HYBRID RENEWABLE ENERGY AS A SOLUTION FOR THE ENERGY CRISIS IN SRI LANKA

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ABSTRACT

The global energy industry is at the edge of fundamental revolution where renewable energy plays a major role in responding to the challenges ranging from sustainability to environmental protection. However, the use of a single renewable energy source in producing energy has been reducing due to the inconsistency of resource streams. Consequently, the enhanced energy management strategies were developed by integrating renewable resources with a standby entity and hence hybrid renewable energy systems explored to the practice. Producing energy to unlimited increasing demand is a challenging issue currently faced by Sri Lanka. Although some studies have been performed for hybrid renewable energy systems, i.e. wind and solar across the world, this is an understudied area and thus, very little information is available in Sri Lanka. Therefore, the purpose of this paper is to examine the applicability of solar and wind hybrid renewable concept as a solution for energy crisis in Sri Lanka. A comprehensive literature review was conducted to identify the significance and the emergence of hybrid energy sources. Eight (08) semi structured expert interviews were conducted with information related to solar, wind, renewable energy sources, and hybrid systems, by adopting a qualitative research approach. Collected data were then subjected to content analysis in deriving the research outcome. The findings revealed positive perceptions on implementation of solar–wind hybrid renewable energy systems in Sri Lanka and the importance of intervention at policy level for the success. Lack of knowledge on hybrid concept and updated technologies, limited financial investments, and policy incentive dilemmas, were identified as few limitations.

Keywords: *Hybrid Energy System; Renewable Energy; Solar Energy; Wind Energy.*

1. INTRODUCTION

Global electricity trend has accelerated by 250% with the world's population growth over the past 40 years; further it is forecasted a growth of 70% in 2030 with regards to current energy consumption pattern (International Renewable Energy Agency [IRENA], 2014). The energy demand has substantially increased due to recent industrialization, urbanization, and population growth in South Asia. The import reliance for energy needs has raised from 10.43% in 1971 to 24.76% in 2010 of total energy demand, seriously questioning the sustainability of the current energy mix and energy security (Vidyarthi, 2014). The situation has become much more critical in case of countries such as Sri Lanka, Bangladesh, Pakistan, and Nepal (World Bank, 2013).

Rapidly growing world energy consumption has already impacted on sustainability issues, heavy environmental impacts such as ozone layer depletion and global warming, and exhaustion of energy sources and supply difficulties (Perez-Lombard, Ortiz, and Pout, 2008). A significant role will have to be played by renewable energy sources, in moving the world towards more safeguarded, sustainable, and reliable energy gateway in line with these issues (World Energy Outlook, 2015). Renewable energy currently contributes to around 13% of total global primary energy supply and 11% of total energy supply in European Union, whereas the percentage is growing progressively (Johansson, 2013). Concurrently, in developing countries, among the energy policy targets, utilizing renewable is becoming noticeable as a regulatory interference for the promotion of renewable based clean energy generation (Wijayatunga and Prasad, 2009).

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Sri Lanka has a long history of using renewable energy, dating back to early 20th century, when most tea plantation companies installed small hydropower plants for their power generation (Wijayatunga, 2014). According to Generation and Reservoir Statistics (2017), total primary energy requirement of the country has been met with Thermal (31%), Thermal oil (28%), Coal (20%), Hydro (17%), followed by Wind (3%) and Solar (1%). Even though the current government policies have given a target of 20% renewable energy by 2020, it is the economic and practical realities that hold back the development of renewable energy sector (Withanaarachchi, Nanayakkara, and Pushpakumara, 2015).

Subsequently, Hybrid energy systems are becoming energy systems of choice for future energy deficit issues (Perera, Attalage, Dassanayake, and Perera, 2013). Hybrid renewable energy systems (HRES) thatconsist of solar, wind, biomass, and other energy generation and storage units, have been widely studied in recent years. Many studies have reported on modelling, and control and optimization of hybrid energy systems from design to operation (Wang, Palazoglu, and El-Farra, 2015). A combination of resources with a back-up unit, or a hybrid system, is economical, and possibly will increase system sustainability and depress energy production costs (Rahman, Khan, Ullah, Zhang, and Kumar, 2016).The latest status of hybrid renewable energy system (HRES) technological advancement is the outcome of accomplishments in many research fields that have expressed at tremendous potential in precisely predicting the reliability of integrating solar, wind, and other renewables (Nema, Nema, and Rangnekar, 2008). As many countries are now on the verge of moving towards implementing hybrid renewable energy systems, Sri Lanka has also taken an important decision with integrating HRES. Hence, this paper examines the applicability of hybrid renewable energy concept as a sustainable energy solution to the expected future energy deficit in Sri Lanka. The paper structure begins with an introduction to the study followed by a literature review on world energy challenge, significant role of renewable energy, growth of solar and wind energy, and the emergence of HRES in section 2. Section 3 presents the research methodology whereas section 4 presents the suitability of solar and wind sources as a hybrid energy solution in Sri Lankan context with strategies for the successful implementation of a solar wind hybrid system. The final section summarises conclusions derived from the research findings and recommendations.

2. LITERATURE REVIEW

2.1. INTRODUCTION TO WORLD ENERGY CHALLENGE

World energy is at the heart of transformation at present, together with the aim of intensifying energy security and leading to a sustainable future (International Renewable Energy Agency, 2014). The world's population is increasing daily, which is predicted to reach 9.6 billion by 2050 (Pathak, 2014).

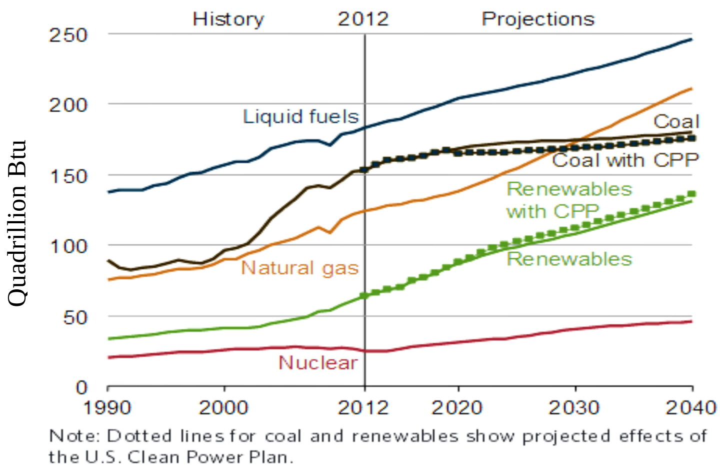

Figure 1: Total World Energy Consumption by Energy Source from 1990 to 2040

Source: World Energy Outlook (2010)

The immense growth of economy during the past decades, particularly the emerging economies, has encouraged world energy consumption significantly, putting an exceptional pressure on succeeding energysaving (Huang, 2014). Owing to the crucial role of energy in everyday life and multi-dimensional strategic importance of sectors, the multi-aspect, regularly international, spatially differentiated, and dynamic nature of energy sector issues, are concerned (Bhattacharyya, 2007).Moreover, highlights of World Energy Outlook (2010) regarding the total world energy consumption by energy source predicted up to year 2040 with regards to past few decades, is presented in Figure 1.

As depicted in Figure 1, world energy consumption is rising gradually and the dotted lines show projected effects on the future energy consumption of renewable. Global energy crisis also raise uncertainties on recovering and remaining amounts of non-renewable resources such as coal, natural gas, and oil, due to the fact that new resources are not being created because currently the world possess only those created million years ago (Pathak, 2014). Eventually, the world would run out of these resources whereas reserved oil, gas, and coal, is expected to last for 35, 37, and 107 years respectively, during which, coal happens to be the isolated fossil fuel remain after 2042 (Shafiee and Topal, 2009).

2.2. SIGNIFICANT ROLE OF RENEWABLE ENERGY

Global fuel crises, over dependency on fossil fuels, greenhouse gases (GHGs), climate change, and global warming, are the significant challenges of energy sector that was strengthened with the extraordinary energy demand owing to the population growth (Mohanty, 2012). The remarkable rapid expansion of energy consumption in the past several decades has extended alarms on exhausting petroleum and other global reserves in the near future, guiding the economy and technologies to largely rely on non-replaceable natural resources (Alrikabi, 2014). Successively, the global ambition on green economy was materialized, which boosts a country’s economy while promising a sustainable environment (Pan, Ma, and Zhang, 2011) during which the requirement for energy efficiency solutions has directed to a significant interest in renewable energy sources (Henriques, Hedges, Owen, and Poole, 2016).

Renewable energy sources have become the world’s fastest emerging energy source over the last few decades while the consumption of renewable energy is increased by an average of 2.6% between years 2012 to 2014; this would be 4 quadrillion Btu by 2040 (International Energy Outlook, 2016). The term “renewable energy” has derived from a broad diversity of resources, generally based on self-renewing energy sources such as sunlight, wind, water falling, internal heat of earth, and biomass such as energy crops, industrial, agricultural waste, and municipal waste (Bull, 2001).

2.3. GROWTH OF SOLAR AND WIND ENERGY

Solar and Wind technologies are economically worthwhile in the present day in an increasing number of markets, which further make important stages to enlarge commercialization, since they are abundant intercontinentally (Bull, 2001). For both solar and wind systems, not only the fuel cost is constant but also it is zero throughout the system’s life (Bull, 2001) and enormous investments are anticipated during the next 15 years for both sectors (Ying, 2007). It is predicted that wind and solar accounts for more than 10 percent of world electricity production in 2040, up from 4 percent in 2014. The biggest volume growth will come from wind, which by 2040, is anticipated to supply about 2 percent of global energy and nearly 10 percent of its electricity (The Outlook for Energy: A View to 2040, 2016).

Solar energy resources maps developed by Sri Lanka Sustainable Energy Authority (SLSEA) represent the distribution of solar energy potential throughout Sri Lanka in four different aspects. Those are the annual global horizontal irradiation (GHI), annual direct normal horizontal irradiation (DNI), Energy optimizing mounting angles (PV panels), and annual PV electric potential (kWh/kWp) for different regions. The highest potential areas can be identified as Puttlam, Mannar, Kilinochchi, Jaffna, Hambantota, and the coastal areas. Wind energy resources maps developed by SLSEA represents the distribution of wind energy potential throughout Sri Lanka in annual average wind speed aspect. Mannar, Jaffna, Puttlam, and Punarine, have been identified as the best potential areas.

Generation of electricity through renewable energy sources has become a major concern in Sri Lanka with the prediction of present electricity consumption level of 3,950 MW being increased at a rate of 7% annually, which spotlighted the need to generate an additional 3,000 MW capacity by the year 2025 (Ministry of Power and Energy, 2015). Further, Energy development plan for 2015-2025 (2015) states that a considerable amount from 3000MW new requirement is planned to be generated through renewable energy sources that includes building of wind power plants of 600 MW and solar power plants of 3,000 MW in the next ten years. The current solar and wind installations in Sri Lanka totals up to a capacity of approximately 33MW produced through 6500 solar installations and around 129MW generated through the wind turbines by 2016 (Sri Lanka Sustainable Energy Authority, 2016).

2.4. EMERGENCE OF HYBRID RENEWABLE ENERGY SOURCES (HRES)

The distribution of renewable resources is boundless, yet the use of a single source to produce energy is not reliable ever since the resource stream is not constant (Rahman, Khan, Ullah, Zhang and Kumar, 2016). The regular drawback to wind and solar energy alternatives are their unpredictable nature and their reliance on the environment and climate changes (Pradeepkumar, Azhagiri, Senthilkumar, and Kumaragurubaran, 2016). Consequently, enhanced energy management strategies are recommended (Dursun and Kilic, 2011), whereas integrating of resources with a standby entity, or a hybrid renewable energy system, assists in addressing this matter of unreliability (Dagdougui, Minciardi, Ouammia, Robbaa, and Sacile, 2012). Furthermore, Pradeepkumar *et al.* (2016) stated that a continuous power production will possibly be anticipated with a hybrid power system by combination of two or more resources, utilizing the potentials of one resource to rise above the limitations of the other source.

Hybrid energy systems are becoming energy systems of choice for future energy deficit issue (Perera, Attalage, Dassanayake, and Perera, 2013) that consist of solar, wind, and other energy generation and storage units, which have been widely studied in recent years. A combination of resources with a back-up unit or a hybrid system is economical and possibly will increase system sustainability and depress energy production costs (Rahman, Khan, Ullah, Zhang, and Kumar, 2016). As per the findings of Atwa, Saadany, Salama, and Seethapathy (2010), probabilistic-based planning techniques are proposed for determining the optimal fuel mix of different types of renewable Distributed Generation (DG) units to minimise the energy loss per annum in the distribution system without disrupting the system constraints.

Moreover, Rezaie, Esmailzadeh, and Dincer (2011) determined that the hybrid technique can grant higher efficiency, lower energy costs, and progress sustainability, through lower emissions, and concluded that it is more desirable than standalone systems with relate to the above cited three indicators. Similarly, Ehyaei, Ahmadi, Atabi, Heibati, and Khorshidvd (2012) concentrated on three perspectives; economic, energy, and emissions, for investigating an onsite hybrid system outfitted in a residential building, and ascertained that a hybrid system can accomplish a first class performance.

2.5. OPTIMAL ENERGY COMBINATION FOR A HYBRID RENEWABLE ENERGY SYSTEM

Ascertaining optimum system combination is an important fact at the premature design stages of Hybrid Energy Systems (Gupta, Saini, and Sharma, 2011). Having considered the complications of fluctuating project sites and intended functions, determining the optimal renewable energy combination for a specific site can be identified as a challenging process. Numerous investigations have been worked out to achieve the best energy fusion of a hybrid energy system and the combination relyon the accessible renewable energy resources and the load demand of the specific site (Rahman, Khan, Ullah, Zhang, and Kumar, 2016). Moreover, conflicting dynamics such as cost, greenhouse gas emission, operation efficiency of renewable energy, and unmet load fraction are considered to achieve multi objective optimization (Agustín, López, and Ascaso, 2006; Agustín and López, 2009). Fadaee and Radzi (as cited in Perera, Attalage, Perera, and Dassanayake, 2013) reported that it is important to adjust to the multi objective optimisation process to match a particular hybrid energy system with the local environment.

As per the findings of Yang, Wei and Chengzhi (2009), an optimum sizing method is necessary to guarantee the most efficient, reliable, and economized techno-economically optimum mix of renewable energy sources. Several sizing algorithms are available based on probabilistic approach, graphical construction method, iterative approach, artificial intelligence method (Wei, Chengzhi, Zhongshi, Lin, and Hongxing, 2009), numerical approach (Kellogg, Nehrir, Venkataramanan, and Gerez, 1996; Kaabeche, Belhamel, and Ibtiouen, 2011), and heuristic techniques (Hochmuth, 1997) have been recommended to develop the optimum combination.

3. RESEARCH METHODOLOGY

The plan of the research, which is used to move from the research question to the conclusion, is defined as research design (Tan, 2002). As per the view of Yin (2011), the research design can be performed either at commencing or during progressing, since research design can be changed during the cause of study. The design of this research includes literature survey, expert opinion survey, data analysis, and the discussion of research findings, respectively.

In-depth expert opinion survey was used for the study since the research topic was associated with detailed data requirement. On the other hand, the experts available with the specific knowledge related to hybrid renewable energy systems were very less within the industry. Hence, obtainable sample size was less. Therefore, the research was conducted under the qualitative approach by considering its advantage over the quantitative approach. Further, the information gathered were mostly the opinions of the interview participants and needed to be evaluated in a descriptive way. Hence, the research compelled the qualitative research approach.

Hence, eight (08) experts were interviewed using semi-structured interview guideline as the major data collection technique. The interviews were conducted among industry experts in the fields of solar, wind, and hybrid renewable energy systems (refer Table 1). Content analysis, which is a qualitative data analysis technique, analyzed the collected data by considering its merits over other techniques. Among the several data analysis softwaresto support the content analysis, this study selected NVivo (2011), which contained graphical presentation of interpreting relationships.

Table 1: Profile of Interview Participants (IP)

IP	Discipline	Experience (Years)	Field of expertise	Awareness of the hybrid concept
IP1	Former Director/Senior Lecturer	35	Expert in the field of solar, wind, biomass, and hybrid	Well aware
IP2	Director General	20	Expert in the field of solar, wind, and hybrid	Well aware
IP3	Managing Director/ Visiting Lecturer	30	Expert in the field of solar, wind, and hybrid	Well aware
IP4	Training Engineer	15	Expert in the field of solar and wind	Well aware
IP5	Senior Lecturer/ Consultant	16	Expert in the field of sustainable design and construction	Aware
IP6	Senior Lecturer/ Consultant	15	Expert in the field of solar	Aware
IP7	Senior Lecturer/ Consultant	16	Expert in the field of solar	Aware
IP8	Senior Lecturer/ Consultant	15	Expert in the field of high voltage engineering, electric power, and wind	Aware

4. RESEARCH FINDINGS AND DISCUSSION

4.1. SOLAR AND WIND ENERGY IN SRI LANKA: INSTALLATION AND CURRENT PRACTICE

This section presents research findings of factors considered during the installation and current practice of solar and wind, based on experts' opinions.

As revealed during interviews, the location and solar irradiation, shading, technology used, angle of installation, maintenance of the solar panel, cooling technique for the panel, tracking method, quality of electronic components, intermittency and fluctuation, reactive power, storage, area available for the installation, orientation of the roof, investment, and the return on investment were identified by the experts as important factors to be considered during the installation of solar panels. Figure 2 illustrates each factor with number of responses.

The experts reported that Jaffna, Mannar, Hambantota, and Puttlam areas have the highest irradiation levels, which further reinforce literature findings. All interview participants believed that panel location is affected by the shading from buildings, trees, or clouds, which disturb the sunlight entrance where system requirement was not achieved. The norm is that country of origin basically impacts the technology where German technology is preferred more in installations.

Nodes

Name	Sources	References
Factors considered when installing solar PV	7	39
Location and solar irradiation	5	9
Angle of installation	3	3
Tracking method	1	1
Technnology	4	5
Quality of electronic components	2	2
Shading	3	3
Maintenance of the panel	3	3
Cooling technique for the panel	3	3
Intermittency and fluctuation	1	1
Reactive power	1	1
Storage	1	1
Area available for the installation	1	1
Investment	2	3
Return on investment	1	1
Orientation of the roof	1	1

Figure 2: Factors Considered During Installing Solar Panels

IP1 stated that angle of installation is not sharp 90^o and depends on direct radiation and diffused radiation. The suitable angle can be decided through SLSEA solar maps. Solar panel efficiency drops without periodical cleaning during proper intervals [IP1, IP4, and IP7]. The findings revealed that operating temperature of the panel highly influence the efficiency. Supporting to this fact, IP1 stated,

> "*Ambient temperature is usually higher in Sri Lanka. Central province has better efficiency due to lower temperature. Although the outer environment temperature is 30^{o}C, the panel temperature is about 50-60^{o}C, which is less efficient. Usually, Hambantota solar panels have an increased temperature of 70^{o}C.*
>
> *Therefore, cooling technique for the panel is an important fact. This may be natural cooling through rain and wind. But if it's artificial cooling, it will not be cost effective. It will be easy to make the environment cool through growing grass instead of having pebble roads but that will also incur a maintenance cost.*"

As revealed by IP1, if these factors act negatively, the average solar panel efficiency of 17% can reduce. Although it cannot be exactly determined, there are norms that can be related with efficiency and can quantify the efficiency drop. Only about 10-15% of the average 17% efficiency can be varied through these factors, but not by a bigger percentage such as 50%-60%. All experts agreed that Roof top solar panels were the most popular installation in Sri Lanka. It revealed three schemes, which are currently used in connecting the solar panels; net metering, net accounting, and net plus schemes.

Similarly, Figure 3 illustrates the factors to be considered during the installation of wind turbines: Wind velocity, wind speed class, distance between the turbines, maintenance and cleaning, shape of the blade, technology used, turbulence level, variance of the wind in a year, conversion and grid connectivity controls, upstream, investment, required land space, height of pylons, interruptions and environmental issues, and capacity of the turbines as have identified by the experts.

The findings revealed that the annual average wind speed also can be identified through the resource maps developed by SLSEA. Wind speed class in the site relates to the wind velocity. IP1 mentioned that,

> "*... usually class 7 is the best whereas at a height of 50m, a7-8m/s average velocity is present. Mannar and Jaffna are in class 7 range and Hambantota in class 5-6 range. The class is decided by the energy*

availability in kWh per m^2. How much energy can be generated for 1 m^2 is reflected in this class. This can be converted to velocity or to energy. Usually class 4-5 is the minimum requirement and 6-7 is the best."

Nodes

Name	Sources	References
Factors considered when installing wind turbines	7	44
Distance between turbines	3	4
Technology	4	4
Velocity of the wind	6	6
Turbulence level	3	3
Variance of wind in a year	4	4
Conversion and grid connectivty controls	1	1
Maintenance and cleaning	5	5
Upstream	1	1
Shape of the blade	2	4
Wind speed class	3	3
Investment	3	3
Required land space	2	2
Height of pylons	1	1
Interruptions and environmental issues	1	2
Capacity of the turbine	1	1

Figure 3: Factors Considered during Installing Wind Turbines

The norm for the distance between the turbines is to have a distance of 5-6 times a diameter of the blade. For example, if the diameter is 100m, the distance between two hoods should be at least 500m. From behind, it should be 8-9 times diameter distance. Dust on blade surfaces should be cleaned to gain the best energy production though wind turbines [IP1, IP3, IP4, and IP8].

The interview participants reported that Pitch controlling changes the angle of blade according to the wind direction. Stall controlling is simpler than pitch controlling where the blade from its shape changes its performance according to the velocity.

The shape of the blades are called *aero foil shape*. The profile of the blade is changing daily and blade material developments such as carbon fiber with low weight are invented [IP1].

IP1, IP2, IP5, and IP7 mentioned that three (03) bladed horizontal axis wind turbines is the most popular and matured technology, where two (02) blades has a balancing issue. There are improvements in blade profiles.The two connectivity practices which are currently used in installing wind turbines in Sri Lanka were *grid connected* and *off grid installations*.

Moreover, the study identified competencies and confines related with solar and wind energy at two different stages named during installation and during operation. Table 2 reports the summary of experts opinions received during the interviews.

Table 2: Competencies and Confines of Solar Panels and Wind Turbines in Sri Lankan Context

	Solar	**Wind**
Competencies during installation	– Technology development – Increased cell efficiency – Good solar potential – Availability of solar maps – Supportive government policies – Higher number of suppliers – Availability of loans	– Availability of wind resource maps – Abundant wind supply – Supportive government contribution
During operation	– Specialization savings – Lesser maintenance	– Technology and knowledge flow – Technology inventions

	Solar	Wind
	– Availability of norms on modelling	
Confines During installation	– Technological barriers – Less investments – Higher initial cost – Damages through lightning – Longer pay back periods – Limitations through guidelines	– Limited number of experts – Undeveloped infrastructure – Difficulty in handling higher capacity turbines – Higher initial cost – Unavailability of bankable data – Larger area for the installation
During operation	– Limited number of experts – No local manufacturing	– Turbulence effect – No proper modelling and controlling – Less local manufacturing

4.2. *Growth of Solar and Wind Energy in Sri Lanka*

As found from the participants, over 500 suppliers are available in the market for solar installations while more than 50 of them are registered at SLSEA. Nearly 83762 households have been provided electricity through solar panels of 10-15kW under Rural Electrification and Renewable Energy Development (RERED) project. It was found that solar energy currently contribute to about 12% of energy generation in Sri Lanka, however, 88%-90% of energy is thermal energy and transport. This makes the conclusion that among the 12% of energy generation, about 10%-12% of energy is for the electricity generation through solar panels.

"Soorya Bala Sangramaya" (Battle for solar energy) program has given a directive to unlimitedly promote solar energy among Sri Lankan citizens. With the introduction of the program, the aim was created to reach an installed capacity of roof top solar to 200MW by 2020, and hence, free solar consultation is granted by SLSEA registered companies. The interview participants mentioned that Jaffna lagoon has a 4000MW capacity of wind energy generation, which is a higher potential with less energy generation cost, and Mannar region has a 400MW wind generation capacity.

4.3. *Issues of Relying on a Single Renewable Energy Source and Emergence of HRES*

Experts have identified four (04) major issues of relying on a single renewable energy source: Fluctuations and seasonal variations, Non-reliability and inconsistency, Higher cost, and Lack of storage.

Through the expert opinions, it was identified that the strategies followed to mitigate issues of relying on a single renewable source were hybrid renewable energy systems, promoting batteries and storage, merging renewables with other energy sources, and choosing constantly available renewable energy sources. Among them, the hybrid renewable energy systems was stated as the best strategy in terms of sustainability and permanency.

In strengthening the hybrid systems, many strategies such as weather forecasting, modelling, regional grid strategy, and local gridding, were identified. The importance of hybrid renewable energy systems were highlighted in terms of addressing future energy deficit problem, reliability and flexibility, energy efficiency and balancing, sustainability, smooth supply, energy security and environment protection, local value additions, space planning, and less energy cost.

4.4. *Emergence of Hybrid Solar-Wind Renewable Energy Generation Approach for Sri Lanka*

Many studies have investigated the hybrid renewable energy concept, but limited studies are available on the application of the concept in Sri Lanka. Renewable energy usage as a hybrid may enhance energy design features through coping up with varying user consumption patterns, reliability, and heading to a sustainable environment. The major reasons identified in hybrid approach to be an apprentice concept in Sri Lanka were, lack of expertise, technology barriers, lower funding, and lower industrial professional interest. It revealed that Pattiyapola is the only place where hybrid renewable energy systems are available in Sri Lanka. This is the world's first 100% green energy driven village, which was ultimately a failure with the introduction of grid connectivity to the village. However, the experts believed that the most popular solar and wind hybrid will be more appropriate for Sri Lanka in terms of abundance, no emissions, and lower human involvement.

Regulatory and policy concessions, abundance and availability of maps, environmental friendliness, long term soft loans, and higher number of suppliers, were identified as the enablers in implementing hybrid solar-wind energy generation approach in Sri Lanka. Technology barrier, funding and investment issues, loopholes in wind energy, knowledge gap, unstable government policies, no local manufacturing, no interest about green energy, conventional systems and energy conservation, higher pay back period, and lack of storage, were identified as major barriers. Figure 4 illustrates the identified enablers and barriers with implementing solar-wind hybrid approach in Sri Lanka.

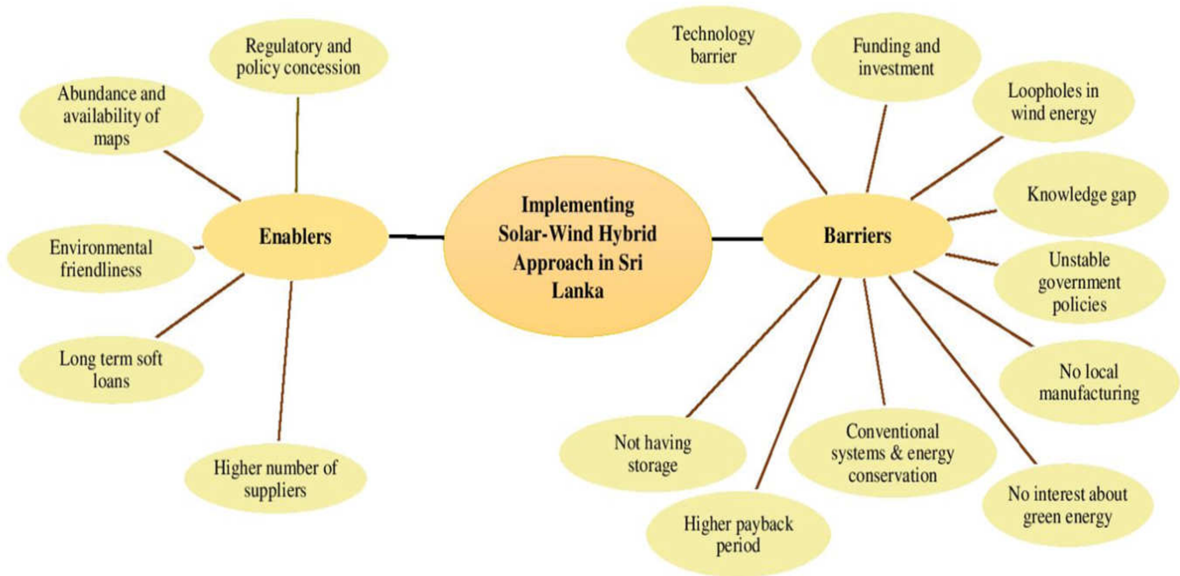

Figure 4: Enablers and Barriers in Implementing Solar-Wind Hybrid approach in Sri Lanka

Furthermore, the study identified three main situations where a solar-wind hybrid approach can be applied in Sri Lanka. Grid connected areas with abundant supply, off grid areas where electricity generation cannot be provided through grid, and for different types of industries such as tea, garment, or cement industries, are the three main situations.

IP2 stated that if all tea factories in Sri Lanka, which is approximately 714 in number, is converted to hybrid energy generating stations, the country can save about 3 - 4 Giga Watt of energy per year. Also, energy generated by combining solar, wind, biomass, and mini hydro, will answer to sustainable tea industry. Funding, incentives, and policy decisions should be improved in order to make more productive. Further, in tea industry, among the major processes of withering, rolling, drying, shifting and grading and packing processes, the drying processes consumes about 4 yards of firewood per day, which is approximately 3.5 trees. Altogether, for the 714 factories in Sri Lanka, it will consume nearly 2500 trees per day, accounting to about 1 million trees per year. This usage of biomass energy for drying process is a huge destruction in terms of forests; therefore, if the drying process can be performed through micro wave and infra-red using electricity generated by solar and wind, it will save about 1 million trees per year for the country. Through a solar and wind hybrid, about 30% of the energy requirement of tea factories can be generated.

5. CONCLUSIONS AND WAY FORWARD

With the worldwide energy challenge and attention towards sustainability and green energy solutions, renewable energy usage plays a major role in the immense process of sustaining energy. It is vital to stand as a nation to face this future energy crisis issue. The effect of being non-reliable and inconstant has made usage of one single renewable energy source to the emergence of a combination of renewable energy sources with a standby source. This was named as “hybrid renewable energy systems,” which has currently become the outcome of triumphs in several research fields that have a remarkable potential in the reliability of integrating solar, wind, and other renewables together. This paper is aimed on investigating the applicability of solar-wind hybrid concept as a sustainable energy solution to the expected future energy deficit in Sri Lanka, where the current practices, competencies and confines in solar and wind energy generation, enablers and barriers while implementing, and the applicability of hybrid solar-wind energy generation approach to the Sri Lankan context, were clearly presented. Finally, the study identified three main situations where a solar-wind hybrid approach can be applied in the country.

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