Overview of Grid-Tied PV Technology: A Review

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Abstract

Global warming has a range of ecological and health impacts, including extreme weather events. Increasing energy related carbon emission is a key causing factor of global warming. In order to mitigate energy related carbon emissions, buildings tend to adopt renewable energy. Grid-Tied Photovoltaic (PV) technology is a globally accepted renewable technology used for built environment. Grid-Tied PV systems are progressively attracting the attention of academia and industry as an alternative power source. This technology is a solution to increasing energy demand and helps to limit environmental pollution. Accordingly, adoption of grid-tied PV system considered as promising alternative to shift from fossil fuel consumption. Therefore, objective of this study is to deliver an overall understanding of grid-tied PV system in order to promote its application. This communication present a comprehensive review on application, benefits and strategies of grid-tied PV system. As the key findings, environmental, economic and social benefits and strategies of grid-tied PV system were determined and presented through a conceptual framework. In response to the increasing concern on renewable energy technologies, this paper proposes to use the developed framework as a basis to understand the benefits of gird-tied PV system, in order to promote application of grid-tied PV system.

Keywords

Grid-Tied PV Technology, Environmental Benefits, Social Benefits and Economic Benefits

1.0 Introduction

Electricity is a critical factor in our society since it ensures the quality of life and smooth run on other economic factors (Hussain et al. 2017). Electricity stands as a major aspect, which is mainly generated via fossil fuels, accompanied with air pollution (Guo et al. 2018). Hussain et al. (2017) further elaborated that the aggregate consumption of fossil fuels has sustained environmental impacts including climate changes, depletion of the ozone, environmental impacts and increased health issues to the living creatures on earth. According to Perez Lombard et al. (2008), building energy consumption has increased ranging from 20% to 40% exceeding the energy consumption in other major sectors including industrial and transportation. Furthermore, population growth, increasing demand for building services and comfort levels, along with the rise in time spent inside buildings influence the continuous increase in building energy consumption. Ever increasing energy consumption, emission of greenhouse gases (GHG) and environmental problems demand a replacement of non-renewable energy sources with renewable energy sources (Boontome et al, 2017). Consequently, buildings are influenced to implement renewable energy systems such as Grid-Tied Photovoltaic (PV) technology to address the shortfalls of traditional energy systems. Grid-Tied PV system is a latest technology, where electricity is generated through solar PV, which is integrated to utility grid (Madeti & Singh, 2017). Furthermore, this technology does not require producing 100% electricity demand for the consumer. As an alternative power source, the Grid-Tied PV systems can be incorporated with the utility grid in order to work more effectively and reliably (Zeng et al. 2012). Increasing electricity demand responsible for energy related carbon emission and growth in global energy consumption. Furthermore, renewable energy technologies such as grid-tied PV system has gained the interest in order to compensate increasing energy demand and to limit energy related carbon emission. Accordingly, this study specifically focus on grid-tied PV technology in order to promote its future usage as an alternative energy source.

2.0 Research Method

A review of previous literature is important to recognize the existing research gaps. Moreover, steering an initial literature review improves and strengthens the research process of the study. Accordingly, books, journal articles, conference proceedings, industry reports, institutional web sites and documents that are specifically related to application, benefits and strategies of grid-tied PV system were referred to develop comprehensive literature review.

3.0 Increasing Global Energy Consumption

Growing energy consumption has raised concern over energy supply difficulties and extreme environmental impacts (Pérez-Lombard et al. 2008). Moreover, statistics predict continuous growth in global energy demand. Annual energy consumption of developing countries will grow at rate of 3.2% per year and this rate will be exceed by 2020 for developed countries (Global Energy & CO_2 Status Report, 2019). Moreover, compared to 2010, energy consumption of 2018 has increased at nearly twice the average growth rate and change in global economy and increasing heating and cooling needs identified as the major causes of increasing energy demand. Figure 1 indicates, global primary energy demand from 2011 to 2018. According to Figure 1, it is evident that there is a rapid growth in total primary energy and 2018 records the highest energy demand compared to last seven years. Figure 1 displays sources of total primary energy demand in 2018, which includes gas, renewables, oil, coal and nuclear. Moreover, as per the Figure 1 in 2018 gas, oil and coal facilitate the majority of total energy demand compared to renewable energy.

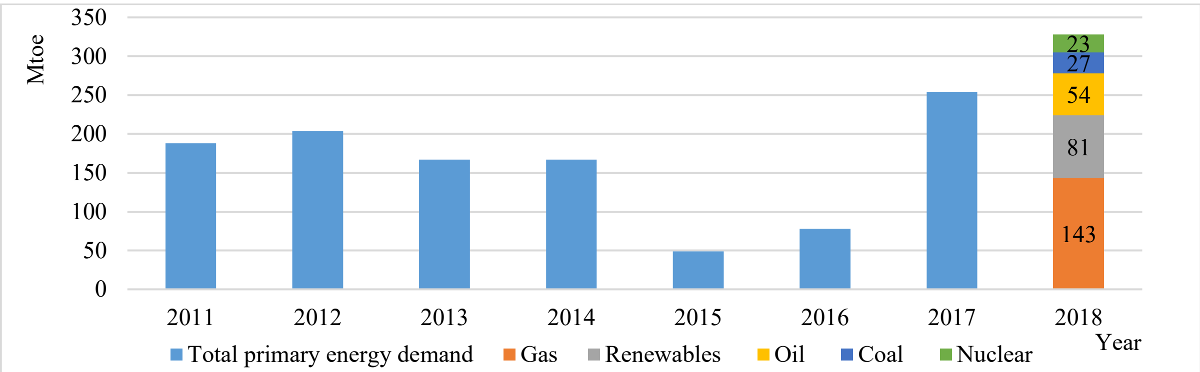

Figure 1: Global primary energy demand 2011 – 2018

According to global energy and CO_2 status report (2019), increasing electricity demand in power sector, responsible nearly for half of the growth in energy consumption. In order to compensate the increasing electricity demand, usage of coal and gas power plants has rose causing a boost in CO_2 emission by 2.5%, indicating energy related carbon emission as 13Gt in 2018. Table 1 indicates global electricity generation by source.

Table 1: Global electricity generation by source

Electricity generation (TWh)		**Growth Rate (%)**	**Shares (%)**	
	2018	**2017-2018**	**2000**	**2018**
Total Generation	**26, 672**	**4.0%**	**100%**	**100%**
Coal	10 116	2.6%	39%	38%
Oil	903	-3.9%	8%	3%
Gas	6 091	4.0%	18%	23%
Nuclear	2 724	3.3%	17%	10%
Hydro	4 239	3.1%	17%	16%
Biomass and waste	669	7.4%	1%	3%
Wind	1 217	12.2%	0%	5%
Solar Photovoltaic	570	31.2%	0%	2%
Other Renewable	144	4.2%	0%	1%

Table 1 indicates the total electricity generated (TWh) by different energy sources in 2018. According to Table 1, in 2018 the global electricity consumption rose by 4% compared to 2017 and 74% of total electricity generated by non-renewable sources in 2018. Compared to the electricity consumption data presented in 2000, renewable energy consumption has increased in 2018 but energy consumption of coal and gas power plants also rose significantly.

4.0 Energy Related Carbon Reduction Strategies used in Global Context

Global warming and carbon emission have become a critical factor and as result companies and organizations are adopting carbon footprint projects in order to identify their own involvement to climate change (Matthews et al. 2008). Renewable energy based electricity power generation and energy efficient cooling and lighting systems have been adopted by energy consumers to reduce their energy related carbon emission of buildings (Abdallah et al. 2015). Furthermore, amongst sustainability measures, organizations are motivated to use renewable energy sources as a carbon reduction mechanism for buildings.

Electricity produced through fossil fuels increase the carbon dioxide level of the atmosphere and as a result, countries are focusing to replace fossil fuel with renewable energy technologies (Aliprandi et al. 2016). Renewable Energy enables its consumers to reduce their electricity cost and environmental impact compared to traditional centralized electricity generating systems such as coal-based power plants (McCabe et al. 2018). Further to authors, renewable energy consumption is a solution for the current increasing energy demand and rising environmental impacts. Solar Energy, Wind Energy, Biomass Energy, Geothermal Energy and Tidal power can be identified as main renewable sources, which contributes for electricity generation (Alrikabi, 2014). Compared to traditional energy sources, renewable energy technologies were expensive to install and operate during its life cycle (Chien & Hu, 2007). Further to authors, the aforementioned financial barriers have been narrowed significantly over the past two decades.

Among renewable energy sources, solar energy is a widespread abundant and pollution free renewable energy source, which has various forms including solar photovoltaic, solar heat, solar thermal electricity and solar fuel (Singh, 2013). According to author, solar power electricity generated either using photovoltaic or concentrated solar power. Photovoltaic system directly converts solar radiation to electricity (Ahmadi et al. 2018). Moreover in concentrated solar power system, solar power is converted to heat and then to electrical energy. Categories of photovoltaic solar systems can be identified as stand-alone PV system, grid-tied PV system and hybrid solar power system (Bimenyimana et al. 2018). According to Fragaki and Markvart (2008) stand-alone PV systems are operated independently, which is not connected to utility gird. And compared to stand-alone PV system grid-tied photovoltaic systems are designed to operate in parallel with the local utility grid (Tous, 2012).

5.0 Grid-Tied PV Technology and Its Applications

Wang et al. (2017) explained, solar is an alternative energy source capable of reducing GHG emissions and air pollution. Furthermore, photovoltaic is one of the promising solar energy technologies available in the current market, which is capable of converting sunlight into electricity power. There are four (04) main applications of solar PV system and they are off-grid domestic photovoltaic systems, off-grid non-domestic photovoltaic systems, grid-connected distributed photovoltaic systems and grid-connected centralized photovoltaic systems (Zahedi, 2006). Mahela and Shaik (2017) described that compared to other PV power systems the population of grid-tied PV system have been increasing in the market as an alternative power source for fossil fuels.

Solar grid connected PV system allow solar power produced from photovoltaic to penetrate the already existing public utility grid (Nwaigwe, Mutabilwa & Dintwa, 2019). According to Karki et al. (2012), two main categories of grid tied PV system are displayed in Figure 2 and Figure 3. Figure 2 depicts the grid-tied PV system without batteries and Figure 3 displays the PV system with battery storage.

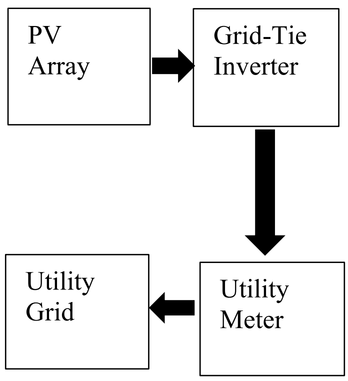

Figure 2: Grid-tied PV system without batteries

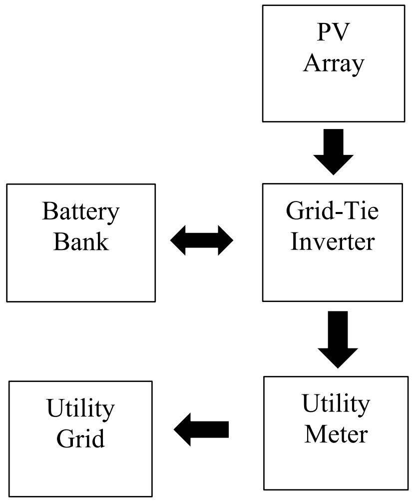

Figure 3: Grid-tied PV system with batteries

Grid connected PV system range from various sizes such as small scale system (generally, rooftop and building integrated PV, in kW) for residential purposes and large scale systems (in megawatt size) for solar power stations (Parida et al. 2011). A typical grid-tied system includes PV array, inverter and grid system. (Adaramola, 2014). Solar systems generate relatively low voltage output and requires high step-up voltage for grid integration, which is achieved using high efficient DC-DC converter connected to the PV system (Mahela & Shaik, 2017). Moreover, solar system includes an inverter to convert DC power to AC power. Accordingly, major elements of a grid-tied PV system are shown in Figure 4.

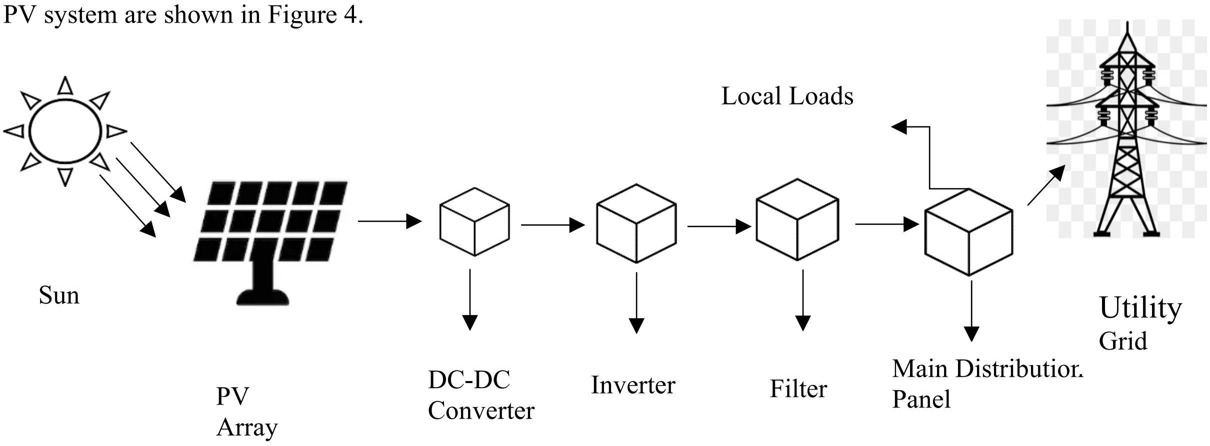

Figure 4: Grid-Tied solar PV system

As stated by Tomar and Tiwari (2017), performance of grid-tied PV system depends on inclination of PV array, efficiency of inverter, load profile and climate condition. According to authors, the successful performance of grid-tied PV system ensure several benefits such as demand shifting from peak to off peak hours, minimizing peak load demand, reliable power supply, high utilization rate and tradeoff between tariff structure and achievement of sustained sellback price.

Demand of solar photovoltaic is increasing with the improvements of its applications (Parida et al. 2011). Further to authors, different applications of solar PV includes water pumping, power source for remote building, solar home system, satellites, communications and megawatt scale power plant. The last decades, there has been a significant progress in application of grid-tied PV system (Kouro et al. 2015). Moreover, research efforts have been concentrated on different applications of grid tied PV in recent years. The summary of some research studies on application of grid-tied PV in different sectors are presented in Table 2.

Table 2: Application of grid-tied PV – secondary findings

Source of Reference	**Application of grid-tied PV**	**Research findings**
Wei & Temitope, (2014)	Adoption of solar grid-tied PV-system in a residential building	Compared to conventional electricity supply, in the long term solar grid-tied PV system is cost effective to the consumer
Allouhi et al. (2016)	Grid-Connected PV systems installed on institutional buildings: technology comparison, energy analysis and economic performance	Findings indicate that grid-tied PV system has the potential to decrease carbon emission by 5.01 tons of CO_2 with regards to the selected cases.
Ghenai & Bettayeb, (2019)	Grid-Tied solar PV/fuel cell hybrid power system for university building	Findings indicate integration of local utility grid with renewable power is an efficient approach to achieve renewable energy targets along with affordable cost of energy.
Sharma & Galipeau, (2012)	Optimization of residential grid-tied PV systems without net-metering using load management	Adoption of load management into a residential grid tied PV system can boost its self-consumption by 30-50%.
Locment et al. (2010)	Electric vehicle charging system with PV grid-connected configuration	Study highlights that it is significant to have a grid-connected PV system for electric vehicle charging facility.
Díez-Mediavilla et al. (2013)	Performance of grid-tied PV facilities: A case study based on real data	This study propose a new method to calculate the performance of grid-tied PV system.
Alam Hossain Mondal & Sadrul Islam, (2011)	Potential and viability of grid-connected solar PV system in Bangladesh	Findings indicate that solar PV can generate 50174 MW. Further, it was identified that the unit cost of grid-tied solar PV electricity is less than grid electricity, if the carbon tax and current oil price are considered

6.0 Environmental, Economic and Social Benefits of Grid-Tied PV

This section presents literature review and classifies benefits of grid-Tied PV technology under three main categories: environmental, economic, and social.

Environmental Benefits

Solar PV technology is a sustainable way of generating electricity and it contains several environmental benefits such as minimizing air and water pollutions while reducing demand for conventional resources (Gunerhan et al. 2008). Furthermore, grid-Tied PV technology perform as a renewable and clean energy source, which are essential components to deliver environmental benefits. Almaktar et al. (2013) stated that PV technology accounts zero noise, air and water pollution during operation itself. Furthermore, application of grid-tied PV system enables cities to support aesthetic and greener concepts. According to Tsoutsos et al. (2005), the major environmental benefits of grid-tied PV technology is reduction of environmental greenhouse gases emission and prevention of toxic gas emissions.

Economic Benefit

Grid-tied PV reduces the electricity supply demand from grid, which ease the burden on local power grid (Almaktar et al. 2013). Furthermore, grid-tied PV technology has very low maintenance requirement and low maintenance cost during its life span. Grid-tied PV can support the economy of the country and creating job opportunities (Pillai et al. 2014). Moreover, solar industry create business opportunities for installers of PV power systems, manufacturers, product distributors, engineering and architectural companies. Under economic benefits, solar PV system is comparatively costly to install in buildings therefore in countries like United States provide several financial incentives including tax credits, cash rebates, net metering, solar set aside and solar renewable energy credits, which performs as key drivers to enhance the PV demand (Burns & Kang, 2012). Comparatively grid tied PV systems are beneficial than separate PV power plant because of zero requirements of additional land, less expenses on supporting structures and there is an indirect energy conservation impact due to the participation of consumer in their own electricity supply (Polo & Haas, 2012).

Social Benefits

Social benefits of grid-tied PV technology includes increase of national energy independency, diversification and security of energy supply, support of the deregulation of energy markets and acceleration of the rural electrification in developing countries (Tsoutsos et al. 2005). Furthermore, another significant social benefit include creating job opportunities with the expansion of solar technology market.

7.0 Strategies for implementing Grid-Tied PV System

Cucchiella et al. (2016) explained that without government incentives the life cycle cost of grid tied PV system would exceed the saving from the renewable energy system. According to Polo and Haas (2012), worldwide programs are conducted to promote the application of grid-tied PV system and few of them can be listed as follows.

- 'Japanese Residential PV System Dissemination Programme' since 1994
- Introducing favorable feed-in tariffs for PV users in Germany with the amendment of 'Renewable Energy Act' in 2004
- In 2008, PV usage in Spain increase with the favorable feed-in tariffs for PV users

Promotion strategies of grid-tied PV system includes rate based and enhanced feed in-in tariff incentives, green pricing models, soft loans, NGO marketing and public building program (Palo & Haas, 2012). Studies in Europe countries showed that National Government and European community has introduced many financial strategies to promote the use of PV systems, which ensure the PV industry remains competitive on the world-wide market (Campoccia et al. 2007). As per the authors, the most popular strategies of Europe are feed in tariff, capital subsidies, net metering which allows a significant reduction of costs related to PV system. Campoccia et al. (2007) mentioned the financial strategies for PV systems introduced in European countries and presented in Table 03.

Table 03: Financial strategies available for grid-tied PV system in European countries

EU Country	Feed-in tariffs	Net metering	Capital subsidies	**EU Country**	Feed-in tariffs	Net Metering	Capital Subsidies
Austria	✓		✓	Latvia	✓		
Belgium	✓	✓	✓	Lithuania			
Bulgaria				Luxembourg	✓		✓
Cyprus	✓		✓	Malta			
Czech Republic	✓	✓	✓	Netherlands	✓		✓
Denmark		✓		Poland			✓
Estonia	✓			Portugal	✓		✓
Finland			✓	Romania			
Finance	✓		✓	Slovak Republic	✓		
Germany	✓		✓	Slovenia	✓		
Greece	✓		✓	Spain	✓		✓
Hungary	✓			Sweden	✓		✓
Ireland			✓	United Kingdom			✓
Italy	✓	✓	✓				

California residential has accepted solar PV system as a good investment in terms of financial perspective since there are several factors enhance the financial viability of solar PV in buildings such as government incentives, net metering facilities, feed-in tariff, high grid electricity cost and declining solar PV system costs (Black, 2004). Collaboration of Sri Lanka Sustainable Energy Authority (SLSEA), Ceylon Electricity Board (CEB), and Lanka Electricity Company (Private) Limited (LECO) have launched a community-based power generation project under the title of Energy Battle in order to promote the installation of solar panels for residential sector, religious places, hotels, commercial buildings and industries energy (Ministry of Power and Energy, 2016). Furthermore, this project operates under the expectation of adding 200MW of solar electricity to the grid by 2020, which indicate the local attention on solar.

Consequently, as the key outcome of this initial review paper, a conceptual framework was developed which graphically represent the importance of applying grid-tied PV system based on the literature review conducted on grid-tied PV system. The developed framework is presented in Figure 5. Furthermore, Figure 5 display the environmental, economic and social benefits of grid-tied PV system. Moreover, financial incentives provided for grid-tied PV users are listed derived from economic benefits of the system.

8.0 Conclusions

Global warming increasing in an alarming rate causing climate changes. Energy related carbon emission has identified as a major cause of environmental changes. Consequently, renewable energy technologies are emerging to reduce the impact of fossil based energy consumption. Among renewable energy technologies, grid-tied PV system has gain the attention as an energy and carbon reduction strategy. Thus this paper aims to provide overall understanding of grid-tied PV system in order promote its application. This paper has identified concept of grid-tied PV technology and its applications worldwide. Furthermore, benefits of grid-tied PV has recognized under the categories of environmental, economic and social aspects. Besides the benefits of grid-tied PV system, financial incentives have been identified, highlighting the strategies of the grid-tied PV system. Finally, conceptual framework was developed as the major deliverable of this paper where it can be used as a basis of understanding to promote grid-tied PV for the users. Further, it would also be the first step in achieving the whole aim of the total study of improving grid tied PV application in Sri Lanka. As a further research area, the researcher can carry forward this study to identify economic viability of grid-tied PV system specifically in local context.

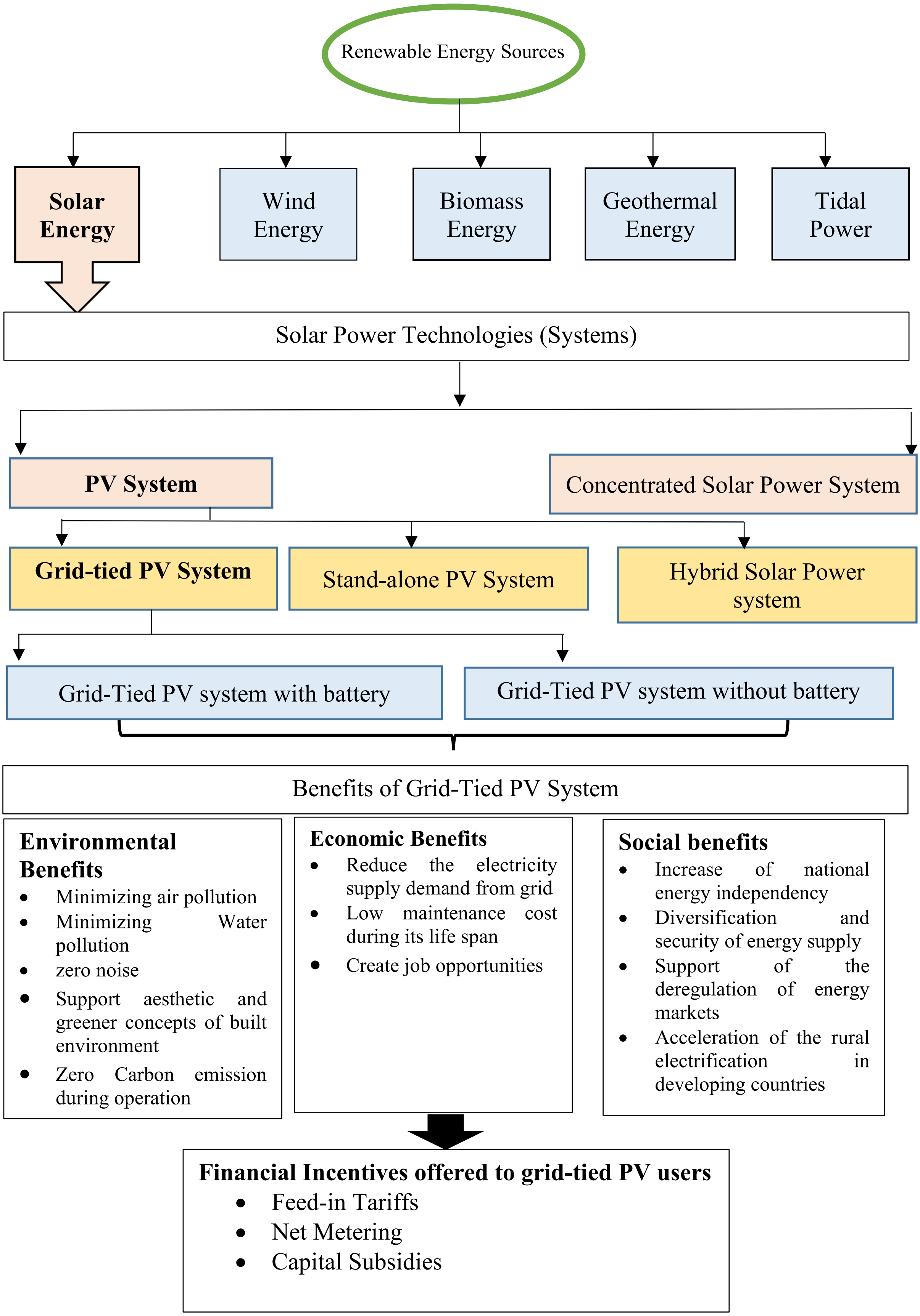

Figure 5: Conceptual Framework

9.0 Acknowledgement

The authors wish to acknowledge the support received from the Senate Research Committee of University of Moratuwa under the Grant SRC/LT/2019/06

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