A STUDY OF APPLICATION OF PHOTOVOLTAIC SOLAR SYSTEM IN DETACHED INDIVIDUAL RESIDENTIAL BUILDINGS IN SRI LANKA

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Degree of Master of Science

Department of Building Economics

University of Moratuwa

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Thesis is submitted in partial fulfillment of the requirements for the degree
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DECLARATION

"I declare that this is my own work and this thesis does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

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ABSTRACT

Energy, its demand and supply has become one of the defining factors in the economy of many countries. Sri Lanka (SL) is not an exception where the current demand for the energy is exceptionally intense and the country is seeking for renewable sources for a more sustainable energy supply. In present status quo, Sri Lankan energy mix significantly depends on fossil fuel leading to environmental pollution due to carbon emissions. Research on non-renewable energy sources is rather a necessity than a luxury. As a result of that, many new energy sources are introduced to the world. Most importantly, Sri Lanka as a third-world country, cost-effective sustainable solutions for energy generation are essential in reaching a sustainable goal. The residential building sector accounts for the largest energy consumer when considering the whole life cycle of the buildings. Briefly, solar photovoltaic (Solar PV) is the most cost effective, environmentally friendly solution for energy generation in residential buildings, but the lack of knowledge and misconceptions kept people away from using solar PV. The contribution of construction project managers in introducing novel energy sources and finding solutions is of paramount importance. On this note, this research aims to assess the application of photovoltaic solar system in detached individual residential buildings. The research apprehends mix method with including a market survey with questionnaires and two case studies with interviews. The responses for the questionnaire survey were analyzed using the Relative Important Index. Manual content analysis was carried out to analyze the case study data. The two case studies represent two households with solar PV and the building owners responded to the interview survey. This research study compared the effects of energy consumption due to implementation of PV Solar vs conventional residential buildings, and identified strategies to enhance solar PV panel application in residential buildings in Sri Lanka. This research study initially conducted an extensive literature review followed by a market survey and case studies to conclude that the solar PV is beneficial for the detached individual residential buildings. Furthermore, the study confirmed that solar PV is a viable for the conventional energy generating sources in the residential sector.

Keywords -: Sustainable buildings, Solar PV, Residential buildings, Project management, Challenges

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LIST OF ABBREVIATIONS

Abbreviation	**Description**
AC	Alternating Current
ASHP	Air Source Heat Pump
BIPV	Building Integrated Photovoltaic
CO2	Carbon Dioxide
CSP	Concentrating Solar Power
DC	Direct Current
GHG	Greenhouse Gas
GHI	Global Horizontal Irradiation
GREEN SL	Green Sri Lanka Rating System
HVAC	Heating, Ventilation, and Air Conditioning
PV	Photovoltaic
SAH	Solar Air Heaters
TFSC	Thin-Film Solar Cell
TPV	Thin-Film Photovoltai

CHAPTER 1- INTRODUCTION

1.1 Research Background

The sustainable development is a modern maneuver that has become largely popular across the society, influencing the construction industry to focus on environmentally friendly building constructions, socially, and economically responsible buildings (Berardi, 2013; Liu et al. 2018; Niemets, Kravchenko, Kandyba, Kobylin, & Morar, 2021). Xu and Chan (2013) pointed out that these buildings are referred to as green building or the sustainable buildings.

Sustainable buildings consume crucial and valued resources like water, electricity, and other energy, raw building materials and even the land more resourcefully and efficiently compared to the usual conservative building constructions. Further, the advantages that can be enjoyed has inspired the industry to focus on the concept of sustainable buildings and its development possibilities (Hakkinen & Belloni, 2011). In their study (Geng, Ji, Wang, Lin & Zhu, 2019) pointed out that operational costs of sustainable buildings are much lower than that of the conventional buildings. Moreover, Newsham, Veitch and Charles, (2008) indicated that, performance of sustainable buildings can be improved easily to generate higher efficiency and productivity of their consumers. Similarly, Dwaikat and Ali, (2018) stated that sustainable buildings will bring down the usage and wastage of natural scarce resources which will be beneficial to the national economy. The benefits of sustainable buildings have been identified by many scholars as less costly to operate and save energy on an average of 30% (Fan, 2003) improved health situation for building users (Balaban, & de Oliveira, 2017) reduction maintenance cost (Madew, 2007) and indicated the uncertainty of actual costs to be incurred and benefits to be enjoyed act as the major obstacles of green buildings (Hwang & Tan, 2012).

Each stakeholder involved in the green construction process plays a pivotal role in developing the conceptual construction process. One of the major roles is being project managers of such projects and their main responsibility is to assist the company to attain the long-term goals and objectives in the construction industry (Garbharran, Govender & Msani, 2012; Fox, Fong, Hills, Skitmore, & Hon, 2008). According to Alvarez-Dionisi, Turner, and Mittra (2016) and Tabassi, Argyropoulou, Roufechaei, and Argyropoulou, (2016) project managers play a key role in encouraging sustainable building constructions through adopting sustainable concepts into their performance and personal practices. Due to the current high demand for limited and nonrenewable energy sources, the limited natural energy sources are being overused around the world ever since. The carbon footprint is on an upward spiral starting from the industrial revolution. From 1971 to 2015 consumption of energy around the world has increased by 150% and most of them are from non-renewable energy resources (Azzi, Duc, & Ha, 2015; Li, & Liu, 2017; Praveen, 2020). Authors further stated that since the mid-1800s, the level of CO_2 in the atmosphere has increased by 40% (Kang, Lee, & Stewart, 2016). According to Stauch and Vuichard (2019), there should be a tracking transformation in energy systems, specifically the low-carbon technologies to achieve the climatic goals. Authors further indicated that solar power generation is one of the key technologies where solar photovoltaic (Solar PV) is identified as one of the most efficient energy generating sources (Stauch & Vuichard, 2019). Most of the developing countries are still using hydropower as the main energy generating source.

Sri Lanka is a developing country using hydropower as an energy generation strategy for decades but to accommodate present energy demand, it has started coal and diesel power plants as well. Sri Lanka predicts an annual growth of demand for electricity as 6.5%. As of 2016, the energy generation mix was comprised of hydropower contributing to 25% of the total energy generation while crude oil, coal contribute 31% and 35% respectively and finally 9% of other renewables, not to ignore the developments in wind power and solar energy (Danthurebandara, & Rajapaksha, 2019). Consumption of coal power and diesel power plants generated negative impacts on the environment, economy and the society as well. It is also found that the emission of CO_2 is 262kg per capita of electricity generation, and it reports a rapid growth when compared to the year 2000 figures which were 164kg per capita (Assessment of Power Sector Reforms in Sri Lanka, 2015). Therefore, Sri Lanka is in need of sustainable and green concepts to be embedded into the new and existing developments to reduce the impact. The Green Sri Lanka rating system (GREEN SL) has been introduced by the Green Building Council and the Urban Development Authority of Sri Lanka for existing buildings as well as for new developments to reduce the carbon foot print by integrating green concepts to the buildings. The use of renewable energy has also been a major aspect. Since 2012, emerging and developing countries have started adding solar PV capacity to their grid (Beuse, Dirksmeier, Steffen, & Schmidt, 2020), and Sri

Lanka is not an exception. Further, the project life cycle cost has proven that energy cost during the maintenance and operating costs of the buildings are significantly high than the capital investment of implementation of solar PV panels. Considering the above-mentioned factors, the clients are now looking forward to investing in more sustainable projects. Photovoltaic solar is one of the popular renewable energy generation sources widely in discussion that could lead to sustainable development because photovoltaics is becoming a viable solution for clean on-site energy production and utilization (Mendis, Huang, Xu, & Zhang, 2020). Since, Sri Lanka is a tropical country and solar power is widely available throughout the year. In present, the use of photovoltaic solar is popular among residential projects because any excess produced can contribute to the national supply by net metering. This allows the people to consume energy without any disruption and can have an extra income by selling the excess units generated to the national supply by net accounting. This will positively help the economic development of the society, and also the process is environmentally friendly hence the discharge of greenhouse gases (GHG) to the atmosphere will be reduced. The implementation of solar PV energy is now becoming an essential part ensure the residents, buildings and cities are stepping towards low carbon energy transition (Saretta, Caputo, Frontini, 2019).

Buildings in the developed countries are responsible for approximately 50% of the total energy consumption and release of GHG for about 30%. The building's functioning energy varies based on the physical, operational, and functional features, as well as climatological and sequential properties of the building (Fathi, Srinivasan, Fenner, & Fathi, 2020). Khan, Asif, and Stach (2017) mentioned that, the energy demand among residential buildings is expected to be doubled in 2025, compared to 2009. When considering the energy end-use sectors of an economy, the residential building sector in Sri Lanka is a dominant consumer by 50-70% of the energy used for operations such as heating, ventilation, and cooling (Geekiyanage, & Ramachandra, 2018).

When focusing on the residential building sector, it can be identified in many subcategories such as separate single houses occupied by one family, residential apartment complexes, condominium complexes, and townhomes (Hirt, 2015). These categories display distinctive differences between each type based on their market segment, usage and intensity of the energy. According to Geekiyanage and

Ramachandra (2018) detached single houses occupied by one family and multi-family condominium buildings are the two major energy-consuming housing sub-sectors in Sri Lanka.

The detached single-family homes appear to be the most suitable place where the mass energy consumption can occur (Minuto et al., 2020). Therefore, installation and adoption of solar PV in single-family homes can reduce the monthly energy expenditure to a greater extent over time for the owners (Mangiante et al 2020). According to Choi, Rayl, Tammineedi, and Brownson (2011) the United States encouraged to install PV systems to make costs modest with conventional forms of electricity and it had positive feedbacks (Kandt, Burman, and Simpkins, 2010).

1.2 Problem Statement

The rapid environmental degradation and the depletion of resources has led to the development of new technology replacing fossil fuels with renewable energy (Cai et al., 2020). The negative environmental and social impacts have now been identified by the authorities as well as the general public, and the implication of the renewable energy systems are taken into consideration. The whole building sector is accountable for consumption of world energy of about 40% of the total world's energy (Xie, Zhai, Sun, & Ma, 2020). Sri Lanka mostly depends on the Norachcholei coal power plant by 900MW for electricity generation which was started in 2011 and the mini diesel power plants. According to the Statistical Digest published by Ceylon Electricity Board, Colombo, stated that during the years of 2013 and 2016, electricity generation through coal power rose by 240%. Sri Lanka as a country, the increasing cost of importing coal and diesel has already become a burden on the economy.

According to Sansaniwal, Sharma, and Mathur (2018), solar power is one of the renewable sources that could replace the conventional non-renewable energy generation methods, to satisfy the growth of energy demand around the world. Solar PV can be used as green technology and it satisfies the GREEN SL requirements (Wijepala, 2017; Feng, Zheng, Wang, Yu, & Su, 2015; Mendis et al., 2020). Irrespective of its importance, a proper assessment and the application of solar PV is missing in the literature. The suitability of the application of solar PV, the benefits of the application, and the economic feasibility of the solar PV is not carried out considering a detached single-family residence in Sri Lanka. People are hesitant to opt for solar PV due to the lack of available information and the misbelieves (Tillmans, & Schweizer-Ries, 2011). According to the above studies done in this area, need of research in applicability of solar PV in Sri Lankan detached residential building units is vital. Thus, study is an attempt to fill those gaps.

1.3 Aim

The aim of this research is to examine the application of the PV solar systems in detached individual residential buildings in Sri Lanka in order to gain the suitability and the benefits for the residents.

1.4 Objectives

The research aim is intended to achieve through following objectives.

1. Review the various PV systems and types available globally as well as in the Sri Lankan context.
2. Examine the extent of PV solar panel application in residential buildings.
3. Identify the suitability of PV solar panel systems for residential buildings by interview survey from the occupants of buildings with PV solar panels
4. Comparison of effects on energy consumption due to implementation of PV Solar vs non-solar panel in residential buildings (Cost and number of units consumed)

1.5 Research Methodology

A comprehensive review of past literature on the subject arena is conducted to understand the photovoltaic solar systems' application in residential projects' efficiency when compared with the conventional systems, identify the significance of adopting PV solar panels in green building certificate requirements, advantages and disadvantages to the inhabitants with reference to books, journals, electronic sources, and other publications. Furthermore, a market survey was conducted among companies who provide solar PV services, to review the availability of the solar PV systems globally as well as in Sri Lanka and to examine the extent of PV solar panel application in residential buildings . . Case studies were selected from the market survey conducted. Detached single-residential units were selected with solar PV application, afterwards, structured interviews were carried out in the case studies, carried out to identify the suitability of solar PV panel systems for residential buildings and to compare the energy consumption patterns in convention and solar PV systems in residential buildings. Findings collected through market survey and the case studies were analyzed to prove the suitability of solar PV in detached single unit residential buildings. The entire process adapted is further illustrated in Figure 1.1.

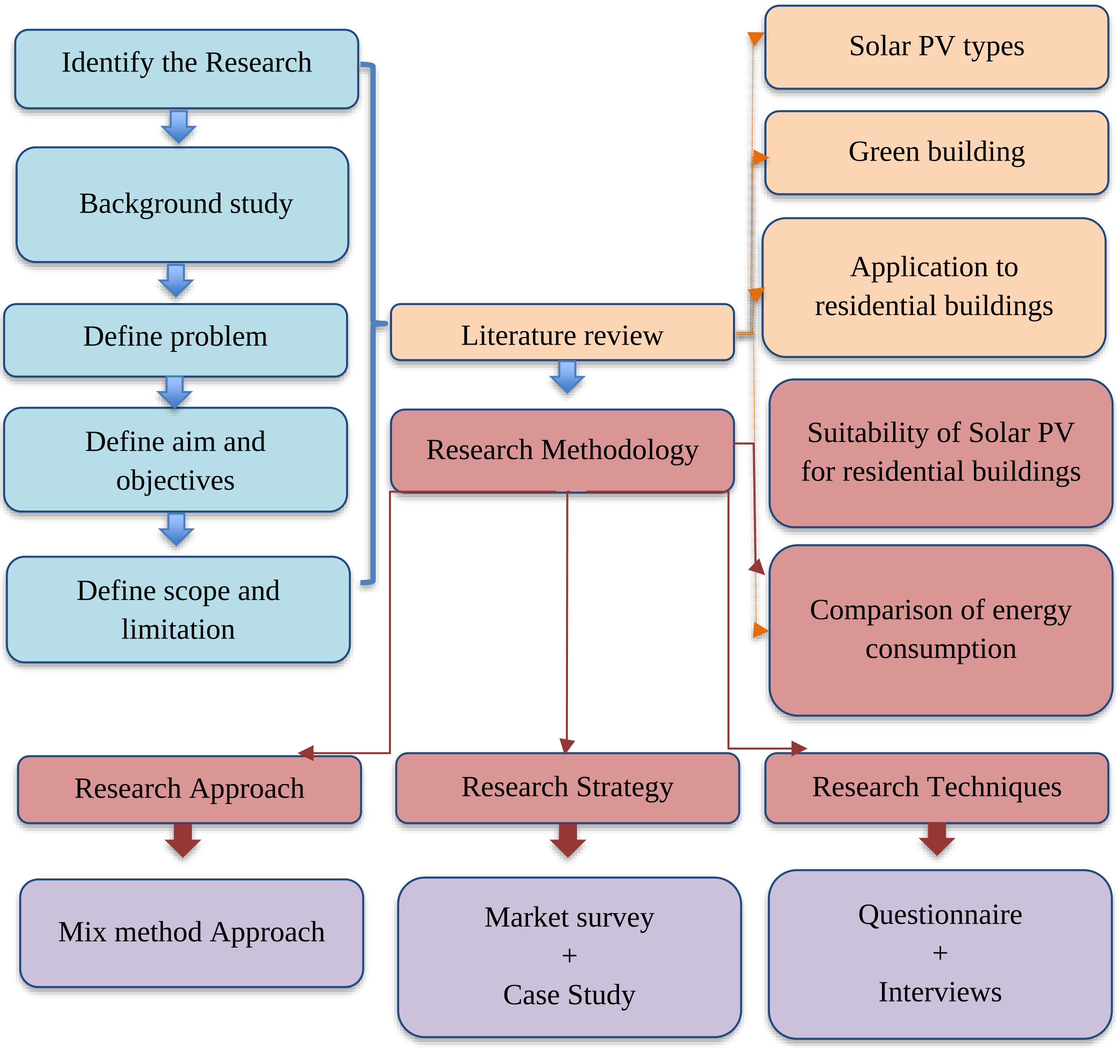

Figure 1.1: Research Process

1.6 Scope and Limitation

The scope of this research is on application of solar PV in detached individual residential buildings in Sri Lanka. Further, this research is limited to residential solar PV users because it is becoming popular in Sri Lanka and also majority of the people have misbelieved of using it.

1.7 Chapter Breakdown

This report comprised of five chapters that demonstrate the entire process adopted, activities carried out and the results obtained are explained.

Chapter one presents an entry to the dissertation through a summarized introduction to the study and its background. The chapter contents cover the areas of research background, problem statement, aim and objectives to be achieved in this study, research methodology and scope and limitations in conducting the research, chapter breakdown are presented relevant to the study.

Chapter two consists of a detailed and critical appreciation of previous scholarly literature and theories scrutinized on the subject area of implementing photovoltaic solar system in residential buildings with special reference to the project management perspective. This provides a detailed logical review on the literature related to energy consumption in buildings, role of the project manager, practice of solar panels, types of solar panels, application of solar PV, and barriers in application of solar PV.

Chapter three comprised of the research methodology. It covers the conceptual framework of the study. This chapter will shed lights on the various types of data gathering techniques, data analyzing methods and tools, research process and actions taken improve the validity and the reliability of the research.

In this chapter, the data collected using the specified techniques are evaluated to bring out a meaningful information. The analyzed data are represented graphically and also reviewed critically. The data are collected through market survey using a questionnaire for thirty-two number of solar PV service providers and two case studies were conducted with structured interviews with solar PV users.

Chapter five provides recommendations and conclusion to the research study using the research findings and the implications analysis through of the data analysis for strategic decision making. This chapter provides conclusions with reference to the research aims and objectives. Moreover, this chapter will recommend research areas that can be further researched in future.

1.8 Chapter Summary

This chapter discusses the research background, problem statement, aim of the research and objectives, research methodology, scope and limitation and chapter breakdown. This chapter discussed on the importance of renewable energy in the developing world. This leads to the problem statement on mitigating environmental impacts from introducing sustainable construction via solar PV or residential units. Solar PV is the most suitable and viable energy source to cater the ever-increasing energy demand. The application of solar PV in Sri Lanka is also discussed in this chapter. Considering all these facts, this study aims at assessing the application of the solar PV system in residential buildings in Sri Lanka. Scope of the research study, limitation and chapter breakdown is also included in this chapter.

CHAPTER 2 – LITERATURE REVIEW

2.1 Introduction

This chapter consists of a categorical review of the past literature findings related to sustainable construction and its importance in the present, due to that the role of the project manager also specifies to the sustainable construction practices. Furthermore, energy consumption in different building types in the world as well as in Sri Lanka. Also discussed about the residential building sector, which is the most energy consuming building sector in Sri Lanka (Geekiyanage, & Ramachandra, 2018), as well as in the world. Energy efficiency is a main topic in the Green Building Rating (GREEN SL) system because it has a major impact on the environment. This chapter also focuses on the practice of solar panels around the world have found sustainable practice for the energy generation with the rising energy demand. Also types of solar panels such as crystalline and thin-film photovoltaics, application of solar PV such as Building Integrated Solar PV (BIPV), indoor thermal comfort, irrigation and agriculture were included.

2.2 Significance of the Sustainable Construction

The construction industry maintains a solid association with sustainable development on the 'triple bottom line' of economic progress, environmental effect, and social growth (Sev, 2009). Construction industry is held responsible for approximately 35%–40% of CO2 releases, consumption of about 40% of raw materials and about 25% of global timber consumption. Moreover, the worldwide industry release of solid waste, consumption of total energy production and usage of water are 40% and 16% respectively. This proves that the global construction sector has a detrimental impact on the environment (Serpell, Kort & Vera, 2013; Energy Information Administration (US), 2012).

Sustainable construction can be defined as usage of renewable, recyclable materials in construction and building projects while minimizing energy consumption and wastage (Yu, Shi, Zuo, & Chen, 2018). The predominant purpose of sustainable construction is to minimize the environmental impact the project has (Aarseth, Ahola, Aaltonen, Okland, & Andersen, 2017). By its nature, construction industry is one of the leading industries that heavily relies upon natural resources. With the growing pressure and concern from governments and pressure groups regarding pollution, destruction, wastage and over usage of limited resources, the construction industry is compelled to minimize the environmental impact they cause (Ding, Feng, Li, & Zhou, 2019). Kivila, Martinsuo, and Vuorinen (2017), indicated that previous scholarly studies have identified the sustainability in projects are recognized in four aspects namely, product related, process related, and organization and people related. Another important point raised by Yu, Shi, Zuo, and Chen (2018) is that sustainability of a construction does not end once the building or the project ends. It is a continuous process (Goh, Chong, Jack, & Mohd, 2020) where the building or the completed project continue to reduce the impact to the environment by recycling the disposing solar PV after its life span (Contreras-Lisperguer, Muñoz-Cerón,, Aguilera, & de la Casa, 2017).

2.3 Practice of Solar Panels

The main idea of using renewable energy in the world has originated due to the increasing exhaustion of natural resources and the increase of GHG emissions (Rozentale, Lauka, & Blumberga, 2018). Increasing demand for energy has moved the people to use non-renewable resources such as coal, lignite, and nuclear. These resources are environmental polluters and it may deplete in the future (Mohamed et al., 2017; Farid, Khudhair, Razack, & Al-Hallaj, 2004; Pielichowska, & Pielichowski, 2014).

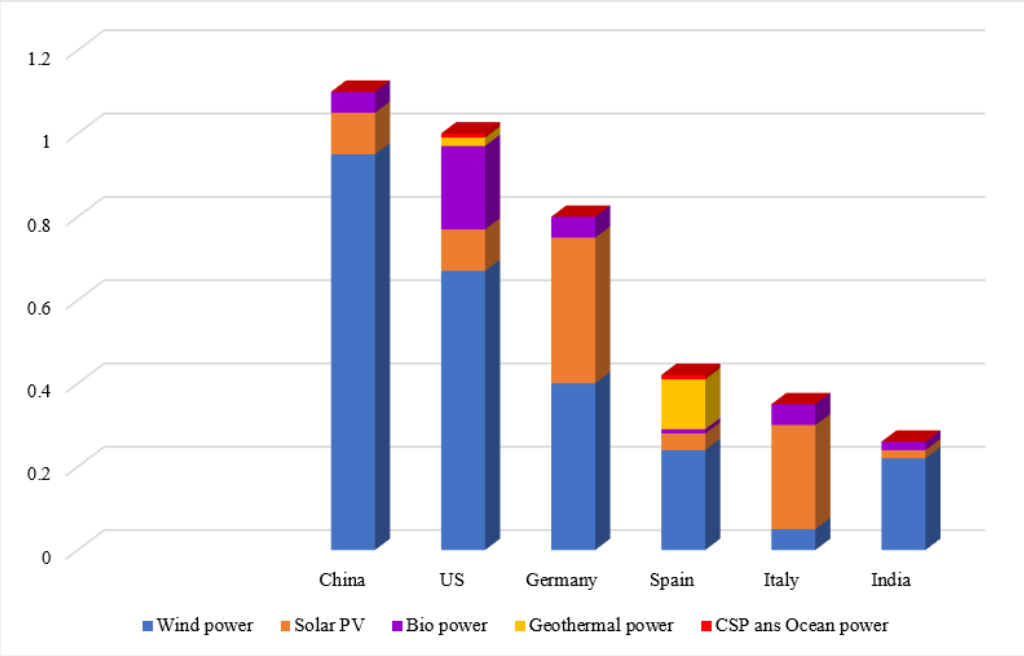

Figure 2.1: Renewable power usage in the world

Source: (Sawin, Sverrisson, & Rickerson, 2014)

Above Figure 2.1, is a graphical representation of renewable energy usage of leading countries such as, Germany, India, Italy, Spain, Germany China and USA. Germany uses the highest level of solar PV as the renewable source of power generation in the world (Sawin, Sverrisson, & Rickerson, 2014).

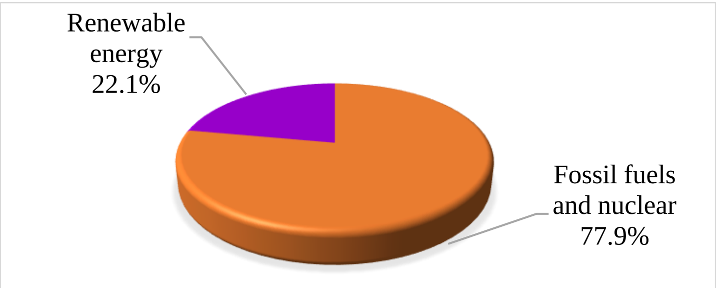

Figure 2.2: Sources of energy production around the world

Source: (Ding, Feng, Li, & Zhou, 2019)

Figure 2.2, shows how the energy has generated using non-renewable sources. From the total production of electricity, highest percentage of global electricity is produced through fossil fuel and nuclear sources. As a percentage, it is 77.9% and these energy sources are proved to be expensive and result in high level of negative impact on the environment, through releasing CO2 into the atmosphere, thus causing air pollution, and only about 0.7% which is an insignificant rate is being generated through solar PV (Sawin, Sverrisson, & Rickerson, 2014).

Figure 2.3, represents the portion of renewable energy sources which were taken from figure 2.2

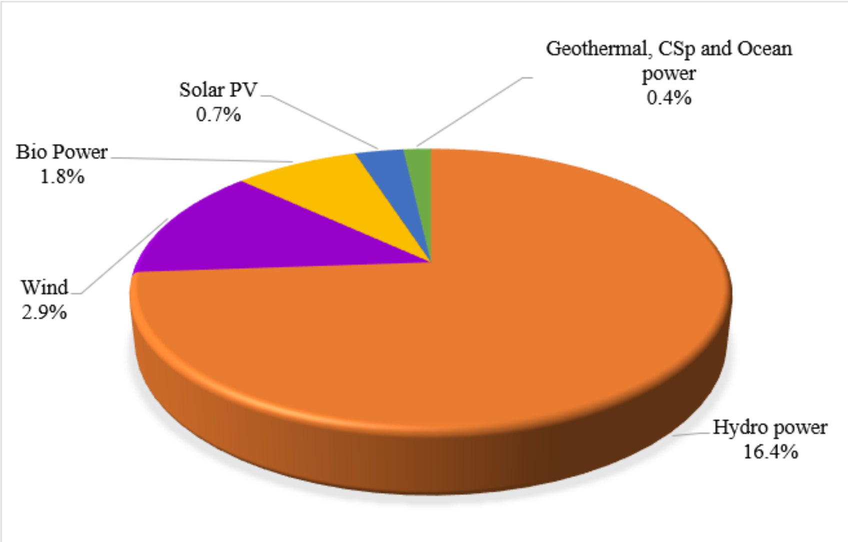

Figure 2.3: Renewable sources of energy production around the world

Source: (Ding, Feng, Li, & Zhou, 2019)

According to figure 2.8, hydropower is the main source for world's energy generation from the renewable energy sources, followed by wind power. Third highest is bio power followed by solar PV. Least is by the geothermal, CSP and ocean power.

However, due to the current upward trend in energy, solar energy is becoming the best option for the energy demand because it has a less environmental impact, and also it is less costly compared against the typical and most popular sources of energy like fossil fuel. Solar power has been identified as the renewable energy source with highest availability and access, because rate at which the sun emits its heat is 3.8×1023 kW, of which almost 1.8×1014 kW is captured by the earth (Panwar, Kaushik, & Kothari, 2011). In Sri Lanka, it is about 15–20 MJ/m2/day (4.2 to 5.6 kWh/m2/day) (Renné, George, Marion, Heimiller, & Gueymard, 2003). Figure 2.4 shows the Global Horizontal Irradiation (GHI).

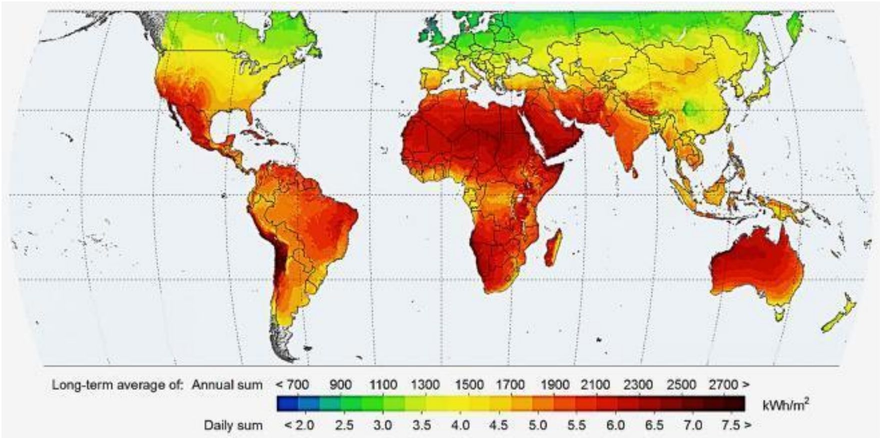

Figure 2.4: Map of global horizontal irradiation (GHI)

Source: Libal, Kopecek, Roever, & Wambach, (2007)

According to Figure 2.9, the Map of global irradiation, it shows that most of the countries around the world receive enough sunlight for energy production using solar. According to the map it clearly represents that the Sri Lanka is located in an area with good irradiation. So that the use of solar PV is benefitted.

2.4 Types of Solar Panels

Generally, solar energy technology can be identified and categorized under two main types. They are namely solar PV and concentrating solar-thermal power (CSP). While PV cells absorb and convert direct sunlight into electric current, CSP uses its reflective shells/surface to concentrate the direct sunlight into a beam that is used to heat a working fluid in a receiver (Edenhofer et al., 2011). A French physicist in 1839 identified the Photovoltaic effect for the first time in the world, which is converting electricity to the photovoltaic effect (Kenneth, & Paul, 1984). The very first usage of it was in space, but in the current context it is widely used for anywhere there is an electricity requirement from small houses to skyscrapers. Solar generated PV energy has proven to become one of the highest promising and most reliable technological advancement in the renewable energy arena (Chowdhury et al., 2020). According to Parida, Iniyan, and Goic, (2011), the solar PV effect is converting sunlight into electricity using semiconductors. The authors further explain the material of the semiconductors and how PV cells reacts and makes room for electrons to flow in one direction creating an electric current, when the photons of the sunlight reached the panel, absorbed by the and eject electrons creating a pool of electrons. Using semiconductor material, the solar PV cell converts the sunlight into electricity, and because of this phenomenon is described as PV's cell aims and guides the free electrons to flow in one direction, which forms an electric current (Parida et al., 2011). There are two main types of PV cells in the world. They are known as Crystalline and thin-films. They demonstrate distinctive different features in terms of their manufacturing costs and efficiency (Kalogirou, 2013). Furthermore, PV modules are commonly rated between 80 Watts (W) and 250 W (NREL, 2019).

As shown in the below table 2.1, the crystalline silicon is the most popular type of solar panel with highest demand in the market so far, that accounts for 85% (Kayali, & Alibaba, 2017).

Table 2.1: Types of solar PV used in buildings

Type		**Pros**	**Cons**	**Efficiency (Electrical)**
Crystalline	Monocrystalline	High efficiency	High cost	17-22%
		No defects or impurities	Light sensitive	
	Microcrystalline	High efficiency	Dislocations	11-17%
		Moderate cost	Short service life	
Thin-film	Copper indium gallium selenide	Low cost	Deployed at the small scale	10-13%
		Moderate efficiency		
		Light weight		
	Amorphous silicon	Manufacturing cost is low	Low efficiency	6-7%
		Advanced efficiency production	Performance instability	
		Heat impact is low		

	Cadmium telluride	Less expensive	Excessive copper doping will result in degradation of the device	10-11%
		Moderate efficiency		
		Large manufacturing volume		

(Adapted from Wang, Han, and Guan, (2020); Kalogirou, (2013); Kayali, and Alibaba (2017)

2.6.1 Crystalline photovoltaic (CPV)

Crystalline photovoltaic is also known as concentrator or concentration photovoltaic of which the principal focus is to generate power through most cost-effective way, predominantly the sun with Direct Normal Irradiance (Burhan, Shahzad, & Ng, 2017). This type is manufactured using cells that are sliced from a single cylindrical crystal of silicon. This considered to be the most productive PV technology that converts around 15% of the direct sunlight energy (Bakos, Soursos, & Tsagas, 2003). But the manufacturing process of crystalline silicon is complicated thus resulting in a significantly high cost (Mughal, Sood, & Jarial, 2018).

There are many advantages of adopting CPV such as, high efficiency through Direct Normal Irradiance (Burhan, Shahzad, & Ng, 2017), low level of temperature coefficients, stable and improved energy production using natural source, low capital expenditure and reduced payback time in financial perspective, low environmental impact through double usage of land like agriculture, lower impact from price changes of semiconductors in the market, cooling water in not needed (Nomura, Ota, Minemoto, & Nishioka, 2014). When considering the disadvantages of CPV, it requires constant cleaning to alleviate soiling losses and has a poor technology standardization (Mughal, Sood, & Jarial, 2018). High CPV cannot use diffuse radiation while low CPV can only utilize a fraction of the diffuse radiation. This is a definite limitation in using CPV (Zhou, Liu, Chen, & Wang, 2019).

2.6.2 Thin-film photovoltaic (TPV)

Thin-film photovoltaic (TPV) is predominantly a thin layer of film of active materials carefully placed on glass in different formats. The film thickness differs from a negligible nanometer to tens of micrometers. (Chopra, Paulson, & Dutta, 2004). Thin-film solar cell (TFSC) is developed and fabricated using the same material layers that are used in general solar panels but this time merging them as thin films. This enables maximum usage of the material and surface while reducing the material cost significantly (Schock, 1996 & Fthenakis, 2009). Solar PV technology is expected to distribute approximately 345 GW and 1081 GW by 2020 and 2030 (Tyagi, Rahim, Rahim, Jeyraj, & Selvaraj, 2013). Most of the developed countries are now using massive solar PV plants for electricity generation.

There are numerous types of TPV solar cells that are used widely. The most popular type of thin-film solar cells is manufactured using cadmium telluride. Another popular material is copper indium gallium selenide (CIGS) which is used to produced thin-film solar cells (Ramos-Ruiz, Wilkening, Field, & Sierra-Alvarez, 2017). Gallium arsenide (GaAs) has shown 30% efficiency in labs but very expensive to manufacture. Lastly the most matured and oldest TPV cell type is Amorphous silicon thin film. It is very much popular for its reasonable pricing, nontoxic nature and availability, even though it is average in efficiency (Stuckelberger, Biron, Wyrsch, Haug, & Ballif, 2017).

They have multiple components such as solar cell arrays, modules, and means to control or to regulate the system for both mechanical and electrical connections, therefore it is designed in a manner to produce higher conversion efficiencies (Kannan, & Vakeesan, 2016). Due to the advancement in solar PV technology, the second and third generation solar PV panels demonstrate the high possibility of production expansion as well as to reduce the manufacturing cost and environmental impacts (Das et al., 2018). TPV is a cheap and simple production process with lesser material consumption, comparatively lighter weight, very much useful in utilizing diffuse radiations, less cleaning required. Meanwhile its disadvantages can be listed as, shorter lifetime, lower efficiency, requires larger space to generates the same energy as CPV modules, difficulty to install, and unstable (Husain, Hasan, Shafie, Hamidon, & Pandey, 2018).

2.5 Solar PV installation systems

The on grid solar systems are the most common and famous system among households and corporate sector (Irfan, Zhao, Ahmad, & Rehman, 2019). They further clarified, these systems use solo inverters or micro inverters and batteries are not required to function. Most importantly these systems are connected to the public electricity grid too and if you generate any excess power, it will be exported to the public grid and you usually get paid for the excess power you generate. Xu, Wang, Solangi, Zameer, and Shah (2019) mentioned, on-grid solar systems will not be able to operate during a blackout due to safety reasons unlike hybrid systems.

Off grid systems are not connected to the public grid and therefore requires battery storage and these off grids solar systems must be designed well to generate enough power throughout the year to meet household's requirements and should ensure those have enough battery capacity to function well even in winter seasons where there is less sunlight (Hlal, Ramachandaramurthy, Sarhan, Pouryekta, & Subramaniam, 2019). Off grid systems are much more expensive compared to on-grid systems as of the high cost of batteries and off grid inverters and much more needed and used remote areas that are far from public electricity grid (Ghenai, Salameh, & Merabet, 2020).

Modern hybrid systems combine both solar and battery powered in one and available in many forms. Systems which are already connected to the public electricity grid can start taking advantages of battery storage due to the decreasing cost of battery storage (Alharthi, Siddiki, & Chaudhry, 2018). This means it will be able to store energy that is generated during the day time which will be used in the night. So, consumers will be able to use both the systems time to time.

Net-metering

Net Metering will allow a customer to use renewable energy within his household or his premises to generate & use electricity and export excess electricity generated to the national grid (Wijayatunga, 2014).

Net-Accounting

Net accounting is much more similar to Net Metering allowing a customer to reduce their electricity bill and earn additional income and the solar power system will export energy to the national grid and those units of energy will be deducted from the electricity bill of that particular consumer (Wijesinghe, Najim, Fernando, & Liyanage, 2020, October).

Net-Plus.

This scheme will allow a consumer to earn income for the total amount of energy units generated by solar power system irrespective of the existing electricity usage (Abeywickrama, Sridarran, Gowsiga, & Dilogini, 2022). Further, the solar power system will export energy to the national grid and it will be metered and the consumer will get paid for these units from CEB.

2.6 Usage of Solar PV in different sectors

In the present application and usage of solar energy is multi-faceted because that’s abundantly available with a very less environmental impact. Solar power is widely used in many aspects like, building heating or cooling, functioning of lights, cooking, drying, heating, operating electrical appliances to name a few (Kannan, & Vakeesan, 2016). According to Chowdhury et al., (2020) the lifespan of an average solar PV panel is 25 years.

2.6.1 Building integrated photovoltaic (BIPV)

BIPV application is becoming popular in residential areas where it is difficult to locate a grid set for electricity. It is simply an array of panels set on the roof or walls (Sheikh, 2008, March). Solar PV cells can easily be mounted above or on an existing roofing model or on a wall system (Zell, Gasim, Wilcox, Katamoura, Stoffel, Shibli, & Al Subie, (2015). This system is an onsite energy generation system also if there is any excess energy produced that can be connected to the main grid (Candanedo, & Athienitis, 2009). This is also a good income source with little or no emission of GHG gases as well. BIPV can improve the energy performance as well as the production of electricity from solar radiation (Saretta, Caputo, & Frontini, 2019). Solar PV is widely used as a mode of remote power generation that can operate electrical appliances or operate through a battery. Common uses of the same can be listed as, water pumping, street and building lights etc. Another key usage of solar PV is that it can be used to charge electrical devices where there is not plug-in power to charge batteries of devices (Kannan, & Vakeesan, 2016).

2.6.2 Indoor thermal comfort

The thermal comfort is the level of satisfaction that expresses the thermal satisfaction one feels, and it varies from person to person. This is measured through, humidity, temperature, velocity and mean radiant temperature of air, metabolism, and clothing thermal resistance (Alam & Salve, 2021). Solar water heating, air heating, and cooling is prevalent nowadays and widely in commercial and residential buildings. Nevertheless, air heating or cooling is also used in agriculture when storing the produce at the optimum temperature (Kannan, & Vakeesan, 2016). There are two main types of solar heaters as, solar air heaters (SAH) and solar water heaters. SAH is unimpacted from winter freezing and has the ability to heat the atmosphere fairly quickly by directly heating the air, thus widely used for room heating in industrial buildings, farmhouses, drying and wheel dehumidification systems (Toğrul, & Pehlıvan, 2003). The solar water heater will heat the water from the tank and then supply hot water (Dhinakaran et al., 2020).

2.6.3 Irrigation

An electrical motor is connected to a microprocessor to control a solar energy system to operate the drip or sprinkler irrigation systems. This ensures the optimal water utilization and efficiency. Hence it is widely popular among the world in irrigation (Runge, & Downie, 2014). According to Rizi, Ashrafzadeh, and Ramezani, (2019) when comparing conventional and solar PV the initial capital, operating and maintenance cost, and diesel pump replacement are 2–4 times higher in conventional than a solar PV pump. It is obvious that the solar pumping system is more environmentally viable because it requires lesser maintenance costs with no fuel cost. Furthermore, Eker, 2005 and Kumar et al., (2020), states that PV water pumping gained more popularity because of the non-availability of electricity in rural areas and an increase in conventional fuel prices.

2.6.4 Agriculture

Solar PV is commonly used in the agriculture field and there are so many techniques powered by solar PV for fluid management of crops, freezing and drying of fruits and vegetables etc. But the artificial ones are not economically and environmentally viable

(Swamy, Rajesh, Pooja, & Krishna, 2013; Goud, Reddy, Chandramohan, & Suresh, 2019; Sallam, Aly, Nassar, & Mohamed, 2015). Not only in the agriculture sector, but solar drying can be used in other industries as well. One of the other applications in solar PV is heating the space during gloomy, cloudy days and during night times. This arrangement avoids heavily relying on and usage of fossil fuel to heat the atmosphere and space. Certain occasions, where gas or oil heaters are used as backup heaters can be replaced with solar PV, like in greenhouses so that the release of CO_2 helps better plant growth (Devabhaktuni et al., 2013). In central and northern China, the solar technology is used for the air source heat pump (ASHP) and it is recognized as a healthy approach to save energy. This is a popular method of space heating and hot water supply (Fan et al., 2020; Chen, & Qi, 2014).

2.6.5 Streetlights

Many countries in the world used Solar PV to power their city streetlights during the nighttime with the use of solar panels attached to the light post. Even in Sri Lanka it is a very common sight to witness solar powered streetlights now a days. During the daytime, the batteries are charged which then powers light-emitting diodes (LEDs) at night, to light the streets (Babatunde, Akinbulire, Oluseyi, & Emezirinwune, 2019). According to Mughal, Sood, and Jarial, (2018) some parts of the world extended the usage of solar PV to power smart sensors attached to streetlights that will direct the drivers during the nighttime for parking spaces and assist in emergencies.

2.6.6 Vaccine Refrigerators

In underdeveloped countries like Sri Lanka, one cannot guarantee the supply of 24-hour uninterrupted electricity, and it is a common factor to find there is no electrical grid (Uddin et al., 2021). Authors further stated that, solar-powered vaccine refrigerators are highly useful for healthcare (hospitals, ambulance) in rural villages to facilitate and store critical medicines (Bakos, Soursos, & Tsagas, 2003). Stability of the temperature is the most important factor when storing vaccines. Failure to do so, vaccines will be damaged due to exposing to the heat beyond advised. For decades medical sector tried many options, including kerosine or battery powered cooling systems, but all had one common issue, unreliability of uninterrupted power to keep the pharmaceutical items, medicines, vaccines, blood packs at all times (McCarney, Robertson, Arnaud, Lorenson, & Lloyd, 2013). On the other hand, PV solar powered vaccine refrigerators, directly convert solar energy retrieved through PV to a DC electric current and uses that energy to freeze water or any other cooling compound or material, and then stored in the energy bank to be utilized during the night times and gloomy or rainy days (Haidari et al., 2017).

2.7 Energy Consumption in Different Buildings

With the rapid growth in global population, demand for buildings and related services, and comfort and luxury expectations and, time spending indoors increases the demand for energy. Energy consumption of buildings is on an upward trend mainly because people nowadays tend to spend 90% of their time indoors (Zhao, Houchati, & Beitelmal, 2017). As a result, indoor thermal comfort plays an important role in ensuring the satisfaction, productivity, and wellbeing of the building residents. Zhao etal., (2017) stated buildings in the developed countries consumes around 50% of the total energy consumption and 30% of GHG emissions. The building's functioning energy attributes depends on the aspects like climatological and historical properties, physical, operational, and functional features of the building. (Fathi, Srinivasan, Fenner, & Fathi, 2020).

Energy consumed in residential and commercial sectors accounts for 20.1% of the total world energy consumption (IEO, 2016). Both residential and commercial sectors have already increased in energy consumption by up to 20% and 40% in developed countries and also have majorly increased in other sectors such as industrial sector and transport and logistics sectors (Perez-Lombard, Ortiz, & Pout, 2008). Commercial buildings use energy management systems to regulate energy consumption (Streltsov, Malof, Huang, & Bradbury, 2020). Commercial buildings can be identified as two main categories (refer Figure 2.5 and figure 2.6) with respect to the total building areas and the cooling (HVAC) system it uses (<20,000m2) and large commercial buildings (≥20,000m2) (Ding, Feng, Li, & Zhou, 2019).

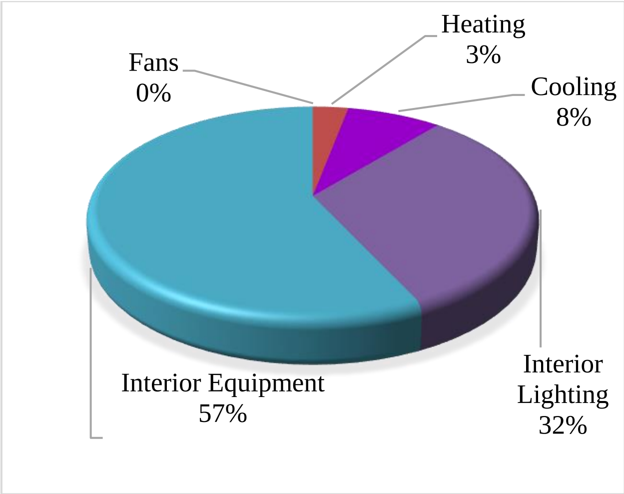

Figure 2.5: Breakdown of energy consumption in small commercial buildings

Source: (Ding, Feng, Li, & Zhou, 2019)

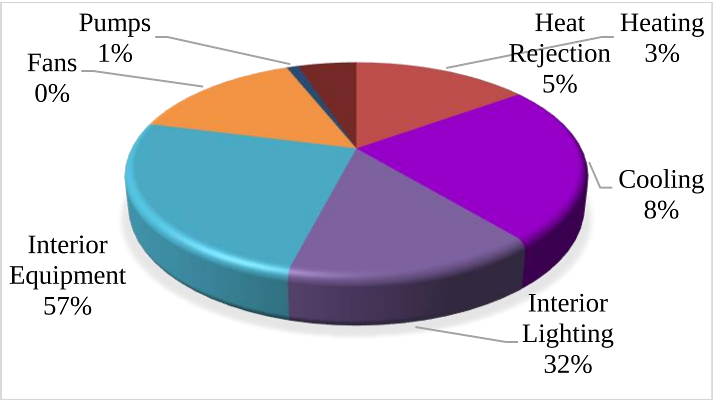

Figure 2.6: Breakdown of energy consumption in large commercial buildings

Source: (Ding, Feng, Li, & Zhou, 2019)

Figure 2.5 and 2.6, compares the energy consumption in two different sizes of commercial buildings in China. In both buildings, the highest energy consumption is for interior equipment, while the least is for the use of pumps and heating in the large and small commercial buildings respectively.

The energy consumption of hospital buildings is different compared to residential and commercial buildings. The main reason for this is, hospitals comprise of completely different and crucial functional areas, machinery and equipment that are unique to hospitals, and the structures in use with reference to different medical needs from simple to the most complexed machineries. Thus, these machineries and systems demand diverse methods of energy, like gas, electricity, hot and chilled water and steam (Kaiser, Eagan, & Shaner, 2001). According to Kaiser et al (2001), the energy consumption in hospitals is twice the general public buildings.

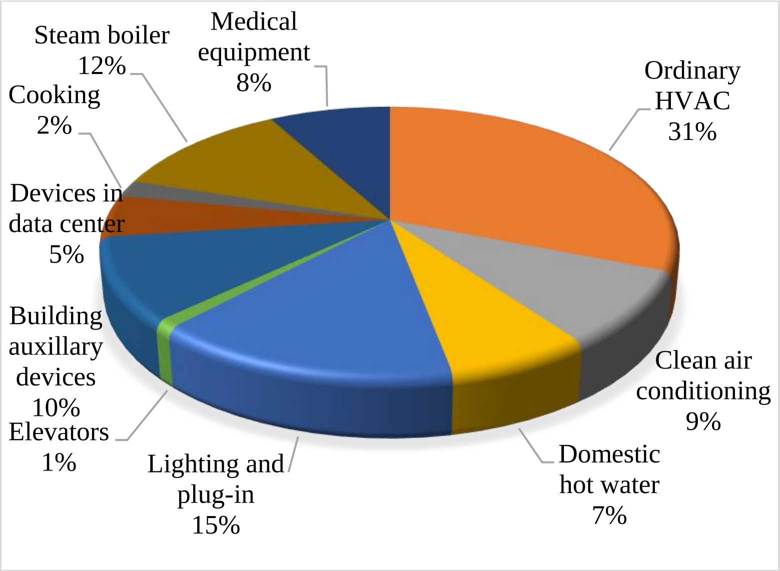

Figure 2.7: Breakdown of energy consumption in a hospital building

Source: (Shen, Zhao, Ge, & Zhou, 2019)

Figure 2.7 shows the breakdown of energy consumption in a hospital building. It represents different areas of energy consumption as a percentage of the whole building energy consumption. The highest level of energy usage in hospitals is dedicated to the ordinary HVAC system which has 31% from the total consumption while the least is used for the purpose of elevators, which is 1% of the total.

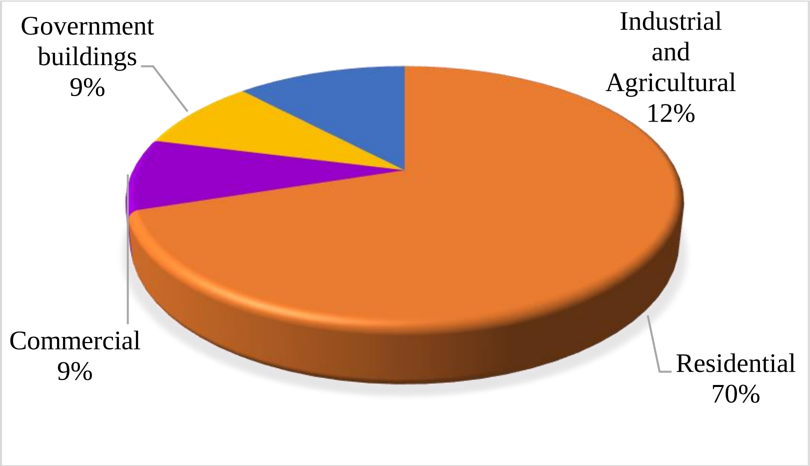

Figure 2.8: Energy consumption in building sector

Source: Salih (2018)

According to figure 2. 8, the residential building sector accounts for the largest portion of energy consumption, followed by industrial and agriculture. The least is from the commercial and government building sector.

2.8 Energy Consumption in Residential Buildings

When considering the energy end-use sectors of an economy, the residential building sector is a dominant consumer by 50-70% of the energy used for operations such as heating, ventilation, and cooling (Geekiyanage, & Ramachandra, 2018). The building segment of Sri Lanka is held accountable for consuming 46% of the total energy consumption. On the other hand, industrial sector consumes 25% of the total energy and consumption of transportation sector 29% (Rajapaksha, Hyde, & Rajapaksha, 2010). Residential buildings can be identified in many subcategories such as singular units of houses used by one family, duplex, apartment and condominium building complexes, and townhomes. These subsections are different from each other based on the structure of the market they target, usage and intensity of energy. Energy consumption in residential buildings varies significantly due to variations in building sizes and geometries, occupant behavior, education level, and limited data (Swan, & Ugursal, 2009). Energy consumption in residential buildings is a directly result of home and kitchen electrical appliances, cooling or heating of the indoors through air-conditioning, fans or thermal control, residential transportation and modes of fuel used (Ding, Feng, Li, & Zhou, 2019). However, in accordance to the culture and lifestyle, a set of potential appliances or devices that are present in the buildings will also affect the variation of the energy consumption (Crawley et al., 2001; Haas, Biermayr, Zoechling, & Auer, 1998). Figure 2.5 shows the energy consumption in residential buildings. According to Geekiyanage, and Ramachandra, (2018), singular and detached units of houses used by one family and multi-family condominium housing complexes are the two major energy-consuming residential building categories.

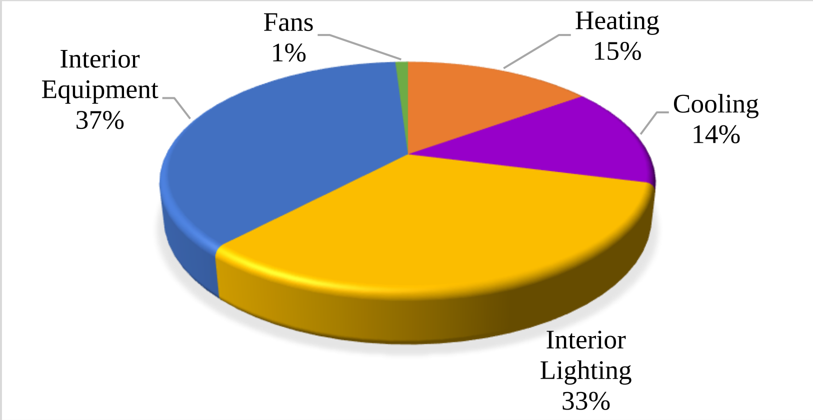

Figure 2.9: Energy Consumption in residential buildings

Source: (Ding, Feng, Li, & Zhou, 2019)

According to Figure 2.9, interior equipment consumes the highest portion of energy followed by interior lighting, and the least is by the operation of fans.

Recently, the urban residential buildings in Sri Lanka are moving toward improving an upward trend in the energy demand (Kumanayake, Luo, & Paulusz, 2018). The country has been moving towards renewable energy sources replacing the imported fossil fuels, also the policies are amended towards a green economy after realizing the need to change to clean energy (Mendis, Huang, Xu, & Zhang, 2020). In the past decades, attention for solar energy increased and attempts have been taken place to assess the amount of solar irradiation that is incidental on building envelopes and evaluate the potential for active and passive solar heating (Compagnon, 2004; Redweik, Catita, & Brito, 2013).

2.9 Barriers in Application of Solar PV

Even though the solar PV industry is evolving rapidly as a renewable energy option, it also faces several obstacles in development (Kannan, & Vakeesan, 2016). Even though this is a sustainable renewable energy sourcing method (Mughal, Sood, & Jarial, 2018), still the adaptation is limited in Sri Lanka. The reasons are in abundance and multi-variant; thus, the researcher will only be discussing the most common and appropriate barriers in adapting PV.

2.9.1 Initial cost

Every new concept struggle with the initial capital investment not just because the amount of the cost, but also the unpredictability of return on investments. Firstly, the manufacturing and installation of solar panels is complexed and demands an expensive, and advanced technology (Ciarreta, Espinosa, & Pizarro-Irizar, 2014; Morthorst, 2000; Menanteau, Finon, & Lamy, 2003; Lesser, & Su, 2008). However, solar PV's investment risk is very high whereas it is negligible in coal and fossil fuel projects. This is measured in terms of project limitation, funding, government backup, transmission and interconnection risks (Do, Burke, Baldwin, & Nguyen, 2020). These economic barriers always become the leading factor that discourages organizations in adopting a sustainable sources of energies and projects (Kannan, & Vakeesan, 2016).

2.9.2 Management barriers

This refers to the reluctance, poor engagement, and lack of interest in adopting novel technologies among the strategic level management (top management). This either can be due to the lack of awareness on the technologies, poor communication, or reluctance to invest on the same. At times, even if the top management extended their support, insufficient and inappropriate management and business portfolio for the target client may be a barrier (Karakaya & Sriwannawit, 2015).

2.9.3 Socio-technical barriers

Many researchers highlighted distinctive quality disparities and standard differences in various countries has made the consumer decision making process a complexed one. In addition, lack of knowledge on the technological advancements is also another contributing factor to the barriers (Karakaya & Sriwannawit, 2015).

2.9.4 Efficiency and the operating lifetime

According to Rehman, Bader, and Al-Moallem, (2007), not only the cost but also the efficiency and the operating lifetime are the challenges faced by solar panels. Solar panels are manufactured using many chemicals so that they are toxic to the environment, and it could be disastrous when disposing of. Therefore, disposing of solar panels is a challenging task for the manufactures as well as for consumers (Li, 2014; Grätzel, 2009).

2.9.5 Misconceptions

Lack of knowledge in advantages of using solar PV among rural communities around the world is one of the major challenges (Li, 2014; Eleftheriadis, & Anagnostopoulou, 2015). Lack of potential influence, policy barriers, and rivalry in markets are the leading factors that limit the progression (Li, 2014; Byrnes, Brown, Foster, & Wagner, 2013). Initial investment can never be recovered, solar PV is only a short-term solution, are some of the leading misconceptions.

2.9.6 Influenced by environmental aspects

Environmental aspects like intensity of sunlight, wind, cloud status has a greater impact over the performance of the solar panels (Hernandez et al., 2014; Kawajiri, Oozeki, & Genchi, 2011). In addition, solar power is not available, or it is not consistent all the time, so it is important to have other energy sources connected to the grid for consistent supply (Wu et al., 2014; Qin, Hu, & Li, 2020).

2.9.7 Need of complex circuits

Solar PV produces only a direct current (DC) and it cannot be used to operate domestic electrical appliances, as they require alternating current (AC). Therefore, to operate these appliances, solar PV require sophisticated circuits and storing systems to enable improved efficiencies (Kannan, & Vakeesan, 2016). Furthermore, there are a few remote possibilities that are being barriers to the solar industry. Large scale PV industries have some indirect effects over environment like, destruction of insects and birds as they are attracted to beams of sunlight (Wu et al., 2014). Managing the toxic fluids in the collectors after use is another concern. Water pollution as a direct result of heavy usage of water to clean and cool turbine generators to increase the productivity (Kannan, & Vakeesan, 2016).

2.9.8 Lack of suppliers and continuity

Lack of suppliers of spare parts and after sales services providers is another common barrier in solar PV technology adaption. Even the companies who does the initial installation eventually experience difficulties in locating required spare parts and with time they will also lose interest in providing continuous technical support to the consumers (Florez, & Ghazali, 2020).

2.10 Chapter Summary

This chapter conducted a critical review on energy consumption in buildings and its significance, critical appreciation on the role of the project manager in sustainable projects, energy consumption of different buildings, energy consumption of residential buildings, practice of solar panels, types of solar panels application of solar PV such as BIPV, indoor thermal comfort, irrigation and agriculture etc. This chapter included a critical review on challenges and barriers in solar PV applications. Further this chapter includes a comprehensive discussion on the importance of sustainable practices in construction sector and how it is related to the renewable energy sources. According to chapter findings, the residential buildings have the highest energy consumption

CHAPTER 3 – RESEARCH METHODOLOGY

3.1 Introduction

This Chapter includes, how this study was conducted from the beginning to the end. Selection of the topic, the background studies, literature review, methodology, collection of data, analysis and the conclusion. This chapter designate the adapted research methodology in search of the research aim. The paradigm adapted for this research is elaborated though detailed analysis of research approach, and research methods. In addition, the data collection and analyzing techniques and the research process also indicated.

3.2 Outline

The Research methodology section mainly answers the two questions; 1) how the data was collected or generated and 2) how the data was analyzed. Research methodology provides specific procedures or techniques used to identify, select, process and analyze data relevant to the research study. The methodology section allows the reader to critically evaluate the overall validity and reliability of the study. This section includes research process and research design.

3.3 Research Process

Research process is a series of steps or activities used to achieve the research objectives. Research process defines the early stages of the research prior to deciding the research methodology (Kothari, 2004). Initially, this research study selected a broad area of research and, then after the literature review researcher narrowed down to choose a research topic. Afterwards, researcher identified a research plan along with the methodology considering the time constraints and availability of the resources. Data collection includes an initial market survey to find the most relevant solar PV application in Sri Lankan residential buildings. After that, researchers conducted case study interviews with Solar PV users to obtain their opinion on beneficial solar panel systems. Case studies were done for the selected residential units based on the data received from the market survey. Refer figure 1.1, for the research process of this study.

3.3.1 Background of the Study

This section focuses on research area of renewable resources with special emphasis on the implication of implementing solar panels on buildings. There are many types of solar panels offering a variety of benefits towards the environment, economy and the society. Background study referred to academic textbooks, journal articles, industry publications, government reports and company published materials. According to the literature review, solar panels are widely researched topic around the world in many industries. Researcher also recognizes that there are ample of previous studies conducted on the various types of solar PV panels as well as the different applications. However, there were very few studies on residential building sector. It was also the researcher's interest assess the application of soar PV in the residential buildings in Sri Lanka. Thus, the researcher was curious on this aspect and focuses to fill the identified research gap.

3.3.2 Literature Review

A thorough literature survey was done on the topics such as, significance of sustainable construction and, energy consumption in different buildings, practice of solar panels, types of solar panels, usage of solar PV in different sectors, barriers in application of solar PV, and strategies to enhance the application of solar. Further, it is understood that comparison of conventional and solar PV on residential buildings has to be tested on real projects.

3.4 Research Design

Research design refers to the holistic strategy the author takes to integrate all the aspects of the research and define their relevance toward the ultimate objectives of the research study (Sellitz & Jahoda, 1995). Durrheim, (2006) defined the research design as a moderator that act as the bridge between the research questions and objectives and its implementation.

The research onion by Saunders, Lewis, and Thornhill, (2009) is a widely popular illustration on the each and every step and stage involved in the research study. It explains the main layers that are required to accomplished to establish a strong research methodology (Raithatha, 2017). This is an effective model that paves way to researchers to design a strong methodology with clearly defined steps to follow (Refer figure 3.1).

3.4.1 Research Approach

As per Saunders et al., (2009) there are three major research approaches. They are deductive, inductive, and abductive approaches. Compared other two, deduction method of conducting research is more appropriate given the fact that adequate amount of past literature and research are available pertaining to the research problem or concept. This enables the researcher the retest the existing theories and frameworks through his study and suggest further development s and new approaches (Gary, 2004).

1. Deductive Approach – Hypothesis developed are tested using quantitative measures. The hypotheses are tested purely based in the quantifiable data gathered using an instrument, most popularly a questionnaire developed using the Likert scale. A large sample population is taken to gather data.

2. Inductive Approach - This is the qualitative approach of a research data analysis. Compared to the deductive approach the sample population is small and mostly the data is gathered using open ended questions, one on one interviews etc.

3. Abductive Approach – This is the mixed method of conducting research where both deductive and inductive features are exhibit in the research study. Lukka and Modell (2010) pointed out, this method is more effective than being stuck in an extreme deductive or inductive approach.

Trochim (2006) in his studies argues that deductive method of research is an approach that stress upon specific over general. Deductive method is a ‘top down’ approach where the researchers start from an existing, already tested philosophical theory and develop their arguments against the hypothesis (Kothari, 2004). Inductive method is a ‘bottom up’ approach where the hypothesis is tested based on opinions and responds of the participants of the sample population and thereby attempt derive a novel theory or a framework (Naoum, 2007; Creswell et al. 2007; Trochim 2006).

However, Dubois and Gadde (2002) argued that in an event of where it is difficult to base the research purely on a deductive or inductive method, there is a mid-path know and mixed method, which comprised of features of the above two. This approach aims to generate testable conclusions and test this through subsequent data collection. The abductive approach is used in this research because the qualitative and quantitative. Therefore, the present study employs abduction approach.

3.4.2 Methodological choice

Research onion defines three types of research methodological choices as quantitative, qualitative and mixed methods and Creswell (2013) has defined each methodology as mentioned below.

3.4.2.1 Quantitative method

Quantitative method is purely based on quantifiable data interpreted in numbers to analyze the variables. Saunders et al., (2009) define quantitative is every so often making use of as an alternative expression for any data gathering or data analysis techniques and procedure which produces or make use of numeric data. Quantitative approach concerns on questions as “how much” and “how many”, and strive to support the facts submissively (Bell, 2005). Quantitative data are worthwhile in evaluating the established theories and hypothesis.

3.4.2.2 Qualitative method

Qualitative research method involves collecting, analyzing and interpreting of non-numerical data that does not focus on quantitative or statistical analysis (Corbin, & Strauss, 2014). This method typically comprises of focused group discussions, observations open ended questions for participants to elaborate their opinions. Thus, it can be argued that qualitative approach has a greater extent of human interaction and communication. This approach is heavily used in developing new theories, concepts and arguments (Clement, Edwards, Rapport, Russell, & Hutchings, 2018).

3.4.2.3 Mixed method

This approach uses both of quantitative and qualitative data collection, analyzing and interpretation techniques process.

Table 3.1: Features of Quantitative, Qualitative and Mixed Approach of Research

Quantitative	Qualitative	Mixed
Pre-determined	Emerging methods	Combination of both quantitative and qualitative approaches
Instrument based questions	Open-ended questions	Both open and closed-ended questions
Performance data, attitude data, observational data and census data	Interview data, observation data, document data and audio-visual data	Mix of all forms of data
Statistical analysis	Analyzing text	Includes both statistical and text analysis
Interpret statistical outcomes	Interpret trends and patterns	Across database interpretations

Source: Creswell (2013).

3.4.4 Research strategy

Research strategy provides the overall direction to the researcher to conduct the study successfully. This is the holistic research structure the researcher should follow when carrying out the research (Sahay, 2016). Research strategy plays a pivotal role in the decision-making process of the research study. Saunders et al., (2009) suggests there are ample of strategies to follow when carrying out research such as surveys, case studies, experiments, narrative inquiry, ethnography etc. Anyhow, the research strategies can be interpreted in a different perspective. As Saunders et al., (2009) suggested, survey is one of the strategies used in research.

This research study focuses on identifying the solar PV usage in Sri Lanka. To fulfill that purpose, it is necessary to carry out a market survey. By conducting a market survey researchers can get a complete idea of the current solar PV usage in Sri Lanka. In order to get a thorough understanding as to what actually occurs in the solar panel market researchers used a survey to get the data. One of the objectives of this research is to find the suitability of solar PV usage in residential buildings. Researcher conducted case studies interviews to obtain data on solar PV usage in residential buildings in the second stage of this research.

3.4.5 Research techniques and procedures

Research technique describes the of data collection method and data analysis technique used in a study (Kagioglou et al., 2000; MacDonald & Headlam, 2011) which elaborates hereinafter. Both these activities are important in a research study. Bryman (2012) pointed out that section of method completely depends on the research methodology. Justification for the adopted data collection method and the method of data analysis is discussed in below.

3.4.5.1. Data collection techniques

The section of data collection covers data origins, data collection techniques in general and data collection limits, while the section on data processing includes how to interpret gathered data to reach a conclusion.

In research there are two sets of data namely, primary and secondary. Primary data which is refers to the direct data gathered. And the other is secondary data which contains information obtained through focused group interviews and discussions, observations, questionnaire etc. The secondary data is commonly gathered referring scholarly articles, books, magazines etc.

- Literature review

A comprehensive review of literature is highly important when conducting research. This helps to demonstrate the author's knowledge on the subject matter, the theories developed and its application on the studies and his/her ability to raise arguments (Randolph, 2009). Further when referring to past literature, it enhances the knowledge of the researcher on conducting research properly Gall, Borg, and Gall (1996). This study also initiated with a broad topic and narrowed down with the literature survey to a specific and a unique study.

- Market Survey

This was done to identify the solar PV usage in the Sri Lankan context. The people who were involved in the solar PV service providers were taken as the participants for the survey. A questionnaire was distributed among them to collect data. Compared to other surveys, some of the major benefits of this approach are that it is inexpensive, requires minimal work and can efficiently gather data from participants (Kabir, 2016).

As part of questions there were open-ended and close-ended questions. To answer some of those questions a Likert scale was given. Subsequently, to figure out the explanations behind certain questions, open-ended questions were added. Then they were analyzed using Relative Importance Index (RII) and content analysis.

Contacted forty number of solar PV service providers for the Market survey and only thirty-two responded to the questionnaire. They were providing services such as installing, importing, distributing, fixing and maintenance of solar PV. As examples Solar Power Partners (Pvt) Ltd, My Solar Energy (Pvt) Ltd, J Lanka Technologies, JA Solar Holdings, Jinko Solar to name a few.

- Case studies

Upon completion, the information obtained from secondary sources was needed to verify the results of the literature. Interviews were chosen as the data collection method to achieve this purpose. This includes mostly having the feedback from participants in a survey through in-person, one on one personal interviews, and focused group interviews. (Kabir, 2016). categorized interviews as structured, semi-structured and un-structured. Prior to an interview, an interview guide was written covering all the essential topics and subjects that needs to be interviewed and gather data during the interview. Structured interviews were conducted for the residential building owners who are using solar PV. The contacts of those participants were taken from the the market survey.

Selection of Case Study Projects

For the purpose of compare and analyze the related costs incurred from conservative practice and solar PV separately, it was required to select the case studies. The case studies were collected from the contacts given by the service providers of their customers. Then the screening was done such as detached individual residential building, area should be 2000 sq.ft. to 3500 sq.ft., number of residents in the buildings, appliances used were taken into consideration when selecting the cases. Comparison of the conventional and the solar PV energy costs should be compared in residential buildings, with similarities in energy usage so that the before and after implementation of solar PV. So that from the findings of the case study were analyzed to find out the most cost-effective energy usage among conventional and solar PV.

3.4.6.2. Data analysis techniques

In order to obtain results, researcher will analyze the collected data. An insight into the methodology of research is very much needed, as it can help to rule out any human bias. Consequently, the techniques of data processing below were adopted for this study.

- Relative Important Index (RII)

The RII was used to analyze the data from the questionnaires from market survey. RII is used to interpret the relative importance and impact of factors involved (Musa, Mohammad, Yusof, & Mahbub, 2017). A typical 1-5 Likert scale can be used here and derive the value of W, considering the weighting given to each factor by the participant. The following equation is used to derive the final outcome of RII.

$$\text{Relative Important Index (RII)} = \frac{\sum W}{A*N}$$

$$= \frac{(5n5+4n4+3n3+2n2+1n1)}{5*n}$$

Where;

W: Weighting given to each factor by the respondent

A: the highest weight in the research

N: Total number of respondents

- Content Analysis

This analysis can be used with a wider variety of audio, visual, and textual data like photos, videos, radio etc. Further, Stemler (2015) stated that this technique is flexible, and it can be of the both natures, empirical or theoretical. To analyze trends and patterns of data gathered, content analysis is also used. qualitative data can be converted into quantitative data for the ease of analysis. The audio records of the interviews are analyzed using content analysis manually.

Then analyzed the Return on Investment and the payback period of the investment.

3.5 Chapter Summary

This chapter describe the areas of research design, process, research strategy that covers data collection processes and data processing approaches. In addition, reasons for selecting those research strategies have been explained in each section.

The case study analysis techniques were selected as the most fitting approach for this study. Market survey, and case studies were selected as the research approaches suitable for data collection methods, as suitable methods for the data to be obtained.

CHAPTER 4 – DATA COLLECTION AND ANALYSIS

4.1 Introduction

Chapter four is dedicated to the data collection and representing of the data analysis of the findings. The results of the analysis which were achieved through data collected from market survey and case study are structured based on the objectives.

4.2 Market Survey – Nature of Solar Panel Application in Sri Lanka

In the market survey, the data collection was done using an open-ended and close-ended questionnaire survey which contained fifteen questions covering the solar PV services available, types of solar PV used, types of building sectors using solar PV, types of residential buildings, solar PV power applications, types of systems or solar PV applications in Sri Lanka. This was sent out to forty number of solar panel service providers which they provide one or several services at once such as solar panel suppling, installing, distributing, importing, and after service. This was done to get an understanding on the overall usage of solar PV in the Sri Lankan context. Thirty-two participants responded to the questionnaire, yielded a response rate of 80%.

4.2.1 Distribution of solar PV in detached individual residential buildings

Firstly, it is important to investigate the areas where solar panel implementation is popular in Sri Lanka. As per Figure 4.1, approximately 81.3% of the participants are mostly working for the projects in Colombo. Which means many of the solar PV projects are taking place in Colombo.

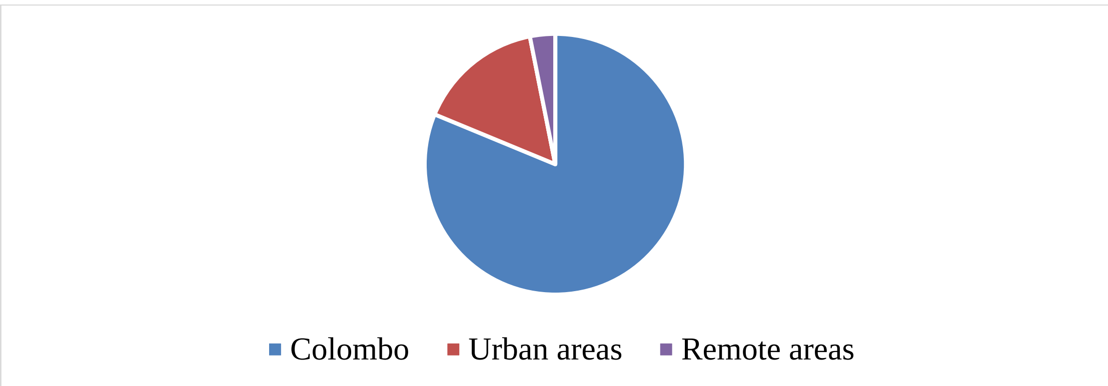

Figure 4.1: Location of the solar PV usage

Figure 4.1 represents the distribution of solar PV services providers who responded to the questionnaire. As depicted in the Figure 4.1, the 32 respondents were from various companies such as (1) supplying and installing, (2) directly importing and installing, (3) distribution and installing.

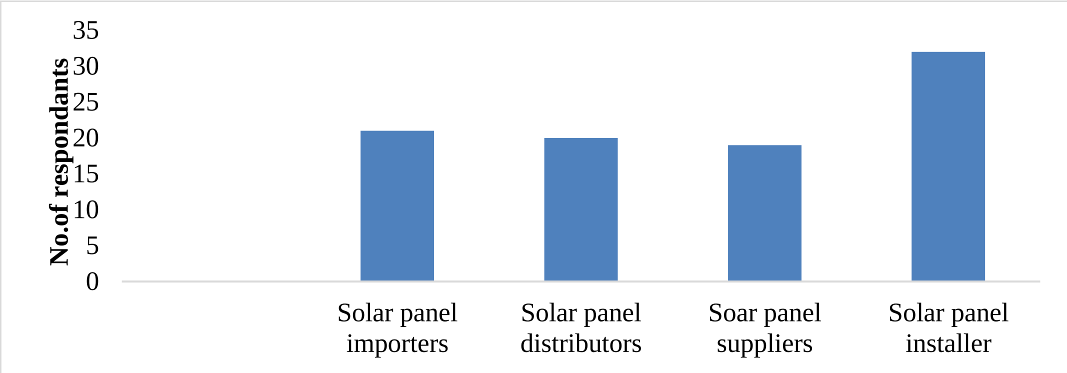

Figure 4.2: Solar panel services available in the Sri Lankan market

4.2.2 Types of Solar used in Sri Lanka

Figure 4.3 represents the various types of Solar panels used in the Sri Lanka. According to Figure 4.3, all the respondents provide monocrystalline and the next highest is solar PV with a 68.8% of uses, and none of the respondents use the concentrating solar power (CSP).

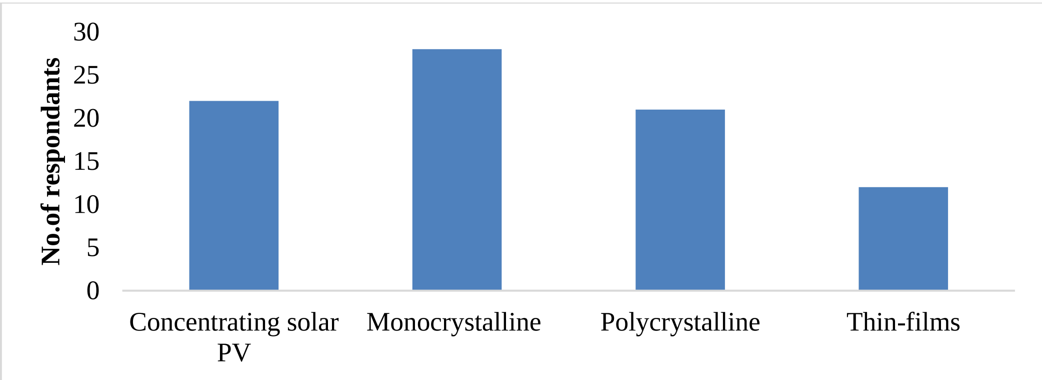

Figure 4.3: Types of solar panels in Sri Lanka

4.2.3 Solar Panel Application in Buildings

To proceed with the research, it was essential to identify the types of building which have integrated solar panels. As demonstrated in Table 4.1, majority of the respondents selected either 5 or 4 from the Likert scale indicating that they have provided their services to residential buildings. The RII for residential is therefore 0.894. Second highest RII (0.794) indicated their services to commercial buildings.

Table 4.1: Types of buildings

Building type	RII	Rank
Residential	0.894	1
Commercial	0.794	2
Industrial	0.788	3
Other	0.738	4
Hospital	0.644	5

These survey results reported in table 4.1 coincides with the literature. Literature review concluded that solar panels are becoming popular in residential buildings (Sheikh, 2008, March). As a result, researcher asked the respondents to identify the type of residential units which uses solar power. There are various types of residential units such as detached single-unit houses, condominiums, apartment complexes and housing schemes. Majority of the respondents have provided services to detached houses. 76.3% of them provided services for housing schemes as indicated in Table 4.2

Table 4.2: Types of residential buildings

Building type	RII	Rank
Individual Residential Units	0.938	1
Housing schemes	0.763	2
Other (government provided residential areas)	0.606	3
Apartments	0.513	4

4.2.4 Usage of Solar PV in Buildings

Table 4.3 represents the usage of solar PV power in buildings. From that 94.8% is used for building-integrated solar PV and the second highest for lighting. In the current context, lighting consumes more than 19% of the global electrical consumption and this consumption is sure to grow continuously (Moadab, Olsson, Fischl, & Aries, 2021).

Table 4.3: Usage of solar PV power in buildings

Usage	RII	Rank
For the total building	0.948	1
Lighting	0.688	2
Other	0.625	3
Air cooling	0.625	3
Water pumping	0.544	4
Water heating	0.381	5
Drip or sprinkler irrigation	0.250	6
Air heating	0.175	7

As depicted in Table 4.3, the highest Solar PV usage in Sri Lankan residential buildings can be identified as a for the total energy consumption of the building and not as for the individual usages. While the other uses are only used only for one activity. Second highest RII for the lighting.

Next question was on different installation systems of solar panels. According to the respondents, there are, three types of solar PV installation systems namely, on-grid, off-grid and hybrid systems.

The best alternatives for renewable energy for residential building is grid connected (on-grid) PV systems (Irfan et al., 2019). Because it is also a source of income generation. Conducting a proper performance analysis on these grids connected plants would help the construction sector in planning, designing, operating and maintenance of systems (Kumar, & Sudhakar, 2015).

Researcher asked the respondents to identify the barriers to implement solar panels. As per the responses, the main barrier is the initial cost of installation, followed by misconceptions of the public, in some of the areas the panels cannot be fixed as on grid, because in those areas the grid is not stable enough.

Many research studies suggested these barriers in the literature as well. Promoting renewable energy and its cost are at the pinnacle of the energy policy debate in the world (Ciarreta, Espinosa, & Pizarro-Irizar, 2014).

Lack of information and awareness about the benefit among the society are also a barrier for the implementation of solar PV (Painuly, 2001). Margolis and Zuboy (2006) conducted a categorical survey to determine the general obstacles solar energy encounter that discusses the micro and macro environment challenges arising from the market, economic, political, and organizational factors (Haukkala, 2015; Ruggiero, Varho, & Rikkonen, 2015). These can typically be the lack of skilled labor, high capital investment, negative perceptions derived by comparing the costs against the traditional energy sources like coal, low public subsidies granting to promote these type of energy solutions (Child, Haukkala, & Breyer, 2017).

Finally, the respondents were asked to identify the reasons for the barriers. According to them the reason are as follows:

- The bank loans only get approved for solar panels capacity of more than 20kW.
- Lack of maintenance standards, poor customer care services generating negative image on the trade lead to many misconceptions.
- Insufficient installation of transformers for the main grid transmission, has led to the instability of the transmission of electricity generated through solar power from one place to another.

However, the participants argued that the solar PV is a better investment when compared to the conventional energy while improving the aspects of greener & smarter life.

4.3 Case Study

Jensen and Skytte (2002) pointed out that renewable energy sources can drastically reduce the electricity bill of users as renewable energy generation process owns a comparatively low variable costs compared to traditional fossil-fuel electricity.

The cases were identified through the companies participated in the market survey and only one company agreed to share the contacts of their clients. From those contacts only two individuals agreed to provide information of the solar PV installed. Then the case study was conducted with the structured interviews to the building occupant of the selected cases. This section presents the findings from the case studies in order to identify the suitability of the solar PV panels in the residential buildings. As well as to compare the effects on the energy consumption due to implementation of PV Solar vs non-solar panel residential buildings.

The two residential buildings are located in suburbs of Colombo, both are two storied houses, with an equal number of occupants and both of the owner installed solar PV to get the electricity bills reduced. Table 4.4 presents the profile information of the cases considered for the study.

Table 4.4: Profile of Cases

Building	**Building 1**	**Building 2**
Location	Mt. Lavinia	Moratuwa
Type	Two Storied house	Two Storied house
Floor area	2200 sq. ft.	3500 sq. ft.
No of occupants	05	05
Year of completion of the building	1996	2017
Year of solar installation	2020	2021
Duration of the solar PV usage	1 year	Less than 1 year
Motivation for solar installation	Energy bill reduction and source of income	Energy bill reduction
Capacity of the Solar PV	5kWh	4.7kWh
Changes to existing building	None	None
Challenges encountered	None, Cash purchase	None, Cash purchase
Usage of electricity before (monthly)	Rs.12,000.00	Rs.10,000.00
Present energy bills (monthly)	Only Rs. 36 as a LECO rental	

Time taken for reduction in energy cost	3 months after implementing solar PV	
Approximate cost reduction	Rs.12,000.00	Rs.10,000.00
Significant difference in cost and units	Yes	Yes
Additional income per month	Rs. 3000.00	Rs. 3000.00
Changes in availability of the appliances	No	Yes, Added air conditioner
Initial installation cost	Rs.870,000/- LECO – Rs.20,000/-	Solar-Rs.750,000/- LECO - Rs.40,000/-
Maintenance cost/frequency	Yet to occur	Yet to occur
Replacement cost/Frequency of replacement	Yet to occur	Yet to occur
Typical life-time of the solar PV	30 years	30 years
Benefits	Only the rental as the electricity bill, Additional income	Only the rental as the electricity bill, Additional income, Additional esthetic appearance to the roof
Drawbacks	Roof maintenance requires technical support	Don’t have experience about it
Reduction in electricity generation during rainy or gloomy days	Slight reduction in the electricity generation, but can be used from the previously generated	Slight reduction in the electricity generation, but can be used from the previously generated

Pay-back period	4.9 years	5.06 years
Return on investment	(15,000*12)/890,000 = 0.202	(13,000*12)/790,000 = 0.197

As presented in Table 4.4 both building 1 and 2 are located in Colombo with the floor area of 2200 sq. ft. and 3500 sq. ft, respectively. Both the buildings have equal number of occupants. Although the two buildings were completed in different period, the solar installation taken place more or less at the same period, for building 1 in 2020 and for building 2 in 2021. The main intention of occupants of the building 1 were to reduce the electricity cost by installing PV panels and also as an income generator by selling the additional unit to the Ceylon Electricity Board (CEB). According to owners of the buildings, PV panels could bring additional income by Rs.3000.00 per month. The building 1 owner's intention was the reduction in the electricity bill and as an income generator. However, in case of building 2, the primary purpose of installing PV panels was solely to reduce the electricity cost, investment opportunity was not one of his intentions as in the case building 1.

Both buildings had installed almost similar capacity panels of 5kWh and 4.7kWh, respectively. According to literature, usually there should be a minimum roof area to install the solar PV which is 200 sq.ft. Both buildings did not go through any structural changes to install PV panels. The area of the roof surface and the inclinations were enough. The minimum roof area requirement is 6sqm for 1kW of panel. Both buildings had adequate roof areas to install solar PV panels. Both the owners of the buildings confirmed this during the interviews. Solar PV panels were directly fixed on to the existing roof.

Literature suggested that loan facilities can be an advantage for the solar PV uses because the initial cost is high. The occupants in building 2 mentioned that there was a 4% loan facility for the solar PV uses. But the occupants of both buildings confirmed that they did not get a loan and they made a cash purchase. For building 1 the initial cost was Rs.890,000.00 and for Building 2 it was Rs.790,000.00.

Next set of interview questions were on electricity usage on pre and post PV implementation. Owner of the building 1 mentioned that the monthly electricity bill before PV installation was on average Rs. 12,000.00. For owner of the building 2, monthly electricity bill was Rs. 10,000.00 prior to PV installation. Both the building owners mentioned that they have five occupants in the residence (refer table 4.4). Building 1 and Building 2 has similar appliances and five number of occupants before installing solar PV panels. Owners of the buildings mentioned that after installing solar PV panels, their electricity bill was only Rs. 36 as the rental and sometimes, they even received an additional income for the units they sell to the CEB. According to owners of the buildings they receive an additional monthly income of Rs.3,000.00 approximately by this investment, and therefore consider their initial thoughts on PV panels as an 'income generator' is beneficial. Owner of the building 2 was also experiencing a similar cost reduction in monthly electricity bills. Due to the reduction in electricity bills, owner of the building 2, added an air conditioning unit to his house. It is interesting to note that even after adding and air conditioning unit, the electricity cost was almost zero for building 2. However, both the household had to pay only Rs.36.00 per month as Lanka Electricity Company (LECO) services. Both the building owners mentioned this service charge is negligible compared to the monthly electricity cost prior to solar PV installation.

The next set of questions were focused on the cost factors of the solar PV. The initial cost for the implementation of the solar was Eight hundred seventy thousand rupees (Rs. 870,000.00) for a 5kW capacity PV panel and Rs. 21,000.00 for the LECO charges. For building 2, the initial cost is Seven hundred fifty thousand (Rs. 750,000.00) for 4.7kW capacity PV panel. LECO charges for solar PV installation are Rs. 40,000.00. As reported in Table 4.4, Building 1 and 2 installed solar PV panels in 2020 and 2021 respectively. Therefore, both the buildings have not come across any kind of maintenance as well as replacements yet. For both the building owners, first two maintenances are offered by the solar PV installation company free of charge. Afterwards the maintenances should be done in every 6 months and the cost will be Rs. 3,500.00 owner of the building 1 mentioned the PV company offers full replacement costs if there is a faulty installation or an error within the solar PV panels during the warranty period of 25 years. However, these after sales offers vary from one solar PV installation company to another. According to both building owners the life-span of solar PV panels installed are 30 years.

Then the questions were focused on the benefits and the drawbacks of the solar PV usage in residential buildings. Owner of the building 1 highlighted the reduction in electricity cost and additional income from investment as major benefits. Building owner 2 also mentioned the same as main benefits. According to the literature, the aesthetic appearance was given as a drawback of Solar PV panels. Slooff et al., 2017 stated the appearance of PV panels on roofs are not very attractive. However, according to owner of the building 2, installing PV panels were aesthetically pleasing, contradicting to the general view in the literature.

Owner of the building 1 mentioned that the main drawback from this is the difficulty in roof maintenance. Owner of the building 1 mentioned that, before installing solar PV, for a regular roof maintenance, can just hire a handyman, but now, they had to book and appointment with solar PV installation company before hiring a handyman because removing of the solar PV panels need a special skill. Building 1 was built in 1996, and it required minor roof maintenances up to now. Owner of the building 1 added these minor maintenances are now time-consuming tasks after solar PV installation. The PV company should now provide technical support to remove or adjust solar panels to fix a minor water leak from the roof. Owner of the building 2 did not report and drawbacks from the system.

Both the owners of the buildings were next asked about the consistency in electricity generation especially on gloomy days. Both the owners of the buildings mentioned there is a reduction in electricity generation on gloomy days, yet there is a possibility of using the excess electricity generated on previous days from the solar PV. As a result, this is not an issue for them so far. Since the system of the solar PV is connected to the national grid, the system automatically connects to the grid when there is a need.

Pay-back period of the buildings were calculated dividing the initial cost incurred and the monthly benefits obtained. Payback period less in the first building 1 compared to the building 2. So, considering the life span of the PV panels (30 years) it is beneficial because the incurred initial cost will be covered in first 5 years, the next 25 years the reducing energy cost and income generated monthly will be a total saving and an income for the building owners. Return-on Investment, according to the building owners they receive Rs. 3000.00 per month by selling the excess units sell to the CEB, but due to the prevailing economic and energy crisis in Sri Lanka the CEB does not pay for the excess units they buy from the detached individual buildings.

4.4 Chapter summary

Data collection, analysis and representation is utmost important steps in conducting research. Chapter four is dedicated to representing the analysis of data collected through the questionnaire, market survey and two case studies carried out. Forty questionnaires were distributed, and thirty-two responses received for the market survey and two structured interviews were carried out for the two case studies. The questionnaires were analyzed using Relative Important Index, content analysis is used manually to assess the interview results. The findings confirm the suitability of solar PV panel systems for residential buildings. Further, this chapter presents a comprehensive result analysis of the research for the author to use to prove recommendations and conclusions in the next chapter.

CHAPTER 5 – CONCLUSIONSAND RECOMMENDATIONS

5.1 Introduction

This chapter provides conclusions based on the findings from literature review, market survey and the case studies. Initially, this chapter emphasizes the aim and objectives of the study and explains how these were achieved.

This is followed by contribution of the current research to existing knowledge. Subsequently, recommendations are provided based on the findings of this study in order to suggest strategies to enhance the use of solar PV in residential buildings in Sri Lanka. Then, the limitations of the current research are elaborated. Finally, the chapter provides a summary of this research study.

5.2 Achievement of objectives

Objective 01 - Review the various PV systems and types available globally as well as in the Sri Lankan context

This objective was achieved by the literature review and the findings from the market survey. Globally available solar PV types were identified through the literature review, while the types available in the Sri Lankan context identified by the Market survey. In the global context there are several types of solar PV panels mainly categorized in to two segments namely, crystalline and thin-film. Crystalline basically focuses on the efficiency even with a low irradiation because of that the crystalline solar PV are costly. On the other hand, thin film solar PV has a lower cost compared to crystalline. However, both the panels have advantages as well as the disadvantages. In the Sri Lankan context there are mainly, crystalline and thin-film solar PV available.

Objective 02 – To examine the extent of PV solar panel application in residential buildings

This objective was reviewed from the literature survey which indicated most energy consuming building sector is residential buildings. The questionnaire survey further explored the solar PV applications in residential buildings. When considering the residential buildings detached single unit residential buildings are the best building type for solar PV installation. That is because the occupants can get the best outcomes from this arrangement. When considering the other residential types such as condominiums, the roof area is minimal to produce energy for all the occupants in the building.

Objective 03 - Identify the suitability of solar PV panel systems for residential buildings by interviews from the occupants of buildings with solar PV panels

Interviews were done for the selected case studies. The owners of the buildings were interviewed with a set of structured questions. Both the buildings used the solar PV for the total energy consumption of the buildings. There were no special structures needed to install solar PV, the existing roof was used. According to them the installation of the solar PV is costly but it is worth spending initially because it is an investment. Furthermore, the occupants stated there are special loans introduced by the banks in Sri Lanka for the people who are willing to get the solar PV installed to their houses. Issues with the higher initial cost can be sorted with these kinds of monetary facilities.

Objective 04 - Comparison of effects on energy consumption due to implementation of Solar PV vs non-solar PV residential buildings (Cost and no of units consumed)

This was achieved through structured interviews carried out for the case studies selected. The findings of the case studies were represented in the chapter 4 and it described accordingly with the cost and the units of energy consumed. Chapter 4 also included a comparison with and without solar PV installations. It is important to compare conventional vs Solar PV system to the same buildings as it provides a clear picture of the expenses and benefits during its operation. The doing the comparison on the same building before and after is more effective because the other factors are constant while the energy source only changes.

Objective 05 - Strategies to enhance PV solar panel application in residential buildings in Sri Lanka.

In the last objective, the intention was to enhance the solar PV application to the residential buildings in Sri Lanka. The strategies are discussed in the recommendation section in relation with the barriers described in the literature and the findings from the market survey and the case study. It is essential to educate the owners of the houses about the benefits of the solar PV rather than using the conventional energy. Clearing up the misconceptions with the people can be done by showcasing the real-life examples.

5.3 Overall Conclusions

After analyzing the research finding and outcomes, the author is confident that the expected objectives of the research are encountered satisfactorily. The author carefully reviewed a comprehensive level of past literature and scholarly articles on the research topic thus, the research findings of this study are closely aligned with what other scholars have argued and stated. The research findings of this study indicate that there is a significant level of knowledge and demand for the solar PV adoption in Sri Lanka. Thus, it is concluded that Sri Lanka possesses a strong potential for growth opportunities for usage of solar PV for residential buildings for the effective development of the individuals and the society as whole.

5.4 Recommendations

Based on the results generated through the data analysis, the below stated recommendations are developed by the researcher as per the findings. The author strongly believes that further steps should be taken to promote solar PV and broaden the awareness among general public on the usage and adoption of the same as a renewable energy source. It is noticed that Sri Lanka lacks a systematic approach and government backup to introduce renewable energy sources for residential building constructions in suburban and rural areas in the country to be more precise. Thus, the following actions are recommended:

- As stated in the chapter 2 due to the lack of information about the solar PV among the general public in Sri Lanka it is possible to recommend, enhance public awareness (Education): First and foremost, every Sri Lankan should be familiar with the concept of solar PV as the future of renewable energy. They should be educated on both pros and cons of solar PV, a proper cost benefit analysis that compares the current energy generated through coal and fossil fuel majorly. Once their doubts are clarified and questions are answered with logical answers it will be easy to convince them to consider solar PV as a solution for energy generation.

- As previously mentioned in chapter 2, there were special loan schemes introduced for the implementation of solar PV for residential building for a lower interest rate, so that the people get motivated, because of that it os possible to recommend, Government Engagement: Government engagement is highly appreciated in this type of long-term sustainability projects. Government support and backup in terms of tax concessions, subsidies, and grants to implement will encourage locals to adopt to Solar PV for their domestic usage.
- As previously mentioned in chapter 2, there were special loan schemes introduced for the implementation of solar PV for residential building for a lower interest rate, so that the people get motivated, because of that it is possible to recommend, Bank loans and Tax reliefs: Bank loans at a very low rate and tax waive offs to reduce the costs will positively impact influencing people to install solar PV as it takes the financial burden off to a certain extent since solar requires considerably a high initial investment.
- As stated in the chapter 2 due to the lack of information about the solar PV among the general public in Sri Lanka because of that it is possible to recommend, Education from School Level: Include not only the usage and the benefits of solar PV in education curriculums but also expose the student to the technical knowledge on manufacturing and operating a solar PV. Solar PV for residential buildings can be taught for students as a concept at school and encourage them on practical group activities on designing and development of solar panels for them to grasp technology behind them.
- As stated in the Chapter 2 lack of knowledge among the construction professionals it is possible to recommend, Continuous Professional Development (CPD) sessions: This will boost existing knowledge among the construction professionals on the subject arena while paves a way to fill their knowledge gaps. Further this will enhance their ability to spread knowledge to their customers to get into solar PV in the initial stage of the building designs and the novel insights and latest development s in the technologies of solar PV used globally.
- Research and Development: This is where countries like Sri Lanka lags behind compared developed countries. They invest heavily on R&D as that is the only

way to improve products and services. Sri Lankan entities and government is suggested to invest on R&D on renewable energy sources like solar PV as it is the future. Constant R&D ensures continuous growth and sustainability, thus contribution to the industry and country at large is immense.

Inconclusion, the above stated list of recommendations can be considered as few of the crucial steps of sustainable renewable energy sources to be widespread around Sri Lanka.

5.5 Limitations

When conducting this research several limitations were encountered by the author such as time factor limitation, difficulty in locating ample amount of projects due to lack of availability that undertake solar PV as an energy source of their residential construction to get more precise information, lack of in depth knowledge among construction sector professionals with regard to renewable energy sources and solar PV, Solar PV being a beginner stage concept in Sri Lanka in residential buildings thus only handful of constructions are taken place so far resulting in even the most experienced construction professionals with more than twenty years of industry exposure in the industry most of the time fail to share practical knowledge and impact due to lack of knowledge and work exposure. Hence, it was revealed that only a few numbers of solar PV companies available in Sri Lanka, as well as the solar PV installed in residential buildings.

Further, this study is only limited to solar PV adoption in residential buildings in Sri Lanka. It does not discuss the usage in infrastructure projects, commercial buildings and industrial workshops, manufacturing plants etc. Thus, this study does not provide a holistic view of Solar PV usage of either the construction industry or country at large. It only discusses one aspect of it. Therefore, this report does not reflect the complete opinion of the entire construction industry.

5.6 Further Research

The author requests futures researchers to study further on this concept in Sri Lankan context with special reference given to the residents who are already using solar PV, construction companies who promote solar PV as a lucrative option for energy to broaden the viewpoint and to discover interesting insights on where the country stands.

Further it is suggested to conduct a categorical research study on industrial companies like apparel who are heavily invested on solar PV as to assess their experience on the subject. In addition, below aspects can be researched in terms of implementation of solar PV,

- Strengthen the building approvals with the energy consumption factor to encourage the implement solar PV for the residential buildings
- Cost benefit analysis for the residential buildings with solar PV considering the Whole Life Cycle of the building.
- Strategies to promote solar PV in residential buildings in underdeveloped countries, A case analysis in the context of Sri Lanka
- A comprehensive assessment process for solar PV in residential buildings: A case analysis in the context of Sri Lanka

Similarly, research areas stated above can lead to the better awareness of solar energy and it will strengthen the sustainable improvement and continuous development of the solar PV implementation process in Sri Lanka while ensuring enhanced community standards and rural development in the country.

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ANNEXURE 01

Application of Photovoltaic Solar System in Residential Buildings in Sri Lanka: A Project Management Perspective

Dear Sir/Madam,

I am a postgraduate student from University of Moratuwa following a MSc Project Management course in the Department of Building Economics. Presently, I have undertaken research under the above topic and the attached questionnaire is used as the pilot survey to identify the application of solar panels in residential buildings.

It would be an immense support for me if you could spare me a few minutes from your valuable time to fill in the questionnaire attached herewith. I assure you that the information collected through this questionnaire will be used only for research purpose and confidentiality of the data will be maintained at all times.

I really appreciate and would like to thank you for your valuable contribution to this research. If you are interested to know the outcome of the research, it would be my pleasure to share it with you.

Thanking you

Kind regards

Ruwanara Fernando

Postgraduate student

Department of Building Economics

University of Moratuwa.

Email: ruwanaraprabuddhi@gmail.com

QUESTIONNAIRE

Respondent's details

Name: Company name:
Mobile no (Optional): E-mail:

You may ask for e-mail as well

1. What is the nature of your business?
    a. Solar panel importers ☐
    b. Solar panel distributors ☐
    c. Solar panel suppliers ☐
    d. Solar panel installer ☐
    e. Other ☐

    ……………………………………………………………………………………
    ………………………………………………………..

2. What types of solar panels are in your business?
    a. Solar PV ☐
    b. Concentrating solar power (CSP) ☐
    c. Monocrystalline ☐
    d. Polycrystalline ☐
    e. Thin-films ☐
    f. Other ☐

    …………………………………………………………………………………
    ………………………………………………………………….

3. How long have you been in this industry?

4. For what type of buildings are more towards applying solar panels? Please rate your answer from 5-1

    a. Residential ☐
    b. Commercial ☐
    c. Hospitals ☐
    d. Industrial ☐
    e. Other ☐

    …………………………………………………………………………………
    ……………………………………………………………………

5. If your answer is residential, What type of residential buildings?
    a. Individual residential building ☐
    b. Housing scheme ☐
    c. Apartments ☐
    d. Other ☐

……………………………………………………………………………
……………………………………………………………………

6. What applications are there PV panels used in buildings?
    a. Building integrated photovoltaic ☐
    b. Drip or sprinkler irrigation systems ☐
    c. Water pumping ☐
    d. Water heating ☐
    e. Air heating ☐
    f. Air cooling ☐
    g. Lighting ☐

If there are any additional applications, please list it here.

a. ……………………………………..
b. ……………………………………..
c. ……………………………………..
d. ……………………………………..

7. In which areas solar panels are been implemented,
   Colombo
   Out of Colombo
   Urban areas
   Suburbs
   Remote

8. In your opinion, what is the overall supply significance or the present trend of solar panel implementation is Sri Lanka;
   Building wise
   Location wise
   Cost wise

9. What are the benefits of solar panel implementation in Sri Lanka?
   ……………………………………….
   ………………………………………
   …………………………………………
   …………………………………………

10. What are the barriers for implementation of solar panels?
    ……………………………………….
    ……………………………………….
    ………………………………………

11. What are the reasons for those barriers?

ANNEXURE 02

Application of Photovoltaic Solar System in residential buildings in Sri Lanka: A Project Management Perspective

Interview Questions

1. Location of the building?
2. Type of the building?
   - ☐ Single storey
   - ☐ Two storey
   - ☐ Three storey
   - ☐ Above three storey
3. Floor area of the building: …………………………………………….
4. No of occupants in the building: ….
5. When the building was built?
6. When did the solar installed?
7. How long have you been installed the solar panels?
   - ☐ Less than 1 year
   - ☐ 1-5 years
   - ☐ 6-10years
   - ☐ 11-15years
   - ☐ More than 15 years
8. What motivated the implementation of solar PV?
   - ☐ Energy cost reduction
   - ☐ Energy Saving
   - ☐ Pollution-free
   - ☐ As an investment
9. What is the capacity of installed solar PV panels?
   - ☐ Less than 5kW
   - ☐ 5-10kW
   - ☐ 11-15kW
   - ☐ 16-20kW
   - ☐ More than 20kW
10. What changes made to the building to implement solar?
11. What are the challenges encountered when implementing solar?
    - ☐ Initial cost is high
    - ☐ Changes in the existing building
    - ☐ Obtaining bank loans
    - ☐ Insufficient roof area

12. What was the usage of electricity before installing solar?
13. Are you experiencing any reduce in the energy bills? Y/N
14. How long it had taken to show a reduction in energy cost?
15. Approximate cost or the units reduction in energy bills?
16. What is the usage of electricity units and cost before and after implementation of solar PV?
17. Do you recognize a significant difference in the electricity cost after installing solar?
18. How many units of electricity has reduced from the bill after installing solar?
19. Availability of the appliances in the building before and after installing solar?

Before

- ☐ Television
- ☐ Refrigerator
- ☐ Geezer
- ☐ Water pump
- ☐ Air conditioning
- ☐ Oven
- ☐ Electric cooker
- ☐ Other

After

- ☐ Television
- ☐ Refrigerator
- ☐ Geezer
- ☐ Water pump
- ☐ Air conditioning
- ☐ Oven
- ☐ Electric cooker
- ☐ Other

20. What is the initial installation cost?
21. What is the typical maintenance cost?
22. How often the maintenance occurs?

☐ Quarterly ☐ Half yearly ☐ Annually

23. What are the replacement costs?
24. How often the replacement occurs?

☐ Quarterly ☐ Half yearly ☐ Annually

25. What is the typical life-time of the solar PV panels?
26. What are the benefits of installing solar?

- ☐ Reduce or eliminate energy bills
- ☐ Environmentally friendly
- ☐ Income generation
- ☐ Availability of the solar power

27. What are the drawbacks of installing solar?

- [ ] Doesn't work at night
- [ ] Initial cost is high
- [ ] Visually not attractive
- [ ] Maintenance cost is high