ISSN 2664-4150 (Print) & ISSN 2664-794X (Online)
South Asian Research Journal of Engineering and Technology
Abbreviated Key Title: South Asian Res J Eng Tech

| Volume-5 | Issue-6 | Nov-Dec- 2023 | **DOI: 10.36346/sarjet.2023.v05i06.002**

Review Article

The Dynamics of Pakistan's Renewable Energy Sector: Tidal Energy Potential; a Literature Review

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Article History
Received: 07.11.2023
Accepted: 12.12.2023
Published: 20.12.2023

Abstract: A developing country's economic interest is to determine when its national income approaches that of developed nations. The availability of energy, natural resources, and geographic location are important factors in this. Renewable energy appears to be the answer of the future, while traditional electricity sources like gas and oil are scarce, costly, and harmful to the environment. Pakistan has the ability to meet its electricity needs, addressing issues like power shortages, pollution, and high production costs. The country is strategically located and has an abundance of renewable resources. If this potential is fully realized, Pakistan might even start exporting electricity. Although the nation has started wind, solar, hydroelectric, and bioenergy projects, tidal energy is still mainly unexplored. Recent research provides evidence for the consideration of tidal energy as a potential renewable source for Pakistan's energy needs. The exploration and utilization of these renewable resources not only address the energy needs of Pakistan but also contribute to global efforts in adopting sustainable energy practices. Efforts towards harnessing tidal energy in Pakistan should be intensified, especially along the coast where natural tidal lagoons are prevalent. In-depth surveys and thorough investigations are crucial, particularly in the creek regions of Sindh province.

Keywords: Tidal Energy, Renewable Energy, Technology, Pakistan.

INTRODUCTION

Background of the Study

In recent years, there has been a global transition towards sustainable and renewable energy sources, prompting nations to explore and leverage their native renewable energy potential (Akhtar *et al.*, 2020). Within the context of Pakistan, a nation experiencing a burgeoning demand for energy and committed to reducing reliance on fossil fuels, the investigation of novel technologies for harnessing wind and tidal energy emerges as a promising pathway (Bawany *et al.*, 2019). Wind and tidal energy, both abundant and underutilized resources, present a sustainable solution to meet Pakistan's growing energy demands while contributing to environmental preservation (Khan & Bhuyan, 2021). This exploration into innovative technologies aligns with Pakistan's renewable energy objectives and positions the country at the forefront of pioneering and environmentally friendly energy solutions.

Energy stands as a paramount driver in the contemporary world, serving as a key determinant of a country's prosperity and economic vitality ((Farooq & Zhang, 2020). One major difficulty facing Pakistan, a developing country, is meeting the rising energy demands of industry and consumers. In the contemporary economy, electric energy has developed into a vital resource for companies and consumers alike. Unfortunately, the main sources of electricity used worldwide, and in Pakistan in particular, are nonrenewable and are expected to run out or, at the very least, cause a serious shortage in the near future. (Elghali & Elbaset, 2018). Recognizing this dilemma, renewable energy resources emerge as a pivotal solution to ensure sustainable energy availability.

As a developing nation, Pakistan's progress and development are intricately linked to its per capita consumption of electricity. A rising trend in per capita energy consumption, no matter how gradual, serves as a clear indicator of a country's advancement. Figure 1 shows Pakistan's annual per capita energy consumption and shows the country's impressive growth rate between 1970 and 2006. The peak energy consumption per person was 488.56 kWh in 2006.However, from 2007 to 2016, this peak was not surpassed, signaling a period of stagnation with evident fluctuations. The average consumption during this timeframe remained at 444.51 kWh, indicative of a static phase in Pakistan's progress.

It is crucial to note that the latter years witnessed a severe energy crisis, exacerbating the challenges faced by the country. To overcome these challenges and ensure sustained progress, there is an urgent need to transition towards renewable energy sources, which can play a pivotal role in mitigating the adverse effects of energy shortages and fostering long-term sustainable development. Industries and individuals have been grappling with a significant challenge of load-shedding. There were up to eighteen hours of load shedding per day in some parts of the nation.

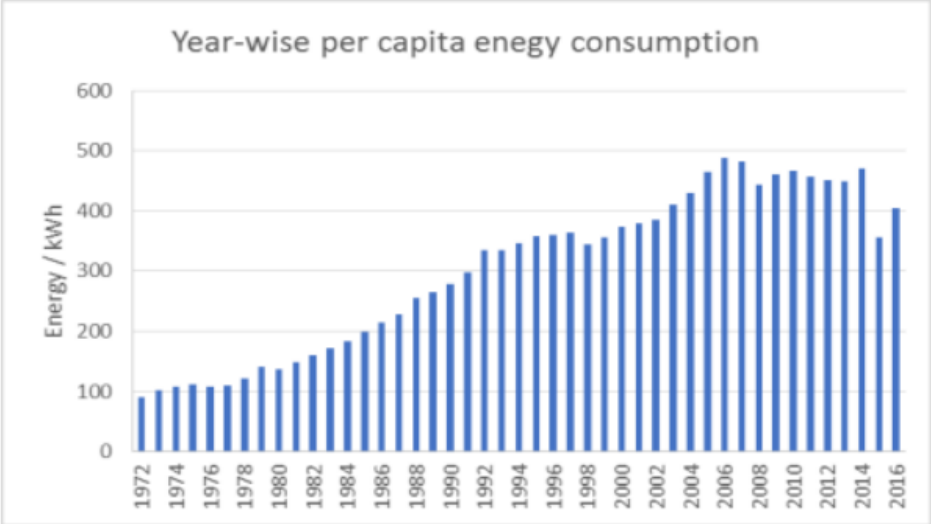

Figure 1: Pakistan's per capita consumption of electricity

Figure 2 shows the percentage distribution of total energy consumption for the years 2006 to 2015 among the various energy sources (Gas, Oil, Hydro + Nuclear, Coal, and LPG). Over the last ten years, there have been no significant changes in the relative contributions of each energy source. Remarkably, since renewable energy sources were just recently added to the energy mix, their contribution is not shown on the graph

The Reasons behind Pakistan's Energy Crisis

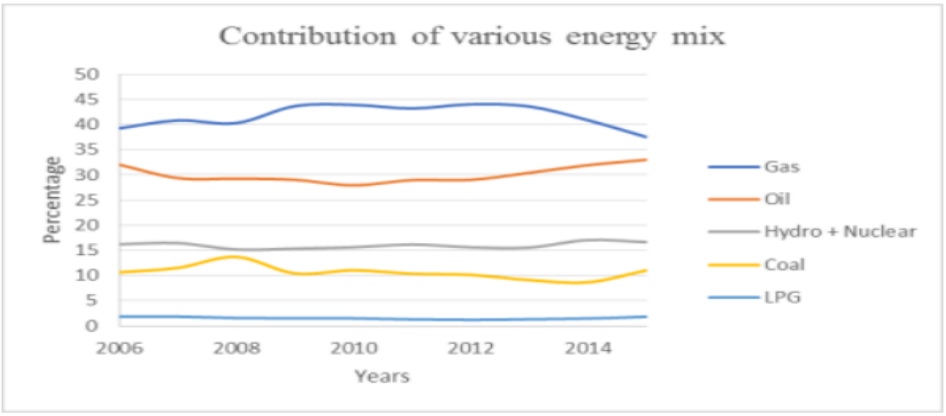

Fig. 2: The contribution of different energy resources to the energy mix from 2005 to 2015.

The causes of Pakistan's energy crisis are not new; in fact, they were expected given the country's growing population and extensive use of contemporary technologies. The rise in energy demand is directly correlated with the pervasiveness of contemporary technologies. In particular, electricity is now a basic requirement for home climate control and lighting. The proliferation of electronic devices, such as televisions, computers, and internet devices, has further

intensified the need for electricity. The increasing prevalence of air-conditioners in residences, institutions, and offices has added to the overall demand. Additionally, the exponential rise in the use of cordless and cell phones, coupled with the establishment of micro-industries in densely populated areas for supplementary income, has exacerbated the energy crisis. Some other contributing factors include:

i. Uncertainty in the political and economic spheres;
ii. Price fluctuations for oil; and
iii. Distribution system shortcomings
iv. Equipment aging
v. Inadequate attempts
vi. Inappropriate use of energy resources

Pakistan's Use of Renewable Energy

Regarding renewable energy in Pakistan, resource management is actively carried out by two major organizations. First off, research and development (R&D) in the field of renewable energy is the primary focus of the 2001-founded Pakistan Council of Renewable Energy Technologies (PCRET). The second organization was founded in 2003 with the goal of accelerating the adoption of renewable energy technologies in Pakistan by promoting and facilitating their development (Mirza *et al*., 2007; -7). AEDB and PCRET have both been crucial in promoting and carrying out renewable energy initiatives. The following sections provides a concise intro to each renewable energy type also their current status in Pakistan.

Wind Energy

Wind power, with its historical applications in water pumping and grain milling, has experienced a resurgence in recent decades as a vital energy resource. Wind power has become a viable and affordable alternative to traditional energy sources in recent decades, despite its historical origins. Ackermann and Söder claim that during the past 35 years, the cost of electricity produced by wind power has drastically dropped, coming down to roughly 1/6 of what it was previously (Ackermann., 2000).

Until 2013, Pakistan had not fully tapped into its wind energy potential. However, in that year, Pakistan initiated the production of energy from wind farms, marking a significant step forward. The inaugural official and commercial wind farm were established in Jhimpir, beginning operations in 2013. Wind resources are abundant in the southern parts of Pakistan, especially along the coast in the provinces of Sindh and Balochistan. By the end of 2015, Pakistan was producing electricity with wind turbines scattered across the Sindh Province towns of Jhimpir and Gharo. Currently, 308.2 MW of electricity are produced by six separate wind farms [9].

Eight more wind farms with a combined capacity of 477 MW are predicted to come online in the upcoming year. Eight wind farms total—two in Gharo and six in Jhimpir—are located in Sindh Province. In addition, fourteen more wind farms are being built, some of which should start producing electricity by the middle of the following year.

And others by the first quarter of 2019. Two of these fourteen wind farms are in the process of developing feasibility studies, and they collectively aim to generate an additional 663 MW of electricity. Notably, many of these wind farm projects are owned and operated by private companies. One such project, initiated by Sachel Energy Development (Pvt.) Limited in Jhimpir, is poised to produce 50 MW of electricity in the near future, contributing to the diversification of Pakistan's energy portfolio.

Hydel Power

Among the earliest methods of power generation, hydroelectricity stands out as a time-tested and renewable energy source. Hydropower is a natural and sustainable way to generate electricity, much like other renewable energies. It is also known for being inexpensive, environmentally friendly, and clean. In addition to having longer lifespans, hydropower plants also require less maintenance and operating money. In 2000, the energy produced by hydropower made up about 6% of the energy produced by oil (Earthscan Publications, 2000). Worldwide hydropower generation has been increasing; Norway and New Zealand, for example, generate over 99% and 75% of their electricity from hydropower, respectively (Mirza *et al*., 2008).

Pakistan had two hydroelectric power plants when it was founded in 1947: one in the province of Khyber Pakhtunkhwa at Malakand, and the other in the province of Punjab at. At that time, 10.7 MW was the total hydropower capacity (Mirza *et al*., 2008; Bhutto *et al*., 2012). Significant advancements occurred following the Indus Water Treaty of the 1960s with the building of the Mangla and Tarbela dams, which house hydropower stations with installed capacities of 1000 MW and 3478 MW, respectively. With an installed capacity of 1450 MW, the Ghazi Barotha hydropower station was put into service in 2004 [14].

Fortunately, Pakistan has a wealth of hydropower potential, which is demonstrated by irrigation canals and natural water flow systems. Figure 3 shows the annual production of hydropower-generated electricity from 2005–2006 to 2014–2015. The data shows that the generation of hydropower has not changed significantly over the past ten years.

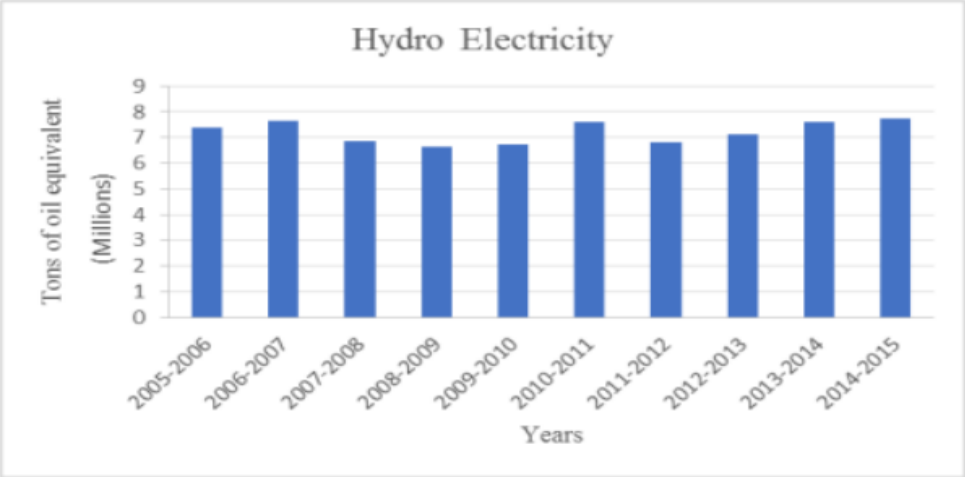

Figure 3: Hydropower generation of electricity by year.

Pakistan currently has 128 hydropower plants in operation, while another 877 are under development and 1500 are in various stages of implementation. 815 possible locations have been found, and their individual generating capacities range from 0.1 MW to 40 MW. An overview of the quantity of possible locations and hydropower potential in each province is given in Figure 4. Notably, the provinces of Gilgit-Baltistan and Khyber Pakhtunkhwa have a significant hydropower potential, whereas the potential in Sindh and Balochistan is significantly lower. In order to take advantage of the abundant water resources in Khyber Pakhtunkhwa, where some projects are locally owned, the Pakistani government actively encourages the installation of small and mini hydropower stations.

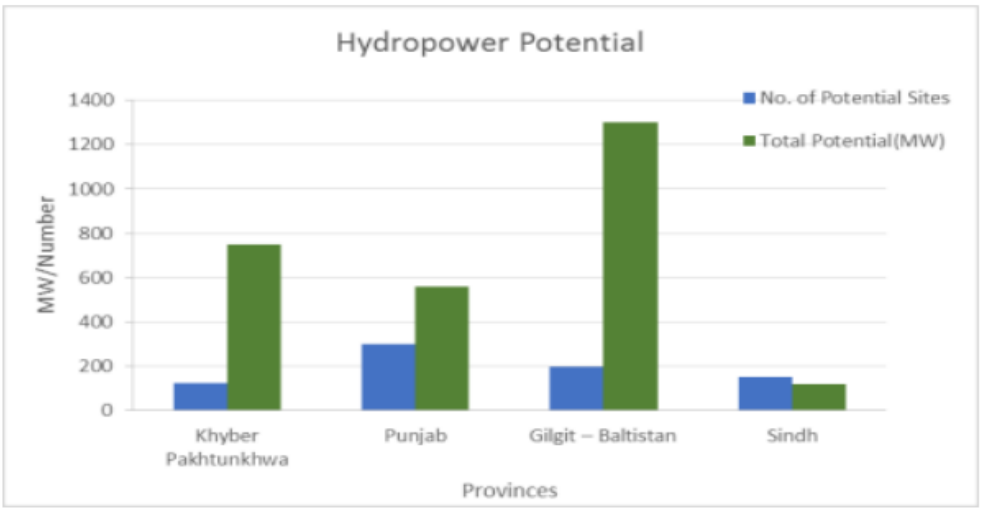

Figure 4: Number of hydropower potential sites by province and associated hydropower potential

Solar Energy

The sun produces massive amounts of energy through a variety of nuclear reactions, and this energy is known as solar energy. The two main types of solar energy are heat energy and light energy (Glaser, 1968). These renewable energy sources can be used to generate electricity as well as heat and light for homes (Singh, 2013). Solar energy is considered a superior clean energy source when it is used in applications like solar heating, photovoltaic systems, artificial photosynthesis, and solar thermal electricity (Mekhilif *et al.*, 2011). Its advantages include low maintenance requirements, a long system lifespan, predictable power outputs, and ease of installation.

Earth receives 174 petawatts of solar radiation per year from the upper atmosphere, of which 70% is reflected and 70% is absorbed by clouds, seas, and land masses. Pakistan has the good fortune to have one of the highest solar irradiances in the world, which makes it possible to use solar power to potentially produce a sizable amount of electricity (Mirza *et*

al., 2003). With over 50,000 megawatts of solar energy resources, the Institution of Engineers Pakistan, Karachi Centre (IEP) estimates an average annual solar irradiance of 5.5 kWh/m2/day. Pakistan's solar potential is estimated by the Islamabad Chamber of Commerce and Industry to be 100,000 megawatts. Pakistan currently consumes less electricity than this abundant solar power, which is available year-round throughout the entire nation, by about 27,000 megawatts.

There are currently 24 solar power projects under construction that were started between 2011 and 2015 and are scheduled to be put into service the following year. Eight projects are in Sindh Province and sixteen are in Punjab Province. By the end of 2018, Pakistan wants to reach a capacity of 1556 MW for solar power generation. Figure 5 shows the annual cumulative capacity of solar power generation.

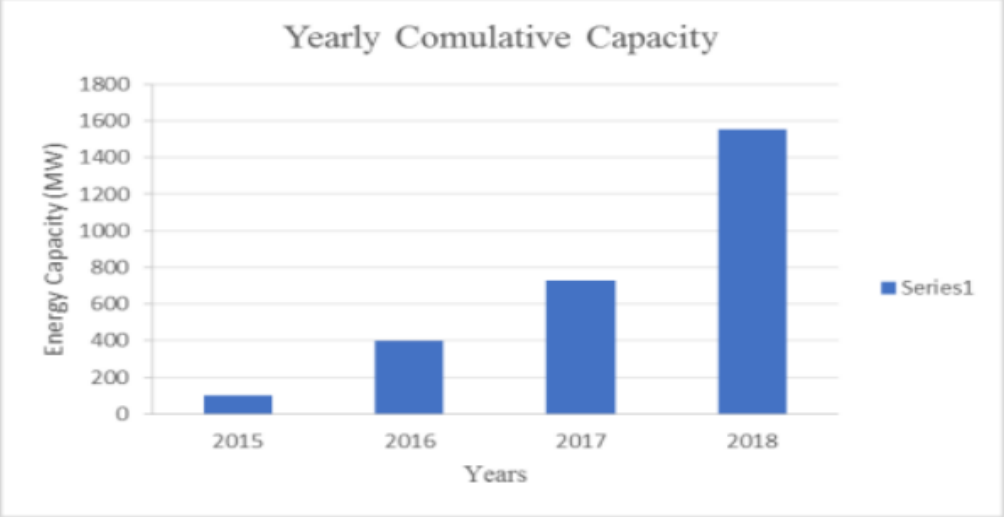

Fig. 5: Year's wise overall capacity of Solarpower in Pakistan.

Wave Energy

The energy produced by tides and ocean waves is referred to as tidal energy, or tidal power, and it offers future generations a clean and sustainable energy source (Insaf *et al*., 2016). According to Insaf *et al*., (2016), there are two primary causes of it: (i) the gravitational pull of the sun and moon on seawater, where the moon's gravitational force is roughly twice that of the sun; and (ii) the centrifugal forces acting on the Earth-sun and Earth-moon systems. Tides are caused by the combined action of two water bulges that are created by centrifugal forces and gravitational forces, one toward the moon and the other along the Earth.Tides and waves represent oscillating energy, and current technologies utilize turbines to generate energy from incoming and outgoing waves. Utilizing the kinetic and potential energy of the tides, tidal current turbines can produce electricity.

Compared to some other renewable energy sources, tidal energy is less difficult to use and has a lot of potential for producing electricity. (MontllonchAraquistain, 2010; Rourke *et al*., 2009). Extremely high tidal currents up to 7 m/s have been observed in a number of locations across the world (Rourke *et al*., 2009). In many nations, tidal energy has gained popularity as a fossil fuel substitute for producing electricity during the last few decades (Ambreen Insaf *et al*.,). Notably, France built the La Rance tidal barrage in 1967, making it the first nation to use tidal energy extensively (MontllonchAraquistain, 2010).

The residents of coastal areas in Pakistan endure challenging living conditions due to the shortage of electricity. Harnessing tidal power, an indigenous capability, could significantly improve the socio-economic conditions of these inhabitants. Unfortunately, there has been limited research on the tidal energy potential in Pakistan, with only a few surveys conducted by the National Institute of Oceanography. According to the surveys, the average current velocity ranges from 2.05 to 2.57 m/s, with some creeks reaching as high as 4.11 m/s. These creeks stretch from Korangi Creek near Karachi to Kajhar Creek near the border between Pakistan and India. The combined potential power output of these creeks is 1100 kW. Furthermore, the coastal belt of the Balochistan province's Kalmat Khor and Sonmiani Hor exhibit potential for tidal energy harvesting (Zaigham & Nayyar, 2005).

The Alternative Energy Development Board (AEDB) and the Pakistan Council of Renewable Energy Technologies (PCRET) claim that tidal energy is still mainly untapped and unexplored in the nation. With it's roughly 1000 km of coastline and its intricate system of creeks in the Indus delta, Pakistan offers a chance to make use of tidal heights of two to five meters.

Exploration of the power resource potential along the coastline is necessary to secure future energy supplies for the provinces of Sindh and Balochistan.

Two studies (Insaf *et al*., 2017; Baig *et al*., 2017) were carried out by Insaf *et al*., to estimate the tidal energy potential at various locations in Karachi, Ghizri and Jhari. According to the research, Ghizri Creek, with a proposed basin area of 5.02 km2, can generate approximately 2.29 MW of electricity in the summer using a one-way generation scheme and a tidal turbine efficiency of 40% (see Figure 6). Furthermore, using tidal range technology and a proposed basin area of, Jhari Creek in the Indus delta of Sindh province has the potential to generate 4.96 MW of electricity during the summer, utilizing tidal range technology with a proposed basin area of 7.68 km2 (see Figure 7).

Fig. 6: Ghizri Greeek

Fig. 7: Jhari Greek

A comprehensive study on tidal resource arrangement was conducted at MianiHor (refer to Figure 9) (Ambreen *et al*.,). MianiHor is situated in Somiani Tehsil of the Balochistan province and boasts a lagoon that spans over 40 km in length. The site demonstrates considerable tidal potential, and with the implementation of appropriate tidal technology, it has the capacity to generate sufficient electrical power to meet the requirements of nearby villages and other locations.

Another study focused on Hajambro creek (refer to Figure 8) (Mirza *et al*.,), located in District Thatta of the Sindh province. This creek, extending over 10 km, holds substantial potential to fulfill the electricity needs of the communities residing in its vicinity. The lack of essential amenities has led to continuous migration of people to other cities. Harnessing tidal energy effectively at Hajambro could potentially halt this migration trend.

Fig. 8: Hajambro Greek

Fig. 9: Miani-Hor Greek

In the Indus Delta region, there are a total of seventeen major creeks, including the four previously mentioned. An estimation suggests that the power generated from all these creeks could amount to approximately 84.32 MW. Consequently, employing tidal range technology in Karachi and the Indus Delta region has the potential to generate a total of 86.61 MW. This electrical power would be effectively utilized for provide electricity to approximately 145,000 units to 165,000units households residing in the vicinity of these two sites.

CONCLUSION

The era of globalization has intricately linked energy, economics, and politics, with energy playing a pivotal role in shaping lives in this age of advanced technologies. A continuous and uninterrupted supply of electricity is essential for economic progress, and the quest for efficient, cost-effective, and sustainable sources of renewable energy is crucial to meet the growing demands of humanity. The 21st century has witnessed a manifold increase in energy demand, leading to shortages in consumption and production. Using renewable energy resources, which are widely accessible and capable of closing the gap between supply and demand, is the most practical course of action. There is now widespread agreement on the use of natural resources as sustainable and safe energy sources.

Pakistan is blessed with a wide variety of renewable energy sources in large quantities due to its advantageous geographic location. Wind farms are a good fit for places like Balochistan, Sindh, and the northern regions, while Punjab and Khyber Pakhtunkhwa have abundant hydropower potential. Punjab and Sindh hold great promise for producing biogas. As a result, the nation as a whole has a great deal of potential for using renewable energy.

Recent studies assessing tidal potential in Pakistan have yielded encouraging results, positioning tidal energy as a new contender in the country's renewable energy mix. However, further investigations and surveys are necessary to fully understand and harness the potential of tidal energy. The exploration and utilization of these renewable resources not only address the energy needs of Pakistan but also contribute to global efforts in adopting sustainable energy practices.

Efforts towards harnessing tidal energy in Pakistan should be intensified, especially along the coast where natural tidal lagoons are prevalent. In-depth surveys and thorough investigations are crucial, particularly in the creek regions of Sindh province. These areas hold significant potential for extracting tidal stream energy and warrant detailed studies to fully comprehend and unlock their renewable energy capabilities. Conducting comprehensive research in these specific coastal and creek regions will provide valuable insights for the effective utilization of tidal energy resources in Pakistan.

Conflicts of Interests: Authors declare no conflict of interests

Acknowledgment

I would like to express my sincere gratitude to my corresponding authors for their invaluable support and contributions to this research. Their guidance, insights, and collaborative efforts have greatly enriched the depth and quality of this study. I am deeply thankful for their dedication and assistance throughout the research process.

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