# MARINE ENERGY RESOURCES: SOME PERSPECTIVES FOR PLANNING AUDITS

**Offshore Wind Energy Farm**

Photo: TebNab| Shutterstock.com (As accessed from: https://www.energy.gov/eere/wind/articles/grand-challenges-close-gaps-offshore-wind-energy-research)

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## About the Research Paper

Blue Economy sectors have attracted enhanced attention of the policymakers owing to the untapped vast potential in the world's seas and oceans on the one hand and concerns for managing the fragile blue environment and sustainability of the marine ecosystem on the other. This research paper provides guidance and tools to the auditors for the purpose of their replicability and scalability in the field of auditing. Blue Economy, being a relatively new and under-audited area, while conceptualising and developing a toolkit for this sector is challenging, the relevance of such a toolkit for the auditor is enormous. This research paper is designed to facilitate audits on Blue Economy and may serve as a comprehensive resource for the planning and execution of audits, enabling the systematic gathering, analysis, and documentation of data as well as the collection of essential audit evidences. In addition, this research paper can serve as a valuable resource for policymakers and researchers actively engaged in the developing marine renewable energy resources in India.

This paper on **"Marine Energy Resources: Some Perspectives for Planning Audits"** forms a part of the Occasional Research Paper (ORP) Series, with a special focus on the Blue Economy sector. It is the twelfth such volume in the ORP series, which was introduced in May-June 2022. This also represents iCED's new pathway to emerging as a Centre of Excellence for Audit of the Blue Economy.

### Feedback

We strive for constant improvement and encourage our readers to provide their valuable feedback/suggestions. Please send us your suggestions and comments about this Research Paper to iced@cag.gov.in.

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## Declaration by Research Associate

I, **Dr. Gulshan Sharma,** hereby declare that Research Paper titled "Marine Energy Resources: Some Perspectives for Planning Audits" submitted to iCED is my own work and no part of it has been published anywhere else in the past. The facts and figures given in the paper are true and authentic to the best of my knowledge.

I concur with the modifications/corrections carried out during the report evaluation based on inputs provided by me.

**01 February 2024** | **(Dr. Gulshan Sharma)**
**Jaipur** | **Research Associate, iCED**

## Acknowledgement

I wish to express my deepest gratitude and sincere thanks to Ms. Sayantani Jafa, Additional Deputy Comptroller and Auditor General and Director General, iCED, for giving her invaluable guidance throughout the research work. I would like to express my sincere appreciation to Dr. Nanda Dulal Das, Director (Training and Research), iCED for his valuable supervision, guidance and constructive suggestions and inputs for this research work carried out as a Research Associate at iCED. I also offer my sincere thanks for the help and feedback offered by Shri Kamal Kumar Sahal, Consultant, iCED and Shri Saurabh Sharma, Assistant Administrative Officer, iCED. This Research Paper would not have been possible without their generous support, constructive feedback, and constant encouragement.

**01 February 2024** **(Dr. Gulshan Sharma)**
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# Foreword

Environmental sustainability enjoins every Supreme Audit Institution's constant up-scaling of their audit focus on issues related to the environment and sustainable development. Given its cross-cutting, dynamic, and multi-disciplinary nature; capacity building and inputs informed by research becomes an essential pre-requisite for human resource management and reporting on public accountability in these areas. The strategic objectives of iCED, inter-alia, include the sharing of knowledge related to environmental auditing among public auditors, policymakers, and researchers to broaden perspectives in this sensitive area.

Research Associates and young Interns at iCED have been working on emerging issues of environment and sustainable development, i.e., Climate Change, urban flooding, Municipal Solid Waste Management and many such relevant topics of contemporary interest. Research on different sectors of the Blue Economy has recently accelerated at iCED in line with the vision of Shri Girish Chandra Murmu, Hon'ble Comptroller and Auditor General of India, of iCED evolving as a Centre of Excellence for Audit of the Blue Economy. This publication is a part of iCED's overall innovation-based approach to bring fresh insights and perspectives to environmental audit initiatives.

In line with commitments at Conference of the Parties 26 (COP26), India is working towards achieving 500 Gigawatts of installed electricity capacity from non-fossil sources by 2030. India has a coastline of about 7,517 km and experiences significant wind, sea-wave and tidal variations, making it a potential candidate for harnessing these renewable energy sources.

Despite making quick progress with other Renewable Energy sources, India has not been able to efficiently utilise its tidal potential, although the efforts to evaluate and harness tidal power had been initiated long back. India started tidal power projects in Gujarat and West Bengal but as of now, both of these projects are not functioning owing to high operational costs and other environmental concerns. Tidal Energy is still in Research and Development (R&D) phase and has not been implemented on a commercial scale in India. The same is equally applicable for Offshore Wind Energy, energy from sea waves and Ocean Thermal Energy Conversion (OTEC) projects.

Considering the various dynamics at play and in alignment with iCED's mandate as a Centre of Excellence for Audit of the Blue Economy, we have undertaken the preparation of this research paper. This being a very fledgling area, still in its nascent stage of development, the research paper may help the formulation of initial insights in audit planning. The matrices of potential and kinetic energy indicated in the paper provide a scientific paradigm to understandings the issues at stake. This Research Paper is the twelfth volume of the Occasional Research Paper Series, undertaken since May-June 2022 at iCED.

I would like to extend my appreciation to the author of this paper, Dr. Gulshan Sharma for her commendable efforts. Furthermore, I wish to acknowledge and commend the dedicated contributions of the entire team at iCED, whose collective efforts have transformed this paper from concept to reality. Needless to say, with this publication, iCED once again reaffirms its dedication to being a specialised hub of dynamic in-house research, under the aegis of the Comptroller and Auditor General of India. It also opens a new pathway into research in the multi-faceted complexity of the Blue Economy and its Audit, where iCED now acts as a Centre of Excellence. We eagerly anticipate and welcome any feedback and suggestions on this Research Paper.

**01 February 2024** **(Sayantani Jafa)**

**Jaipur** Additional Deputy C&AG & Director General, iCED

## Message from the Director (Training and Research)

India's commitment to increase its Renewable Energy capacity is not only driven by efforts to mitigate climate change but also by the urgent need to secure its energy future. Offshore Wind Energy, OTEC, energy from sea-waves and Tidal Energy, with its inherent predictability and less environmental impact, holds the best choice of being a reliable and sustainable energy source along India's vast coast.

The extensive and diverse coastline of India spanning multiple regions and states provides a unique opportunity for the development of Tidal Energy projects. From the Gujarat coastline in the west to the Bay of Bengal in the east and the southern coasts along the Indian Ocean, each region offers its distinct potential for Tidal Energy generation. However, it is imperative to acknowledge that despite these favourable conditions, the Tidal Energy potential or other Marine Renewable Energy potential have not been harnessed. In light of this, this research paper has been envisioned and developed to give a fresh perspective and approach capable of providing insights into the energy potential of specific locations through standardised formulas. In this pursuit, this paper has leveraged data from esteemed institutions such as Indian National Centre for Ocean Information Services (INCOIS) as well as other reliable sources, to highlight the case of Tidal Energy in India.

This paper may serve as a valuable resource that is equipped with systematic framework for auditing, supported by reliable data and standardised methodologies.

I am sincerely grateful to Ms. Sayantani Jafa, Additional Deputy Comptroller and Auditor General and Director General, iCED for leading us with her visionary insights and constant encouragement to take the efforts ahead. I would also like to acknowledge the contributions of all those who directly or indirectly contributed to making this paper a reality and appreciate their efforts. I sincerely believe that this Occasional Research Paper would serve as a good source of information on Marine Renewable Energy sources, with an emphasis on Tidal Energy, which can be suitably adopted during various stages of Audit.

**01 February 2024** **(Dr. Nanda Dulal Das)**

**Jaipur** Director (Training and Research), iCED

## Abstract

In the context of India's relentless pursuit of cleaner and more sustainable energy sources, Marine Renewable Energy, especially Tidal Energy source holds considerable potential. The nature of predictability and low environmental impact make it an attractive choice for enhancing both environmental and energy security along India's extensive coastline. However, despite favourable conditions, the potential of Tidal Energy remains unutilised in India, due to high cost of their construction and operations.

This paper endeavours to highlights different available marine energy options with a special focus on calculation of the energy potential at specific locations by utilising standardised methods. By accessing data from institutions like the Indian National Centre for Ocean Information Services (INCOIS) and other reliable resources, this paper seeks to showcase India's immense Tidal Energy potential, which is yet to be fully harnessed, highlighting the challenges faced therein. This paper also highlights some of the audit reports relating to Marine Renewable Energy sectors, which provide important dimensions to the understanding of the auditors.

## Abbreviations

| | | |
|---|---|---|
| AFD | - | Agence Française de Dévelopment |
| AHEC | - | Alternate Hydro Energy Centre |
| BOS | - | Balance of System |
| CRISIL | - | Credit Rating Information Services of India Limited |
| HRED | - | Department of Hydro and Renewable Energy |
| INCOIS | - | Indian National Centre for Ocean Information Services |
| IORA | - | Indian Ocean Rim Association |
| IREDA | - | Indian Renewable Energy Development Agency Limited |
| ISRO | - | Indian Space Research Organisation |
| KE | - | Kinetic Energy |
| MNRE | - | Ministry of New and Renewable Energy |
| NIK | - | Najwyższa Izba Kontroli |
| NIOT | - | National Institute of Ocean Technology |
| NISE | - | National Institute of Solar Energy |
| NIWE | - | National Institute of Wind Energy |
| OTEC | - | Ocean Thermal Energy Conversion |
| RD&D | - | Research Development and Demonstration |
| RE-RTD | - | Renewable Energy Research and Technology Development |
| SECI | - | Solar Energy Corporation of India Limited |
| SSS-NIBE | - | Sardar Swarn Singh National Institute of Bio Energy |
| WBREDA | - | West Bengal Renewable Energy Development Agency |

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## 1. Introduction

In recent years, a growing global population and socioeconomic growth are driving an increase in global energy demand (Nagababu, Kachhwaha and Savsani 2017). Much of this demand is fulfilled by fossil fuels, which contributes to greenhouse gas emissions and Climate Change, highlighting the need to increase the share of Renewable Energy sources with minimal environmental impact (Khojasteh, et al. 2018). Marine Renewable Energy resources are at the forefront of long-term solutions to the world's energy demands. These resources, which tap into the tremendous potential of our oceans, provide a varied range of Renewable Energy sources. The energy generated by Tides, Offshore Wind, Ocean Thermal Energy Conversion (OTEC), and Green Hydrogen are important and largely unexplored Renewable Energy sources in the pursuit of nation’s sustainable and decarbonised energy sources.

### 1.1 Literature Review

Renewable Energy has inherent advantage of sustainability vis-à-vis other sources of energy, which are finite and runs the risk of exhaustion in the future. Figure 1 illustrates the source-wise distribution of cumulative Renewable Energy generation, with thermal accounting for the largest share at 74.25 per cent, renewable making up a substantial portion at 12.53 per cent and Hydro contributing 9.98 per cent. Small hydro, Nuclear and other sources collectively represent less than five per cent of the total Renewable Energy output (Central Electricity Authority 2023), highlighting the dominance of Thermal, Renewable, and Hydro in the Renewable Energy landscape.

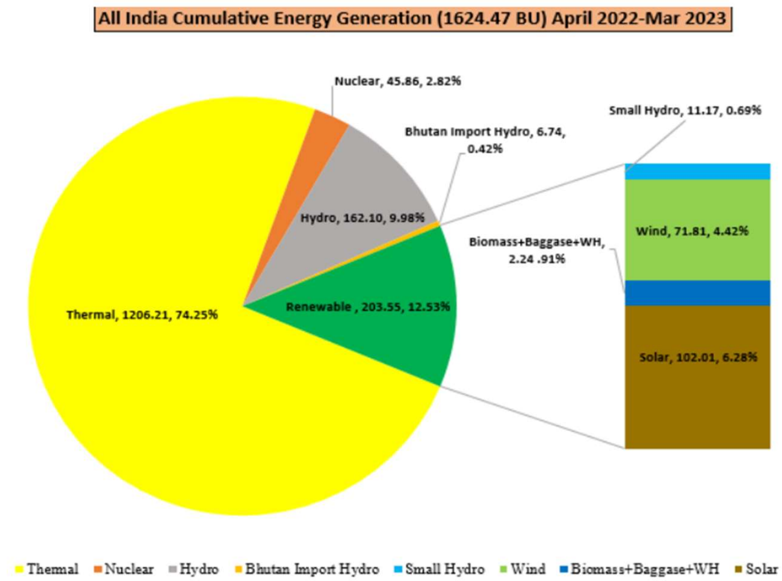


**Figure 1: All India Cumulative Energy Generation in India and Share of Renewable Energy (Excluding Large Hydro*)***
***Source:*** *(Central Electricity Authority 2023)*

Marine Renewable Energy sources serve as alternatives to fossil fuels. Marine Renewable Energies are preserved in a variety of ways including kinetic energy (in the forms of tides and waves), thermal energy (temperature difference), chemical energy (chemicals from the ocean), and biological energy (ocean biomass). Some research predicting the annual energy generation harvested from the ocean have shown several different results. Andres et al. mentioned that the potential for deploying a power converter from ocean energy could reach 337 Gigawatt (GW) with the produced annual electricity of 885 Terawatt hour (TWh) (Andres and Lopez 2017). While Derakhshan (Derakhshan 2018) forecasted the potential as ranging from 4 to 18 million tonnes of oil equivalent (mtoe), Zafar et al., estimated that about 32 Terawatt (TW) of electricity could be harvested globally using marine resources (Zafar Ali Khan 2022). Furthermore, a more detailed potential was estimated by Khan et al., who found that the tidal, wave, and Ocean Thermal Energy Conversion (OTEC) had potentials of 800, 2000, and 10,000–87,600 TWh respectively (Khan and Kalair 2017).

Theoretical electricity generation potential varies among technologies, and when considering the combined potential of all ocean energy technologies, IRENA, 2020 found that it falls within the range of 45,000 to well above 130,000 TWh per year (Figure 2). This implies that Ocean Energy has the capacity to cover more than twice the current global demand for electricity ( IRENA 2020).

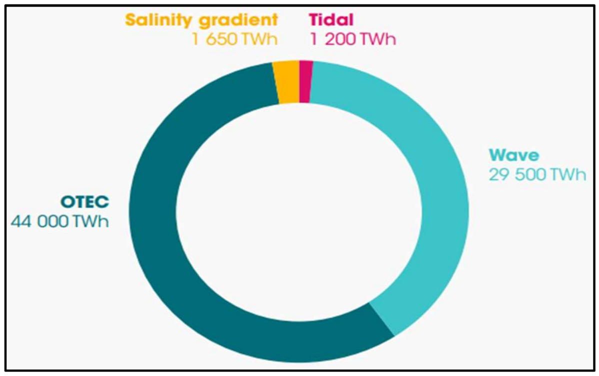


**Figure 2: Electricity generation potential from ocean energy technologies**
**Source:** *( IRENA 2020)*

Even though the energetic potential of Marine Renewable Energies is unquestionable, estimates of the amount of energy that can be harvested are associated to uncertainty and the global challenge remains is how to extract the energy, bring it to shore, store it, and export it in a cost-effective way. Depending on the source, the energetic potential of the different Marine Renewable Energies may vary significantly (Taveira-Pinto 2020).

Further in this paper, Section 1.1.1 examines budgetary allocation for research and development of Renewable Energy sector in India, while Section 1.2 examines the types of Marine Renewable Energy Sources. Among the all Marine Renewable Energies, Tidal Energy appears to be a viable, time-tested and large-scale power generation options, as seen in countries like France and Canada (Power-Technology 2014). The present status of Tidal Energy and efforts undertaken for promotion of Tidal Energy are presented in Section 1.3. Section 2 outlines the need for this study, and Section 3 depicts the research's aims. Section 4 delves into the methodology employed and the framework for assessment of Tidal Energy potential, followed by Section 5, which presents the results obtained. An exploration of challenges related to the development of Ocean Energy sources, including high cost and environmental impact, is discussed in Section 6. Finally, Section 7 serves as the concluding part of the article, summarising Way Forward in Tidal Energy.

Plant Development followed by pointers for audit derived from the study.

### 1.1.1 Budgetary allocation for Research and Development in Renewable Energy Sector

During the examination of Demands for Grants (2021-22), the Ministry furnished the following with respect to budgetary allocation and actual expenditure incurred on research, design and development in New and Renewable Energy during the last three years.

A fund of ₹ 10,222 crore has been allocated towards the Renewable Energy sector in the Union Budget 2023-2024. The outlay is an increase of 48 per cent over the last year's allocation of ₹ 6,900.68 crore (Budget Estimates) and 45.3 per cent over the revised estimates of ₹ 7,033 crore (MNRE 2023). Further, the Standing Committee on Energy noted that no funds have been spent by the Central Government on the development of tidal power (Standing Committee on Energy 1993).

- **Reduction in Research and Development Funds:** It is observed that the funds allocated to the Ministry of New and Renewable Energy (MNRE) for research and development have been reduced significantly at the revised stage in the last few years. The Ministry could not completely utilise even the reduced amount in these years (2017-20) (MNRE 2021).
- **Committee's recommendation:** In light of these observations, the Committee recommended that the Central Government should not reduce the funds for research. The Central Government should provide significant support for un-harnessed sources such as Tidal Energy (PRS Legislative Research 2021).

### 1.2 Types of Marine Renewable Energy

The key Marine Renewable Energies are:

#### 1.2.1 Ocean Thermal Energy Conversion

Ocean Thermal Energy Conversion (OTEC) technology, a Renewable Energy System (RES), exploits the temperature difference (often around 20°C) between the sea surface and the seabed (typically around 1 km depth) to generate power in either an open or closed cycle system. Despite being conceptualised many years ago, OTEC technology has failed to achieve the advancement seen in other RES. While several research programs were launched in the 1980s and 1990s, interest in OTEC has subsequently faded due to the spread of more efficient and reliable RES (Aresti, et al. 2023). The availability of sea temperature differences, different technology types, and the positioning of OTEC structures are some of the issues explored in terms of efficiency and effectiveness. While OTEC had faced setbacks in India since its inception in 1980, recent developments spearheaded by the National Institute of Ocean Technology (NIOT) are reigniting the nation's commitment (OEE 2023). The NIOT, an autonomous institute under the Union Ministry of Earth Sciences (MoES) is establishing an

OTEC plant with a capacity of 65 kilowatt (kW) in Kavaratti, the capital of Lakshadweep (Down to earth 2022).

Zafar et al., found that tropical areas around Southeast Asian countries have the highest temperature difference; hence, these countries have a higher potential for the application of OTEC (Zafar Ali Khan 2022). When all Ocean Energy technologies are compared, OTEC shows the highest potential (Asian Development Bank. 2014), and 98 nations and territories have been recognised as having feasible OTEC resources in their Exclusive Economic Zones (EEZ). According to recent research, OTEC may provide all of the world's power generation capacity while not affecting the ocean temperature profiles (Aresti, et al. 2023). Furthermore, OTEC resources are also available within 10 km of the Caribbean and Pacific Ocean coasts with many island countries. OTEC appears to be particularly well-suited and economically feasible for distant tropical islands where generation may be coupled with other sources such as air cooling and freshwater generation (Jaafar 2012).

Alsebai et al., discovered that in Malaysia, particularly in the Sabah Trough, the possibility of generating electricity from ocean thermal energy has piqued interest, and that the temperature difference (3°C at 2900 m water depth compared to 29°C at the surface) at Sabah Trough makes OTEC viable to be harnessed in Malaysia ( Alsebai, Kang and Yaakob 2023). According to Jaafar, the power generated from Sabah Trough may exceed 50 MW (Jaafar 2012). In a study by Thirugnana et al., the power generated by an OTEC system shows deployment in the Malaysian EEZ near Sabah's coast. The results show that the plant can generate power equal to or four times higher than the Malaysian government's target set for 2025 (Thirugnana, Jaafar and Yashugana 2021).

### 1.2.2 Offshore Wind

According to the treaty agreements at the Conference of Parties (COP26), the Government of India (GoI) aims to lower the intensity of carbon emissions, reducing their impact by 45 per cent below the year 2005 level of the country's Gross Domestic Product (GDP), and to achieve installed cumulative electric power capacity of about 50 per cent from Renewable Energy by 2030 (Nagababu, Kachhwaha and Savsani 2017). India started taking strong measures to make energy more accessible for everyone and to attain energy security actions to generate its own Renewable Energy sources steps for developing its renewable sources of energy. To achieve this, the GoI took initiative for offshore wind power development ( IRENA 2020).

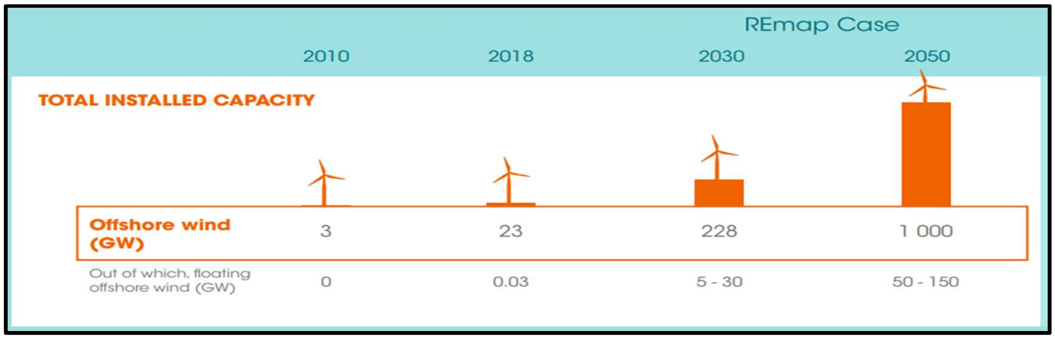


**Figure 3: Summary of offshore wind projections** **Source:** *( IRENA 2020)*

Offshore wind energy in India is in its infancy, marked by the MNRE's (MNRE 2021) targets of 5 GW and 30 GW by 2022 and 2030 respectively. Summary of offshore wind projections is shown in Figure 3 ( IRENA 2020). IRENA forecasts that Offshore Wind Energy could escalate 150 GW of installed capacity by the year 2050.

In a case study, developers proposed the Cape Wind project (the first offshore wind farm in the United States) (Bureau of Ocean Energy Management 2024) in November 2001, proposing 130 wind turbines with a maximum electrical output of 468 MW (National Geographic n.d.).

Another case study by the Netherlands Court of Audit reveals that ambition of 40 per cent cost reduction of Offshore Wind Energy would not be difficult as between 2013 and 2023, there has been significant reduction in cost, as transpired from the tender quotation of the Hollandse Kust wind farm. The cost quoted in this tender is an impressive 70 per cent lower than the 2013 estimate. The audit attributes lower material cost, increasing innovation in the sector, economies of scale and stronger financial management and Government assurances as the key for such cost reduction. The audit was initiated to verify claims made by the Minister of Economic Affairs and Climate Policy regarding the anticipated cost reductions and the possibility of the Netherlands hosting the world's first subsidy-free wind farms (Netherlands Court of Audit 2018).

### 1.2.3 Green Hydrogen

India has set its sight on becoming energy independent by 2047 and achieving net zero by 2070 (Ministry of Electronics and Information Technology 2024). To achieve this target green hydrogen is considered as a promising alternative. It is produced using electrolysis of water with electricity generated by Renewable Energy (Hassan, et al. 2023). Hydrogen can be utilised for long-duration, acts as a replacement of fossil fuels in industry, offers clean transportation (Oxford Institute for Enegy Studies 2020), decentralised power generation, and marine transport (Invest India 2021). The National Green Hydrogen Mission was approved by the Union Cabinet on 4 January 2022, with the objectives of Making India a leading supplier and producer of Green Hydrogen in the world (NITI Aayog 2022). In light of this to fulfil the target of National Green Hydrogen Mission, India has declared its ambition to become an exporter of hydrogen to Japan, South Korea, and Europe (Ministry of Information and Broadcasting 2022).

- **India's Progress towards Green Hydrogen**

  India's annual demand for hydrogen was estimated to be 6 million tonnes (MT) in 2020. It is predicted that the price of hydrogen will drop by 50 per cent by 2030. By 2050, there will be a five-fold increase in the demand for hydrogen, reaching 28 MT, with 80 per cent of that demand is expected to be green in nature (NITI Aayog 2022). Some of the prominent industrial mammoths such as Reliance Industries Limited (RIL), Gas Authority of India Limited (GAIL), National Thermal Power Corporation (NTPC), Indian Oil Corporation Limited (IOCL) and Larsen and Toubro Limited (L&T) plan to foray into the green hydrogen space for making India energy independent in coming years (Invest India 2022).

### 1.2.4 Tidal Energy

Tidal Energy is a form of Renewable Energy that harnesses the power of the tides in the ocean to generate electricity (Aggarwal 2021). Coastal areas experience two high and two low tides every day because the Earth rotates through two tidal bulges every lunar day, which is 24 hours and 50 minutes. High tides occur every 12 hours and 25 minutes apart, and it takes six hours and 12.5 minutes for the water at the shore to go from high to low or vice versa ( Alsebai, Kang and Yaakob 2023). Tidal Energy has been used for centuries in various forms, but modern technologies have made it possible to harness tidal power on a larger scale. The energy of the moving water as it rises and falls with the tides is a type of kinetic energy. Tidal power is a type of hydropower that uses this energy to turn a turbine and generate electricity. There are several methods used to harness tidal power, including tidal barrages, tidal turbines, and tidal fences (Charles Rajesh Kumar 2020).

#### 1.2.4.1 Methods for harnessing Tidal Energy

There are currently three different ways to get Tidal Energy:

**(i) Tidal Barrages**

A tidal barrage is a dam-like structure built across a bay or estuary. As the tide rises and falls, water flows through the barrage, turning turbines to generate electricity (Rourkee, Boyle and

Reynolds 2010). Tidal barrages have been used in a few locations, such as the Rance River in France and the Sihwa Lake in South Korea (Sundar 2017).

**(ii) Tidal Turbines**

Tidal turbines operate similarly to wind turbines, but they are placed underwater in areas with strong tidal currents. As the tides flow, the turbines rotate, converting the kinetic energy of the moving water into electricity (Aggarwal 2021). Tidal turbines can be installed individually or in arrays, and they are designed to minimise their impact on marine life. Several tidal turbine projects have been deployed, including the MeyGen project in Scotland and the Minas Passage project in Canada (Chen, Ahmed and Benbouzid 2018).

**(iii) Tidal Fences**

Tidal fences, also known as tidal barrages or tidal lagoons, are structures consisting of multiple turbines arranged in a line across a channel or strait. As the tidal currents flow through the turbines, they generate electricity (Frankel 2006). Tidal fences are particularly suitable for areas with strong tidal currents. One example of a tidal fence project is the proposed Swansea Bay Tidal Lagoon in the United Kingdom (Sean Petley 2016).

Tidal Energy has several advantages as a Renewable Energy source. It is predictable, as tidal patterns can be accurately forecasted years in advance, unlike other variable Renewable Energy sources like wind or solar power. Tidal Energy is also highly efficient, with a high energy density compared to other renewables. Ongoing research and technological advancements continue to improve the efficiency and viability of Tidal Energy projects worldwide (Nazri, et al. 2018).

### 1.3 Tidal Energy Potential in India

In December 2014, the Indian Institute of Technology, Chennai, in collaboration with the Credit Rating Information Services of India Limited (CRISIL), did a research on "Tidal and Wave Energy in India: Survey on the Potential and Proposition of a Roadmap". The study was supported by the Agence Française de Development (AFD) and the Indian Renewable Energy Development Agency Limited (IREDA) as part of an agreement between IREDA and MNRE (Sundar 2017). According to this analysis, India's theoretical tidal power potential is approximately 12,455 megawatt (MW). The Gulf of Khambhat and the Gulf of Kutch on the West Coast were found to be the most appealing sites. The Ganges Delta in West Bengal's Sundarbans also contains suitable places for small-scale tidal power generation (MNRE 2021).

State-wise estimated potential of tidal power in different States in India, as highlighted in the report, is provided below:

*Table 1 : The state-wise estimated theoretical potential of tidal power*

| **State** | **Estimated Theoretical Potential of Tidal Power (MW)** |
|---|---|
| Gujarat | 10,425 |
| West Bengal | 900 |
| Odisha | 400 |
| Tamil Nadu | 230 |
| Maharashtra | 200 |
| Andhra Pradesh | 100 |
| Karnataka | 100 |
| Kerala | 100 |
| **Total** | **12,455** |

**Source:** (MNRE 2021)

Large chunk of India's Renewable Energy capacity is from sources such as solar, wind, and hydropower. Tidal Energy is still in the early stages of development and had limited commercial-scale installations (Walker 2013).

### 1.3.1 Present Status of Tidal Energy

As of the present status, Tidal Energy is still in Research & Development (R&D) phase and has not been implemented on a commercial scale in India (Chen, Ahmed and Benbouzid 2018). The earlier efforts for harnessing tidal power were not successful due to high capital costs ranging from ₹ 30 crore to ₹ 60 crore per MW (MNRE 2023). Tidal Energy is considered as a dense and enormous source of energy, but still there remain issues relating to technology used for power generation because of continuous fluctuation in tidal current (Frankel 2006). In India, most of the coastlines experience low tidal current (Aggarwal 2021), requiring viable improvement in technology (Subhashish Dey 2022).

As per the distribution of subjects among the Ministries under Allocation of Business Rules, Tidal Energy has been allocated to the MNRE (Khaitan & Company 2019).

In the 1980s, the GoI began efforts to evaluate the Tidal Energy potential within the country's coastal regions (Khare 2021). This initiative aimed to harness clean and Renewable Energy from tidal sources. **Areas with identified Tidal Energy Potential**: Initial surveys conducted during this period identified specific regions with significant Tidal Energy potential. These areas included:

- The Gulf of Khambhat and the Gulf of Kutch in Gujarat.
- The Gangetic delta in the Sundarbans region in West Bengal (MNRE 2023).

**Project Initiatives**: Based on the findings of surveys and the identified Tidal Energy potential, the GoI initiated two Tidal Energy projects in different regions:

- A project named Durgaduani Tidal Power Project with an installed capacity of 3.75 MW in West Bengal in 2007 (MNRE 2021).
- A larger project with an installed capacity of 50 MW was established in Gujarat in 2011 (PRS Legislative Research 2021).

### 1.3.2 A Case Study of Tidal Energy in West Bengal

The MNRE sanctioned the demonstration project to the West Bengal Renewable Energy Development Agency (WBREDA) in October 2007 (Down to Earth 2006). As mentioned above, the project's goal was to set up a 3.75 MW capacity Tidal Energy plant at Durgaduani Creek in the Sundarbans region (WBREDA 2023).

- **Estimated Cost**: The initial estimated cost for the project was ₹ 48 crore.
- **Funds released**: An initial amount of ₹ 3 crore was released by the MNRE to support the project's development.
- **Bid and Cost Escalation**: Unfortunately, only one bid was received for the project. The bid revealed an estimated project cost of ₹ 238 crore, which translated to approximately ₹ 63.5 crore per MW. This was significantly higher than the initial estimate (MNRE 2021).
- **Project Abandonment**: In light of the exorbitant cost and the substantial increase from the initial estimate, the Government of West Bengal decided to drop the Tidal Energy project.
- **Refund of MNRE Grant**: Following the project's abandonment, WBREDA refunded the MNRE grant that had been initially provided for the project (MNRE 2023).
- This situation underscores the challenges and complexities that can arise in Renewable Energy projects, particularly those involving emerging technologies

like Tidal Energy (Aggarwal 2021). Cost considerations, as well as feasibility and practicality, play a significant role in determining the viability of such projects. While the project did not proceed, it is essential for policymakers and developers to carefully evaluate the economic feasibility of Renewable Energy projects to ensure that resources are used efficiently and effectively (MNRE 2021).

### 1.3.3 Comparative International Case Studies illuminating the Potential of Tidal Energy

Several countries have embraced the potential of Tidal Energy and embarked on innovative projects to harness its power.

- **United Kingdom (*MeyGen Tidal Array):*** Located in the Pentland Firth, Scotland, the MeyGen tidal array is one of the largest Tidal Energy projects in the world. It consists of a series of underwater turbines that generate electricity from tidal currents (Kerr 2018). Second (***Swansea Bay Tidal Lagoon)*** one was to be constructed in south coast of Wales, United Kingdom (UK). Welsh Government approved the plan and offered to invest £ 200 million, later UK Government withdrew its support. In January 2023, plans of a new Swansea tidal lagoon project called "Blue Eden" emerged but this time the multi-billion pound project would be fully funded by the private sector (Youle 2024).
- **Canada (*Bay of Fundy):*** Known for having the highest tides in the world, the Bay of Fundy in Nova Scotia is a prime location for tidal energy development. Various projects have been proposed to tap into the immense tidal power potential in the region (Marine Renewables Canada 2024).
- **France (*Raz Blanchard Tidal Stream Project):*** Situated off the coast of Normandy, this project involves harnessing tidal currents using underwater turbines. It's part of France's commitment to expanding renewable energy sources and reducing carbon emissions (TIGER 2022).
- **South Korea (*Sihwa Lake Tidal Power Station):*** Located in Gyeonggi Province, the Sihwa Lake Tidal Power Station is one of the world's largest tidal power plants, with ten water turbine generators each with an installed capacity of 25.4 MW, the power plant produces 552.7 GWh of electricity annually enough to support the domestic needs of a city with a population of 500,000 (Ahluwalia 2023) (International Hydropower Association 2016).

According to a study conducted by Seng Lim, Sibu, Kota Belud, and Pulau Jambongan in Malaysia emerge as promising sites for Tidal Energy generation, boasting an estimated electricity potential of 8.604 GWh/year ( Seng Lim 2010). Additionally, (Nazri, et al. 2018) investigated 16 locations along the Malaysian coastline, concluding that the tidal range in these areas holds significant potential for power generation. Further, insights from (Sakmani, Lam and Hashim 2013) study identified Mentagor Island as suitable for tidal stream energy. The global installed capacity for tidal range currently stands at 98 per cent, thanks to just two large installations: a 240 MW plant deployed in France in 1966, and a 254 MW plant deployed in the Republic of Korea in 2011. Presently, projects totalling 10 MW are operational, the most advanced of which is the MeyGen project in Scotland. Anticipated deployments in the next two years and beyond are expected to exceed 1 GW by 2025, reflecting the growing momentum in Tidal Energy development.

Expansion beyond these plants, however, has been slow, due to significant challenges associated with deployment of the technology, including, high capital investment, limited site availability and high environmental impact ( IRENA 2020).

### 1.3.4 Cost and Environment Aspects in Tidal Energy Generation

Tidal Energy generation presents a unique set of considerations when it comes to cost and environmental aspects (Aggarwal 2021). In the case of Tidal Energy, factors such as the strength of tidal currents, water depth, and infrastructure requirements can all impact the overall project cost. The capital cost for a Tidal Energy project is site-specific. Regarding the two projects attempted in India, the capital cost was in the range of ₹ 15 crore to ₹ 60 crore per MW at the prevailing price (PRS Legislative Research 2021).

The current issues restricting the development of tidal systems are the high construction costs and the environmental impact (Fergal O'Rourke 2011). The construction of a tidal barrage requires a vast quantity of materials to withstand the huge loads produced from dammed water. The resulting high construction costs are considered one of the greatest issues. Second issue is found to be salinity of water responsible for the corrosive erosion of the turbine material (Aggarwal 2021). Water quality within the basin may also be affected, due to changes in sediment transportation, resulting in changes in water turbidity (Frankel 2006). The changes in sediment transportation are not all negative and may cause marine life to flourish at sites, where they are not normally found. However, construction of tidal barrages i.e., building a dam across an estuary or bay may change the flow of the tidal currents, affecting the marine life within the estuary (Taveira-Pinto 2020). Nonetheless, development of tidal plants presents several significant challenges that require careful consideration and innovative solutions (Aggarwal 2021).

In light of these efforts and the unique challenges associated with Tidal Energy, there is a growing need for understanding this challenging, yet promising sector of Renewable Energy resource.

## 2. Significance of Analysis on Tidal Energy?

This paper with a focus on Tidal Energy, despite its current position as a less dominant and more expensive Renewable Energy source with environmental limitations, remains essential for several reasons. Firstly, innovation often starts at the early stages of a technology's development. This paper can lay the groundwork for making the auditors aware of the advancements and constraints in development of tidal energy. As Tidal Energy holds potential, auditors play a pivotal role in ensuring that projects are conducted transparently and efficiently, adhering to environmental regulations.

With the help of this paper that includes standardised templates, frameworks, and guidelines that auditors can use to ensure consistency and completeness in their audit processes. Audit can assess whether measures implemented by the Government were effective in achieving sustainable Tidal Energy. Audit can assess the contribution of the activities that take place in this regard and evaluate their performance by providing information to the citizens.

## 3. Objectives

The broad objectives of this paper are:

### 3.1 Knowledge Sharing and Capacity Building

This first objective is to facilitate knowledge sharing and capacity building by providing educational resources, case studies, training materials, and access to relevant research and industry developments. This helps to promote awareness, understanding, and adoption of Tidal Energy technologies and practices.

For auditors, understanding the connection between knowledge sharing and capacity building about Tidal Energy developments and Government’s efforts to harness tidal power is paramount. Knowledge sharing ensures that auditors have access to accurate and up-to-date information, enabling them to meaningfully engage towards the development of this field. Moreover, as budgetary allocation for Renewable Energy development remains a focus for the auditors, analysis of budget allotted to different Renewable Energy sources would be helpful. Further, discussion on the scope of development of Tidal Energy or recommendations for its development would require an understanding of issues plaguing this sector.

### 3.2 Assessment of Tidal Energy Development Potential

The second objective is to provide tools and methodologies for assessing the Tidal Energy development potential at a specific location or region. This involves data analysis, modelling, and mapping to identify suitable areas for Tidal Energy development. Site assessment is a crucial step, involving the selection of optimal locations for Tidal Energy installations based on the collected data. Energy calculation methodologies then utilise this data to estimate the energy potential accurately, providing a foundational framework for informed decision-making in Tidal Energy development. By evaluating these elements, auditor can contribute to the transparency and credibility of Tidal Energy projects, ensuring that they are based on sound scientific foundations and align with regulatory and industry standards.

## 4. Methodology

The Tidal Energy calculation involves several factors related to the tidal patterns, area, and efficiency of the Tidal Energy conversion technology. The methodology vis-à-vis stated objectives are provided in Table 2 below:

*Table 2: Methodology Employed to Achieve Stated Objectives*

| Sl. No. | Objectives | Methodology |
|---|---|---|
| 1. | Knowledge sharing and capacity building | This paper involved collection of secondary data on budgetary allocations, initiatives, programmes, and activities undertaken by the Ministry or Government departments responsible for Renewable Energy development. This data was obtained from Government budget documents, reports, and financial records. |
| 2. | To determine Tidal Energy development potential | For meeting this objective, tidal data was used for energy calculations. This approach allowed for the precise evaluation of energy potential at various locations. |

### 4.1 Tidal Data collection

This step involves collection of data on tidal patterns, including the amplitude (difference in water level between high tide and low tide) and frequency of tides in the target area from tidal gauge stations, satellite observations, or tidal databases (refer to Table 2).

### 4.2 Site assessment

This step involves identifying a specific location within the target area where Tidal Energy potential is high and can be harnessed. Factors to consider include water depth, tidal range, and tidal current velocities. These factors influence the available energy potential and the selection of appropriate Tidal Energy technologies (Sundar 2017) (refer to Table A1).

### 4.3 Power Density Calculation

This step involves calculating the power density, which represents the amount of power that can be extracted from a unit area of the tidal resource. Power density is determined by multiplying the water density, gravitational acceleration, and the cube of the tidal current velocity. The equation is:

**Power Density** = 0.5 x Water Density x Gravitational Acceleration x Tidal Current Velocity$^3$

### 4.4 Gross Energy Potential Calculation (Nazani Nazria 2016)

Energy potential refers to the amount of energy that can be generated or harnessed from a particular source or system (Khare 2021). The calculation of tidal basin gross energy potential Ef (J) is calculated by using the following equation:

**$Ef = Az\ \rho g R^2/2$**

Where:

- Az is basin area ($km^2$)
- **ρ** is sea water density ($kg/m^3$) $1.03^{-}g/cm^3$
- G is gravitational acceleration ($m/s^2$) $9.806ms^{-2}$
- R is range difference (m)

### 4.5 Kinetic Energy Calculation

Kinetic Energy (KE) is the energy possessed by an object due to its motion. It is one of the fundamental forms of energy and is dependent on an object's mass and velocity. The tidal generators make use of KE of the water stream which spins the turbine and drives the generator to produce electricity (Rourkee, Boyle and Reynolds 2010).

To calculate the KE of a tidal plant, the values for density (ρ), cross-sectional area (A), and velocity (V) are considered. The formula for calculating KE is:

$$E_k = 0.5 C_p\, g\, A_s\, V^3$$

Where:

- $E_k$ is the KE (GW)
- Cp is the turbine power coefficient
- g is the acceleration due to the earth's gravity (9.807m/s$^2$)
- As is the swept area by turbine blades (m$^2$) and
- V is the velocity of the tidal current (20cm/s)

### 4.6 Plugging the values into the Equation

Substituting the respective values into the equation provides estimates of Potential Energy (PE) and KE across the selected Indian coastal stretches, and are provided in Table 5.

### 4.7 Source of Data

Tables 3 and 4 lists the various sources and references of tidal data used in the analysis.

***Table 3: Key Government Institutions/Departments related to the Tidal Energy Sector in India***

| Government Institutions/ Departments | Responsibilities |
|---|---|
| Indian National Centre for Ocean Information Services (INCOIS) | INCOIS, under the Ministry of Earth Sciences, plays a significant role in ocean data collection, including tide data, to provide real-time information and forecasts related to the marine environment. INCOIS is the foremost choice for tide gauge data collection in India due to its expertise in oceanography, provision of real-time data and forecasts, all of which collectively contribute to its credibility and effectiveness in ensuring accurate and reliable tidal data for diverse applications across the country's coastal regions (INCOIS 2023). |
| National Institute of Ocean Technology (NIOT) | NIOT is an autonomous institute under the Ministry of Earth Sciences, which conducts research and development activities related to ocean technologies, including Tidal Energy (NIOT 2023). |
| Indian Space Research Organisation (ISRO) | ISRO uses satellite data to monitor coastal areas and study oceanographic phenomena, which include tidal patterns and variations (ISRO 2023). |

| | |
|---|---|
| Ministry of New and Renewable Energy (MNRE) | MNRE is the primary Ministry responsible for promoting Renewable Energy sources, including Tidal Energy, in India. It formulates policies and programmes for the development and deployment of Renewable Energy technologies and provides financial incentives and support for projects (MNRE 2023). |
| Ministry of Power | The Ministry of Power plays a significant role in the development of Renewable Energy projects, including Tidal Energy, as it deals with the generation, transmission, and distribution of electricity in India (Ministry of Power 2023). |
| Ministry of Environment, Forest and Climate Change (MoEFCC) | MoEFCC is responsible for environmental clearances, regulations, and approvals for Tidal Energy projects. It ensures that these projects comply with environmental and ecological standards (MoEFCC 2023). |
| Indian Ocean Rim Association (IORA) | India is a member of IORA, a regional organisation focusing on cooperation and development in the Indian Ocean region. IORA plays a role in promoting international collaboration on Tidal Energy in the Indian Ocean (IORA 2023). |

Table 3 above serves as a comprehensive repository of the diverse sources of tidal data utilised in this analysis. It encompasses a wide array of references from which the tidal data was collected and collated. These sources range from authoritative Governmental agencies and research institutions to reputable environmental monitoring stations and datasets. Table 4 below provides sources of data against the indicators selected in this study.

***Table 4: Sources of Data against each Indicator***

| S. No. | Tidal parameter | Description | Reference |
|---|---|---|---|
| 1. | Tidal Range difference (metres) | The vertical difference between high and low tides. It indicates the amplitude of the tidal cycle. | 1. National Institute of Oceanography (NIO 2023)<br>2. National Oceanic and Atmospheric Administration (NOAA 2023) |
| 2. | Tidal Velocity (m/s) | The speed at which water flows due to tidal currents. Higher velocities can potentially generate more energy. | 1. National Oceanic and Atmospheric Administration (NOAA 2023)<br>2. National Institute of Oceanography (NIO 2023) |

| | | | |
|---|---|---|---|
| 3. | Sea water density | The density of seawater can vary, but on average, it is around 1.021 to 1.030 tonnes/$m^3$ at the ocean's surface. However, this value can change depending on the location, depth, and other factors. Higher density holds potential for higher generation (Walker 2013). | 1. National Oceanic and Atmospheric Administration (NOAA 2023) |

### 4.8 Framework for assessment of Tidal Energy potential from any coastline based on the parameters

By utilising this framework (as shown in Figure 4), a comprehensive assessment of the Tidal Energy potential can be conducted for any coastline. This evaluation helps to identify suitable locations for Tidal Energy projects, estimate energy production potential, and inform decision-making processes for sustainable and efficient Tidal Energy development.

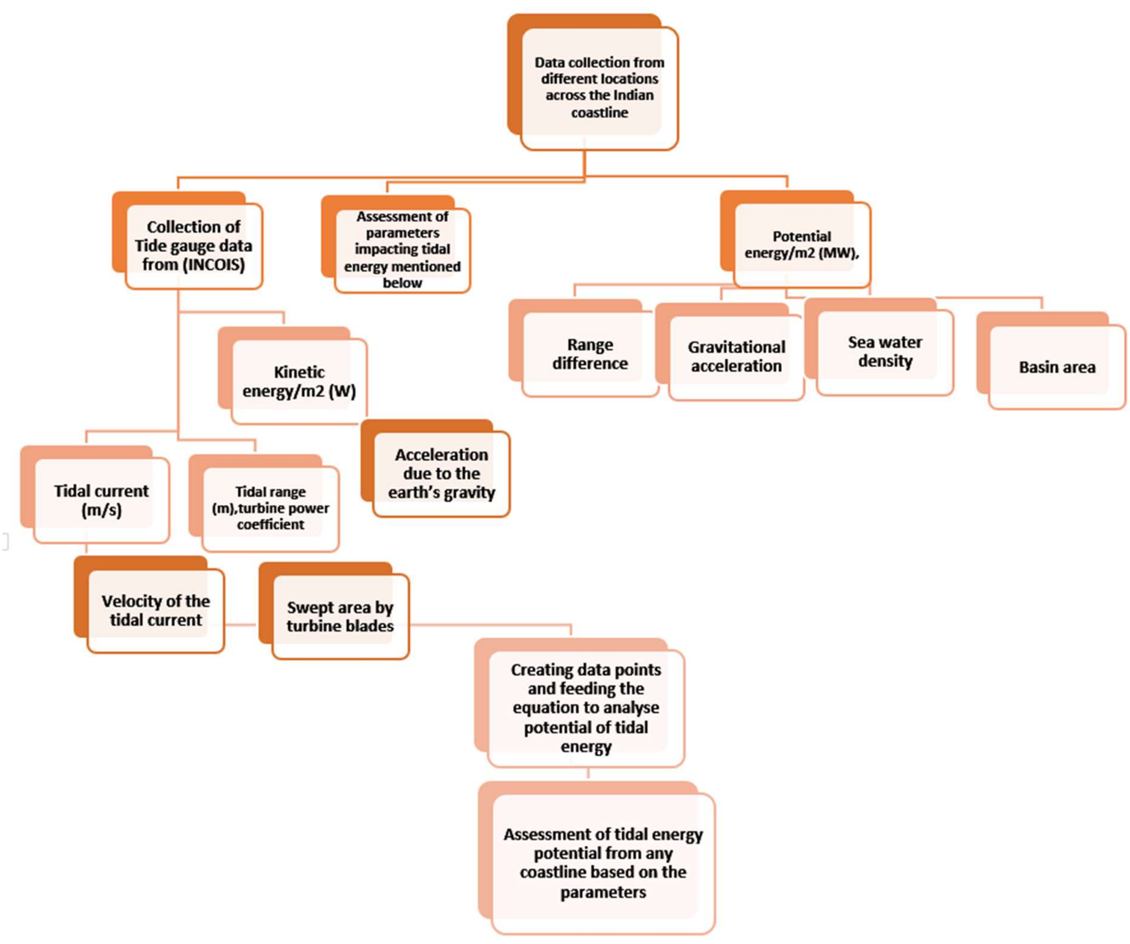


**Figure 4: Framework for Assessment of Tidal Energy Potential**
**(Source:** Created by Author**)**

With the help of this paper, stakeholders can assess the performance, compliance, and overall effectiveness of a Tidal Energy project or facility.

## 5. Results and Analysis

Firstly, before proceeding with the calculation of potential generation, the value of tidal range and velocity of tidal current are identified.

### 5.1 Classification of tidal potential in terms of range

Review of literature clearly indicates that the maximum tidal range[1] is observed in the Gulf of Kutch and Gulf of Khambhat regions with a range of 10–11 m (Khare 2021). The next higher tidal range observed along the Sundarbans area is about 5.5 m, a magnitude of which is experienced at several other locations. The regions may be categorised as Class-I-Tidal range. In addition, the regions south of Gujarat and West Bengal experiencing a moderate tidal range of 3–5 m may be categorised as a Class-II-Tidal range. Creating a tidal reservoir and power plant could be a good option for these regions. In the south, the tidal range is low. These regions may be categorised as Class-III-Tidal range.

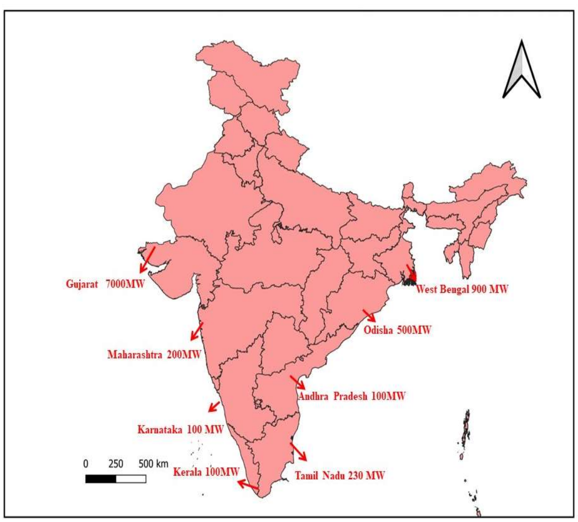


**Figure 5: Demonstrates Location-wise Tidal Energy installed capacity in India. The total available capacity of wave energy in India along the 6000 km of India's float is surveyed to be around 40,000 MW based on preliminary evaluations.**


**Figure 6: Shows the potential locations of India, which are utilised for electricity generation through Tidal Energy system. The Gulf of Kutch is leading Tidal Energy generation site of India is followed by the Gulf of Khambhat, Sundarbans and Seashore of Maharashtra. Source***: (Khare 2021)*

[1] The difference in height between the high tide and the low tide is called the tidal range.

The PE and KE (in Table 5) represents the energy potential of the tides in a specific coastal zone. It provides an estimate of the maximum amount of energy that can be extracted from the tidal flow. Alongside the Gulf of Khambhat and the Gulf of Kutch, another potential location in India is the Sundarbans (as shown in Figure 6 and Table 5) which is not long as such as the other two, but it is also capable of generating electricity in the range of 7.2 MW. It lies in the state of West Bengal. Meanwhile, Figure 5 depicts location-wise Tidal Energy installed capacity in India.

*Table 5: Calculated potential and Kinetic Energy (KE) along the Indian coastline*

| **Coastal region** | **Tidal range(m)** | **Tidal current (m/s)** | **Average available PE per square kilometre (MW)** | **Average available KE per square metre (Watt)** |
|---|---|---|---|---|
| Khambhat | 5-11 | 2.5 | 10.9 | 2604.3 |
| Kutch | 4-9 | 3 | 7.2 | 4500.2 |
| South Gujarat | 2-4 | 1.5 | 1.5 | 1333.4 |
| Karnataka | 1-1.5 | 1.5 | 0.2 | 562.5 |
| Tamil Nadu Coast | 1 | 0.8 | 0.1 | 85.3 |
| Andhra Coast | 1-2 | 1 | 0.2 | 166.7 |
| Odisha Coast | 2-4 | 1.5 | 1.5 | 562.5 |
| Sundarbans | 4-7 | 2-3 | 7.2 | 2604.3 |

**Source:** (Sundar 2017)

It is important to note that this calculation represents a simplified approach and does not account for factors such as turbine efficiency and losses in energy conversion.

## 6. Challenges in Tidal Energy Plant Development

The development of Tidal Energy plants faces significant challenges, including the high cost required to harness the power of ocean tides (Sean Petley 2016). Environmental impact poses additional obstacles, as these projects must navigate stringent guidelines to ensure minimal disruption to marine ecosystems. In this context, various challenges related to Tidal Energy plant development are mentioned below:

### 6.1 High Capital Costs

Tidal Energy projects require significant upfront investment due to the complex infrastructure and specialised technology involved (Walker 2013). The cost of tidal turbines, foundation structures, underwater cabling, and grid connections can be substantial, posing a challenge for project developers (Aggarwal 2021).

### 6.2 Environmental Impact

Tidal Energy projects can have environmental impacts, such as altering tidal patterns, affecting marine ecosystems, and disrupting fish migration. It is crucial to conduct thorough environmental impact assessments and implement mitigation measures to minimise these effects (Kokkranikal, McLellan and Baum 2003). A barrage across an estuary is expensive to build and environmentally impacts a very wide area which may be affected for many miles upstream and downstream. Many birds that rely on the tide uncovering the mud flats for feeding could be affected (Subhashish Dey 2022). Further, damages like reduced flushing and erosion can change the vegetation of the area and disrupt the ecological balance (Aggarwal 2021).

### 6.3 Technological Limitations

Tidal Energy technologies are still evolving (Sakmani, Lam and Hashim 2013), and there are ongoing challenges in optimising turbine design, efficiency, and durability. Developing reliable and cost-effective turbine systems that can withstand harsh marine conditions is a key technological challenge (Sean Petley 2016).

### 6.4 Site-specific nature

Tidal Energy potential varies greatly from one location to another, and identifying suitable sites with optimal tidal resources can be challenging ( Seng Lim 2010). Site-specific factors, such as water depth, tidal range, and seabed conditions, need to be carefully assessed to ensure the viability of Tidal Energy projects (Table A2 in **Appendix-I**) along the coastal stretches of India.

### 6.5 Grid Integration

Integrating Tidal Energy into the existing electrical grid infrastructure can be challenging. Tidal power generation is intermittent and dependent on tidal cycles, requiring effective grid management and energy storage solutions to ensure a stable and reliable power supply (Rourkee, Boyle and Reynolds 2010).

## 7. Way Forward in Auditing Marine Renewable Energy Sources

In the fight against climate change and the quest of a sustainable energy future, Marine Renewable Energy sources stand as powerful allies. As technology continues to rise and the world seeks alternatives to fossil fuels, the role of Marine Renewable Energy, and especially Tidal Energy becomes significant. To minimise environmental impacts and to fully realise its potential, responsible planning, comprehensive research, and international collaboration are paramount. The transition to a low-carbon energy landscape can be accelerated by funding Marine Renewable Energy and Tidal Energy research and development, establishing policy frameworks that encourage the adoption of clean energy, and launching public awareness campaigns.

By embracing Tidal Energy and other marine renewable sources, we not only lessen our carbon footprint but also pave the way toward a cleaner, healthier, and more resilient planet for current and future generations.

### 7.1 International Collaboration

The recently concluded Group of 20 nations (G20) Summit featured energy transition, Renewable Energy, and universal access to energy high on its agenda. In the G20 New Delhi Declaration 2023 (NITI Aayog 2023), all nations agreed to triple Renewable Energy capacity i.e., accelerating the build-out of wind power, solar power, hydropower and geothermal power, globally by 2030 (Koundal 2023).

Encouraging international collaboration and knowledge exchange can help accelerate Marine Renewable Energy and Tidal Energy development (Khaitan & Company 2019). Sharing experiences, lessons, and best practices among countries can promote technology advancements, reduce costs, and foster a global Marine Renewable Energy and Tidal Energy industry (Neill, et al. 2021).

By addressing these challenges and implementing strategies for progress, Marine Renewable Energy and Tidal Energy have the potential to contribute to a sustainable and diversified energy mix, reducing reliance on fossil fuels and mitigating Climate Change (Khare 2021). In light of this, it is likely that the interest in Renewable Energy sources will increase considerably in India in the coming years (Renewable Energy Report 2023).

### 7.2 Important Audit Cases on Renewable Energy and Marine Renewable Energies

Conducting audit at the right time helps Governments in amending policies and taking further effective measures to deliver results in a given field. The International Organisation of Supreme Audit Institutions (INTOSAI) Working Group on Environmental Auditing (WGEA) has a long standing concern for the marine environment. Although the auditing of Marine Renewable

Energy issues in this context is relatively new for many WGEA members, it is now an area of dynamic interest.

**Audit Report of the Comptroller and Auditor General of India on Renewable Energy Sector in India:** This report reveals that considering the significance of Renewable Energy as an alternative to meet the ever growing energy demand of India, the Comptroller and Auditor General of India (C&AG) decided to take up Performance Audit of Renewable Energy Sector in India for the period 2007-14. Notably, this Audit (Report No. 34 of 2015) revealed that the MNRE had not devised any mechanism for claiming of Clean Development Mechanism (CDM) benefits for the off grid Renewable Energy projects. There was lack of awareness with respect to claiming CDM benefits. It was revealed that as against the National Action Plan on Climate Change target of eight and nine per cent for the years 2012-13 and 2013-14, the national achievement was only 4.28 and 4.51 per cent, respectively. Audit observed that although a large number of sanctioned projects were in alignment with focus areas identified under various divisions, realisation of deliverable outcome was not achieved in a majority of projects (C&AG of India 2015).

**Recommendations**

- It was recommended that MNRE needs to pursue with the State Electricity Regulatory Commissions for the adoption of Renewable Purchase Obligation targets in alignment with National Action Plan on Climate Change targets.
- Project Completion Reports of research projects should invariably be vetted by field experts and peer groups before their acceptance, to validate the presented output.

In a report of **Focus audits at the Netherlands Court of Audit 2018 (Enhancing relevance and impact through rapid, responsive audits)** the findings are reported in the Court of Auditors' focus evaluation regarding the cost of offshore wind generation (Netherlands Court of Audit 2018). This audit was initiated by claims made by the Minister of Economic Affairs and Climate Policy that the price of Offshore Wind Energy would drop faster and further than estimated, and that the first wind farms in the world to be developed without subsidies would be built off the coast of the Netherlands. The Court of Audit's study revealed that the objective of decreasing the cost of Offshore Wind Energy by 40 per cent between 2013 and 2023 is achievable. The cost cited in the winning tender for the Hollandse Kust (zuid) wind farm, which had been operated in 2022, is 70 per cent lower than projected in 2013. This significant decrease in the cost quoted in the winning proposal is most likely attributable to innovation, economies of scale, lower raw material costs, better financing arrangements, and more reliable Government assurances (Netherlands Court of Audit 2018).

Furthermore, in 2020 an **Audit report by Science and Innovation** sponsored by the Department for Business, Energy and Industrial Strategy reveals that, in the autumn of 2015, the UK Government launched a programme of Science and Innovation Audits (SIAs) to improve the UK innovation research base. A collaboration was formed in the north of England and Scotland to focus on our strengths and potential in Offshore Renewable Energy (mostly offshore wind, with an assessment of wave and Tidal Energy). It makes no specific comment on other offshore energy sectors, such as oil and gas, or other offshore-based energy opportunities, such as carbon capture and storage. The UK performed consistently well over the three research areas audited (wave, offshore wind, and tidal). The strongest UK performance is perhaps in Tidal Energy research (where the UK is comparatively strong in both quantity and quality) followed by offshore wind (Department for Business, Energy and Industrial Strategy 2024).

During the NIK audit on March 1, 2022, the port of Gdansk was included in the adapted resolution. The findings in Audit report on **Offshore wind energy needs wind in the sails by Supreme Audit Office** revealed that Port of Gdynia was chosen as the marshalling port in the July 2021by Council of Ministers resolution, although it's exact position was not stated. According to a statement, the port of Gdansk meets all criteria of offshore wind investors and permits speedy execution of the first stage of Offshore Wind Energy development in Poland. The port is expected to be completed in the middle of 2025. According to Supreme Audit Office, or NIK, the delayed decision increases the risk that investors may use existing offshore marshalling ports, resulting in limited share of entrepreneurs in the delivery chain. Apart from the lack of approval of the National Recovery Plan by the European Commission poses a threat to the investment financing sources (Supreme Audit Office 2022).

> **Key challenges identified by European Union**
>
> According to Nikolaos Milionis, lead Auditor of the report the auditors commended the Commission's maritime spatial planning for helping identify potential conflicts, provide direction, and finance the development of offshore renewables.
>
> - However, the report highlights that coexistence of different sectors at sea is not yet regular practice, which causes difficulties with the fishing sector in regions where offshore projects are being built.
> - A lack of common projects between countries with shared maritime borders is another missed opportunity to use marine spaces more effectively, according to auditors, while disruptions within the raw materials supply chain could also delay the development of offshore facilities and technology, as the EU depends heavily on imports for their construction (Elissaiou 2023).

Furthermore, audit conducted by European Union (EU), in 2023 on "**Offshore renewable energy in the EU- Ambitious plans for growth but sustainability remains a challenge**" reveals that, national energy and climate strategies have failed to recognise the potential of Offshore Renewable Energy and investigated whether the EU (European Court of Auditors 2023) supported the sustainable development of Offshore Renewable Energy, taking into account its technological, social, and environmental aspects. Furthermore, it was reviewed whether the Commission and member states encouraged the development of Offshore Renewable Energy through an appropriate policy framework, execution of national plans, and budget allocation (European Court of Auditors 2023). Notably, the **findings** revealed that there is no single repository of EU-funded projects that support Offshore Renewable Energy. The Commission **recommended** that to promote the development of Offshore Renewable Energy the Commission should invite members to participate in evaluating proposed draft national energy and climate plans, broken down by technology type and support initiatives to promote ocean energy technologies at sea basin level (European Court of Auditors 2023) The EU's reliance on raw materials may create possible bottlenecks and raises questions regarding the security of supply. The auditors emphasised that the deployment of Offshore Renewable Energy must be sensitive to its social and environmental impacts. The Commission's approach also failed to consider the environmental impact of offshore technologies at initial stages (Elissaiou 2023).

### 7.3 Possible Audit approaches to Audit Marine Renewable Energy

To overcome the challenges in auditing tidal energy, Supreme Audit Institutions (SAIs) can employ effective approach involving international agreements, governance standards, and management principles relevant to tidal energy initiatives. Collaboration with external experts, especially from renowned research and academic institutions, can enhance SAI's expertise in understanding the specialised challenges in Marine Renewable Energy and Tidal Energy projects. Cooperative audits, engaging multiple institutions, enable the experiences and skills for a comprehensive evaluation. Implementing a risk-based approach facilitates the identification and assessment of programmes and sectors influencing Tidal energy, gauging the coordination among responsible agencies. The paper aims at identifying gaps and suggesting possible approaches for conducting audits and research in future. Moreover, it will also help achieving targets under concerned Sustainable Development Goals.

## 8. Conclusion

Despite the perspectives associated with the Marine Renewable Energy and Tidal Energy worldwide, the role of Marine Renewable Energy and Tidal Energy in India remains negligible. This paper has highlighted different aspects of Marine Renewable Energy sources with special focus on the Tidal Energy assessment. This would help a detailed characterisation of Marine Renewable Energy resources with focus on Tidal Energy resources specifically focusing on the factors that constrain or limit the utilisation of such resources. Flowing from the study, it can be highlighted that while Tidal Energy is not yet fully economically viable, Tidal Energy potential in India is high. The challenge is to evolve the cost-effectiveness of future projects through innovative Green Financing etc.

This paper may serve as a valuable resource for auditors involved in the assessment and evaluation of Marine Renewable Energy, especially Tidal Energy projects. The efforts are made to provide auditors a structured framework and tools to effectively audit Tidal Energy plants. By using this research paper, auditors can get useful insights about various aspects, including project planning, resource assessment, technological feasibility, environmental impact, and economic viability of Tidal Energy.

By evaluating different Marine Renewable Energy sources and technologies across different geographical regions, auditors gain insights into the challenges and opportunities associated with each sources and technologies. This comparison allows auditors to conduct a more comprehensive risk assessment, taking into account factors such as regional climatic variations, oceanic conditions, potential and challenges for harnessing different Marine Energy Resources from different regions in India.

# Appendix-I

**Table A1: Assessment of tidal power potential in India by the Ministry of New and Renewable Energy**

**(Refer to in para 4.2)**

Indicates an estimated potential of about 8000 MW with 7000 MW in Gulf of Khambhat, 1200 MW in Gulf of Kutch in Gujarat, and about 100 MW in Ganges delta in Sundarbans in West Bengal.

| Location | Reported potential (MW) | Technology |
|---|---|---|
| Kalpasar (Khambhat) | 7000 | Tidal barraging |
| Kutch/Khambhat | 1200 | Tidal barraging |
| Durgaduani Creeks | 100 | Tidal barraging |
| | | **Source:** (Sundar 2017) |

**Table A2: Probable coastal locations for exploration of Tidal power in India**

**(Refer to in para 6.4)**

| *State* | *Location* | *Latitude* | | *Longitude* |
|---|---|---|---|---|
| *West Bengal* | Sagar Island | 21.4 | | 88.03 |
| | Malta River | 20.5 | | 88.3 |
| | Diamond Harbour | 22.11 | | 88.11 |
| | Calcutta Garden | 22.33 | | 88.18 |
| *Odisha* | Short Island | 20.47 | | 87.04 |
| | Chandbali | 20.4 | | 86.44 |
| | Gopalpur | 19.16 | | 84.55 |
| *Andhra Pradesh* | Vizag | 17.41 | | 83.17 |
| | Cocanda | 16.56 | | 82.15 |
| | Sacramento Shoal | 16.36 | | 82.19 |
| *Tamil Nadu* | Cuddalore | 11.43 | | 79.47 |
| | Negapattam | 10.45 | | 79.47 |
| | Pambam Channel | 9.16 | | 79.12 |
| | Tuticorin | 8.48 | | 78.1 |
| *Kerala* | Quilon | 8.53 | | 76.34 |
| | Cochin | 9.58 | | 76.15 |
| | Beypore | 11.1 | | 75.48 |
| | Calicut | 11.15 | | 75.46 |
| *Karnataka* | Mangalore | 12.51 | | 74.5 |
| | Malpe | 13.2 | | 74.41 |
| | Bhatkal | 13.58 | | 74.32 |
| | Karwar Bay | 14.48 | | 74.06 |
| *Gujarat* | Gulf of Cambay | 21.45 | | 72.14 |
| | Alber Victor | 20.57 | | 71.32 |
| | Nava Bander | 20.45 | | 71.05 |
| | Porbandar | 21.38 | | 69.37 |
| | GoK Okha Point | 22.28 | | 69.05 |
| | GoK Navinar Point | 22.45 | | 69.43 |
| | GoK Khori Creek | 22.58 | | 70.14 |
| | GoK Harshtal Point | 22.56 | | 70.21 |
| | GoK NavMillioni | 23.58 | | 70.27 |
| | GoK Naviwat | 23.05 | | 70.20 |
| | Kori Creek | 23.31 | | 68.21 |

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