Tidal energy technologies: barrages, lagoons and streams.

CIS Education Neoscholar Program
Project on Renewable Energy

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1 Abstract

In this report, we seek to give audience better understanding of tidal energy and how we human utilize it. We explored several tidal power plants, regarding their physical principles, integration into energy grid, economics, and environmental impacts. Specifically, we focused on tidal barrages, tidal lagoons, and tidal current turbines. The former two kinds utilize potential energy of the tides, whereas the last one uses kinetic energy of the tides. Underwater (LV or MV) cables covered in steel protectors serve to transmit electricity produced by these facilities to power station and then to consumers. Next, concerning the environmental impacts, we cannot blindly draw conclusions. As a developing energy, tidal energy is still hiding many things we do not understand. Yet, we can still analyze it with five aspects: clean, compactness, collisions, destruction, and noise. As for the economics, the most troublesome element when talking about renewable energy, general factors influencing costs and expenses of each type of tidal system are analyzed. At this stage, tidal power plants are not economically viable, due to prohibitive capital costs. Maintenance, not as expensive as capital costs, is essential throughout the lifetime. Low capacity factors indicate that tidal barrages and lagoons with high installed capacity do not generate electricity as much as other power plants with low installed capacity.

2 Introduction

The power of tides has actually being discovered since a very long time. Ancient people used tide mills to make use of tides. Today, as science subjects like physics and chemistry mature, more advanced power plants driven by tides become a reality. For example, Rance Tidal Barrage was commissioned in 1966; Sihwa Tidal Barrage in South Korea was commissioned in 2011. Besides, the capability of tidal plants improve year by year: looking at Europe, tidal streams produced 50% more electricity in 2019 than the year before, according to statistics released by Ocean Energy Europe; the output of electricity from tidal power plants soared to 15 gigawatt-hours in 2019[1].

The following parts are organized as: 1)the history of tidal energy; 2)detailed explanations of occurrence of tides and three main tidal power systems: tidal barrages, lagoons and current turbines, inside which we more precisely classify different kinds of projects for each main system; 3) the environmental impacts related to the use of tidal energy; 4) economics of tidal power plants; and 5) conclusions as well as future prospects.

3 History of tidal

The history of people utilizing tidal energy is actually quite long. In fact, the oldest known tide mill could be traced back to 787. These old tide mills shared similar principles with modern ones, with the only difference in form of output of energy (electricity for modern days). Take the mill at Suffolk as an instance. There was a dam built in order to store water, as the tide was at its high period.. After it fell, stored water then moved into a sluice where it made a wood water wheel rotate to turn the machinery[2].

Then, the knowledge, along with its technology, of tide mills spread to North America. In 1921, a book that described various ways to extract energy from the tides was published in London. It was entitled as *Tidal Power by A. M. A Struben*[2].

Dexter Cooper, an engineer, figured out a plan to generate power from tides and implement in Cobscook and Passamaquoddy bays. The investment on this project was quite descent, but stock market crisis in 1929 marked an end to work. Years later, the federal government doubled down on a study of the tidal power plant suggested by Cooper. Nevertheless, the government considered this project to be overly costly and gave away the authority to a committee in Maine state. Franklin D. Roosevelt, one of early supporters of Cooper, the President of the United States commissioned 7 million dollars for the project. The project remained touch and go due to Congress's refusal of further funding and result of cost analysis showing the benefits of this project. Eventually it was unable to be put into practice. Currently, the progress is still stuck mainly for people's concerns about the project's impact on the environment of the bay.[2]

France takes the lead in building tidal power plants today. The very first tidal mill in France was undertaken in Brittany in the 12th century. Seven hundred years later, a tidal power plant was built there. and a tidal power plant was built in the same location after seven hundred years. This plant indicates the ever first commercial tidal power plant and has operated since virtually forty years ago. The heights of its area's tide can reach (over 44 feet) provides an ideal position to mount a tidal power facility. It can produce 240 MW, roughly equivalent to a third of the amount of normal plants burning coals produce. This plant applies tidal barrage, with a dam able to contain around 6.5 billion cubic feet of ocean water, in order to generate this amount of electricity[2].

4 Physical principle

There are two things we have to address here: one related to reasons of why there is tide and another one related to how tidal power facilities work.

4.1 Tides

As mentioned above, tidal energy is produced by tidal movements. Therefore, prior to understanding the mechanisms of tidal power facilities, it is paramount to know where do tides come from. Generally, a tide is created due to a combined effect of gravity of the moon on earth (although there is one of the Sun to the earth, the Sun is too far away to have nonnegligible effects) and movement of the earth and the moon as a system[12].

4.1.1 Gravitation

Every particle of matter in the universe exerts a force (attraction) on other particles. It is proportional to the objects' weights and inversely proportional to the squared distance between them. Thus, the formula to calculate gravitation is as follows[15]:

$$F = G\frac{m_1 m_2}{r^2}$$

where F denotes that force; m_1 denotes the mass of the first object; m_2 denotes the mass of the second object; r denotes the distance between the two objects. G is the gravitational constant.

Since we know that the earth weights 6.0×1024 kg and the moon 7.35×1022 kg, plus their distance is 384,400,000 m, the force between them can be gained: 1.99×1022 N. A force that large can impose a very great influence on the earth's surface. Namely, the side of the earth toward the moon will feel an attraction force of 1.99×1022 N. Therefore, water on this side will get pulled up, which creates a bulge.

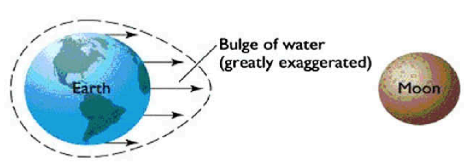


Figure 1 The effects of the gravitation on the earth[12]

4.2.1 Rotation

The moon is constantly rotating around the moon. However, this is said when we stand at a reference point on the earth. If another reference point--in this case, the moon--is chosen, then we can say the earth is revolving around the moon. Since we can approximate this motion as circular motion, the earth must have a centripetal force to maintain this moving status, indicating the occurrence of centrifugal force experienced by another side of the earth that is not toward the moon. The centrifugal force can be calculated using the equation below[16]:

$$Fc = \frac{mv^2}{r}$$

As a result, the water on this part will get pulled, generating another bulge.

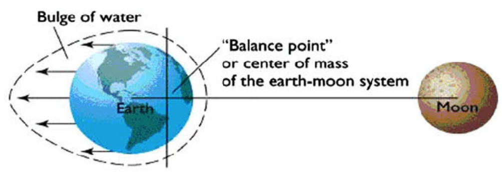


Figure 2 The Effects of rotation on the earth[12]

4.2.2 Combined effects of the two

As each influencer (gravity and rotation) makes a bulge of water, the overall effect is two bulges of water.

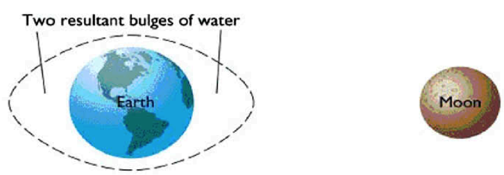


Figure 3 Overall effects on the earth[12]

Besides if a place is in line with the earth-moon system (line that connects earth's and moon's core, it experiences high tides, and when perpendicular to that system, it experiences low tides. Since there are two points on a sphere that make the landmass lined up with the system, and two other points that make it vertical to the system, a landmass will experience two tides at peak and two more at bottom for a full rotation of the earth. The phenomenon of a tide happens twice every 24 h, 50 min, and 28s. [3]

4.2 Tidal power plants

There are several ways to categorize different tidal energy power plants. Here, we differentiate them according to how they make use of tidal energy: one that makes use of potential energy of the tides and another one that makes use of kinetic energy of the tides. In this report, we will focus on three particular tidal power plants: tidal barrages, tidal lagoons, and tidal current turbines.

4.2.1 Tidal barrages

Principles of operation

As its name suggests, a tidal barrage is a bay, enclosed with a barrier, with a huge natural tidal range. Specifically, tidal barrages utilize difference in head energy of water. Head energy or head is a measure of energy per unit of fluids possesses. Head energy includes potential, kinetic, and pressure energy. Thus, in fluid dynamics, to calculate the head energy, we use the following equation[14]:

$$H = Z + \frac{P}{\rho_w g} + \frac{V^2}{2g}$$

The electrical energy is produced by allowing direction-controlled water movement (i.e. inward when at high tides and outward when at low tides. Controlling sluices gates at key points of the tidal cycle assists in the control of water direction. The turbines are placed at these sluices to capture the energy as the water flows in and out[4].

Calculation of energy produced

To calculate the energy the tidal barrages produce, we introduce the following formula[17]:

$$E = \frac{1}{2} A \rho g h^2$$

where:

- A denotes the horizontal area of the barrage basin,
- ρ denotes the density of the water,
- g denotes the acceleration due to the Earth's gravity = 9.81 meters per second
- h denotes the vertical tidal range,

Efficiency of tidal energy

When considering output of electricity from tidal barrages, the construct of turbines are important. The reason is that turbines influence operation limits such as water flow rate, variance in head, and start-stop frequency.

One particular design is Bulb turbines. They are put into practice most frequently owing to their 1) high efficiency (maximum efficiency can go up to 90% and more)[5] small scale with low cost, and 3) capability of reversing the process (i.e. Producing power during flood as well as ebb tides).

4.2.2 Tidal lagoons

Principles of operation

Tidal lagoons utilizes potential energy similar to tidal barrages. The major difference is the way they are constructed. A tidal barrage is usually built on the same, straight line, whereas tidal lagoons' shapes can be pretty flexible: they can be built along the coastlines, or form a U-shape, as can be seen from the figure below.

Figure 4 Location of tidal lagoon Swansea bay[6]

Calculation of energy produced

As mentioned above, the principle of tidal lagoons and barrages are similar. Therefore, the formula to calculate the output of energy produced by tidal barrages applies to here. i.e.:

$$E = \frac{1}{2} A \rho g h^2$$

4.2.3 Tidal current turbines

Principles of operation

Current turbines utilizes kinetic energy of moving water to produce electricity. Tidal current technology shares similarities with wind energy technology[7]. Yet, there differences can be found when comparing their operation conditions. Given some circumstances, water is 832 times denser than air. In addition, flow speed of water is much lower[8]. This means underwater turbines experience greater forces and moments than wind turbines.

Calculation of energy produced

To calculate the energy the tidal lagoons produce, we introduce the following formula[18]:

$$P = \frac{\rho \, A \, V^3}{2} C_p$$

where:

- P denotes the power generated (in watts),
- ρ denotes the density of the water,
- A denotes the sweep area of the turbine (in m^2),
- V denotes the velocity of the flow. and
- C_p denotes the turbine power coefficient

5 TECHNOLOGY IMPLEMENTATION

To use head energy of water, there are several ways to achieve: 1) single-basin tidal barrages and 2) double-basins tidal barrages (since tidal lagoons share similar technologies, here we focus on tidal lagoons). To extract kinetic energy of the tides, there are 1) vertical-axis current turbines and 2) horizontal-axis current turbines.

5.1 Tidal barrages

5.1.1 single basin

Single basin tidal barrages are those which only have one water storage tank inside the dam. According to different phases (time periods) of the tides, we can further divide single basin system into three modes: ebb generation mode, flood generation mode, and two-way generation mode.

ebb generation mode

within this mode, the barrages open sluice gates when tide is rising, coming toward inland until the tide reaches peak point. Then, sluice gates are closed to retain the water. As the tide continues to recede, the sluice gates will open when the head difference is enough (typically half of the tidal range). This mode can have a 40% maximum efficiency.

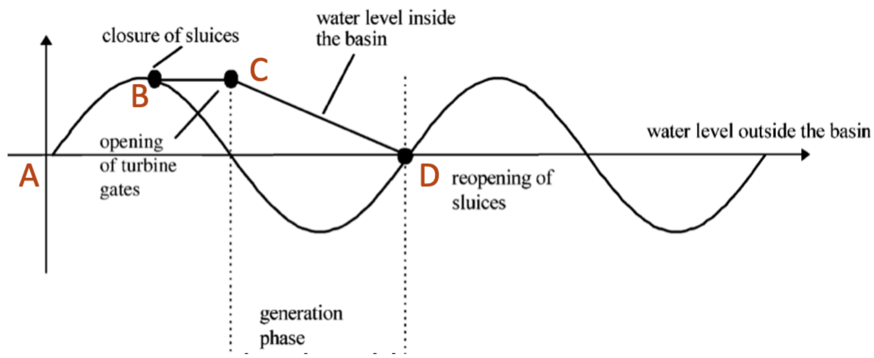


Figure 5 water level inside the basin of ebb generation[4]

flood generation mode

When choosing this mode, barrages use the energy of incoming rising tide directly as it moves toward the inland. Different key points to open or close the sluice gates and corresponding water levels inside the basin can be seen from the picture below.

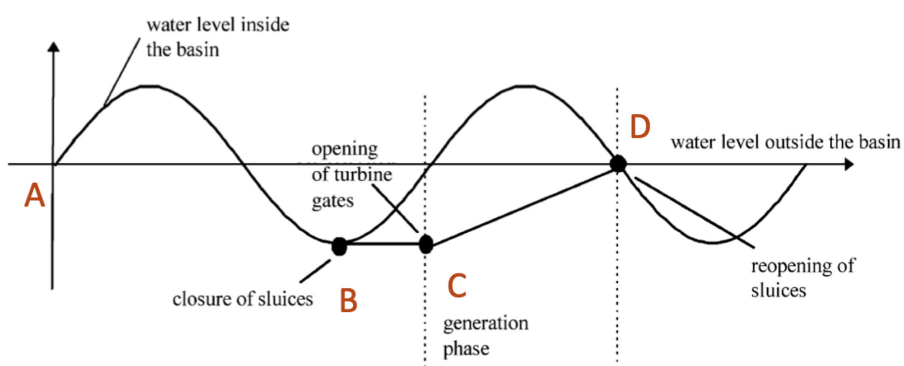


Figure 6 water level inside the basin of flood generation[4]

Two-way generation mode

In this mode, barrages essentially use both ebb and flood phases of tides to generate electricity.

5.1.2 Double basin

For a double-basins tidal barrage, it has a main basin and a minor basin. The main basin works with same mechanism of a single-basin system using ebb generation. Namely, it stores water and at right point releases water to make turbine rotate. The difference to single basin system is a section of the electricity produced in ebb phases is applied to pump water into the minor basin, creating a storage. The reason to do this is because this can make adjustments of the delivery of electricity according to consumer demands, which is also an advantage of a double-basins system over single-basin system.

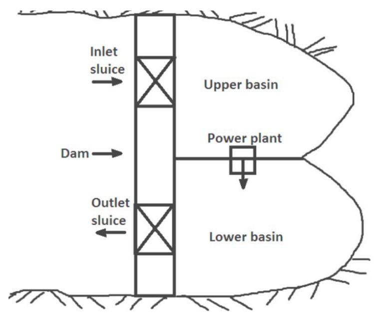


Figure 7 diagram for a double basin system [7]

5.2 Tidal current turbines

5.2.1 Horizontal-axis turbines

According to different numbers of blades they use, we can divide turbines into three major kinds:

1. Free flow (three blades)
2. SeaGen (double two blades)
3. Open hydro (multi-blades)

Although horizontal-axis turbines can have different number of blades, they work essentially the same.

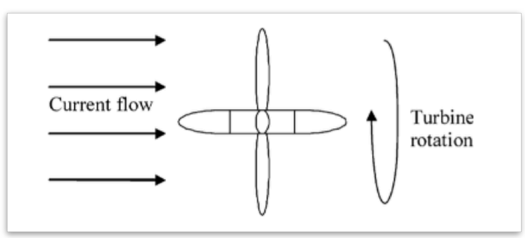


Figure 8 Horizontal-axis turbines[4]

5.2.2 Vertical-axis turbines

According to different ways of installation, vertical-axis current turbines can be grouped into:

1. Instream energy system
2. Kobold (floating structure)
3. Lucid energy (in pip structure)

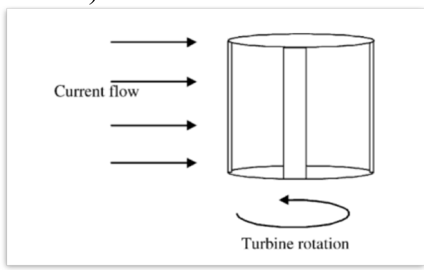


Figure 9 Vertical-axis turbines [4]

The picture below shows some typical examples of current turbines.

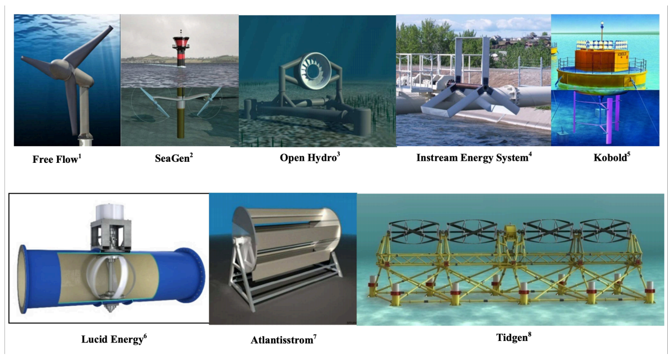


Figure 10 Some examples of hydrokinetic energy [8]

6 Typical system description

Here we specifically choose a single-basin tidal barrages using the ebb generation mode. First, we begin by looking at some important parts of barrages and terminologies. Sluice gates are the gates which can be manually controlled to open or close, which determines the status of water: whether moving or static. Head difference: to understand head difference, it's important to know head. head is a measure of energy a volume of fluid, in this case water, and its unit is length instead of joules. Therefore, when considering head difference, we always compare it with the length of tidal range. Tidal basin: tidal basin is the storage tank that can be retained or released by people in order to make the turbines work.

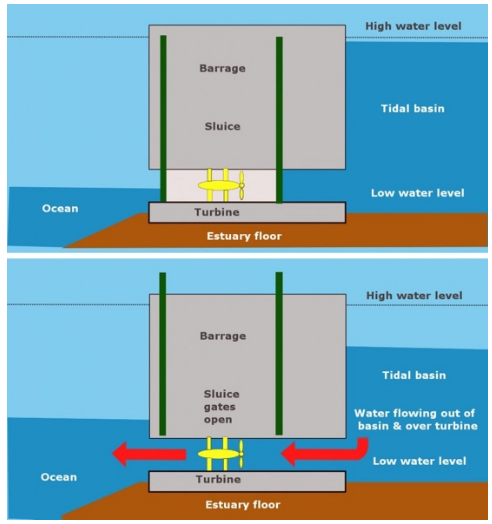


Figure 11 Single basin system using ebb generation [9]

Next, there are several steps in order for this system work:

At the top half of the picture, water level is higher in right side, which means presence of tidal basin, whereas the other side has lower water level. This means presence of head difference. As a result, water from the right wants to flow to the left side. Therefore, we can build a dam across them, within which is able to store the water by water storage tank and control the come and go of the water through switch of the sluice gates. Steps involved are as follows:

1. As the tide rises, the basin is continuously filling up, but the sluice gates are kept close. In this way, the water is trapped inside the basin, ready for the next stage.
2. After the tide has reached its peak height, the sluice gates are still close until the tide is receding, or ebbing, to an extent that the head difference is large enough (typically half of the tidal range)
3. As water flow through the barrages, it will rotate the turbine, which generates electricity.
4. After the tide is completely ebbing, the gates are then closed, waiting for the next incoming tides.
5. This process repeats day by day.

7 System integration into the energy grid

As much energy as all these described tidal power plants can produce, some ways to store, transmit, or distribute such huge amount are required. Many inland renewable technologies such as solar PV cells operate with an electric network connection. Unfortunately, the grid capacity is relatively low near costs. The lack of connection availability becomes one major impediment to the development of marine technologies.

That being said, currently to store and transmit the energy being produced by tidal power facilities are through on-shore substations, which are mostly built on the nearest coast. Substations and tidal power facilities are connected by underwater LV or MV cables (e.g. 11 kV). The substation is connected to the national grid, which then distributes the electricity. The process can be seen from the picture below.

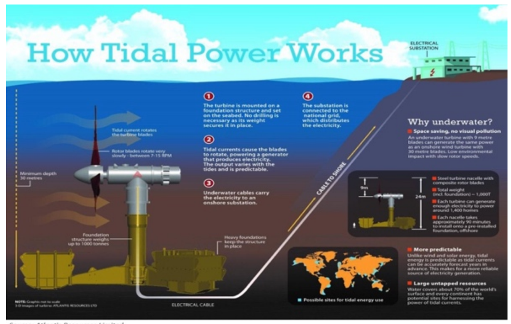


Figure 12 Connection to the grid [13]

Typically, the cables are laid on the seabed and close to shore. They are covered in steel protectors. On the shore, cables terminal is in connection to 11 kV breaker and to the bus bar. When retrieving a cable, the end of each cable is capped by the heat-shrinking caps and attached to the buoy [10].

8 ENVIRONMENTAL IMPACTS

8.1 Overall

For the environmental impact of tidal energy, we cannot blindly draw conclusions. First, the application of tidal energy will certainly have an impact on the natural environment, but these effects cannot be understood separately. Secondly, we still can't fully understand these influences. I choose five aspects as the main analysis: clean energy, compact space, risk of collisions, ecological damage and noise.

8.2 Clean energy

Tides produce green energy, considering its zero emission of greenhouse gases.

When it comes to global warming potential, in terms of Global Warming Potential, namely, the carbon footprint, the influence of tidal power plants can compare to that of other forms of renewable energy such as solar power and wind. Of course, tidal power has definitely performed better on global warming potential than traditional (i.e. fossil-based) energy-extracting technologies.

By using tidal energy to generate electricity, people can greatly reduce the use of coals. In the process of burning coal, it will cause serious pollution to the environment.

However, tidal power generation can reduce the emissions of sulfur dioxide and suspended particulates in the air and can effectively prevent the invasion of typhoon. [1]

8.3 Compactness

The constructions of tidal power plants merely consume small volume of space. In fact. Sihwa Lake Tidal Power Station located in South Korea, the worldwide largest tidal project is easily added to a 12.5km-long seawall to help the coast defeat flooding and to assist agricultural irrigation.[20]

In stark contrast, one of the largest wind farms like Roscoe wind farm in Texas, US, consumes 400 km^2 of farmland. Another example is Fowler Ridge wind project built in Indiana, which consumes 202.3 km^2.

Even compared to solar farms, tidal power plants are smaller. For example, a cover of 43 km^2 is by Tengger Desert solar Park in China, and a cover of 45 km^2 is by Bhadla Industrial Solar Park in Rajasthan.

8.4 Risk of collisions

Tidal power can influence marine life. Even through tidal projects ensure a mechanism of safety which can automatically turn off the turbine as surrounding live animals are approaching. Yet, as everything has its own defect, this system results in decrease in energy production. The table below shows the result of a specific marine animal, eels, passing through the tidal projects.

	Cohort 1	Cohort 2	Cohort 3
Eels passing through channel	40%	28%	38%
Of total eels passing through channel:			
% rotor transits	1.4%	5.3%	6.1%
% collided	0.3%	1.0%	1.1%
% killed	0.2%	0.7%	0.7%

Table 1 Summary of rotor transits and collisions for all eels passing through the channel to the mouth of Strangford Lough [21]

8.5 Ecological damage

The installation of a barrage may result in corresponding changes of shoreline within the bay, which poses influences on a large scale of ecosystem relying on tidal flat. Besides, constructions of barrages can also change the way water flows, which can lead to less flushing of the bay, therefore resulting in suspended solids and a decrease in saltwater. Consequently, some fish may get killed which then affects other animals such as birds or mammals preying on those fish.

The water in the reservoir and the water flowing in the sea area cannot be exchanged smoothly, which means that the water in the reservoir requires land water supply. If the river water with large runoff or sediment concentration flows into the reservoir, the water temperature, salinity, and sediment concentration in the reservoir will change, and the stable environment in the reservoir will be destroyed. If the reservoir Tidal power plants, along with all forms of offshore power plants, may impose sounding effects to the surroundings, where live animals may be influenced the most.[22]

8.6 Noise

The acoustic output underwater generated by tidal power facilities can be greater than, for example, tidal power plants, because their devices are built in the water. The figure below shows that the spectrum, time, and space characteristics of the noise radiated by the running Tidal Turbine are described by the acoustic section around the tidal turbine. According to the figure, we know that the acoustic output can have changing effects on sea animals. Those of which communicate with others through echolocation will be influenced the most considering different frequencies and amplitudes different tidal energy devices can have.

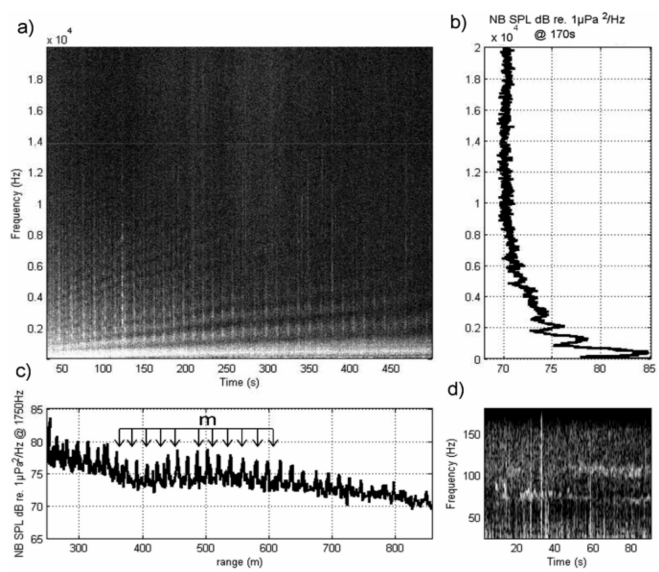


Figure 13 The spectrum, time and space characteristics of the noise radiated by the running Tidal Turbine are described by the acoustic section around the Tidal Turbine. [23]

Although it seems that tides may have some unpredictable effects on the environment, compared with the benefits, these hazards are worth trying. The development of tidal energy must be the future trend. From above, it is obvious that the building tidal power stations will influence the surrounding environment. Therefore, we should take appropriate measures to tackle it in a timely manner. However, these constructions also let people reap benefits. All in all, the advantages of tidal power plants can outweigh the disadvantages so long as people can make effective administration and setup, with great amount of power being obtained from these facilities to assist in people's use of energy.

9 Economics

9.1 Overall

Economics is one of the most key factors contemporary engineers and scientists have taken into consideration when implementing a project. The lifecycle of a whole project involves researching, manufacturing, delivery of materials, installation, operation, maintenance, decommission, etc. The corresponding costs are usually necessary.[24]

There are a limited number of tidal projects we can install. Firstly, not everywhere can be utilized since the site's potential (i.e., tidal ranges) has a direct impact on how much tidal energy can be exploited. For example, the UK is at an advantage of its location; it is estimated that the UK has about 50% of the potential tides in Europe; Severn Estuary in the UK has the second strongest tides in the world.[26][39] It has been argued that the power plants can act as obstructions slowing down the flow of water.[24] Therefore, a careful analysis of the costs becomes one of the most essential parts, so the most compromise project can be designed.

9.2 Factors influencing costs

This section covers some of the basic factors that can influence the expenses of tidal power plants. Understanding these will help compare the future development of different types of renewable energies in the next chapter.

9.2.1 Capital Costs

Capital costs are always prohibitive for barrages and lagoons. Due to the lack of experience, installation can be difficult – only a few projects have been constructed. Therefore, it is hard to estimate the capital cost. Because of their high capital cost, many countries cannot undertake the financial risk. As shown in Figure 15, tidal barrages have remarkably high capital costs, about 100-fold those of hydropower stations. Below explains the reasons of high capital costs:

- Constructing a tidal barrage or a tidal lagoon needs a large amount of concrete and steel compared to tidal stream generators. Building lagoons can be even more expensive because all sides of impoundments must be constructed, although the lagoon can be installed along the shoreline, which would be one side of its impoundment.[24]
- Another sector of the capital cost is the delivery of materials and installations. This is usually done by vessels carrying the components of tidal turbines and materials for installation from the base port to where the power plant is constructed. The distance from the base port might not be the main problem for every project, but due to the slowed velocity of the vessel, the time used to travel between the base port and destination is prolonged.[25] This is why the construction of a tidal project is usually completed more than 10 years. Problems such as high paying to the workers, financial compensation offered by the local department can all raise the capital cost. Such a long constructing period poses threats, i.e., damages from extreme weather to the physical property of the uncompleted plant, and this will be an expense of maintenance.

Type of Power Plant	Capital Cost / £ million
Severn Barrage (estimated)	34000
Tidal (typical barrage)	30000
Swansea Bay (lagoon)	1300
CCGT (typical)	55
Hydro (typical)	320

Table 2 Shows rough capital costs of some typical power plants [30]

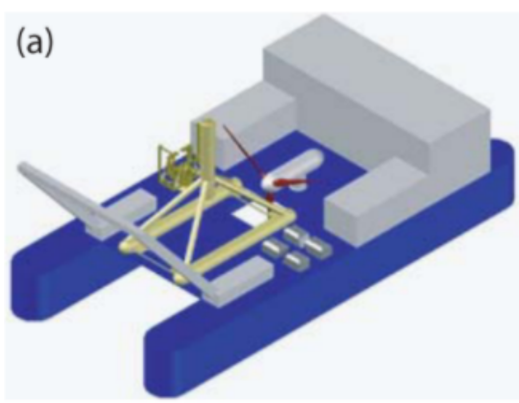
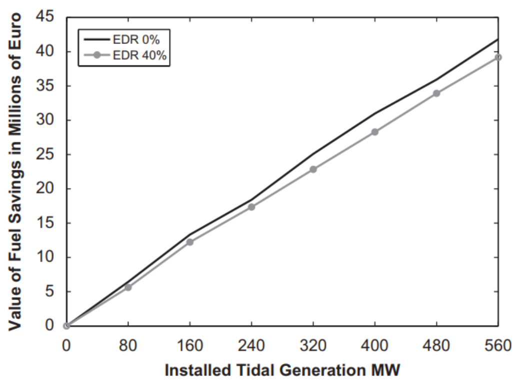


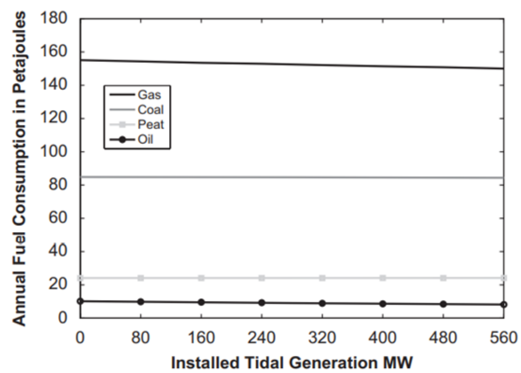
Figure 14 A vessel carrying the components of turbines [25]

9.2.2 Operational and Maintenance Costs

Operational and maintenance costs do not cost much. There is no operational cost since tidal power plants do not run on fuels. As shown in Figure 17, after the tidal power plant is constructed, it begins to pay back, but due to the small figure of installed capacity compared with the consumption of fuel, the value of fuel reduced is very low.[26] On the other hand, one of the benefits they have is the long-lasting period, i.e., Severn Barrage has over a 120-year lifetime, and during this long period, if there is no accident, the project is worth the money and efforts.[27] On the other hand, a long-term project will normally not attract funding from private sectors because of the high uncertainty and immaturity.



(1)



(2)

Figure 15 (1) shows the annual cost of fuel saved when a tidal power plant of corresponding capacity is installed [26]
(2) shows annual consumption of fossil fuels when tidal power plant of corresponding capacity is installed [26]

Maintenance is essential for tidal power plants because the conditions are not perfect offshore. However, maintenance costs are much lower than capital costs, but there are many processes carried out in a fixed period. Firstly, regular blade cleaning and changing the grease in the bearings and gearbox is needed to reduce the frictional force, hence the efficiency of the power plant is ensured. Secondly, a periodical inspection of all components every two to four years will make sure the system is not false.[25]

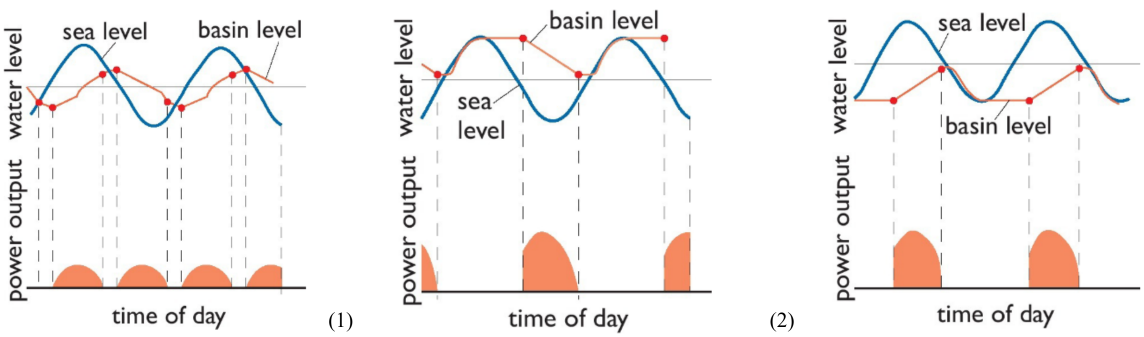
9.2.4 Local Economy

Apart from the cost of the power plant itself, the influence on the local economy is considered. For instance, areas constructed current generators and lagoons obstruct ships, making it difficult for offshore delivery. There are also benefits, i.e., during the construction period, there is a great employment possibility for the local workers, because constructing tidal power stations requires a huge labor force. They also make water sports feasible, because current velocity is slowed down when water passes through the turbines. Tidal barrages are at unique advantages of:

1. being a tourist attraction, therefore boosting the development of tourism
2. a new road or a rail crossing the barrage (e.g., Rance Barrage) [24]

9.2.5 Demand for Electricity

It is important that the electricity generated can be used effectively. Despite the accurate predictivity of tides, our demand cannot completely match the electricity generated. One reason is that the electricity demand is varying all the time. For instance, lights are usually switched off in the morning and switched on in the evening. Similarly, during spring tides, electricity output is maximized. However, the use of electricity might be lower than the electricity output. In addition to its short operating period, electricity generated can often exceed the demand during the period. Hence much electrical energy is wasted.[24]



(1) (2)

(3)

Figure 16 shows the output of a typical barrage in one day (1) two-ways (2) ebb (3) flood[1]

9.2.6 Capacity Factor

$$Capacity\ Factor\ = \frac{Actual\ output}{Maximum\ Output\ (Installed\ Capacity)}$$ [24]

The capacity factor is an element used to estimate the electricity output. Even if we assume that the efficiency of the power plant is 100%, installed capacity does not give us how much energy (electricity) we can generate, because it only means the maximum power of the power plant. Before we convert it to the energy by times capacity by 3600 seconds to get the electricity output per day, the capacity factor must be taken accounted for. Shown as:

$$Electricity\ Output = Installed\ Capacity\ \times Time\ \times Capacity\ Factor$$ [24]

where time is usually 15 days. The reason why this period is the favored period is that the time between two successive spring tides (spring neap cycle) is 15 days, shown in Figure 19[24]

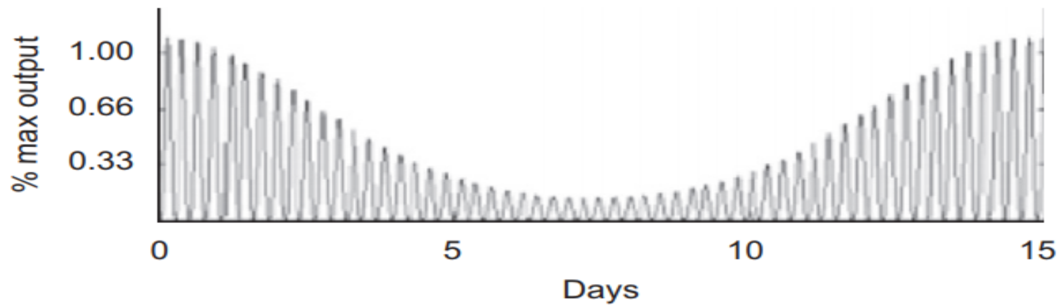


Figure 17 The power output of a tidal device in 15 days [26]

Name/Type of Power Plant	Capacity Factor / %
Rance (tidal barrage)	28
Sihwa Lake (tidal barrage)	24.8
Severn Barrage (proposed)	23
Hydro Power Plant (typical)	45
Nuclear Station (typical)	77
Combined cycle gas (typical)	84

Table 3 Capacity Factor of different power plants [24]

Tidal barrages and tidal lagoon are not always operating due to their short temporarily operational period, so they will not get high capacity. A two-way generation usually has a lesser capacity factor since there is no enough time for it to open the sluice at spring tides, evidence is shown in Figure 18.[24] A low capacity factor means that a tidal power station generates the same amount of electricity as another form of power station with a higher capacity factor and a lower installed capacity.

10 Future prospects

10.1 Overall

Whether a kind of technology can be developed is largely dependent on its viability on the physical principle - it must be well designed to run, concern about environmental impacts, worth the investment and humanity (not included in the paper). It is unlikely that there is a perfect scheme, therefore comparison between forms of energy is crucial. They must be competitive and suit the current situation. For example, the rising energy consumption and the increasing amount of carbon dioxide emission have increased the need for renewable energy. Although the consumption of tidal power saw a 19% growth in 2019, it only accounts for a negligible proportion of today's total energy consumption.[37] The development of tidal energy to generate electricity is short. Despite the large potential, it has high financial risk. As a result, it is less cost-effective than other renewable energy at this stage.

10.2 Comparison with other renewable energy

The renewable energy market is extremely competitive these days because of the increasing concerns about climate change and the increasing electricity demand. Hence, the priority for governments is to replace the consumption of fossil fuels by using clean renewable energy. Because of high capital costs and restricted locations, tidal power is ignored by many governments, organizations, etc., while other energy, for instance, hydro, wind, solar have been thriving for decades.

10.2.1 Similarities to other forms of energy

Most of them usually do not need operational costs except for biomass, because most of them are fuel-free. But that does not mean there are no greenhouse gases released, for example, installation and manufacturing often contribute to carbon emission. But one purpose of renewable energy is to reduce carbon emission, so people have to see which reduces the most carbon dioxide overall. Secondly, renewable energy is usually not reliable – they are intermittent. As a result, if we want to replace fossil fuels with renewables completely, batteries will be necessary.

10.2.2 Differences to other forms of energy

Then differences between tidal and other forms of renewable energy help us choose from massive numbers of renewable energy. Firstly, tidal energy has high predictability due to the repetitive movement of the Moon, and the self-rotation of the Earth. Relatively higher capital cost is the most obvious drawback.

Ocean Energy

This category contains tidal, hydro, wave, OTEC, etc. They are often dependent on location, and they usually have much potential except for OTEC – the conditions for it to work are strict. The kinetic energy of water is what powers them, so they all require turbines and generators. Because of that, they are harmful to marine life. Tidal is the only source that is not derived from solar energy.[34]

Solar Energy

To achieve higher efficiency installing and manufacturing, solar cells become expensive per unit, whereas a typical tidal plant can convert 80% electricity.[9] However, the efficiency has been increasing in recent years thanks to the dedication of researchers. Nevertheless, it has an even shorter working life than stream generators, maintenance is needed even good materials are used. However, solar panels are versatile, it can be implemented in various applications, for example, calculators, space heating, electricity generation, etc. [24]

Geothermal Energy

It is probably the most similar form compared with tidal power. Firstly, it also contributes a small proportion of the world's energy consumption, at the same time, the resource of geothermal energy is very large as well. Secondly, the locations of the geothermal power plant play an important role. Lastly, the capital costs of geothermal are also expensive due to the expanses of drilling and installation. However, geothermal has one special advantage: it has a continuous output.[31]

Biomass

Compare to other forms of renewable energy, biomass has also a large resource, and it is very accessible (it comes from many sources). However, generating electricity by biomass has a similar disadvantage to fossil fuels, it has to be burnt. Then, it releases greenhouse gases, so it is not clean energy.[24]

10.3 Existing and Proposed Projects

By looking at all the existing projects and some of the major proposed projects, we get a full prospect of short-term development of tidal energy. Firstly, as shown in Appendix 1, in 1966, the world's first and largest tidal barrage was installed in La Rance, France, with 240 MW installed capacity. Recent focuses have shifted to tidal currents generators. In 2017, the biggest project on tidal stream generator called Meygen was commissioned in Scotland, UK. Nevertheless, Keygen is also a tidal array, which means several turbines are installed in the project. Meygen is still in development: Phase 1B (A total of 3 phases). In the end, the total capacity will be 398 MW after finished.[28][36]

There are more than 100 proposed projects, whereas only 9 are in operation.[24][36] Some of the major ones are listed in Appendix 2 Although we cannot ensure which type of tidal power plant they will be for every single one, the number of stream generators/arrays is increasing. Although the first lagoon, which is in Swansea Bay, UK, had been rejected by the government soon after proposed, it revived in 2019. It was rejected because of the extravagant capital cost, and it revived due to the interests of several companies and organizations. They are also planning to add solar panels to the lagoon increasing the energy output by more than a third, so the wasted areas are fully exploited. From this example, we can see even the UK government was not very confident with the technology.[35]

Lastly, the tidal power plants in Russia will have a very high capacity because it has one of the strongest tides in the world. However, Barker [29] said, 'The extreme climatic conditions and ice within Penzhinskaya Guba for many months of the year could make any tidal power scheme extremely challenging.' Besides, the site is far from the dense population, which makes the delivery of electricity harder – long cables and more energy loss.[29]

10.4 Future Trend - New Technology

After discussing the pros and cons of tidal power plants and other renewables, we know that tidal power is not reliable and popular at this stage. Hence, we believe that a breakthrough in a particular technology can make it one step forward. For example, there is a new form of tidal technology called dynamic tidal power, which is theoretically viable. Dynamic tidal power can solve problems such as restricted locations because it does not use head difference, so it will be available in many places. However, without analysis and testing, we cannot ensure the effectiveness of this technology.[33] Hence, this is the direction we need to be focusing on. All in all, the tremendous potentials of tidal power plants enable us to believe in their promising future. We hope, someday, more tidal projects and reliable technology will be conducted.

11 Conclusions

As renewable energy, the prospect of tidal energy is promising. Their advantages are very clear: “high predictability” and “abundant potential sources”. However, people are also concerned about the overall profits and hope to make use of the best resource, so we have compared forms of energy together and compare the types of systems within the type of energy. Unfortunately, tidal energy is not dominant in the renewable category. Restrictions on locations, destruction to the environment, financial pressure can all affect the feasibility of tidal power plants. Because of these, we came out suggestions for tidal energy, 1) Accurate analysis of the risks and its overall impact; 2) Design new, innovative tidal systems, like dynamic tidal power, which maximize profits and mitigate the impacts on the environment and society.

After reading this report, we hope you gained the basics of tidal energy, its history, physical principles, etc. Although tidal energy has a long history, it has not been so long that people started using it to generate electricity, so it is not as mature as other forms of energy, and it does not contribute to electricity generation as much as other forms of renewable energy. Finally, despite of its drawbacks, which are likely to be solved in the future, we believe this huge potential resource will be fully exploited to help us in various aspects.

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14 APPENDIX

Appendix 1

List of operating tidal power plants [13]

Name of Tidal Power Plant (Operating)	Type	Installed Capacity / MW	Country	Commissioned year
Sihwa	Barrage	254	South Korea	2011
Rance	Barrage	240	France	1966
Annapolis	Barrage	20	Canada	1984
MeyGen	Stream Generator	6	UK	2017
Jiangxia	Barrage	3.2	China	1980
Kislaya Guba	Barrage	1.7	Russia	1968
Uldolmok	Barrage	1.5	South Korea	2009
Eastern Scheldt	Barrage	1.25	Netherlands	2015
Bluemull Sound	Barrage	0.3	UK	2016

Appendix 2

List of some proposed tidal power plants (the type of some power plants has not been decided) [13]

Name of Plant (Proposed)	Type	Capacity/MW	Country
Penzhinskaya	*	87,100	Russia
Mezenskaya	*	24,000	Russia
Tugurskaya	*	3,640	Russia
Servern	Barrage	8,640	UK
Incheon	*	1,320	South Korea
Garorim Bay	*	520	South Korea
Swansea Bay (Revived)	Lagoon	320	UK
Alderney	Stream Array	300	UK
Gulf of Kutch	*	50	India
Skerries	Stream Array	11	UK