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Review of Renewable Energy Applications and Feasibility of Tidal Energy in the United Arab Emirates

Odai Mawafaq Fandi, Sharul Sham Dol* and Mohammed Alavi

Department of Mechanical Engineering, Abu Dhabi University, Abu Dhabi, United Arab Emirate.

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**Corresponding author: sharulshambin.dol@adu.ac.ae (Sharul Sham Dol)*

Abstract
Renewable energy and energy sustainability are vital in meeting the exponential growth of energy demand due to the increasing population and industrial requirements. However, the renewable energy source unpredictability is still a concern for continuous energy supplies. The United Arab Emirates (UAE) has been investing in the renewable energy technologies over the years particularly in solar, nuclear, wind, waste to energy, and hydropower. However, this seems insufficient still, and the shortage of fossil fuels has triggered an alarming energy discussion. Therefore, this work aims at looking for tidal energy feasibility in the UAE apart from reviewing the shortcomings of the existing renewable energy sources in the country. The tidal energy is new but is highly predictable, and if applied properly, it could add to the sustainable solutions. Based on the preliminary study, tidal lagoons with the area of 102 km^2 integrated with double cycle reversible turbines can be installed at the Saqar Port in Ras Al Khaimah, the UAE. The location that has an average of 1.6 m head difference is sufficient to meet 1% of the total UAE's energy demand.

Keywords: *Ebb, Head Difference, Renewable Energy, Saqr Port, Tidal Energy, Tidal Lagoon.*

1. Introduction
Renewable energy is the world's solution for the exponential growth in the economics, industries, and country populations. The United Arab Emirates (UAE) is considered as one of the leading countries in utilizing the renewable energy. Initially, the UAE has launched the Abu Dhabi future energy company in 2006, which hosted various international exhibitions like the work future energy summit in 2008, and then in 2009, the emirates nuclear energy corporation. The International Renewable Energy Agency (IRENA) established its main office in Abu Dhabi in 2009, and recently, it was moved to the Masdar city, in 2012 [1]. The UAE started the vision of "green economy initiative", in which the first solar plant was launched in 2013 with a capacity of 13 MW as phase 1, and to reach phase 5 in 2021 with a total capacity of 900 MW [2]
The objectives of this paper are to review various current renewable energy applications in the UAE in order to determine the advantages and disadvantages of these initiatives, and to analyze the feasibility of the tidal energy technology in the country. The proposed location for this tidal power plant will be made based on the tide's statistics and its suitability for energy sustainability.

2. Renewable Energy Types
Renewable energy is the energy utilized from either a natural source such as sun, wind, tides, geothermal heat, and waves or from unnatural sources, which is continuously available such as the waste to energy. These major types of energy sustainability will be discussed in the next sections along with their impacts. The UAE has been analyzing these applications since 2006 till they reach 44% renewable out of the overall country's energy demands, and the development is on the way to achieve the 2050 vision [1].

2.1. Solar energy
Solar energy is the first type of renewable energy resource, which has been utilized by converting the sunlight into other energy forms resulting in getting electricity out of this process through a pre-designed solar system; the key factor in all solar designs is the different types of collectors responsible for absorbing the solar radiation, and can be distinguished through different ways by

their movement type (stationary and concentrated) or by the working fluid.

Electricity can be produced by using solar system in two ways, the first one by directly utilizing the sunlight into current using PV (photovoltaics), and the second way indirectly by CSP (concentrated solar power). The total of both combined, form around 1.3% of the current world energy production [3].

2.1.1. Solar energy disadvantages

Considering the advanced stage of the solar technology with various market applications and the high solar energy potential in the world (i.e. in the middle east, about 412.4 Exajoule potentially), it comes with a lot of challenges and disadvantages:

1. High initial cost per MW and relatively higher running cost ($35 to $55 per megawatt-hour), also the high energy storage that depends on the project environment [4].
2. Pollution that solar systems may affect land and water use as well as habitat loss. Solar systems are always linked to the usage of some toxic materials and hazardous products during the PV system manufacturing process such as gallium arsenide, hydrochloric, sulfuric and nitric acids, and hydrogen fluoride [5].
3. One of the major points prior to initiate a solar project is the site selection, which should go through a process of statistics of solar irradiation availability and considering that other factors like sand and dirt may pose a challenge. This will lead to a higher maintenance cost, as it is the case in the UAE projects.
4. Large installation area (i.e. solar farm).
5. The typical efficiency values of the PV cells range between 7% and 20%, except for the concentrated PV cells, which are much more efficient but it requires solar tracking system [3].
6. Dust accumulation on the PV solar cells is one of the major factors that affect its performance. The losses could reach 80% reduction of efficiency on a monthly basis as it can be shown in figure 1 [6].

Figure 1. Dust accumulation on PV panels [6].

2.2. Nuclear energy

In general, electricity production in nuclear power plants is done by splitting atoms in a nuclear reactor to heat water and turn it into steam that can be used to rotate a multi-stage steam turbine. Nuclear plants are known with their very high initial cost but low running cost, which make these plants hard to build for countries looking for a short-term solution. The first plant in the world was built in 1954 in the Soviet Union known as the Obninsk nuclear power plant. Few nuclear plants are available in the middle east, and one of them is the Barakah nuclear power plant in the UAE (Figure 2). This project was kicked-off in 2012 on 4 phases with a total capacity of 5.6 GW. The first 3 phases came to operational in 2021, while the last phase or unit reached 89% completion as of April, 2021 [7].

Figure 2. Barakah nuclear energy plant [7].

2.2.1 Disadvantages of nuclear energy

1. Raw material availability (uranium)
2. High initial cost
3. Nuclear waste
4. Water pollution
5. Fuel availability

2.3. Wind energy

Wind is generated due to the uneven heating of the earth surface. The wind energy or wind power is achieved by converting this wind into mechanical or kinetic energy of the wind turbine to run the electric generators, which is either connected to a local grid or storage system. The kinetic wind energy (E) depends on the medium speed and the mass contained in the volume that will flow through the rotor, $E = \frac{1}{2}mv^2$ (Joule), and the medium is normally air. The wind turbines vary in their standard power rating and their swept area or rotor diameter, which can be small (0.2 m) up to 100 m. The wind turbines have two types, vertical axis rotor (VAWT) and horizontal axis rotor (HAWT), and both work with similar principles with small differences in the designs. VAWT has a simple design without

YAW system, and it has a low tip speed ratio, while HAWT is the most common type, and their blade shapes can increase the output power [8].

China, USA, and India have the biggest wind farms in the world, while the largest project in the middle east will take place in Saudi (Dumat Al Jandal wind farm), which contains 99 wind turbines with a total capacity of 400 MW. It was marked in April, 2021 as 50% construction work completion, and is expected to go live in 2022 [4].

The UAE took the initial steps some years ago to work on the wind energy mapping across the country by the Masdar company, and found out a lot of challenges to build utility scale projects especially in the northern emirates, which require additional infrastructure to initiate such mega projects. Sir Bani Yas wind farm was the first achievement of wind energy in the UAE reaching 30 MW capacity.

2.3.1. Wind energy disadvantages

Wind energy harnessing requires specific conditions to avoid threats to nature and unpredictable energy supplies:

1. Noise from the blade's rotation is required to be minimized.
2. Location constraints–the location for wind turbines is normally far from residential and main grids.
3. Threats on wildlife–the blade's rotation can be harmful for birds' migration [3].

2.4. Waste to Energy (WtE)

WtE is a process of getting electricity or heat from the treatment of waste using different technologies such as incineration, de-polymerization, and gasification. The Shenzhen East WtE plant in China is considered the biggest WtE plant in the world with a total capacity of 165 MW and treating 5600 of solid waste annually (Figure 3). The UAE launched different WtE projects, one of them in Al Warsan, Dubai, with the capacity of 20 MW more.

Figure 3. Architect's design of Shenzhen East WtE plant [9].

2.4.1 Disadvantages of WtE

One of the most important advantages of renewable energy is reducing the pollution of the traditional ways; however this point is not valid for the WtE power plants in which some of the main disadvantages are mentioned below:

1. Air pollution
2. Incineration utilizes a small portion of energy and wasting bigger portion
3. Climate change
4. It is not considered fully renewable as it is counting on the available waste, and this waste is coming from natural resources.

2.5. Hydro energy

A hydro energy power plant converts the energy of the water that flows through the turbines, and normally it happens due to gravity. There are 3 main types of hydro plants: diversion, pumped storage, and impoundment [10]. The impoundment is the common type, which uses a dam to store a flowing water in a reservoir and pumping it back through the hydroelectric turbines. The diversion type creates a canal in a flowing river to divert the water into the hydro power plant and the last type, pumped storage that uses battery or storage as water is pumped to a higher-level reservoir on the low demand periods, and it is pumped back again to a lower reservoir through turbines on the high demand periods. The similar plant was made in Hatta Dam, UAE, with a total capacity of 250 MW (Figure 4). There are also another types such as point absorber and surge flaps but they are more on energy harnessing that utilizes the surge motion of waves to generate electrical power [11].

Figure 4. Hatta dam in Dubai.

2.5.1. Hydro energy disadvantages

1. Environmental impact on the rivers
2. Require specific locations-disturbances to flora and fauna

3. Flood risks
4. High initial cost

2.6. Geo-thermal energy

The heat stored in the earth layers can be utilized as a source of renewable energy. Usually, a geo-thermal power plant will require a temperature range of 300–700 ˚F, which can be reached in the earth crust layer. The geo-thermal power plants are working based on 3 basic types: firstly, the dry steam plants that are using the steam directly to run the steam turbines to rotate a generator; secondly, the flash steam plants in which a simple cycle starts by taking the high pressure and temperature water to produce steam to run the turbines. When the steam is condensed, it turns to water, which is pumped back to deep reservoir for re-heat and re-use, and last type is the binary cycle power plant, which is working on the same principle as a heat generator. The advantage of this type is that it utilizes a lower boiling temperature fluid to run these turbines. Figure 5 illustrates the process of ocean thermal energy conversion (OTEC) cycle.

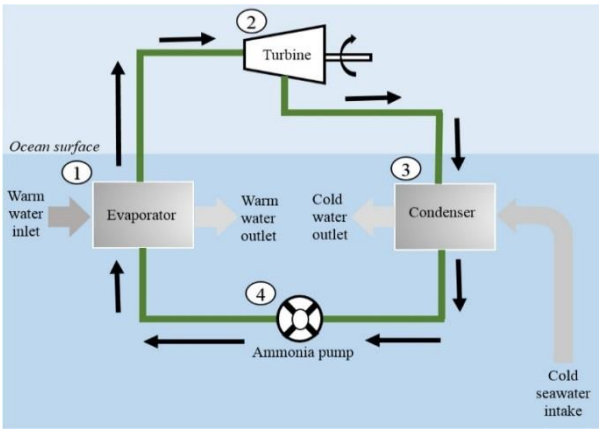

Figure 5. Process of OTEC cycle [12].

OTEC can work in many locations in the MENA region, especially in the Persian Gulf. In spite of the OTEC high initial costs, it can offer a new clean source of energy, especially if the temperature difference is very high between the water near to surface and that the cold water deep in the sea. This can lead to increase sufficiency in power generation.

2.6.1. Disadvantages of geo-thermal energy

Geo-thermal power plant is known with their low efficiencies as the highest reported number was 21% in vapor dominated system and 12% as average efficiency of these plants [12]. There are other disadvantages that are required to be considered as listed below:

1. It requires a specific location.
2. High initial and running cost.
3. Instability of the earth surface as drilling to deep is critical, and this may be mandatory to reach the required high temperature.
4. Sustainability as pumping the water back to the reservoir should happen faster than the steam been used, which may cause a shutdown of the plant due to running out of steam.

2.7. Biomass energy

Biomass energy is achieved by using plants or animal material (waste) as a fuel and converting it to heat to rotate steam turbine, which is driving a generator. Biomass is considered as renewable since waste will never vanish, and it is a continuous source. It has a high potential in the UAE to initiate such plants especially that the country is controlling all the residential and industrial waste through third party companies approved by The Abu Dhabi Waste Management Centre (TADWEER). The additional type of biomass that can be applied in the UAE is the composite waste from palm trees, which can be considered sustainable resource due to the high availability of palm trees and the suitable weather. Figure 6 shows the stages of generating electricity using biomass station.

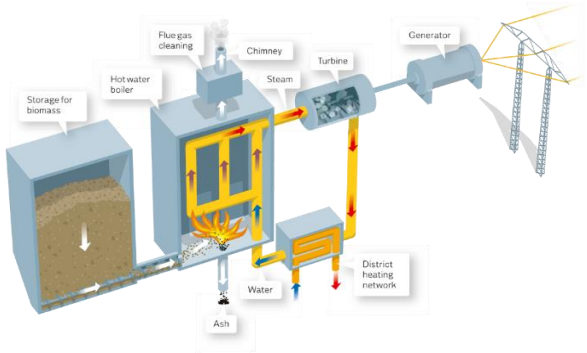

Figure 6. Biomass power plant [13].

2.7.1. Disadvantages of biomass energy

1. Biomass has a lower efficiency compared to biofuels.
2. The requirements for a high storage space for the biomass.
3. Not totally clean energy as it leads to emissions.

3. Literature reviews

The work of [14] has investigated the existing technologies and projects harnessing the tidal energy in the world, and then the authors proposed a new design that was made based on a low tidal head difference (~ 1 m) to be applied in the UAE. This design consists of sets and arrays of piston cylinder unit of tidal harvester. This design was found to be efficient for a low tidal

head difference, about 8 times less than Le Rance barrage, while both are covering the same area of 22 km^2. If both designs were having the same tidal height, the power output will be similar (around 240 MW) and that can be significant to meet the UAE's energy demand.

In the work of [15], the authors have studied the possibility of generating power by integrating the tidal energy system at the Strait of Hormuz. The two main types of tidal systems are proposed, which are the tidal barrage system and the dynamic tidal system. The comparative study was done to decide the most efficient and reliable system to develop, by conducting CAD modeling, CFD, and structural analysis. The tidal barrage system was found to be more efficient and reliable for the purpose.

In the study of [16], the authors have discussed the increasing tidal power role in generating electricity based on the tidal strength. Finally, the scope of tidal electricity generation in the UAE advancements have been discussed, and recommendations have been introduced to start utilizing the tidal energy.

As mentioned earlier, there are two kinds of tidal systems, i.e. tidal barrage system and dynamic tidal system. Tidal barrage systems consist of tidal power generation, which works similar to hydropower, using sluices that control the tidal flow and power turbines to generate electricity. Ebb generation employs gates that allow water to fill a basin to its regular level before closing at high tide. The water is then held back for a few hours until the tide recedes, after which the gates are opened and the water rushes through turbines, generating energy until low tide.

Turbines are used in two-way generating to produce electricity throughout both flood and ebb tides. Unlike ebb generation, all the water continues to flow through the turbines, and is not held back; instead, it is allowed to flow freely and continuously turn the turbines. Although the energy produced is often lower than that produced by ebb generation, electricity is produced over a longer period of time, which might be advantageous depending on the energy demand for a certain area [14].

Tidal barrages change the flow of saltwater into and out of estuaries, affecting the quality of the water, and as a result, negatively affecting and displacing marine species in the vicinity. Furthermore, the barrage systems have substantial development costs, making it difficult to justify such large sums of money, particularly when environmental hazards are taken into account [17].

Dynamic tidal power (DTP) is another and untested technique for tidal power production. It would include making enormous dam like structure reaching out from the coast directly to the sea, with an opposite obstruction at the far end, framing a huge 'T' shape. This long T-dam would meddle with coast-equal swaying tidal waves that run along the banks of mainland racks, containing powerful water driven flows [18].

A DTP dam is a long dam of 30 km to 60 km which is constructed opposite to the coast, running straight out into the sea, without encasing a territory. The flat speed increase of the tides is impeded by the dam. In numerous beach front zones, the primary tidal development runs corresponding to the coast: the whole mass of the sea water speeds up one way, and later in the day back the alternate way. A DTP dam is adequately long to apply an effect on the flat tidal development, which produces a water level differential (head) over the two sides of the dam. The head can be changed over into power utilizing a long arrangement of regular low-head turbines introduced in the dam [19].

On the disadvantage side, the financial feasibility is assessed to be gone after dam lengths of around 30 km. Different concerns include shipment courses, marine environment, residue, and surges in storms.

4. Energy demand and consumption

Energy demand in any country is always considered as a basic term to initiate projects and plan the energy trends, and it is linked to the economic and population growth of the countries, planning the energy supply and demand for all sectors including the manufacturing will require a reliable and stable energy resources.

4.1. The UAE energy consumption

The UAE consumed 131442.88 GWh in 2019, while 128104.93 GWh was consumed in 2018, about 69% increased between 2018 and 2019. The UAE was initially fully counting on natural gas and oil in producing energy, then initiated plants for biofuels and waste as well as coal; however, renewable energy started in 2013 with stable phases and plans utilizing the research and visions targeting 75% renewable by 2050. As of 2021, the UAE is counting on renewable with 44% of the total country energy production [20].

4.2. Utilized renewable energy in the UAE

UAE started working on renewable energy around 15 years ago, and their current projects are summarized in table 1 and aided by figure 7. The

table represents the current renewable energy projects in the UAE and its total capacity.

Currently, renewable energies especially the solar energy technologies have been increasingly integrated with daily applications such as the solar-powered LEDs (light-emitting diodes) lighting systems used at roadways and walkways in Abu Dhabi's carbon-neutral Masdar City (Figure 8). There is also solar-powered speed control camera on the highway in Abu Dhabi, United Arab Emirates (Figure 9). The recently concluded Expo 2020 Dubai has 440-feet-wide steel canopy that includes over 1,000 solar panels, making it one of the most striking architectural designs of the event, capable of producing its own energy, cooling, and water (Figure 10).

Table 1. Current renewable energy projects in the UAE and its total capacity.

Plant type	Project name	Cost per KWh	Total capacity
Solar energy	Shams 1 in Abu Dhabi	4.97 fils	100 MW
	Concentrated Solar Power (CSP) project		150 MW
	Mohammed bin Rashid Al Maktoum Solar Park		1 GW
Nuclear energy	Barakah nuclear energy plant	0.355 fils	5.6 GW
Wind energy	Sir Bani Yas Island		30 MW
WtE	Mussafah Sea Port plant	NA	100 MW
	Al Warsan 2 plant		60 MW
	Sajja area plant		80 MW
Hydro energy	Hatta pumped storage hydro power plant	Used as storage	250 MW with 1500 MW storage capacity

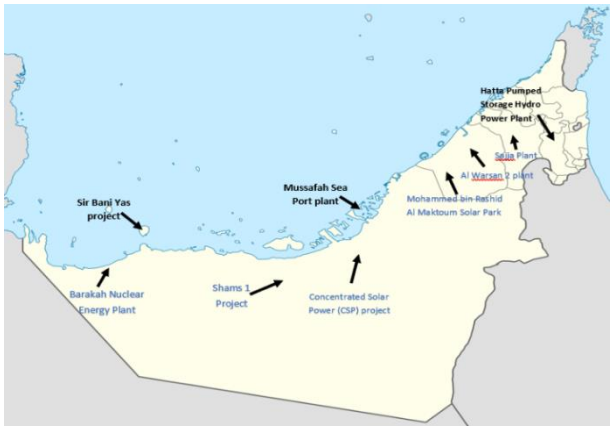

Figure 7. Locations of current renewable energy projects in the UAE.

Figure 8. Solar-powered LEDs at Masdar city.

Figure 9. Solar-powered speed control camera in Abu Dhabi.

Figure 10. Energy trees that host solar panels at Expo 2020 Dubai.

5. Tidal (Ocean) energy

Tidal energy can be defined as converting the tides power into another form of energy, usually electricity by different methods and designs. Tidal energy has a high potential and it is a very active

research topic (e.g. see [3, 14 and 21]). Tides are forming cyclical movements during the day due to the gravity effect of the moon and sun. The moon and sun act like pulling the ocean water on earth while it is rotating, which is causing the high and low tides. This difference is captured and harnessed to a valuable energy form.

5.1. Why tidal energy in the UAE?

With the UAE total coastline length of 1,318 km along Gulf of Oman and Persian Gulf and the country's vision towards the renewable energy is important reason for tidal energy projects. Also energy resource diversity is the key for energy sustainability and moving toward UAE 2050 vison is making the tidal projects the next step even with the high cost and effect on marine life. This can be mitigated by creative designs and choosing a proper location for the project. Tide reports and records were taken for the last few years and Saqr Port area in northern emirates near the Gulf of Oman is considered as a good location with an average of 1.6 m tidal head difference, and it is far from the residential areas.

5.2. Proposed location

There are several ideas on tidal designs that can be implemented in the UAE, and this depends on the chosen area for the tidal feasibility. The tide statistics were taken over years in 33 different locations within the UAE by the National Centre of Metrology and Saqar Port in Ras Al Khaimah UAE (Figure 11) was chosen in this study due to:

Figure 11. Saqr Port in Ras Al Khaimah [15].

1. Average tidal head difference is 1.6 m, which is considered good compared to the other locations.
2. Saqar Port location is far from the residential areas.
3. Shallow water reduces the project initial cost, and it is an advantage for building the dams.
4. Lower impact on marine life.

Apart from the tide statistics that are in favor for this location, The Saqar Port location is far from residential areas that can be good in terms of tidal barrages constructions and disruptions to the shorelines. Water cannot be replenished, and hence, dirt gets settled within the coast. The feel of these environmental impacts can be minimized if the tidal power station is carefully chosen albeit the energy storage could pose a challenge [22].

5.3. Utilization of tidal energy types in the UAE

Table 2 below indicates the three types of barrage tidal plants, taking in consideration our proposed location (Saqar Port). The first type is not applicable as it requires a natural dam area similar to La Rance tidal barrage, while the second and third types are promising projects as the research papers (e.g. see [23, 24]) proposed similar designs, comparing of different types of tidal energy systems.

Table 2. Types of tidal energy systems.

Type	Definition
Tidal barrages	Creation of huge concrete dams with sluice gates and turbines installed at the bottom of the dam.
Tidal stream generators	This type is similar to the idea of wind power generation as the water flows across blades that turn a turbine generator assembly (Figure 12).
Dynamic tidal power	This type consists of long partial dam perpendicular to the coastline, the height difference between the top of the dam, and the low tide forces the water through the turbine generator.

Figure 12. Tidal stream generator [15].

5.4. Tidal lagoons

This type of plant works based on building a lagoon (basin) either on the side of coast line same as the proposed tidal lagoon of Swansea Bay in Canada, which is considered as one of the most promising locations for tidal plants in the middle of the ocean. The map of Swansea Bay tidal lagoon is shown in figure 13.

Tidal lagoons have different design ideas; single (one way, 2 ways and 2 ways with pumping) or double (simple double basin and double basin with pumping) [25]. In this paper, single basin

two-way cycle is proposed with pump storage at Saqar Port. The principle of this design is generating the power during both of the flood and ebb type tides, and it is suitable for low head difference (1.6 m). With the double cycle, generating the power is taking place during filling and emptying of basin by using the reversible turbines. The filling process occurs when the ocean is at high tide, while the water in basin at low tide level and the emptying occurs when the ocean is at low tide and basin at high tide level [26].

Figure 13. Swansea Bay tidal lagoon [14].

The flow of water in both directions is used to drive the reversible turbines. Each turbine drives the generator. Electricity is generated during the 2 short periods; during each tidal period of 12 hours 25 minutes or once every 6 hours and 12.5 minutes. The following equations are used to calculate the tidal energy [27]:

$$\mathbf{E} = \frac{\mathbf{1}}{\mathbf{2}}\,\mathbf{A}\,\mathcal{P}\mathbf{g}\,\mathbf{h^2} \quad (1)$$

$$\mathbf{A} = \frac{\mathbf{2E}}{\mathcal{P}\mathbf{gh^2}} \quad (2)$$

where:
E= Barrage tidal energy
A = Area of plant (tidal pool)
h = Vertical head
$\mathcal{P}$ = Mass density (water)
g = gravitational constant

Also, as per the usage and demand report, which was published by the UAE governmental portal [1 and 7], the total of installed capacity all over the emirates is 131442.88 GWh. The aim was to meet 1% of this number and based on the characteristics of Saqar Port:

Total UAE capacity = 131442.88 GWh (3)

$$\mathbf{A} = \frac{\mathbf{2} \times (\mathbf{131442.88} \times \mathbf{0.01}) \times \mathbf{10^9}}{\mathbf{1025} \times \mathbf{9.81} \times \mathbf{1.6^2}} \quad (4)$$

Thus the required dam area to meet 1% of the UAE total consumption is equal to 102,226,716 m^2, approximately around 102 km^2 with total capacity of 365 MW.

5.5. Disadvantages of tidal energy

Over decades, the tidal energy researches and projects were trying to mitigate the impact of tidal projects and reach a high percentage of perfection. However, these impacts still pose huge challenges for the researchers and energy plant operators such as the impact on marine life, which was studied and faced disagreements with the fishermen and local authorities in different places over the world. This impact can be mitigated by choosing the suitable location far from fishing areas and local residents. This was one of the reasons for delaying the constructing mega projects in the most tidal potential place over the world (such as in Bay of Fundi Canada) [28]. Choosing the location is another challenge as some tidal project types require the existing geographical structures along with the required head difference. Moreover, the high initial cost was considered and studied in different projects like La Rance, Shiwa, and several mega projects. Tidal energy may require high initial cost, similar to the case for wind and solar energy experienced many years ago.

6. Conclusion

The overly reliance on energy sources from fossil fuels is required to be reduced for environmental hazards. Renewable energy comes as a potential solution for these issues along with other advantages such as being relatively clean energy and low running cost. The UAE's long coastline is a big advantage to initiate the tidal energy project. Utilizing the tidal energy in the UAE is an opportunity to ensure and maintain a reliable energy resource. Several ideas (tidal barrages, tidal stream generators, and dynamic tidal power) have been investigated and evaluated. Based on the preliminary study, the tidal lagoons with the area of 102 km^2 integrated with double cycle reversible turbines can be installed at the Saqar Port in Ras Al Khaimah, the UAE. The location has an average of 1.6 m head difference, and is sufficient to meet 1% of the total UAE's energy demand.

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