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Can Sri Lanka be a net-zero nation by 2050?—Current renewable energy profile, opportunities, challenges, and recommendations

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ABSTRACT

Sri Lanka as a country has tremendous potential for harnessing energy from renewable sources such as solar, wind, and hydro. However, as of 2018, only 39 % of Sri Lanka's energy generation capacity was harnessed through renewable energy sources. The continuous increase in electrical energy demand and the drastic increase in vehicle population over the past few years have resulted in much of its annual income being spent on purchasing fossil fuels from foreign countries. This has placed the country's future at risk due to the predicted shortage of fossil fuel reserves and in release of an unexpected level of harmful emissions to the environment. In the meantime, Sri Lanka also has an ambitious plan of achieving Net Zero by 2050. The study conducted a systematic review followed by a time series analysis to first identify the present state of the renewable energy progress of the country and through the time series analysis recognize any discrepancies in these efforts. The initial findings revealed the lack of coordination amongst relevant institutions and contrasting government policies such as the increase in investment for non-renewable energy resources as well as backing away from providing initial investment needed to boost the usage of renewable sources for businesses and smaller entities. The study further identified sectors such as transportation and non-renewable power generation activities as the two main barriers deterring the country from having a feasible plan for its efforts for net zero by 2050. From a non-governmental perspective, the study also recognized the knowledge gap and lack of awareness in the wider population of the long-term benefits of switching to renewable sources.

List of abbreviations

Abbreviations			
°C	Celsius	MT/ha	Metric Tonns per hectare
CEB	Ceylon Electricity Board	MW	Megawatt
CO_2	Carbon Dioxide	NGO	Non-Governmental Organizations
EPI	Environmental Performance Index	PCM	Phase Change Materials
GHG	Green House Gas	PV	Photovoltaic
GHI	Global Horizontal Irradiation	RandD	Research and Development
GW	Gigawatt	RE	Renewable Energy
GWh	Gigawatt Hours	RET	Renewable Energy Technologies
HC	Highland Complex	REUF	Renewable Energy Utilization Framework
HDR	Hot Dry Rock	RPS	Renewable Portfolio Standards
IRENA	International Renewable Energy Agency	SDG	Sustainable Development Goals
km	Kilometers	SEA	Sustainable Energy Authority
km^2	Square Kilometer	SGE	Salinity Gradient Energy
kW	Kilowatt		
kW/m	Kilowatt/ Meter		

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(*continued*)

Abbreviations	
LED	Light Emitting Diode
M	Meters
mJ/ m2	Millijoules Per Square Meter
m/s	Meters per second

1. Introduction

According to the Environmental Performance Index (EPI) rankings of 180 countries published in 2018, Sri Lanka was in the 70th position while Switzerland and Burundi were ranked 1st and 180th places, respectively (Wendling et al., 2020). EPI is a measure of the environmental health and ecosystem vitality of a country. At present, the mass-scale burning of fossil fuels around the world has become a major environmental threat to the well-being of this planet. Having access to clean, reliable, and affordable energy is not only considered a prerequisite for the elimination of poverty but eventually, it is also a dimension to measure the economic development of a nation (Agyekum, 2020). Being a country, which is heavily reliant on fossil fuels, air pollution is becoming a growing problem in the nation unless the government promotes and implements clean energy technologies for the nation's energy needs (Priyankara et al., 2021).

As per the International Renewable Energy Agency's estimates, 39 % of Sri Lanka's Total Energy Supply (TES) stemmed from renewable energy sources in 2020. When compared with its counterparts in the SAARC region, Sri Lanka's contribution to TES from renewable energy sources (as a percentage contribution to TES) stood above countries such as Maldives (1 %), Afghanistan (19 %), India (24 %), Pakistan (24 %), Bangladesh (26 %) and well below the percentage contributions of Nepal (75 %) and Bhutan (87 %) respectively. While the country's renewable energy contribution remains above par when compared within the region, Sri Lanka's renewable energy contribution to the TES had a −1.8% growth in comparison to its contribution in 2015, making Sri Lanka the only country within the SAARC region to record a negative renewable energy source contribution growth during the 2015–2020 period (IRENA, 2021). However, recent evidence suggests that Sri Lanka, as a developing nation, has identified the importance of renewable energy sources, and specific policies are being taken to facilitate its development. Despite identifying some key renewable energy sources such as hydro, solar, wind, and wave energy, there is still a lack of a robust policy framework for harnessing the full potential of the alternative/renewable energy sources available to the country (Shi et al., 2018).

The study will examine the present energy profile of Sri Lanka in terms of the available energy sources and their potential together with the possible developments in the next few years in extending the country's energy generation capacity as per the Renewable Energy Utilization Framework (REUF) (Ogbonnaya et al., 2019). Furthermore, this study also utilizes a time series analysis to further investigate the configuration of the Sri Lankan renewable energy sector. Given the wide scope of renewable energy, the review aims to mainly focus on the REUF framework and studies addressing renewable energy sources complement the framework, two key research questions were formulated to address the aims of this study, as shown:

1. What is the present configuration of Sri Lanka's renewable energy profile?
2. How can the present configuration inform the future of Sri Lanka's renewable energy situation?

The outline of the article is as follows; Section 2 analyses the existing work surrounding Renewable Energy (RE) in the Sri Lankan context, and Section 3 goes on to explore the current situation of the Sri Lankan RE sector and the country's present Green House Gas (GHG) emission profile. Section 4 aims to develop the RE knowledge of Sri Lanka through a comprehensive systematic literature review and a time series analysis. The recommendations based on the analysis, limitations and policy implications of such initiatives are discussed in Sections 5 and 6, respectively.

2. Renewable energy supply of Sri Lanka

Renewable energy sources undoubtedly will play a key role in the world's future. RE sources predominantly involve biomass, geothermal, hydropower, solar, wind and marine energies to name a few (Panwar et al., 2011). The global interest in harnessing RE sources is no secret given how climate change has become unavoidable unless there is a drastic reduction in fossil fuel emissions at a global level (Kaartemo and Gonzalez-Perez, 2020). Many countries and governments have given priority to dealing with this issue through policy to balance the complex issue of achieving economic growth while maintaining a sustainable environment (Rehman et al., 2019). The key renewable energy sources of Sri Lanka are examined in the next few paragraphs.

2.1. Solar energy resources

As a country located on the equatorial belt, there is a considerable amount of solar energy available for Sri Lanka year-round. When looking from a historical standpoint, the Stockholm Environmental Conference in 1972 provided the impetus for the Sri Lankan government to start looking at alternative energy, and solar energy was considered a strong option by the ministry-appointed committee in 1975. This work established Sri Lanka's interest in the RE sector and a pilot project with the United Nations Environmental Programme (UNEP) that installed 10 kW solar Photovoltaic (PV) arrays in the village of Pattiyapola (Gunaratne, 1994).

Given the geographic location and the available sources of renewable energy sources in Sri Lanka currently, solar energy is identified as the most common method in use (Board, 2020). The continuous supply of solar radiation without any seasonal variations further adds to the value of harnessing this energy source as a feasible alternative energy strategy in the island nation (Manjitha and Munasinghe, 2021). The utilization of solar power in a country has many usages including household lighting, heating as well as in commercial use (Malinowski et al., 2017).

Given the rising demand for renewable energy sources, the installed capacity of solar power in megawatts (MW), as well as the overall number of solar connections in the country, have also seen an upward trend (Bandara and Amarasena, 2020). When looking at the extent of available solar resources in the country, the annual solar distribution varies from 15 to 20 MJ/m^2 per day 4.2 to 5.6 kWh/m^2 per day with lower values recorded in the Central and South-Central regions (Chamara and Beneragama, 2020). At present, the government has added 200 MW of solar energy to the national grid and is in the process of increasing this level to 1000 MW by the end of 2025 (De Silva, 2020). Fig. 1 highlights the horizontal irradiation map in Sri Lanka and the potential PV power locations based on the country's demographic.

2.2. Wind energy resources

According to the geographical advantages, surrounding solar energy, Sri Lanka is in one of the largest monsoon belts of South Asia with year-round monsoon weather creating steady strong winds in the country (Amarasinghe and Perera, 2021). Sri Lanka's history of using wind power dates back to the 3rd century B.C. and as showcased in Fig. 2 the country currently boasts over 5000 km^2 of windy areas that are considered to have excellent wind resource potential areas (Sri Lanka Sustainable Energy Authority Ministry of Power and Energy, 2019). The wind power sector of Sri Lanka saw its first activity in the year 1988 as

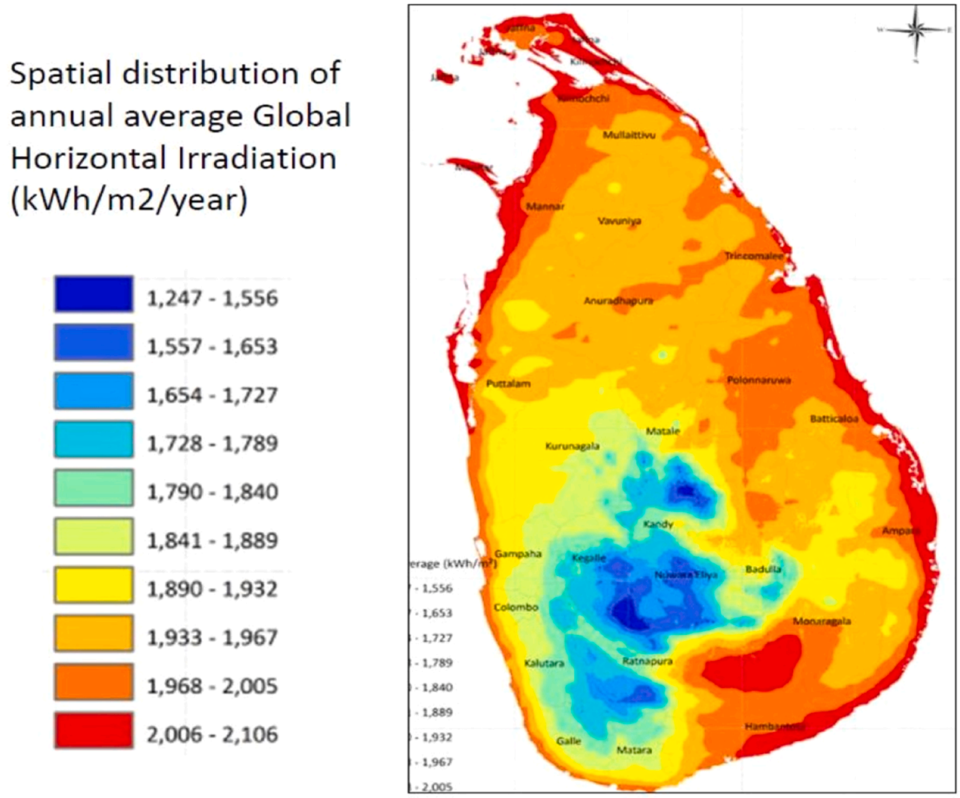

Fig. 1. Global Horizontal Irradiation (GHI) in Sri Lanka.
Source - (Sri Lanka Sustainable Energy Authority Ministry of Power and Energy, 2019).

research was conducted to establish a pilot wind project in the Southern Province (Juleff, 1996). Out of the many renewable energy options present, wind power is often considered the most economically viable and environmentally friendly source for Sri Lanka. In addition to the monsoon weather, the central highland of the country creates defined wind patterns. The combination of the central highlands and the monsoon-based climate makes Sri Lanka one of the windiest locations in the world (Amarasinghe and Perera, 2021).

Additionally, Sri Lanka could expand beyond onshore winds to the offshore wind networks as presented in Fig. 3. Offshore winds are identified as wind energy harnessed from the forces at sea and transformed into electricity to be utilized for onshore purposes (National Grid, 2022). In the context of Sri Lanka, wind speeds northwest of the country range from 7.5 to over 9 m/s with water depths below 50 m deep. The total area has an offshore wind technical potential of 45 GW and a total score of over 92 GW (World Bank Group, 2020).

2.3. Hydro-energy resources

Hydropower is energy derived from falling water. Today, it is one of the most cost-effective ways to generate energy and is often the chosen technique when available (Sri Lanka Sustainable Energy Authority Ministry of Power and Energy, 2019). Hydropower has played a significant role in power generation in Sri Lanka since the installation of the first hydroelectric power station at Laxapana in 1950 (Thambawitage, 2019). Sri Lanka has a sound hydropower potential due to its physical structure, which includes rain-fed central hills. The amount of water that flows through a place during a particular period and the vertical drop through which the body of water passes define the hydropower potential of a water source, which is either a moving or flowing body of water. As a result, a high volume of water and sudden water drops are referred to as valuable hydropower sources (Sayanthan and Kannan, 2017).

At present, hydro projects having capacities below 10 MW, are allowed to be developed by the private sector as run-of-the-river plants and larger hydro plants are to be developed by the Ceylon Electricity Board (CEB) (Ceylon Electricity Board, 2022). Almost all economic potential for hydropower generation in large-scale power plants has already been realized and developed. The majority of the large hydropower schemes are linked to the Mahaweli and Kelani, and those can be considered Sri Lankan's two main rivers, on which the CEB has produced 1370 MW of large hydro and 20.5 MW of small hydro (Asian Development Bank, 2019). Most of the major hydropower stations in Sri Lanka are aged over 25 years, from their total lifespan (Khaniya et al., 2020). The most promising locations for hydropower generation are highlighted in the Fig. 4 diagram.

2.4. Biomass resources

In the context of Sri Lanka, biomass has been the only native, stable, and primary energy source that has contributed significantly to fulfilling the country's overall energy requirement over centuries (Leelaratne, 2016). As of 1985, 71 % of the country's primary energy requirement was derived from biomass (Wijensinghe, 2017) by 2015 this percentile had declined significantly to approximately 39 % of the country's energy output with imported crude oil providing the highest share (Approximately 43 % in 2017) of the national energy output (Asian Development Bank, 2019). Biomass is primarily used to satisfy domestic energy needs in local households with 69 % of Sri Lankans using it to fulfill their cooking energy requirements (Musafer, 2020). Despite the continued usage of biomass in the country, limited attention has been given to developing it as a formal source of energy. The country's current biomass output averages in the range of 26 MW despite the country having an estimated potential of generating up to 2400 MW from biomass alone (Asian Development Bank, 2019; Leelaratne, 2016) . Given the potential for this resource, the Sri Lankan government is planning to launch an expedited and comprehensive action plan and

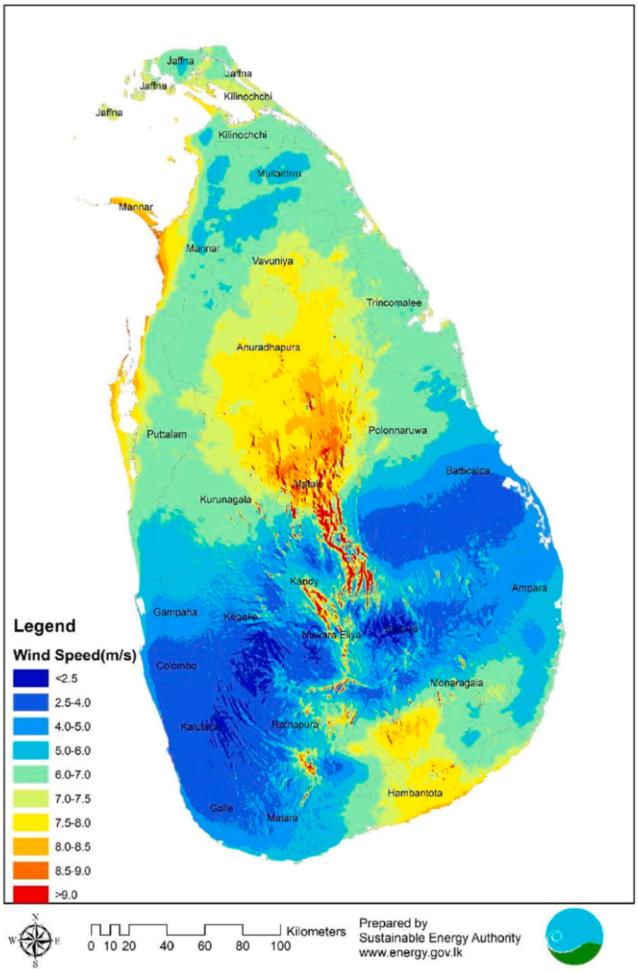

Fig. 2. Wind resources map in Sri Lanka.
Source- (Sri Lanka Sustainable Energy Authority Ministry of Power and Energy, 2019).

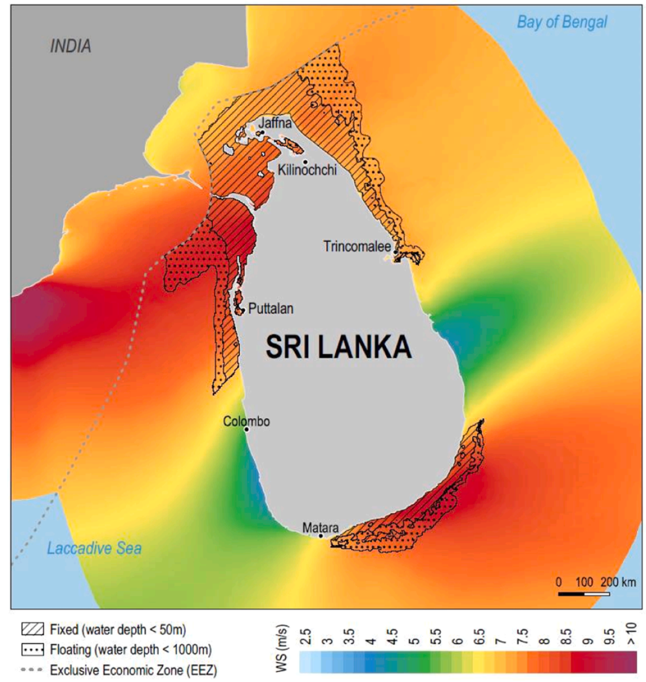

Fig. 3. Off-shore wind resource.
Source- (Sri Lanka Sustainable Energy Authority Ministry of Power and Energy, 2019).

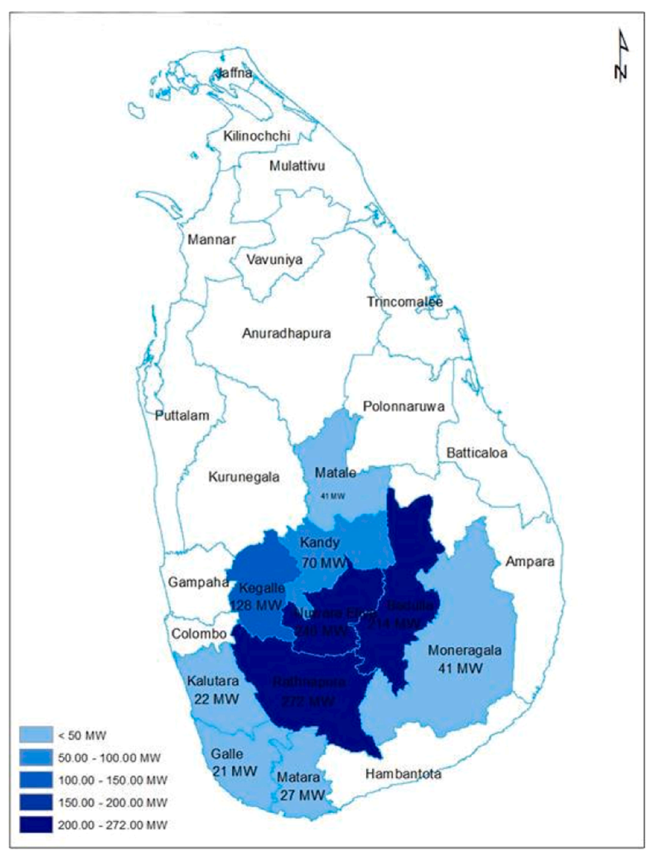

Fig. 4. Hydro resource map of Sri Lanka.
Source - (Sri Lanka Sustainable Energy Authority Ministry of Power and Energy, 2019).

island-wide implementation which may allow the country to achieve its ambitious goal of establishing 105 MW of biomass power plants by 2030 (Asian Development Bank, 2019).

The commercial adaptation of biomass as an energy source remains at a preliminary stage in Sri Lanka (Ariyadasa, 2015) with notable exemptions in several industry sectors such as agriculture, brick and lime manufacturing, hospitality and Small and Medium Enterprises (SMEs) in pottery, ceramics and textiles that uses biomass as the main source for thermal energy generation up to a respectable proportion (Punchihewa et al., 2016). Existing research suggests a tremendous possibility for Sri Lanka to adapt biomass formally and commercially as a more comprehensive energy source. As shown in Fig. 5, several areas in Sri Lanka including Badulla, Monaragala, Batticaloa, Kurunegala, Rathnapura, and Anuradhapura have been identified to have excellent biomass density with a capability of producing more than 6.00 MT/ha of biomass resources annually. The Sri Lanka Sustainable Energy Authority (SLSEA) has an ambitious plan of capitalizing on this resource potential by establishing approximately 56 biomass power plants each with power generation capacities ranging from 3 MW to 10 MW during the 7 years from 2019 to 2025 (Sri Lanka Sustainable Energy Authority Ministry of Power and Energy, 2019). Given Sri Lanka's tropical climate and excellent growing conditions year-round, there is a significant potential for developing such biomass-based power plants to generate 'dendro--power' through large-scale dedicated plantations or as small scale-plantations throughout grower schemes (Arachchige and Sakuna, 2019; Ariyadasa, 2015). Local researchers have also identified the

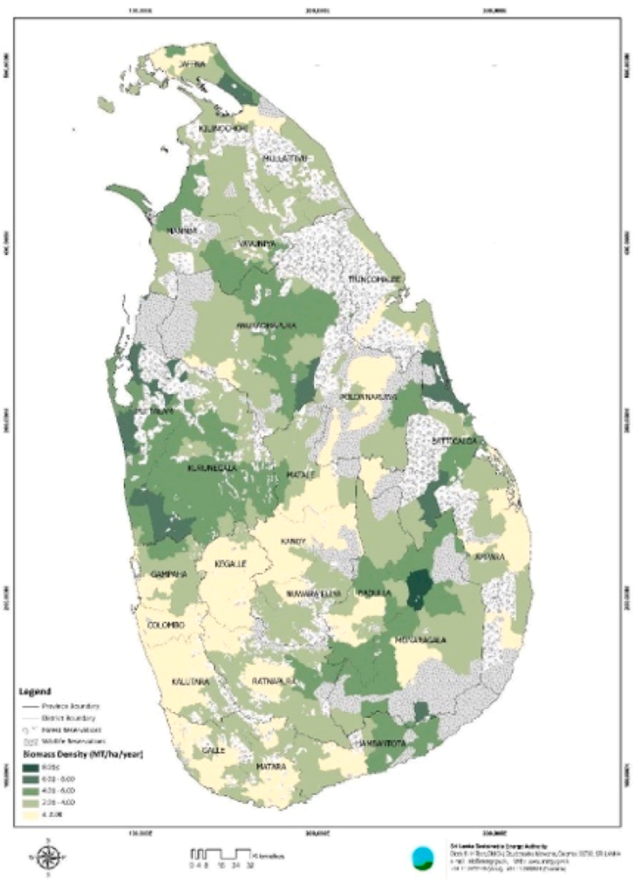

Fig. 5. Biomass density of Sri Lanka- energy plantations.
Source - (Sri Lanka Sustainable Energy Authority Ministry of Power and Energy, 2019).

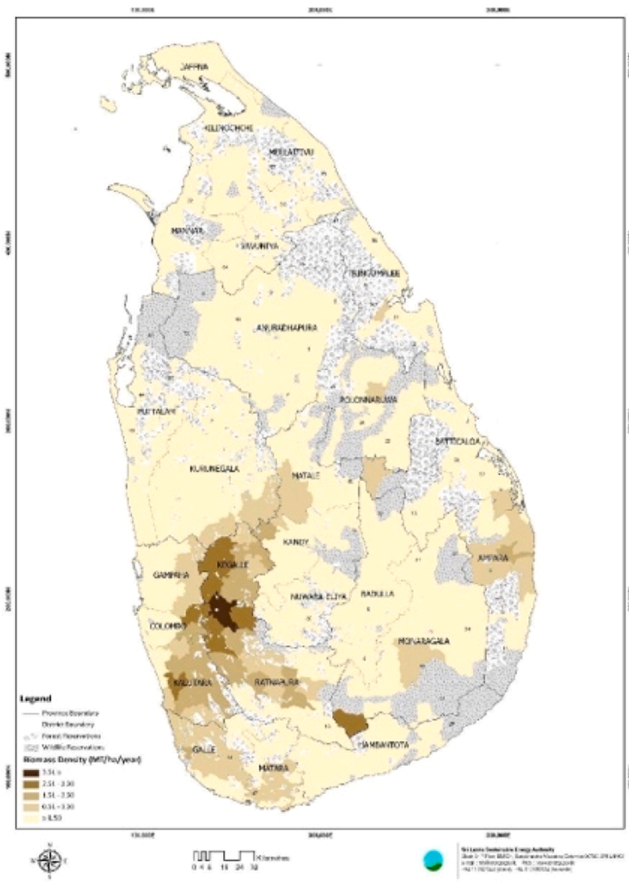

Fig. 6. Biomass density of Sri Lanka – Agro Residues.
Source - (Sri Lanka Sustainable Energy Authority Ministry of Power and Energy, 2019).

potential for using ‘Gliricidia sepium’ a multi-purpose, rapidly growing, and highly adaptive short-rotation coppicing tree typically growing wild throughout Sri Lanka as a viable option for biomass energy generation in the country (Atapattu et al., 2017; Dissanayake, 2021). Additionally, as resources required to produce biomass are mostly available in rural parts of the country, local authorities must explore the possibility of establishing biomass plants in such areas, which will aid in energy generation and the stimulation of local economies (Sugathapala, 2022).

Moreover, commercial biomass generation in Sri Lanka is currently limited to wood while several other sources such as charcoal, agro-residue, animal residue, and municipal and industrial solid waste that are widely available remain largely underutilized in the country and could be utilized more effectively in the future (Ariyadasa, 2015; Elledge et al., 2012). For instance, as showcased in Fig. 6 several areas in the Western, Central and Sabaragamuwa provinces and several other areas in Sri Lanka have been identified to produce significant amounts of agro residue predominantly in the forms of paddy and straws, coconut shells and husks, coir dust, bagasse, sugarcane tops, maize stalk, and cobs (Perera et al., 2005). Sri Lanka however failed to attract investors to launch large-scale agro-residue-based biomass products primarily due to difficulties in collecting enough residues continually to make it a viable investment (Konara and Tokai, 2022). Moreover, Sri Lanka has the second-lowest energy self-sufficiency rate in the South Asian region (Hou et al., 2019), showcasing a clear need for the incentivization of industries such as coconut, tea, and rubber that naturally produce agro-residue to achieve self-sufficiency in generating their energy requirements through biomass generation as opposed to further burdening the national electricity supply (Dasanayaka, 2012).

2.5. Ocean-based (wave/tidal) resources

Sri Lanka is an island nation that has a coast of 1340 km in length which provides the potential to have ocean wave power as an additional energy resource to the overall power generation in the country (Jayarathne, 2012). The estimate of the potential wave energy for an island nation like Sri Lanka is crucial for their future sustainability efforts, even if wave energy extraction is still in the development stage.

Sri Lanka is annually experiencing two monsoon periods: the northwest monsoon and the southwest monsoon. Some previous studies mention that the west coast power generation for a year is around 10–15 kW/m and south coast wave power generation is around 15 kW/m – 20 kW/m (Lokuliyana et al., 2020). Fig. 7 illustrates the annual wave power sources starting from the west coast to the south coast. According to Fig. 7, certain studies emphasize that Galle to Hambantota coastal belt is the most suitable area for wave power generation because it has low variability and swell waves compared to other coastal areas (Maduwantha et al., 2020). Research evidence points toward an ideal opportunity for Sri Lanka to develop ocean-based energy resources because of being an island nation (Vithana et al., 2019).

Also, it emphasizes that Yala to Thirukkovil as having the highest potential in generating wave-based energy on the south-eastern coast of Sri Lanka. According to the ocean-based studies and as detailed in Fig. 7, M6 area records the highest recording wave power in Sri Lanka while M1 records the lowest values based on geographical positioning (Karunarathna et al., 2020). Existing research has highlighted that overall, the southwest and the south coast of Sri Lanka are recording the highest levels of wave power compared to other coastal areas of the country (Sri Lanka Sustainable Energy Authority Ministry of Power and Energy,

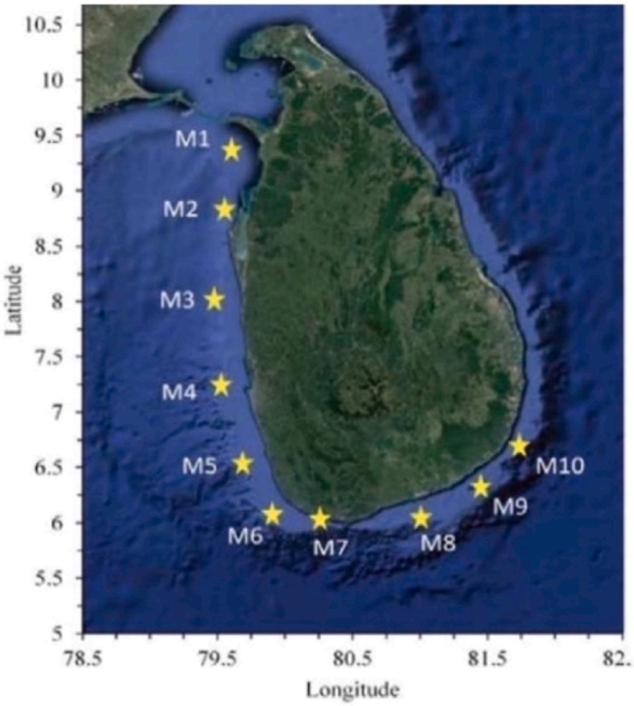

Fig. 7. Annual wave power.
Source- Sri Lanka Sustainable Energy Authority Ministry of Power and Energy, 2019).

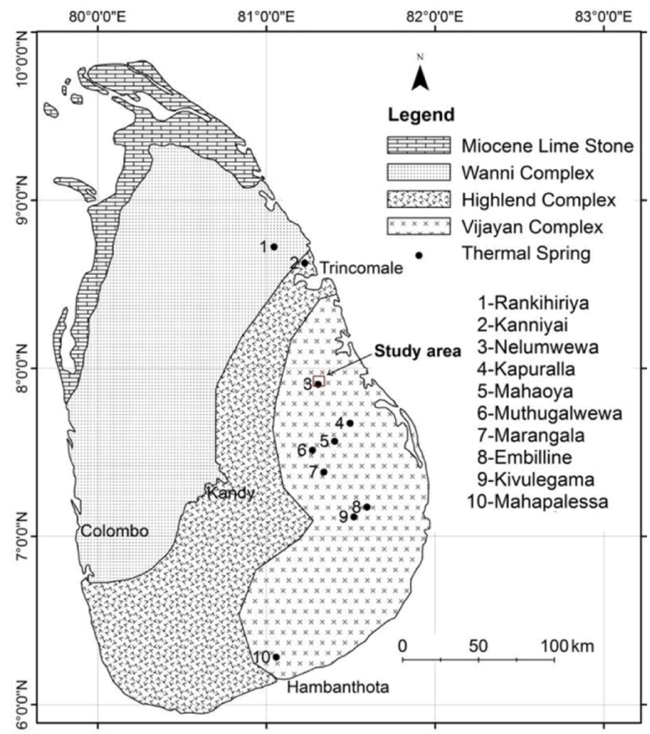

Fig. 8. Geology map of hot springs in Sri Lanka.
Source- (Kumara, 2014).

2019). Furthermore, the preliminary assessment of wave energy in Sri Lanka stated that it is reported that high power occurs on the west coast at deeper water, whilst it does so on the southeast coast at somewhat shallower depths (Ariyarathne and Jayarathne, 2020).

2.6. Geothermal energy resources

The inherent warmth of the ground or in other words geothermal energy is broadly available and an indigenous energy source in the world. At present, the geothermal energy source is used for space heating, industrial heating, and generating electricity at the domestic level. Also, there are potential direct uses of geothermal energy such as steaming and drying agricultural products, paper production, sugar processing, and health and recreational purposes (Kumara, 2014).

Sri Lanka has few hot springs which are not associated with any volcanic terrain and the country has around 5 % of geothermal power which can be utilized for power generation in the country. The remaining raw heat in the springs can be used as a hot water supply to domestic consumers and this will bring an additional income to the National Water Supply and Drainage Board of Sri Lanka (Wijetilake, 2011). There are ten identified springs in Sri Lanka, Rankihiriya, Kanniyai, Nelumwewa, Kapuralla, Mahaoya, Muthugalwewa, Marangala, Embilline, Kivulegama, Mahapalessa (Fig. 8) (Kumara and Dharmagunawardhane, 2014) where the outflow temperature varies between 35 and 72 °C and the reservoir temperature changes around 140–150 °C (Anuranga Bandara and Subasinghe, 2020). These kinds of geothermal systems are identified as low enthalpy geothermal systems and there are "four main geothermal systems including vapor dominated, hot water, pressed Hot Dry Rock (HDR) and magma systems" (Anuranga Bandara and Subasinghe, 2020).

Moreover, the researchers have identified 4 heat resources as suitable locations for geothermal power supply. Those are Nelumwewa, Mahapelessa, Kanniya and Kapurella (Fig. 8). There is also a mention of the hot springs located in Wahawa Padiyathalawa area that generates a temperature of 50–60 °C (Anuranga Bandara and Subasinghe, 2020). Currently, geothermal sources in Sri Lanka are mainly used for recreational purposes as opposed to economic reason and is based on a narrow stretch parallel to the Highland Complex (HC) and the Vijayan Complex (VC) as seen in Fig. 8.

2.7. Other possible renewable energy sources

In addition to the energy sources discussed above, there are some other sources used across the world in harnessing renewable energy such as desalination gradient, hydrogen-based sources, phase change materials, and so forth. An important focus in this is the construction sector which is constantly looking to address the varying temperatures inside the structures (Skovajsa et al., 2017). Phase Change Materials (PCM) are incorporated at a mass scale by directly mixing them into the construction materials including floor, ceiling, panels, etc. as applications (Da Cunha and de Aguiar, 2020). With the global demand for space heating and cooling rising in commercial and residential properties, phase change materials and their new integrations are useful and essential focal points. The implementation of PCM has a variety of inputs and renewable sources such as example the use of coconut oil ceilings to improve the thermal performance in commercial buildings (Alqahtani et al., 2020) Sri Lanka is a country with an abundance of coconut, which could further develop PCM such as coconut oil as a future renewable energy source. Interest has also mounted on the development of low emissions off-grid renewable energy sources and salinity gradient is identified as one such source providing the water-energy nexus challenge with a clear solution (Tristán et al., 2020).

The chemical energy of Salinity Gradients (SGE) is available mostly in the coastal areas where the different water flows mix such as a river meeting the sea. Controlling the mixture of the water and capturing its energy before it's released means electricity could be produced without any greenhouse gas emissions (Marin-Coria et al., 2021). The naturally occurring process makes coastal areas an ideal one to take advantage of the chemical mises of both freshwater and saltwater (Seyfried et al., 2019). Other applications to Sri Lanka are in the early discussion stages which include the ability to work on green hydrogen technology using excess wind to move from an energy deficit to a surplus situation (Fernando et al., 2023). Wind energy has the potential to be harnessed and transformed into hydrogen using an electrolyze. This hydrogen can then find diverse applications, including powering fuel-cell vehicles like trucks, buses, and trains, fueling ships through the conversion to liquid ammonia, and serving as a viable alternative to natural gas for residential heating (Staffell et al., 2019). This idea directly corresponds to Sri Lanka's plan toward net zero by 2050 as it needs a mechanism to minimize gas emissions in industries as well as gradually transition from fossil fuel to green energy production techniques (Dailymirrror, 2022).

3. Methods

The study aims to understand the present configuration of the renewable energy profile of Sri Lanka. To achieve this, the study has combined a systematic literature review with a time series analysis. Mixed-method research is often popular in many research contexts as it aims to overcome the limitations of mono-method research (Kelle, 2006). The study looks at the REUF framework and only the areas of policy, quantification, technologies, energy conservation and continuous improvements (Fig. 9).

The review process is composed of five stages as seen in the work of (Tranfield et al., 2003). The first stage was coming up with research questions that reflect the aim of the study. The second involved collecting papers relevant to the topic from relevant databases including Scopus, Web of Science, Science Direct and Emerald Insight. The study ensures the use of literature and peer-reviewed articles from reputed databases (Dasanayaka et al., 2021). This also meant that book chapters, conference proceedings and working papers were excluded to only focus on peer-reviewed journals. The initial search was focused on the keywords of "Renewable Energy Policy Exploitation" OR "Renewable Energy Policy Integration" AND "Policy" OR "Quantification" OR "Technologies" OR "Conservation" OR "Improvements". Next, the search was refined on the time scale with articles in the past 20 years from 2003 to 2023. The rationale behind this was to gain an understanding of the Sri Lankan renewable landscape in the past two decades and what key changes have happened in that period regarding the selected dimensions from the REUF framework.

In the initial search, a total of 240 papers were chosen excluding any of the duplications from the selected four databases. The selection criteria of articles included a manual screening process which meant that it was matched against the criteria of the REUF framework to determine the relevance. Hence the title, abstract, and keywords were matched against the criteria of the framework. Articles which had no direct relevance to the keywords were excluded. This meant that after exclusion there were 145 articles directly relevant to the keywords. The in-detail review of the articles meant that some of them were not directly related to the core concepts of the REUF framework, which was the most important criterion. This meant that 31 articles were selected for the final analysis. These articles mostly addressed issues surrounding the national policy, potential technology, and conservation and less on quantification and continuous improvements were seen. A thematic content analysis technique was mainly utilized to analyze the findings of the selected journals under the five primary themes identified based on the REUF framework namely (policy, quantification, technology, usage, and improvement).

Secondly, as the study adopts a time series analysis, historical data on Sri Lanka's net zero activities needed to be extracted. The country's current energy generation profile along with its current GHG emission rates was needed to understand the country's potential to achieve net zero emissions. This was done through secondary data collected from a multiplicity of sources including the World Bank, International Renewable Energy Agency (IRENA), British Petroleum Reports, Sri Lanka Sustainable Energy Authority, and statistics derived from the Sri Lanka energy profile in ourworldindata.org. Afterwards, the section moves on to analyze a time-series graph (prepared based on World Bank data) of the GHG emissions of the country for the past 5 decades.

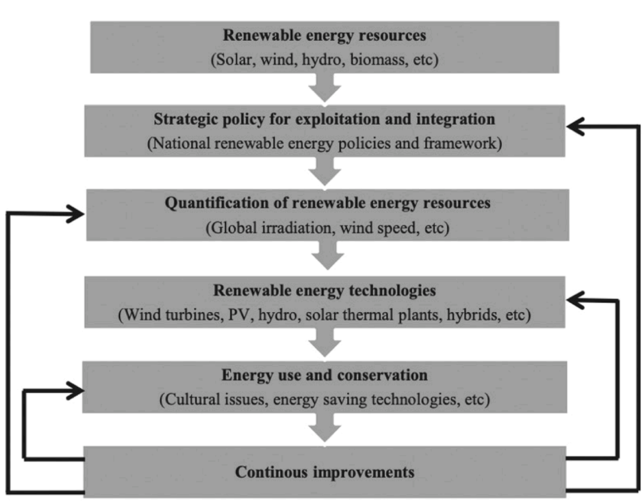

Fig. 9. Renewable energy utilization framework (REUF).
Source- (Ogbonnaya et al., 2019).

4. Findings

The insights identified in the findings section are primarily two-fold. Firstly, this section focuses on producing the findings of the systematic literature review based on the REUF framework proposed in the methodology. As highlighted in the second research question, given the fact that this article focuses on identifying how the present configuration can inform the future of Sri Lanka's renewable energy situation, the findings section also focuses on identifying literature about five of the six core pillars of the REUF framework. Moreover, this article also identifies the importance of assessing the country's current energy generation profile along with its current GHG emission rates to understand the country's potential to achieve net zero emissions. Hence, following the systematic literature review, the findings section moves on to evaluate Sri Lanka's past and present energy generation potential with the time series analysis.

4.1. Systematic literature review findings

Table 1 presents the summarized findings of some of the key points reported by the previous works (based on the REUF) on the renewable energy sector of Sri Lanka.

As was highlighted earlier, the literature review findings had five key categories derived from the REUF framework (policy, quantification, technology, conservation, and improvement).

4.1.1. Renewable energy policy

A strategic policy for exploitation and integration of the RE sources emphasizes developing national policies such as energy security, energy economics, environment, financing, technological development, research, and development. Sri Lanka's energy policies and strategies strongly focus on developing conventional and nonconventional renewable energy sources for generating power. Promoting domestic energy resources has become one of the main policy components in Sri Lanka. The three main nonconventional renewable energy sources to be encouraged in Sri Lanka for grid-connected electricity generation are small hydropower, biomass power, and wind energy (Wijayatunga, 2014). From a policy perspective, it is evident that there is a lack of coordination and synergy between various government institutes and there is a need for greater consistency between such bodies in managing the process of building policy and decision-making (Shi et al., 2018).

Table 1
Summary of the previous works focusing on different aspects of REUF.

Component of REUF	Descriptions of study/ Remarks	References
A strategic policy for Exploitation and Integration	Incentivizing renewable energy adoption through newer tariff policies	(Enescu et al., 2023)
	Solar home system strategies of the world bank and its effectiveness.	(Sovacool, 2018)
	Policy for variable renewable energy and how to improve better coordination amongst government agencies in Sri Lanka	(Shi et al., 2018)
	The level of adaptation of biomass as a fuel in the Sri Lankan manufacturing sector	(Punchihewa, et al., 2016)
	Exploring the key features of renewable energy developments in Sri Lanka	(Wijayatunga, 2014)
	Analyses the effect on the economy of carbon emissions and the energy taxes	(Siriwardena et al., 2007)
	The Impact of electricity supply on economic growth in Sri Lanka	(Morimoto and Hope, 2004)
	Energy policy implementation guidelines of Sri Lanka	(Siyambalapitiya, 2003)
Quantification of renewable energy resources	An ethnographic study of the Use of solar home systems	(Turner, 2019)
	Wind and solar power generation capacity assessment	(Amarasinghe and Abeygunawardane, 2019)
	Importance to adopt sustainable practices based on evidence from the construction field	(Jayalath and Gunawardhana, 2017)
	A qualitative factor analysis of renewable energy and sustainable energy	(Sovacool, 2013)
	Socio-geographic perception in the diffusion of innovation: Solar energy technology in Sri Lanka	(McEachern and Hanson, 2008)
Renewable energy technologies	Adopting solar energy technologies to be utilized in the domestic household environment	(Bandara and Amarasena, 2020)
	Building technologies using renewable materials	(Udawattha and Halwatura, 2016)
	Sizing and tracking of combined cooling heating and power systems for bulk energy consumers.	(Jayasekara and Halgamuge, 2014)
	The Impact of the Renewable Energy Portfolio Standards (RPS) on Sri Lanka	(Wijayatunga and Prasad, 2009)
	Discussion of the use of biogas as a renewable energy source in Sri Lanka	(De Alwis, 2003)
Energy use and conservation	Efficiency is enhanced by environmental sustainability practices in the hospitality sector.	(Kularatne et al., 2019)
	Quantifying the energy usage in the garment sector to identify the life cycle impacts through energy sources.	(Muthukumarana et al., 2018)
	Cooling demand of Sri Lanka and how to manage energy efficiently requirements	(Geekiyanage and Ramachandra, 2018)
	Improving the energy efficiency of small and medium size apparel manufacturers in Sri Lanka	(Pathirana and Yarime, 2018)
	Energy conservation strategies in Buildings for Sri Lanka	(Kumanayake et al., 2018)
	Evaluation of the energy management approaches in South Asia	(Abbas et al., 2018)
	The cost of energy associated with micro wind generation.	(Sunderland et al., 2016)
Continuous improvements	Energy transition to Light Emitting Diode (LED) lighting in preserving renewable energy storage	(Jayaratne et al., 2022)
	Solar photovoltaic systems to improve domestic level energy generation in Sri Lankan Households	(Thanthirige et al., 2022)
	The use of net zero building concepts to reduce energy wastage and improve energy efficiency	(Mohamed et al., 2022)
	Developing rail travel with zero-emission sources and the inclusion of renewable energy sources into the railway electrification process	(Binduhewa, 2021)
	Driving innovative solutions necessary for the handloom sector of Sri Lanka to integrate greater sustainable practices into the industry	(Wanniarachchi et al., 2020)
	Developing net zero building concepts to reduce energy consumption and improve efficiencies in commercial properties	(Weerasinghe, Mallawaarachchi and De Silva, 2016)

Source- Author's own.

Furthermore, there is more recent development surrounding how to incentivize the adoption of renewable energy sources such as the purchase of PV panels and installation which has gained momentum from a legislative perspective (Enescu et al., 2023).

4.1.2. *Quantification of renewable energy*

Presently there is a lack of evidence from existing studies on the quantification of renewable energy sources in Sri Lanka. The literature derived through the systematic review demonstrates the global growth of adaptation of renewable energy resources such as the expansion of grid solar products and how the widening adoption of such practices could be context specifically introduced to the market of Sri Lanka (Turner, 2019). There is also some work surrounding the two most frequent renewable energy sources of Sri Lanka, solar and wind energy and how to build capacity for innovative power-generative solutions (Amarasinghe and Abeygunawardane, 2019). The justification for adopting certain renewable practices has shown some evidence as seen with the construction sector as well as domestic household practices (Jayalath and Gunawardhana, 2017) but this needs to be further explored in more recent work as statistical evidence of such practices in Sri Lanka is under-researched.

4.1.3. *Renewable energy technologies*

Renewable energy technologies (RETs) convert renewable resources into usable forms of mechanical, thermal, electrical, and chemical energy. They include solar home systems, residential wind turbines, biogas digesters and gasifiers, micro-hydro dams, improved cookstoves, etc. (Benjamin Sovacool, 2013). Solar irradiation, wind speed, biomass distribution, and aquatic characteristics can be identified as some of the measurements in quantifying renewable energy resources in Sri Lanka. There is evidence of the use of the most common sources such as solar power harvesting in domestic households (Bandara and Amarasena, 2020). There is also evidence in Sri Lanka of the use of innovative construction techniques such as mud concrete on the topic of biomass energy (Udawattha and Halwatura, 2016).

4.1.4. Renewable energy conservation

Conserving renewable energy has been addressed in numerous ways in the found journals. There is attention given from an industry perspective such as the garments sector and how water usage has been minimized in the process both with larger as well as smaller apparel manufacturers across Sri Lanka (Muthukumarana et al., 2018; Pathirana and Yarime, 2018). Like renewable energy technologies, there is some reference to the work on building technologies in Sri Lanka and the innovative solutions available to ensure efficiency improvements are made for conserving energy (Kumanayake et al., 2018).

4.1.5. Renewable energy continuous improvements

Continuous improvement toward net zero in Sri Lanka has a varied approach with an industry-level focus on activities that are already existing. As seen in the literature there is already attention given at the corporate level on how to utilize solar energy and newer solutions in solar photovoltaic systems to be integrated in improving domestic energy consumption patterns (Thanthirige et al., 2022). Continuous improvements also have a spillover effect on certain key sectors of Sri Lanka as we see how the public transportation and rail network electrification process is now in the process of developing renewable energy sources which shows a deeper commitment towards continuous improvement as well as other sectors such as handloom sector which sees more sustainable and renewable energy practices integrated into business models (Binduhewa, 2021; Wanniarachchi et al., 2020).

4.2. Time series analysis findings

Sri Lanka's rapid economic expansion since the late 20th century has positively correlated with the country's overall energy consumption. As evidenced in Fig. 10 the demand for energy in Sri Lanka has continued to grow exponentially and the country has increased its electricity consumption from approximately 2.5 TWh per annum in 1985 to over 15 TWh per annum by 2020. Moreover, as further evidenced in Figs. 10 and 11, renewable energy has contributed to producing nearly the entirety of Sri Lanka's energy requirement up until 1995. However, as the country's total energy requirement neared and surpassed the 5 TWh mark during the 1995–1997 period, Sri Lanka was obligated to look for multiple sources of energy generation to meet this demand and the percentage contribution from renewable energy sources continued to decline considerably from there on with renewable energy sources generating less than 50 % of the country's energy requirement continuously after the beginning of the 21st century (Notwithstanding 2010/13/15).

When assessing Sri Lanka's energy profile depicted in the time series analysis presented in Fig. 12, it is understood that hydroelectric energy has remained the country's single most valuable renewable energy generation source for the last few decades. Until the late 90 s, hydropower acted as the country's key energy generator producing nearly the entirety of Sri Lanka's energy requirement. Over the past decade, hydroelectricity has continued to generate between 3.5 to 7 TWh of energy whilst remaining one of the top three energy-generating sources in the country. Moreover, Sri Lanka has also identified the potential for wind, bioenergy, and solar as alternative energy sources in the past two decades. However, the current contribution from these three renewable sources in comparison to hydroelectricity remains significantly low. Wind energy remains Sri Lanka's second main renewable energy source where, as of 2019 the country's wind power plants contributed nearly 350 Gigawatt Hours (GWh) of electricity to the National Grid (International Renewable Energy Agency, 2021). Furthermore, Sri Lanka' has also seen an increase in the energy generated through bioenergy sources (geothermal, biomass and waste energy) with this segment producing approximately 250 GWh of energy by 2020. However, despite its potential, solar energy has had an uninspiring growth until 2016. Sri Lanka witnessed a nearly 60 % increase in solar power generation (approximately from 20 GWh to 140 GWh) post-2016 primarily resulting from the launch of the government-backed 'Battle for Solar Energy' campaign which aimed to add 1000 MW via solar power by 2025 (Sri Lanka Sustainable Energy Authority, 2022).

Nonetheless, even as of 2019, Sri Lanka's overall energy generation split between non-renewable and renewable energy sources remained at 65 % to 35 %, respectively. As depicted in Fig. 13 the country has continued to harness energy through traditional non-renewable energy sources such as oil and coal (generating 5.9 TWh and 4.2 TWh, respectively) as the primary energy sources.

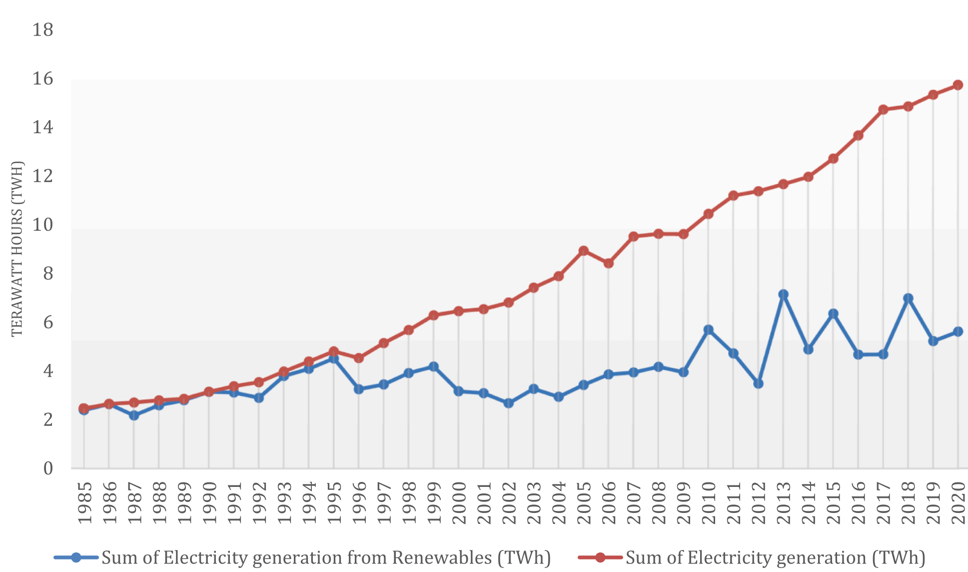

Fig. 10. Sri Lanka's total and renewables-based energy generation between 1985 and 2020.
Source –(British Petroleum, 2021).

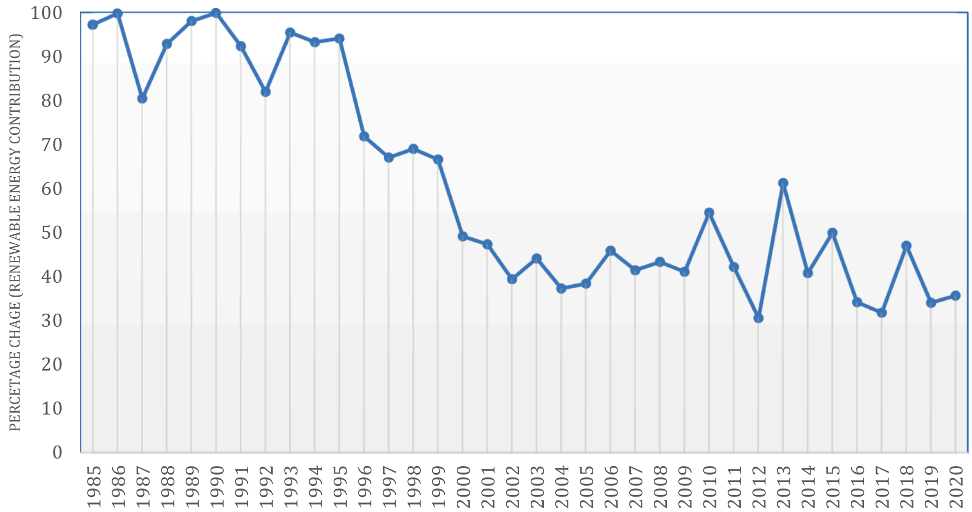

Fig. 11. The percentage contribution of renewable energy to the total energy generation between 1985 and 2020.
Source –(British Petroleum, 2021).

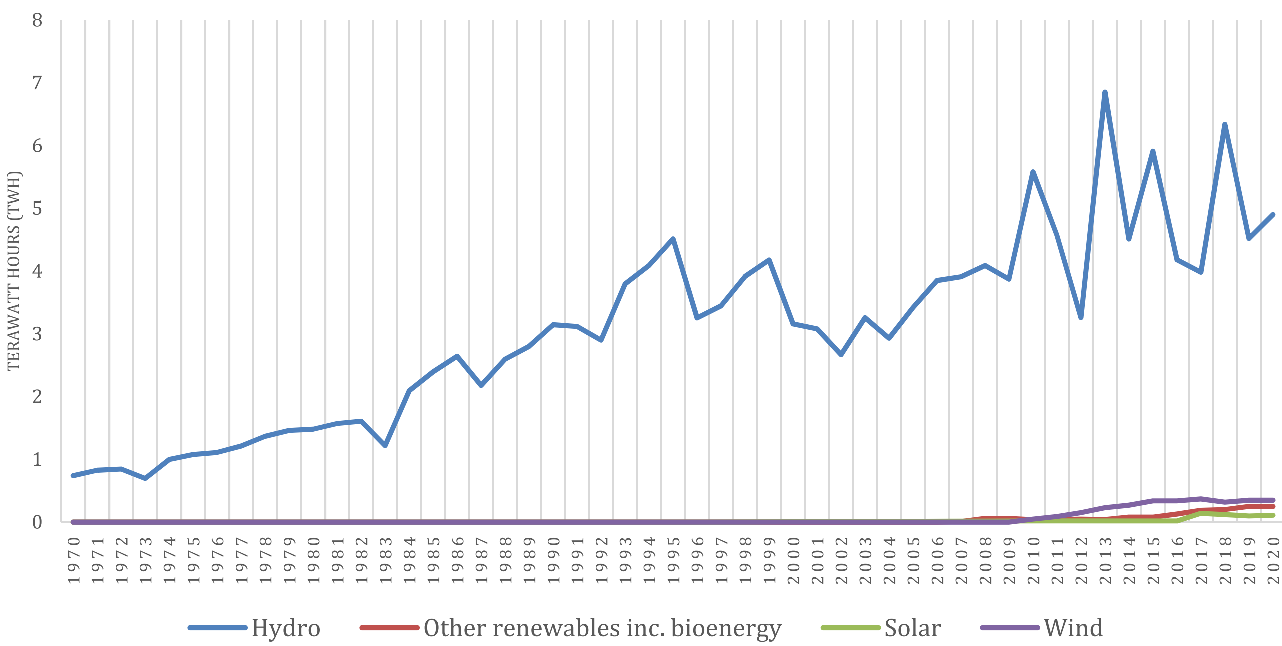

Fig. 12. Renewable energy contribution breakdown between 1970 and 2020 (TWh).
Source – (British Petroleum, 2021).

4.3. Sri Lanka's current GHG emissions outlook

Amidst exploring the renewable energy resources of Sri Lanka, an evaluation was made on the GHG emissions based on the data presented by the World Bank on Sri Lanka. Fig. 14 presents a time series analysis of the GHG emissions of Sri Lanka over the last five decades as reported by the World Bank. The overall emissions have continued to increase over the last 5 decades with an increase of up to 114 % from 1970 to 2018. From 1989 to 1990, the country witnessed a sharp 40 % increase in GHG emissions, which might be associated with the 1988–1989 revolt. Then, after 2009, the GHG level continued to rise notably (notwithstanding 2013), perhaps this might primarily be attributed to the post-civil-war economic boom (ADB, 2017). Much of the post-war development in Sri Lanka was addressed using fossil fuels and this consumption pattern has directly led to the disproportionate rise of GHG emissions in the country (Konara and Tokai, 2022).

In Sri Lanka's current context, its main sources of emissions can be attributed to transport and electricity generation with these two sectors directly contributing to nearly 18 million tons of overall GHG emissions. The Sri Lankan transport sector has remained the major GHG emitting sector in the country over the past decade with its emissions totaling nearly 20 % of the national GHG emissions (Buddika Hemashantha et al., 2019). Moreover, Sri Lanka's significant dependency on the usage of non-renewable energy sources for electricity generation has also played a pivotal role in the continued increase of GHG emissions (S. Dasanayaka and Jayarathne, 2012). As shown in Figs. 13 and 15 there appears to be a positive correlation between the introduction of non-renewable sources for energy generation and the overall carbon emissions of the electricity sector with clear spikes in emissions following 1999 (Introduction of oil-based energy generation) and 2010 (Introduction of coal-based energy generation).

Moreover, recent studies suggest that Covid-19 related lockdowns

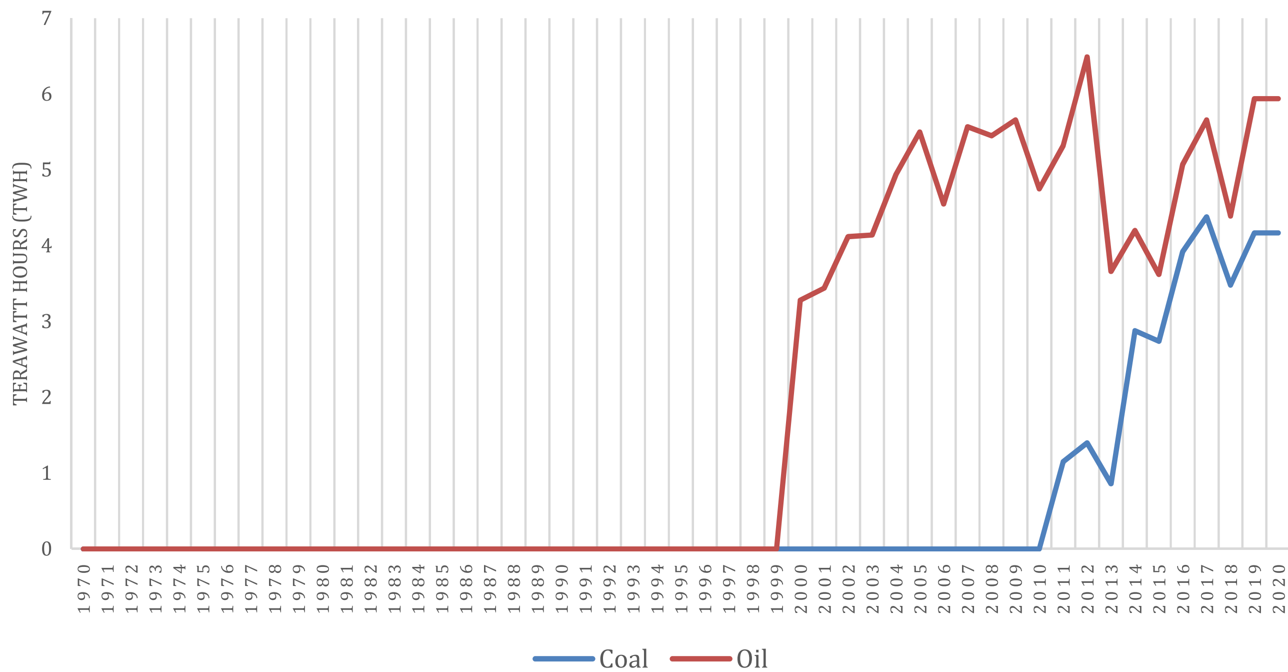

Fig. 13. Non-renewable energy contribution between 1970 and 2020.
Source – (British Petroleum, 2021).

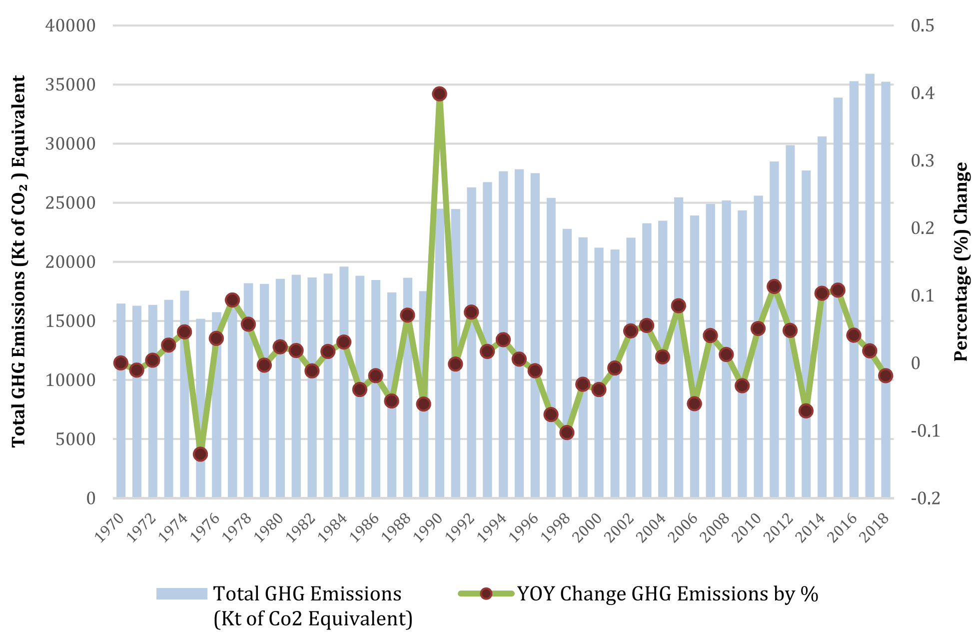

Fig. 14. Green House Gas (GHG) Emissions of Sri Lanka.
Source – (British Petroleum, 2021).

have had a direct impact on the reduction of overall carbon emissions at a global level (Ray et al., 2022). Interestingly Sri Lanka's Carbon Dioxide (CO_2) emissions also had a notable drop from 22.82 million to 21.11 million from 2019 to 2020 with the annual emissions reducing by nearly 1.72 million. Nonetheless, even though some studies have identified a downward trend of air pollutants due to COVID-19 in Sri Lanka (Senarathna et al., 2021) no comprehensive research provides conclusive evidence to suggest that Covid-19-related lockdowns played a direct role in the overall CO_2 emission reductions in the country.

5. Discussion

Given the outlook of the renewable structure of Sri Lanka based on existing work as well as the most present outcome as seen with the time series analysis, the discussion employs a Strengths, Weaknesses, Opportunities, and Threats Analysis (SWOT) to illustrate the factors affecting the future progression of Sri Lanka's renewable energy situation. The study bases its insights for the SWOT from the previous findings section and further supplements it with several previous studies, reports, research studies, and other institutional reports concerning renewable energy sources in Sri Lanka. The study has also considered some of the key news articles and sources on Sri Lanka's renewable

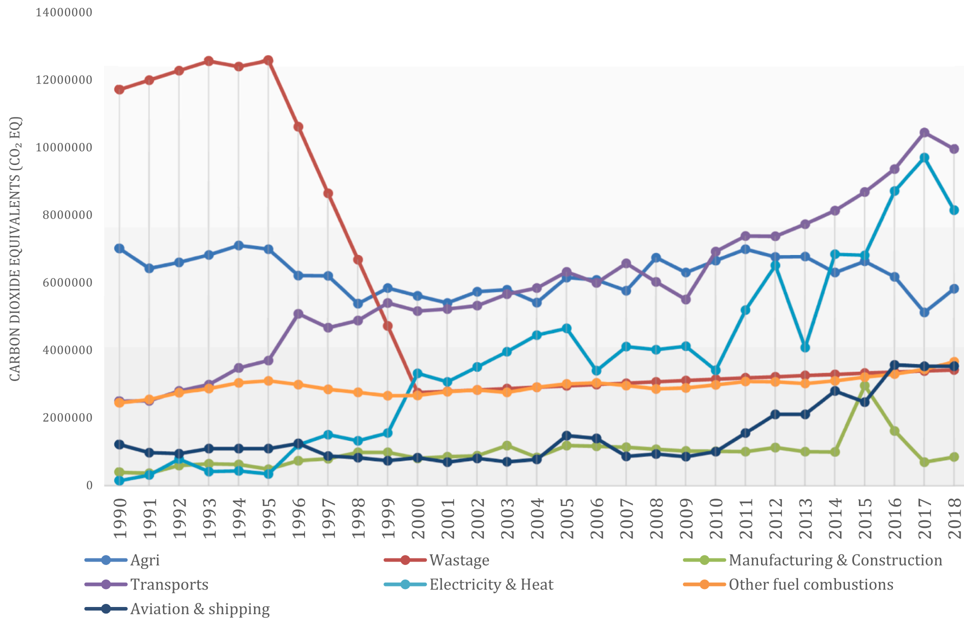

Fig. 15. Green House Gas (GHG) emissions of Sri Lanka (Sector by Sector Analysis).
Source - (British Petroleum, 2021).

energy front in developing the SWOT framework to gain a holistic picture of the current situation. A summary of the SWOT analysis of Sri Lanka is presented in Table 2.

5.1. Strengths

A key reason for the development of renewable energy-related activities in Sri Lanka has been the dedicated institutions surrounding the issue. One of the key pillars of this has been the Sri Lankan Ministry of Environment and National Resource's (MENR) introduction of the required guidelines for sustainable development in 2007 (Athapaththu and Karunasena, 2018). This was the same period in which to ensure the mandate of the renewable energy policy was implemented by the Sustainable Energy Authority (SEA) which was established also in the year 2007 (Amarapala et al., 2022). More recently in 2015, the Sri Lanka Energy Sector Development Plan was introduced highlighting the plans to increase the share of electricity generated from renewable sources to 50 % to 60 % by 2020 (Theiventhran, 2022). Much of the policy framing in Sri Lanka surrounding renewable power was done by the government with the assistance of the CEB which actively developed strategic plans to utilize a variety of sources of energy for power generation and contributing to the national demand (Athapaththu and Karunasena, 2018).

Moreover, given the increased focus on achieving Sustainable Development Goals (SDG) at a national level, Sri Lanka has marginally improved its focus on quantifying its sustainability commitments including that of its renewable energy generation as showcased in the country's progress measurement in the achievement of SDG 7 in its latest voluntary national review of SDG achievement (Sustainable Development Council of Sri Lanka, 2021).

Table 2
SWOT analysis of the renewable energy sector of Sri Lanka.

Strengths	Weaknesses
• Dedicated institutes such as the Lankan Ministry of Environment and National Resources (MENR) • Systematic measurement of renewable energy generation	• The economic cost of using renewable energy. • Limitations in existing renewable energy supply • Lack of consistent national policies and structures • Lack of R&D activities • Lack of technically knowledgeable staff in key decision-making positions
Opportunities	**Threats**
• Growth of NGOs such as the Biomass Energy Association assisting the development of renewable energy sources • Tax incentives for domestic renewable energy manufacturing	• The political instability of the country • Duty-free imports of renewable energy equipment • Volatile exchange rate • Uncertain monsoon weather

Source – Author's own.

5.2. Weaknesses

One of the most significant drawbacks of the current Sri Lankan energy sector is high economic costs in comparison to the non-renewable energy sector, especially in the short to mid-run. The renewable energy industry currently has small economies of scale and prolonged payback periods to cover the required initial investments in developing the required facilities (Shukla et al., 2017). Even from a consumer's perspective the end-user installation costs for renewable energy also remain relatively high in comparison to traditional forms of energy supply thereby making non-renewable energy sources the preferred energy generation typology for most Sri Lankans (Nanayakkara et al., 2021). Despite the potential in the country for both solar and wind, there is still a lack of support for local manufacturing of components as seen in the case of Egypt and its renewable energy sector challenges (Salah et al., 2022).

Moreover, most of the technologies used for renewable energy in terms of wind, solar, and other predominant sources remain relatively new in the Sri Lankan context and therefore the cost of producing a single unit and the initial investments required for relevant facility creation remains significantly high (Shukla et al., 2017). This issue is further burdened by the economic concerns of the small and medium entrepreneurs as the extent of access to join as a renewable energy producer with a low production capacity remains less viable given the doubtful return on investment for SME players (Raybould et al., 2020).

Rural electrification remains a major challenge for the renewable energy sector with a considerable portion of the country's population living in areas beyond the reach of grid electricity altogether. Without access to grid electricity, "off-grid" rural households refer to non-renewable alternatives such as Kerosene instead of seeking renewable energy options (Wijayatunga and Attalage, 2016). Therefore, renewable energy types such as solar still have difficulties fitting into practices of everyday use, especially in a household context.

Moreover, the scale of existing renewable energy projects suggests that in the Sri Lankan context, renewable energy projects are designed to produce limited amounts of power that can fulfill selected services, and therefore renewable energy is widely used and considered as a method of supplementing another form of non-renewable energy as opposed to being used as the primary form of energy production (Kumar et al., 2019). Additionally, existing research also suggests that the per-unit cost of producing electricity via solar and wind remains significantly higher making it difficult for CEB to garner any profits from this venture at present (Fernando et al., 2019).

Throughout recent history the government has given a relatively low priority to renewable energy in national planning while continuing to subsidize fossil fuels, thereby incentivizing energy producers to continue with non-renewable energy production. Moreover, Sri Lanka currently also lacks any direct policy instruments or targets to limit carbon emissions or any other environmental pollutants (de Zoysa and Inoue, 2014). For example, using biodiesel from waste cooking was identified as a promising source to reduce the dependence on fossil fuels in Sri Lanka but, the lack of a clear policy in banning waste cooking oil reselling is needed to improve the situation (Arachchige et al., 2021). Moreover, in sectors such as water resources, the lack of a clear consensus as well as uniformity of a single policy has led to many complexities such as bringing state-of-the-art technology as well as innovations to the respective industries (Jayasiri et al., 2022).

Even in the case of existing renewable energy projects, there is a significant lack of quality management to ensure the consistency of their respective operations (Laufer and Schäfer, 2011). One of the influential factors for such a drawback is the uncertainty of the annual energy production due to the lack of reliable wave resource datasets (Lokuliyana et al., 2020). The lack of policy and a clear framework of regulations has also discouraged the private sector to invest in renewable energy in Sri Lanka which has a detrimental impact on a developing country such as Sri Lanka (Dassanayake et al., 2021).

5.3. Opportunities

Moving towards renewable energy sources is important to reduce the stress on Sri Lanka's balance of payment and allocate more financial resources for other essential imports. If Sri Lanka were to move towards 100 % renewable energy sources as a country it would save US$18 - US $19 billion from coal imports which would directly contribute to the economy of Sri Lanka (Danthurebandara and Rajapaksha, 2019). There are several governments (Sustainable Energy Authority, NERD) and non-government organizations (Biomass Energy Association), promoting biomass as a source of fuel for thermal energy generation. There is a need to therefore streamline the role of such institutions and use their skills to ensure Sri Lanka paves the way towards greater renewable energy generation.

As the interest and implementation of renewable energy sources across the world have grown exponentially, their implementation in the developing world has been relatively slow due to the high maintenance costs as well as initial capital requirements. Currently, CEB offers a concessionary income tax rate of 14 % for individuals in agreement to provide electricity generated using renewable sources (Afker, 2021). Moreover, the government of Sri Lanka has given the solar and wind power sections a zero tax to encourage greater contribution which has resulted in over 200MW generated to the country's national grid and creating over 10,000 jobs (Economy Next, 2019). Therefore, providing greater tax/monetary incentives, the creation of green certificates as well and imposing stricter regulations on the generation and consumption of non-renewable energy sources could further encourage more domestic players to enter this sustainable marketplace (Dassanayake et al., 2021).

5.4. Threats

The renewable energy sector in Sri Lanka is threatened by several external causes. One serious threat is political instability. As an example, the hydropower sector is the most vulnerable to political instability since large hydropower projects need a significant investment of both financial and time, which might last a long period (Weerasekara et al., 2021). As a result, governments prefer to invest in less time-consuming power projects so that they can demonstrate the projects' effectiveness quickly. The instability has also led to the constant change in policy development and the overlap of different ministries and diverging opinions have negatively impacted the overall efficiency of decision-making (Hettiarachchi et al., 2014).

Another concern is the duty-free import of all renewable energy equipment and products, which hurts the local renewable economy. Sri Lanka as a developing nation depends primarily on importing renewable energy technologies from foreign countries with fewer amounts of knowledge transfer taking place (Withanaarachchi et al., 2016). For example, solar panels and other required renewable energy equipment imported from China are attracting more and more customers due to the lower prices despite the questions about their quality and reliability for long-term use (Qaiser, 2022).

The depreciating and volatile exchange rate of Sri Lanka is hurting the country's economic growth. Sri Lanka relies significantly on imported renewable energy technology, which is becoming more expensive due to the decline in the exchange rate (Qaiser, 2022). Moreover, the situation looks further alarming due to the depletion of foreign reserves in the central bank the exchange rate crisis seems to prolong for the foreseeable future (Singh and Yadav, 2022).

Sri Lanka's overall renewable research activities are being burdened by the lack of accurate and contemporary data, especially in line with renewable energy generation and utilization. For instance, as per the latest SDG indicators and baseline data report by the Sustainable Development Council of Sri Lanka, the country has only 5 (out of 13) indicators to measure the performance of SDG 12 (Responsible consumption and production), 1 indicator (out of 8) to measure the performance of SDG 13 (Climate action) and no indicators (out of 12) to measure the performance of the industry, innovation, and infrastructure (out of 12). Therefore, there is a critical need for the country to enhance its overall data collection efforts to facilitate the road toward a net-zero nation. Additionally, while this research takes a commendable attempt at unravelling the renewable energy source potential of the country from a holistic perspective, further research could be conducted on assessing the individual potential of the country's available and prospective renewable energy sources in the future.

Overall, through the discussion SWOT analysis, the study aims to answer comprehensively the two key research questions to examine the present configuration of the Sri Lankan renewable energy sector through its policy framing, quantification, technologies used, conservation and further improvements. The time series analysis complemented this work by identifying how sectors such as transportation and non-renewable electric power generation causing the largest dent in Sri Lanka's effort to achieve the ambitious net-zero goal by 2050. Finally, the findings through the two methodologies which arrived at the SWOT discussion informed us of the outlook for Sri Lanka on its renewable path addressing the second research question. The SWOT detailed the lack of coordination amongst relevant institutions and the need for greater research and knowledge development initiatives to ensure mass-scale adoption of net zero practices were visible as a cross-section of key industries and businesses in Sri Lanka.

6. Conclusions

6.1. Implications of the study

The study aimed to shed light on some of the most pressing issues in the ambitious goal of Sri Lanka achieving net zero status by the year 2050. One of the key concerns with this is despite Sri Lanka's access and the abundant availability of key renewable sources (wind, water, sun) there is a lack of organization and responsibility within different governing agencies and legislative authorities in ensuring the transition is happening. One of the key concerns in this regard is how to turn some of the promising statements into actionable tasks. From a practitioner perspective, the study has revealed that there is significant investment required to install and invest in renewable energy technologies on a mass scale (Shukla et al., 2017). This could also mean that Sri Lanka may seek international funding assistance and cooperation to find carbon emission reductions in terms of aid and other technical assistance (Ranasinghe, 2022).

The study also revealed that despite the growth in renewable sources on a year-on-year basis, the percentage contribution of renewable energy sources is at a steady decline. The findings further reveal that Sri Lanka has transformed from a rural-based economy into an urban-based economy towards manufacturing and services (Ranasinghe, 2022). This could be a key reason why the investment in non-renewable sources such as coal and fossil fuel usage has increased against the larger objective of a net zero achieving objective. From a policy perspective, the contrasting initiatives by the Sri Lankan government and the regulatory bodies could pass a weak and confusing message to businesses and other stakeholders who are concerned and interested in investing in long-term net-zero technologies.

6.2. Limitations

The study conducted a systematic literature review with a time series analysis to gain an understanding of the present situation of Sri Lanka's journey to achieving net zero by 2050.

However, the study has primarily relied on secondary research in the context of Sri Lanka, and this limited our understanding of some of the ongoing changes that are happening in Sri Lanka which is yet to be captured in empirical research. Some of the key sources of existing research such as the Quantification of Renewable Energy Sources from the REUF framework are only available up to 2019 which could potentially be outdated in terms of real time development of active projects.

Secondly, the time series analysis was conducted using World Bank, BP and IRENA reports which are secondary quantitative data. However, the use of such international reports was due to the unavailability of more local data from bodies such as the Ministry of Energy, for example, which may provide a more detailed and relevant update on making clearer decisions for policy building. One of the key findings from this was the growth of renewable energy as well as no renewable energy output and the reasoning behind this was not clear. The quantitative data would make more sense if there was qualitative evidence to supplement the findings. The study findings also revealed several industries such as transport sectors contributing negatively to the net-zero goals by 2050 which could be further explored with empirical evidence.

6.3. Future research potential

The studies attempted to address one of the most crucial topics in Sri Lanka's journey towards achieving net zero status from a both systemic literature review as well as a time-series analysis to provide an initial status update on the condition. The study only utilized existing work and did not report on the active developments in the topic to understand the present configuration and how it informs future decision-making. Future work could elaborate evidence from the government and other empirical data points to centralize the present context comprehensively and provide more feasible solutions. The study also only used the areas of policy, quantification, technologies, energy conservation and continuous improvements as a base for the literature review. Future work utilizing the framework could investigate the literature and other empirical data points to make a deeper sense of dimensions such as the actual renewable energy resources.

As one of the most important nations in the South Asian region, Sri Lanka aims to achieve the ambitious target of net zero by 2050 while trying to overcome several key challenges alongside its progress. The findings of the study revealed the challenges in the internal structure of the nation and the respective authorities' lack of cohesion and clear direction. This study is one of the first studies to connect the various bodies of existing literature to the available data points to first set the present condition of Sri Lanka's journey which allows us not only to assess the oath forward but develop a road map to successfully overcome certain key barriers.

CRediT authorship contribution statement

Isuru Koswatte: Writing – review & editing, Writing – original draft, Supervision, Methodology, Investigation, Formal analysis, Conceptualization. **Janith Iddawala:** Writing – review & editing, Writing – original draft, Software, Methodology, Formal analysis, Data curation, Conceptualization. **Rekha Kulasekara:** Writing – review & editing, Writing – original draft, Software, Methodology, Formal analysis, Data curation. **Praveen Ranaweera:** Writing – review & editing, Writing – original draft, Software, Resources, Methodology, Data curation, Conceptualization. **Chamila H. Dasanayaka:** Writing – review & editing, Writing – original draft, Resources, Formal analysis, Data curation. **Chamil Abeykoon:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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