Wind and Tidal Power as a Dynamic Solution for Sri Lanka's Dependency on Thermal Power Plants

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1 Introduction

According to the last ten years, climate change has been a growing concern that has led nations worldwide to rethink the use of fossil fuels [1]. This applies to every country, including the developing nations. In our case, Sri Lanka, the island nation, occupies an almost total area of 65,610 km^2, with 62,705 km^2 of land and 2905 km^2 of territorial water [2], and 1680 km of coastline in the Indian Ocean [3] until recent time's country's electricity generation depended mainly on renewables like hydropower. Up until the mid-90s, hydropower plants were the primary mode of electricity generation in Sri Lanka. But with the rapid increase in electricity demand, authorities had to seek alternatives. Unfortunately, those alternatives were old-fashioned thermal power plants powered mainly by burning coal and fossil fuels. According to the Ceylon Electricity Board (CEB) data from 2020, about 9936 GWh were generated by thermal coal and thermal oil. Compared with the total generation that year, this was about 37%—thermal coal and 27% thermal oil. In 2020, about 64% of the total electricity generation was produced through thermal power plants [4]. However, in the specific case of Sri Lanka, this trend was accelerated from the 2020s due to the malfunctioning of thermal plants and bad economic situation in

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the country. After the pandemic situation with COVID-19, there are crises with the growing up of the country economy [5].

Moreover, Sri Lanka joined the 2016 Paris Accord Agreement; an agreement with the United Nations Framework Convention on Climate Change (UNFCC) dealing with greenhouse gas emissions. The island should go to the zero-carbon emitting while increasing the generational power [6]. The use of thermal power plants has two main inconveniences. First, the high costs of the electric power generation system are mainly due to the purchase and transportation of explosives. For these reasons, the efforts of Sri Lankan authorities are currently being focused on the design and development of renewable energy-based plans to replace the existing systems. According to the CEB, these efforts will lead to a renewable target between 22 and 24% of the power supply in 2036.

2 Research Study and Methods

Sri Lanka is a relatively large island situated south of India, extending offshore into the Indian Ocean. This allow the island to interact with the seasonally changing monsoon. Monsoonal patterns around Sri Lanka throughout the year are given in Fig. 1.

The southwest (SW) monsoon generally operates between June and October, and the northeast (NE) monsoon operates from December through April. During the SW monsoon, the southwest monsoon current flows from west to east, while during the NE monsoon, the currents reverse in direction [7, 8].

As an island country that lacks the necessary land to install large amounts of onshore wind or solar power, work is being focused on exploiting marine renewable

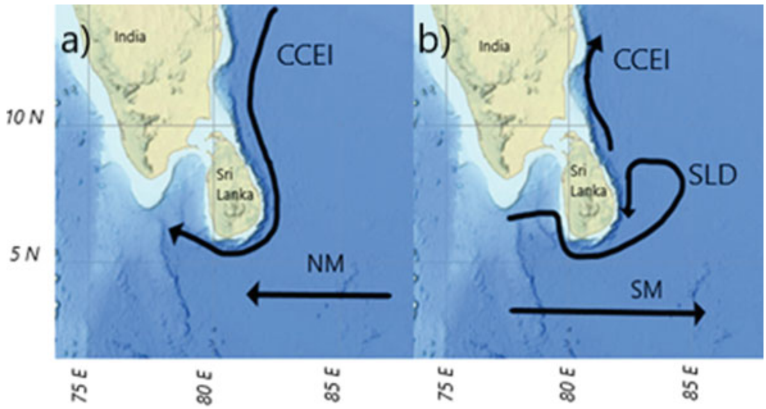

Fig. 1 Monsoonal patterns around Sri Lanka during **a** Northeast monsoon and **b** Southwest monsoon. NM—North monsoonal currents; CCEI—Coastal current from east India; SM—South monsoonal currents; SLD—Sri Lankan Dome

energy sources. In this regard, tidal current energy appears as a very promising alternative, especially for isolated areas, since it requires less grid capacity and reduces costs in energy storage. Wind farms at seas generate the majority of the marine renewable energy, and it is economically beneficial for the small communities in coastal areas [9, 10]. So far, tidal stream energy cannot compete in absolute numbers of power production and cost with solar photovoltaics (PV) or wind energy. Therefore, the use of hybrid wind and tidal platform solutions will be an excellent option to achieve the carbon zero policy for developing nations with access to oceans.

The main purpose of this research study is to propose suitable sites for the installation of combined wind and tidal power plants in Sri Lanka and their usage as an alternative to the excess use of fuel oil and coal-powered thermal plants. In the given figure, they are considering massive maritime traffic around Sri Lanka [11]. Hybrid farms must be installed close to land with less interference to maritime routes and abundant wind in seas and due to the onshore limitations [12]. This research study discusses two sea patch areas close to Mannar and Hambantota to Kalmunai is given in Fig. 2.

Hybrid farms should not disturb the existing marine traffic around the island and as well as local fishing community. However, further, research has to be done on the consequences of man-made structures on existing marine environment and sea bed [14].

2.1 Proposed Sites for Turbine Installation

According to this research paper, locations along the southwest and northeast coastlines of Sri Lanka were considered by available energy density in the Indian ocean [15] (monsoonal wind streams) and other marine economic agents such as fishery marine traffic lines. The proposed locations in the waters around Sri Lanka are given in Fig. 3.

Site a—Northwest of the island including Mannar region considered. Sea patch area for hybrid turbine installation represented below with their respective longitudinal and latitudinal coordinates.

Latitudes: 8.01–8.78;
Longitudes: 79.41–79.84;
Ocean depth range (m): 12–2000.

Site b—Offshore region to the southwest of Sri Lanka which includes sea area from Hambantota to Kalmunai.

Latitudes: 6.18–7.36;
Longitudes: 81.48–82.32;
Ocean depth range (m): 30–2500.

Considering the vast area of selected sea patch sectors, there is more likelihood to launch many hybrid units in near future. The proposed sites have a favorable

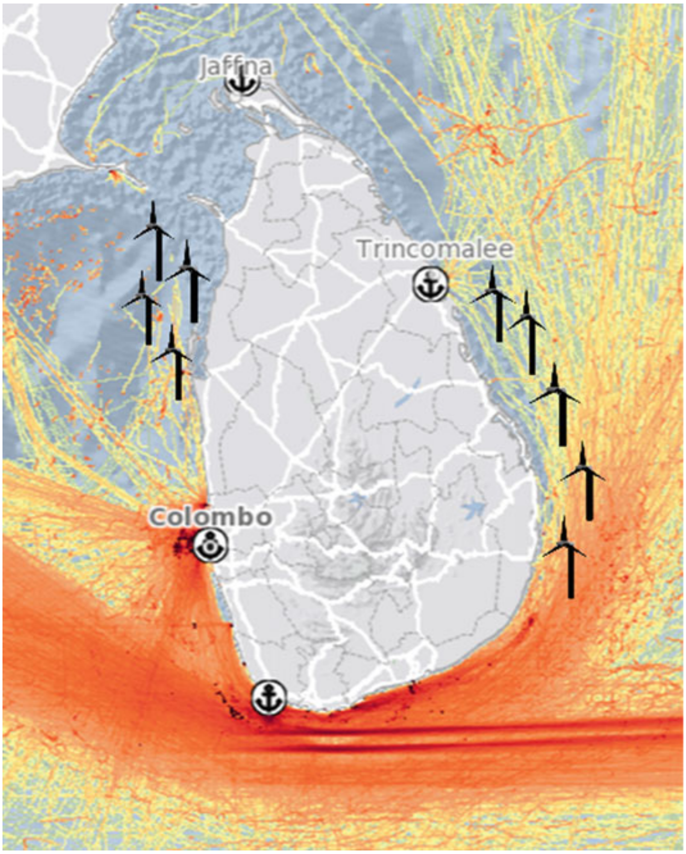

Fig. 2 Major maritime routes along the western and southern coasts of Sri Lanka frequently used routes are marked with bright red, orange, and yellow. Sourced from global maritime traffic [13]

wind throughout the year. Weather changes rapidly in South Asia due to the pressure depression over Bay of Bengal Winds from northeast monsoon and southwest monsoon sweeping the area. The sea becomes rough due to the powerful waves created by abundant winds [16, 17].

2.2 *Wind Patterns for Selected Areas Around the Island*

Wind speed for ten consecutive days for the three selected locations is given in Fig. 4. It is shown that in the selected sectors, wind speeds are varying within a range of 4–8 m/s making it an appropriate location for wind turbine operation. Winds forcing from the Bay of Bengal and equatorial Indian Ocean affects the wind patterns in the selected offshore sites [19].

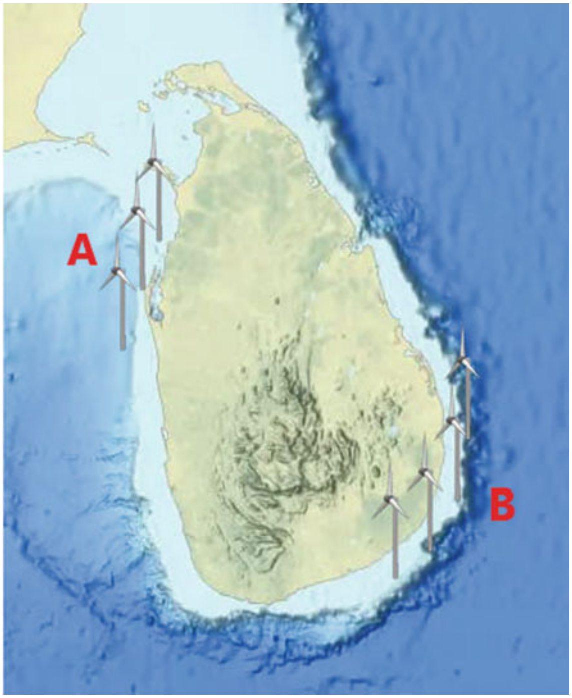

Fig. 3 Area of interest around the island **a** Northwestern coast and **b** Southeastern coast of Sri Lanka

2.3 Tidal Turbines

A crucial element needed for electricity generation is Turbine. Many factors should be considered when it comes to offshore installation. Materials should withstand harsh marine conditions with time [20, 21]. Tidal stream turbines extract kinetic energy from water flow. Except for the medium in which the tidal Turbine operates, its operational behavior is like that of a wind turbine. Tidal stream turbines function according to the principles of aerodynamic lift, and it is more efficient than aerodynamic drag [22]. The density of the medium in which turbine blades operate conclude the more efficient way.

Tidal currents are usually much slower than the wind; however, the dense sea water matches this output power, allowing tidal turbines to generate the same power output. Tidal turbines must withstand harsh conditions under the sea [23].

Tidal turbines can be classified mainly into two groups regarding the design: cross flow turbine and axial-flow turbine. According to this research paper, a hybrid tower is proposed with horizontal axis flow turbines. The principle of working axial-flow turbine with a horizontal axis of rotation is illustrated in Fig. 5. This type of tidal turbine sweeps a large circular area of seawater that flows parallel to the axis of rotation [24]. Mathematically, the amount of power of a turbine can be described by actuator disc theory [25]

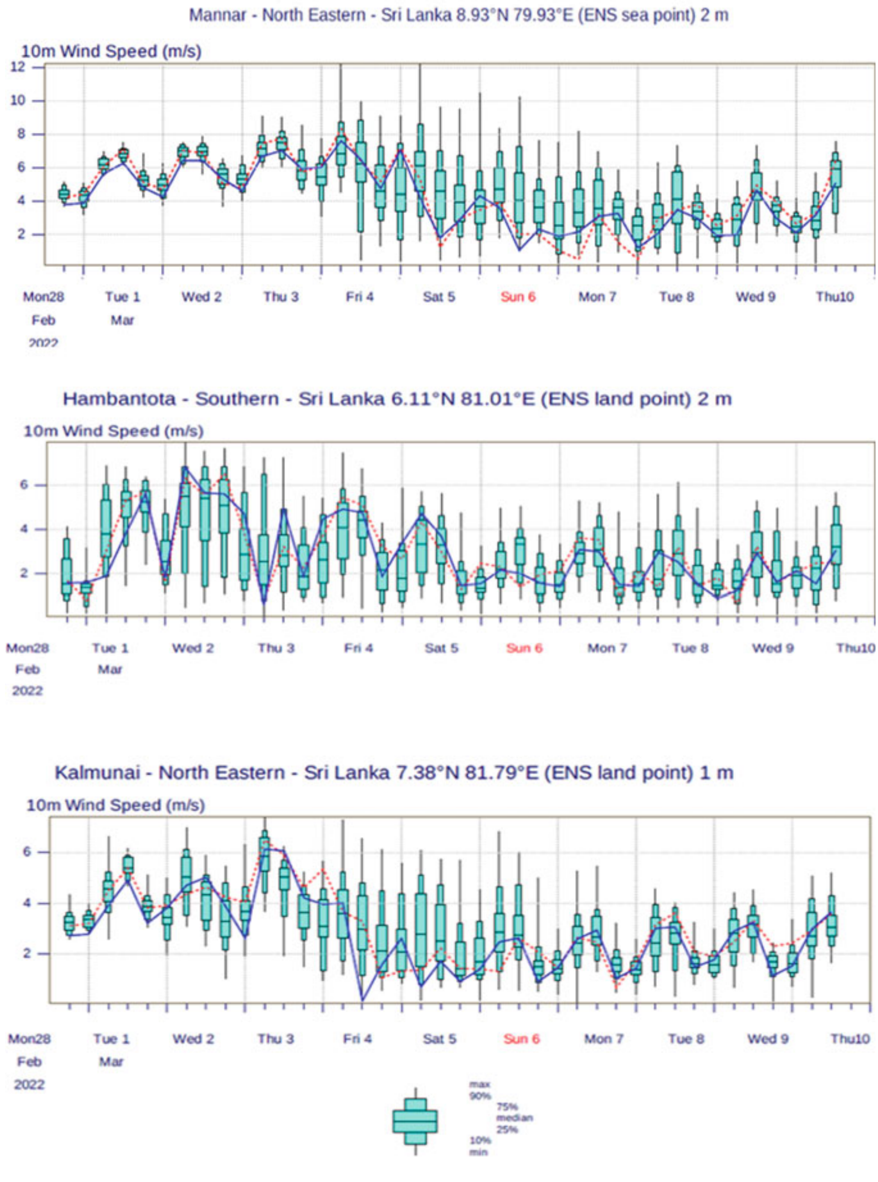

Fig. 4 Wind speed changes during 10 days for proposed sites Mannar, Hambantota, and Kalmunai. Sourced from European Centre for Medium-Range Weather Forecasts (ECMWF) [18]

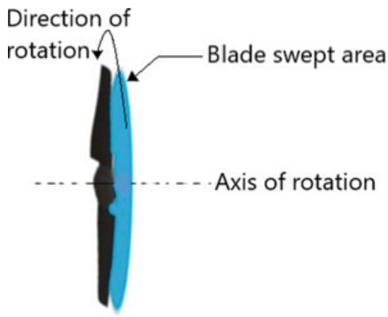

Fig. 5 Tidal turbine blade with axial-flow configuration

$$P_{\text{tidal}} = \frac{1}{2}\rho A_{\text{B.S}} C_{\text{P}} v^3 \quad (1)$$

P_{tidal}—Power (W) generated by the tidal turbine, ρ—Density of liquid (water, kg/m^3), $A_{\text{B.S}}$—Blade swept area (m^2), C_{P}—Power coefficient of tidal turbine, and v—Water flow speed (m/s).

Power generated per m^2 of blade swept area (power density) of tidal turbine can be calculated as below

$$P_{\text{d.tidal}} = \frac{P_{\text{tidal}}}{A_{\text{B.S}}} = \frac{1}{2}\rho C_{\text{P}} v^3 \quad (2)$$

$P_{\text{d.tidal}}$—Power density of tidal turbine (W/m^2).

2.4 *Wind Turbines*

Wind turbines work by converting kinetic energy into rotational kinetic energy. The turbine then converts into electric energy that generates electricity. Wind turbines can extract almost 59.3% of the accessible wind power in the area [26]. Generally, the power is limited by the Betz limit [27]. The amount of energy that wind turbines can extract from wind can be given mathematically shown below [28].

$$P_{\text{wind}} = \frac{1}{2}\rho\pi R_{\text{B}}^2 . C_{\text{P}}(\lambda, \beta) v^3 \quad (3)$$

P_{wind}—Power (W) generated by the wind turbine, ρ—Density of air (kg/m^3), R_{B}—Rotor blade radius (m), $C_{\text{P}}(\lambda, \beta)$—Wind turbine power coefficient with tip speed ratio λ and pitch angle β, and v—Airflow speed (m/s). Operation of a wind turbine is given in Fig. 6.

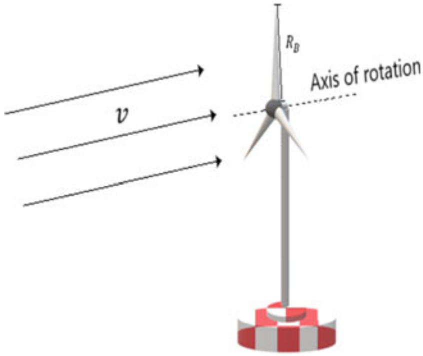

Fig. 6 Principle of wind turbine operation, v—wind speed before reaching the blades, R_B—rotor blade radius

2.5 Hybrid Tower Model with Triple Turbine Complex

The combination of two accessible offshore renewable energy sources, wind + tidal, avoid the hazardous effects of using thermal oil power plants and gives the prospect for future developments in the marine renewable sector [29]. A hybrid tower with both wind and tidal turbines will enhance the ability to extract wind energy and tidal energy simultaneously with less cost compared with separate installations [30]. Model hybrid tower constructed with two tidal turbines and separate wind turbines are given below in Fig. 7.

Hybrid tower shown in Fig. 7 consists a pair of 2 MW underwater tidal turbine which has a total generating capacity of four megawatts. Upper segment which is above the surface of water contains wind turbine unit. Wind turbine has a generating capacity of 6 MW, thus from a single hybrid unit it is possible to extract an estimated value of 10 MW.

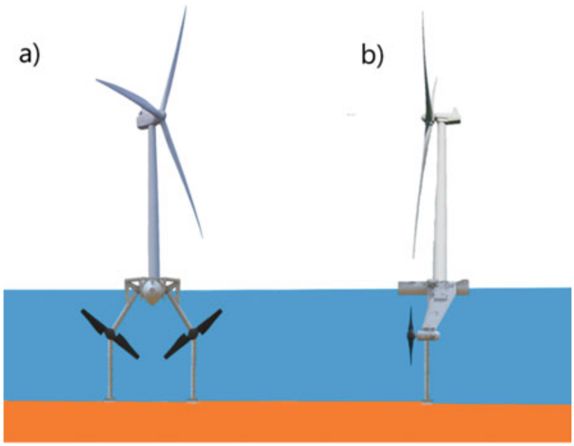

Fig. 7 **a** Model hybrid tower including one wind and two tidal turbines each in one complex and **b** profile-view of hybrid tower

Ease of transmission of electricity from offshore generating platform is also an important factor that is to be considered. The marine renewables currently in operation typically use high voltage alternative current (HVAC) transmission systems due to the relatively small distance to electrical substations, cutting off the excess transmission costs. If the turbine sites are farther away from the coast, using a high voltage direct current system for transmission would be beneficial [31, 32].

The total CO_2 emissions between installed capacities by year for Sri Lanka from 1998 till 2044 are given in Fig. 8.

According to this research paper, a hybrid wind-tidal turbine tower is introduced, and it is expected to reduce CO_2 emissions by 5% at the end of 2031. 7.5% for the year 2036, 10% reduction by the year 2041, and at the end of 2044, it is expected to cut off total CO_2 emissions by 15% using hybrid renewables.

In accordance with Table 1, if the project initiated the total number of 10 MW hybrid units that can be installed by year 2031 will be 24 units. For next five years that number will be almost twice the value achieving a generation target of 460 MW. By year 2044, a total of 140 hybrid units will be operational around the island, hence this reduces the carbon emissions to a considerable extent.

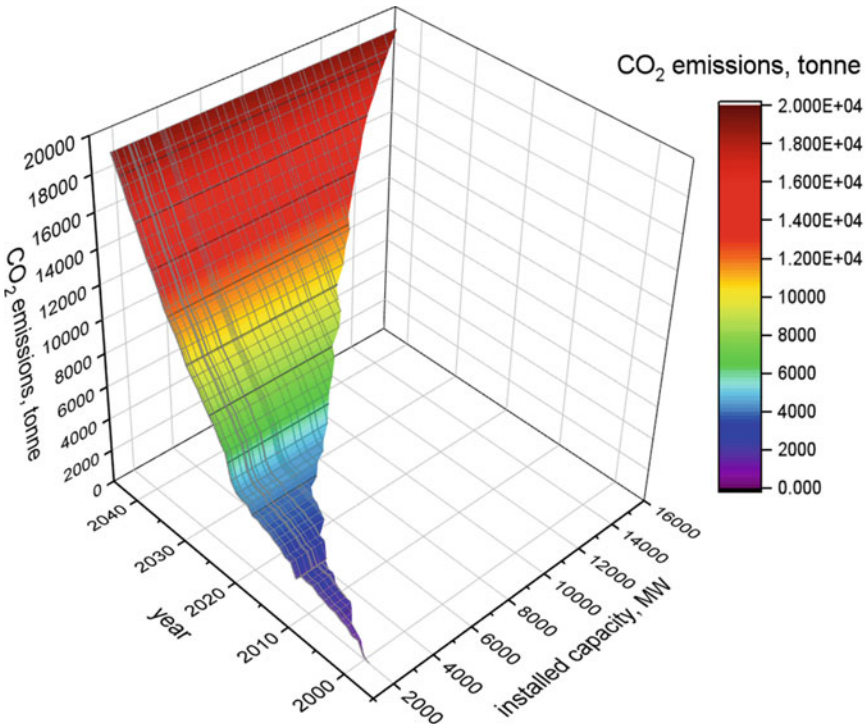

Fig. 8 Total CO_2 emission and prediction according to the installed capacity by year for Sri Lanka from 1998 till 2044

Table 1 Demand, net generation forecast, and required hybrid complexes for 2031–2046

Year until	Demand (GWh)	Net generation (GWh)	Peak demand	Number of 10 MW hybrid towers need to be install at the proposed sites
2031	27.438	29.647	4.755	24
2036	35.100	37.844	6.078	46
2041	43.859	47.288	7.602	76
2044	53.703	57.901	9.317	140

Based on the chart is given in Fig. 9, by realization of the hybrid wind and tidal farm project, it is observed that total CO_2 emissions has reduced according to the predicted values. This shows a good startup to achieve clean energy with the utilization of renewable energy sources.

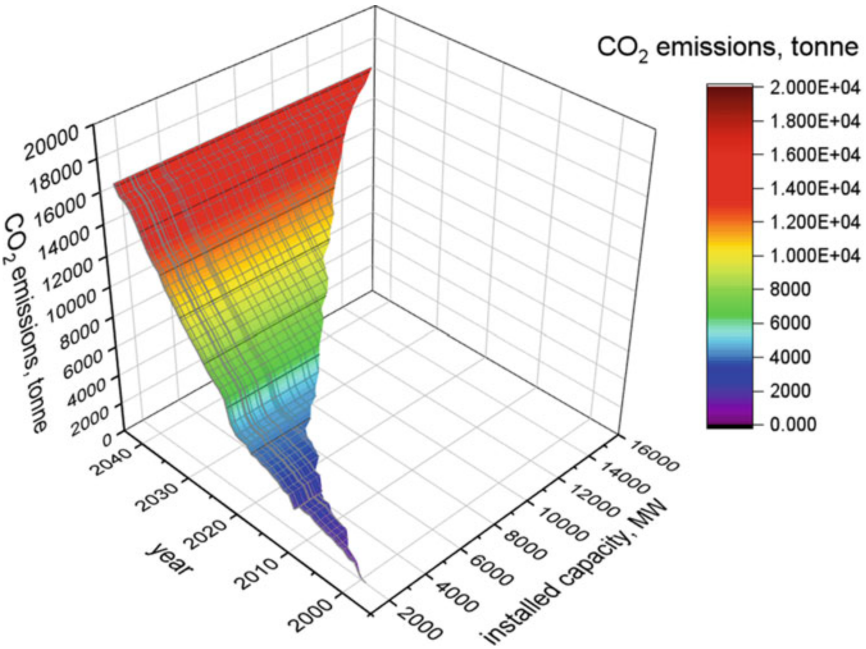

Fig. 9 CO_2 emission and calculation of installed capacity by year for Sri Lanka from 1998 till 2044 during 2030 to 2044 with hybrid power plant as 100% clean energies without producing greenhouse gases

3 Conclusion

This research study has suggested combining tidal and wind current energy to provide continuous electric power by optimizing the operation of 24 hybrid turbines, 10 MW of installed capacity each, considering 12 hybrid turbines for each site by 2031. By 2044, 140 hybrid complexes will be operational around the island, cutting off the CO_2 emissions by 15%. According to this research paper, the hybrid turbines reviewed represent the latest achievements in the MW level offshore renewable technologies in present times. These hybrid turbine technologies will be installed in the proposed wind-tidal hybrid farms. In addition to these industrialized significant hybrid turbine technologies (with sea-bottom supporting structures), research has been carried out to achieve more efficient megawatt-level power capacities. This study accommodates several turbines (one wind and two tidal) on a single platform structure to minimize system installation value and achieve high power generation capacity. To further influence, it is possible to install vertical axial turbines in lagoons such as Puttalam, Negombo, and Batticaloa. Sri Lanka energy sector is heavily dependent on imports. With oil price increasing each year, the government has not been able to pay for thermal power plant fuel. Total availability of power is very high in the country with suitable conditions since island surrounded by Indian Ocean and as shown above more sites are available for the hybrid renewable.

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