [12]. According to David Pimentel, 2001 hydropower contributes significantly to world energy by providing 6.5% of the supply [13]. Biogas is alternative energy source for power generation and heat generation for household use [14]. Wind power has provided energy to pump water and to run mills and other machines, although it is limited by the availability of sites with sufficient wind [15].

Solar power is one of the easily accessible sources of energy that the sun emits at high-speed radiation which is available on large areas of Earth [16]. As reported usage of solar power has no harmful effects on the ecosystem and it is widely applicable efficiently in urban and rural areas, in industrial and domestic conditions due to its easy accessibility and usability. The applications of solar energy can be broadly classified into two categories such as thermal energy systems which convert solar energy into thermal energy and photovoltaic energy system which converts the solar energy into electrical energy.

In order to meet the SDG target by 2030 while increasing the share of renewable energy in the world energy mix with double the global rate of improvement in energy efficiency, it is suggested to focus on research for clean energy and technology, energy efficiency means and models and use of cleaner fossil-fuel technology.

III. READINESS FOR SOLAR ENERGY – A GLOBAL PERSPECTIVE

Restricted access to energy sources is one of the major crises in the world. Energy supply through noncarbon energy renewable sources is considered as the most promising solution for this problem [17]. By considering the economic and environmental benefits, the world has initiated various programs to replace fossil fuels with renewable energy resources.

Research and development of solar energy have existed for many decades in finding new technologies such as solar heating, solar drying, solar thermo-electricity generation and photovoltaic solar energy conversion. According to Siripala, 2014 [18] there are main two categories of solar research. One is focusing on inventing efficient solar cells that can be made at a very low cost, and others have focused on developing very high-efficiency cells even though they are expensive in manufacturing. Among all these researches, one of the main challenges is invention of cost effective efficient solar cell comparing with fossil fuels. Although it is challenging majority of the universities and research institutes worldwide have prominent research programs on solar energy converting devices as they have understood damage done to the environment by using fossil fuels will be irrecoverable [19]. All these efforts require immense amounts of money and resources in order to find a suitable solution to the energy problem [20].

Another aspect is although there are a large number of research programs conducted throughout the world, outcomes with practical applications are expected. The main reason is that lack of knowledge and accumulation of knowledge generated by a large number of projects will be essential to develop a final product. Fundamental research on the related subject areas plays a very important role in developing final applicable devices. For instance, the discovery of the transistor by Bardeen, Shockley and Brattain in 1947 [21] has influenced understanding the fundamental principles of semiconductors.

Victoria *et al*., 2021 [22] has mentioned that solar photovoltaics (PV) which are installed has cumulative capacity at the end of 2019 accounted for more than 600 GW and PVs could become our majority global energy source and an improved representation of this technology with new innovations of solar cell and system levels could highly contribute world energy consumption. Countries like Africa has tend to apply these technologies as PV appear to offer the possibility of ‘green’ electricity for rural areas specially in Sub Saharan Africa [23].

Solar hybrid energy system is a combination of energy sources with different characteristics and an energy storage system. It is important when solar energy itself is not enough in generating constant power for consumption [24]. As an energy source with no carbon or greenhouse gas emission photovoltaic power generation systems has used as an alternative not only for cooking and day-to-day household activities but also in highway service areas especially in China as they are small in size, lightweight and its small occupational space. Usage as an energy source in industrial activities is important as this equipment has a long useful life period ranging from 20 to 50 years with zero pollution emissions as PV consumes no fuel without any noise. It power is generated without water supply is also important as PV systems can be applied for areas which are uninhabited [25].

Developing an environmental-friendly photovoltaic solar panel that can shut high temperature radiation within a panel box was done by Kohei *et al*., 2020 which they include a panel having a decompression-boiling heat collector that can absorb heat from the PV module. There

a single PV system could keep the heat radiation temperature from the PV solar panel surface around 45°C even in summer and able to provide hot water at least 60°C by controlling the flow rate. As mentioned, this system has high efficiency in the utilization of solar energy with a small environmental heat load [26]. Chemical storage of solar energy such as hydrogen production by water splitting using sunlight has been done by Boretti *et al.*, 2021 [27], is an active research area. Among all, photovoltaic solar cell research and development have a prominent place. As a result, semiconductor silicon-based solar cell devices are at the forefront today, while the emerging technology is on the development of thin-film solar cells using other semiconductor materials. China leads in solar power generation globally and India joins as a prominent user in Asia. Israel is one of the pioneer countries that use solar energy for domestic usage and for solar plants. There they have equipped all most all the new buildings to be with solar collectors for water heating while high rates of domestic solar water heating worldwide (about 75% of households).

Companies in the country have solar technologies such as large-scale solar-powered electricity generating plant installed in Southern California's Mojave Desert [28].

Increasing the technology of solar energy systems has been experimented by a number of experiments all over the world by in ceasing their capacities with minimal environmental impacts.

IV. READINESS FOR SOLAR ENERGY IN SRI LANKA

With reference to SDG7, by 2030 it has expected to upgrade infrastructure and technology to enable a move towards sustainable energy sources. Sri Lanka has faced a major economic burden due to the dependence on imported energy resources and their high costs. This section reviews solar power initiatives and institutional and legal framework governing such initiatives in Sri Lanka. Solar energy, one of the clean and free renewable energy resources abundantly available in Sri Lanka that could be a major cornerstone of the future renewable energy systems in the country as the country is located within the equatorial belt. As mapped by the National Renewable Energy Laborite, USA solar radiation varies from 4.0 – 4.5 kWh/m2 /day [29]. According to the data on the CEB website (on 12th November 2021), small power producers contribute only 0.22 GWh countrys' daily electricity generation (Fig. 1.) [30].

When considered the institutional framework for Solar power in Sri Lanka, at present, the Energy and Business Development (MOPEBD), Ceylon Electricity Board (CEB) which contributes to the country's energy generation, transmission and distribution, Sri Lanka Sustainable Energy Authority (SLSEA) which plays a dual role as regulator and facilitator, Ministry of Power & Renewable Energy which involves in the planning of energy policies. Public Utilities Commission of Sri Lanka which is involved in sector governance are leading institutions for the development of this concept of solar energy of Sri Lanka [31]. Other stakeholder institutions and the Ministry of Finance & Planning, Ministry of Environment is helping in developing environmental policies while Central Environmental Authority involves in preparing environmental regulations [32].

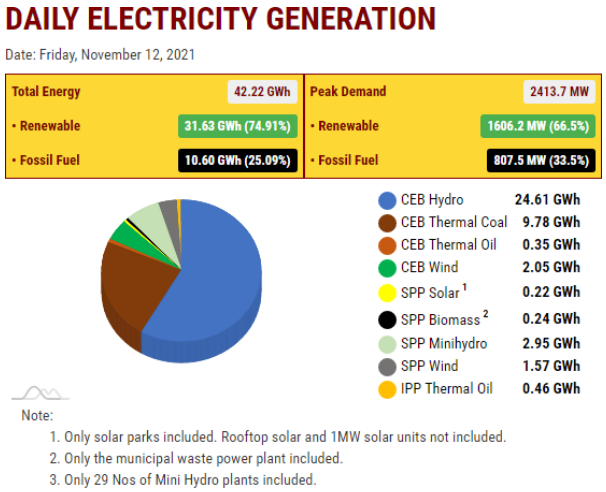

Fig. 1. Daily electricity generation of Sri Lanka (as at 12.11.2021)

Except for all these institutions, Universities and Research and Development (R&D) Institutions of the country are important in R&D and providing training services.Other organizations such as Non-Governmental Organizations and technology suppliers of Sri Lanka are also important in this aspect. CEB has taken the priority to boost access to renewable, clean or green energy power generation in Sri Lanka. As the initial step, the CEB has introduced the cost attract investments for the new technology [33]. As the solar power industry has become matured, CEB gradually introduced the competitive bidding process in line with the Sri Lanka Electricity Act. As found in December 2020, 414 MW of Solar power capacity has been grid-connected. A Gradual transformation from Feed-in-Tariff (FIT) scheme to a competitive bidding process has also been introduced by the CEB aimed at traffic reduction trends in the global market. CEB has already planned 7,000 ground-mounted solar power projects with an installed capacity of 75 kW to be positioned at rural and semi-urban areas of the country. The project was promoted under the theme of "Gamata Balagarayak" and aimed to attract local entrepreneurs for the project [34].

According to SLSEA, the solar resource atlas of Sri Lanka is an important addition to the existing knowledge on solar resources of Sri Lanka. The first solar atlas of Sri Lanka was prepared by the National Renewable Energy Laboratory (NREL) of the USA, in 2005 which has provided a great opportunity in exploring solar resources of the country, leading to gross estimates of solar potential.

The availability of accurate solar resource is crucial for the sustainable development of solar resources in Sri Lanka.

CEA as the key institution of preparing regulations and Environmental Impact Assessment (EIA), has contributed various national projects in this regard by evaluating its value with reference to the environment of the country. Ministry of Power, CEB and Sri Lanka Sustainable Energy Authority (SLSEA) initiated grid-scale solar PV power project, small scale distributed solar PV projects and rooftop solar PV installing commercial scale. As an example, CEA has joined with SLSEA for the EIA report of Proposed Solar Park in Siyabalanduwa, Sri March 2021 [35]. Review of the legal framework for Solar power in Sri Lanka shows that in recent past years the technology of solar energy has rapidly grown with the encouragement of government policies. Its low maintenance cost with low environmental issues makes it easy to cut down the electricity bills.

Sri Lanka Sustainable Energy Authority Act, No.35 of 2007 is one of the leading Act which was there for the establishment of the Sri Lanka Sustainable Energy Authority, to develop renewable energy resources, to declare energy development areas, to implement energy efficiency measures and conservation programs, to promote energy security and to evaluate the reliability and cost- effectiveness in energy delivery and information management [36]. Guideline for Renewable Energy Project Development and Circular: "Speeding up of the Renewable Energy Projects Development Process" is also two major regulatory framework for Sri Lankas' ground-mounted solar power projects. Supplying sustainable and affordable energy services to support socially equitable development in Sri Lanka [37]. In order to move toward energy independence and sustainable development, Sri Lanka should develop a technology mix using available indigenous energy sources such as hydro, solar, wind, biomass while reducing the usage of imported fossil fuel [38].

A review of publically available documents shows initiatives of solar power projects in the country. Rooftop solar systems have become popular with the availability of rooftop spaces in urban and rural areas [39]. The "Rooftop Solar PV Power Generation Project" has provided credit facilities by the Government of Sri Lanka (GoSL) through a loan from the Asian Development Bank (ADB). The credit line for the project is managed by the Ministry of Finance (MoF) and funds are channeled to the beneficiaries through selected Banks (Participating Financial Institutions -PFI). The technical support is provided by the Project Implementation Unit (PIU) in close collaboration with MoF, Ministry of Power, Energy and Business Development (MoPE) and Sri Lanka Sustainable Energy Authority (SLSEA) [40]. Power from the Rooftop Solar PV Installations can be integrated with the National grid through the Utility Providers in Sri Lanka, namely Ceylon Electricity Board and Lanka Electricity Company Private Limited.

Large scale development projects have been planned especially in areas such as Trincomalee, Ampara, Monaragala, Hambantota, Kurunegala and Anuradhapura [41] and in other urban cities such as Colombo. Distributed solar PV resource development has its own challenges such as institutional issues, financial issues, regulatory issues, awareness issues in a country like Sri Lanka. Research has been done by National Renewable Energy Laboratory, Colorado in 2003 on solar resource assessment for Sri Lanka and Maldives. They have applied a gridded cloud cover database at a 40-km resolution to produce updated monthly average daily total estimates of all solar resources (global horizontal, DNI, and diffuse) to input hourly or three-hourly cloud cover observations made at nine weather stations in Sri Lanka and two in the Maldives into a solar model that produces estimates of hourly solar radiation values [42]. There they have investigated the readiness of Sri Lanka for application of this technology by referring data obtained. The net-metering scheme was introduced in 2010 to serve the solar PV rooftop industry with large scale implementation across the country.

On September 6, 2016, the Government of Sri Lanka had launched an enhanced version of the rooftop solar PV program under the theme “Sooryabala Sangramaya” which means “Battle for Solar Power” [43]. This program attempts to encourage institutional users by exporting through a separate export meter without making any change to the electricity users' metering method. With the significant reduction of the cost of solar PV components, the service providers have quickly moved for large industrial customers who own large buildings with good roofs for solar PV systems.

Research on Solar energy has been going on in Sri Lanka for a considerable period, especially concentrating on solar thermal and photovoltaic systems, solar energy materials and solar water. Many universities and research institutes in Sri Lanka are involved in these research programs and among them most of the research are focused on development of low-cost thin-film solar cell devices and the search for low cost semiconductor materials for solar energy applications. Most of these research programs are funded by the National Science Foundation (NSF) and the National Research Council (NRC) [18]. Numbers of research publications are available on new concepts, methodologies, and materials which have been discovered by locals. Commercialization of these innovative products has not yet been realized from this research.

While achieving and realizing the capabilities of solar energy research in Sri Lanka, investment on solar energy research in Sri Lanka is an investment for the future. In order to get rid of the extremely high cost of fossil fuels, Sri Lanka will have to heavily depend on solar energy and other renewable energy resources for its future energy needs. Unless Sri Lanka develops the technology on its own for energy generation, in future it might have to heavily depend on foreign technology to harness the available solar energy. Therefore, continuation and further strengthening of

research and development on solar energy in Sri Lanka will be a meaningful investment for the future.

V. CHALLENGES IN SOLAR ENERGY ADOPTION

Solar power systems face problems with weather conditions and the length of the day. The prices of the equipment in these systems are relatively high. PV system has a high capital cost compared to other conventional energy sources [37]. The surfaces of the photo panels and mirror photovoltaic should always be cleaned of different dust. Certain large areas of the solar photovoltaic station can be a challenge for cleaning.

The effectiveness of photovoltaic plants heating can be reduced due to various reasons. PV-panels may be inefficient in collecting all available solar energy due to a number of environmental factors such as intensity of the sun, cloud cover and wind speed [44].

Lack of awareness of the potential benefits of the solar industry, especially among the rural population around the world is another challenge. Competition with energy sources in the markets and toxicity of the production material of solar cells are also some significant challenges. Instability of the energy supply make it to combine the system with other source of energy. The inability to provide enough supply to meet the need is also a weakness [45]. Large PV systems can cause some undesirable environmental impacts as well.

VI. FUTURE OF THE SOLAR ENERGY

To improve the capacity of current solar systems, new designs would need to be able to capture more light, transform light energy to electricity more efficiently and be less expensive. The cost for designing a product that can track the position of the sun accurately and consistently is an ongoing challenge but innovation on this front continues. As Emily Kerr from Harvard University, 2019 indicates, improving the performance of solar systems should target efficiency [46]. Solar systems with many layers of light- capturing material can capture more photons. As tested solar cells with four layers can capture 46% of the incoming light energy although it is too expensive. But ongoing research may be able to implement these super-efficient cells which will be cost-effective for commercialization. Major market players' involvement in investing more in research and development to increase the efficiency of this innovation is important while improving the sustainability of the resource.

VII. CONCLUSION

Energy is inevitable for an economy of any country. Countries like Sri Lanka incurs huge costs on energy imports causing balance of payment deficits every year. This paper aimed to contribute to the literature through reviewing information on solar power as a renewable energy source and to reveal on adoption in Sri Lanka. Solar power generation demands the most renewable sources of electricity. It has several advantages compared to other forms of energy but is still challenging as a consistent and cost- effective energy source to meet the high energy demand. Several pieces of research have been done by researchers all over the world in order to make it real while overcoming current challenges. Applications of solar energy are popular even in developing countries as the country's location severely affects these solar systems' efficacy. However, improvements in solar systems and their applications will take time and are possible only if they undergo bulk manufacturing and installation. Sri Lanka, as a middle income country needs the integration of policies and strong legal framework in order to achieve the SGD Goal7 and for the effective use solar power as a sustainable energy source. This study emphasizes the need for further research studies on solar power adoption by different countries, issues, and innovations to support reaching sustainable energy goals by 2030.

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