Recommending the most ecological sustainable option for the generation of tidal power in the Severn Estuary

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Abstract: The Severn Estuary has great potential on generating tremendous amount of renewable energy due to its surrounding industrialization, population and the world's second highest tidal ranges. Plans about utilizing and developing the estuary’s tidal power have been raised continually for decades. However, the special location of Severn Estuary determines its great importance on global energy balance and the protection of ecosystem and animal diversity. The tidal fence is considered to be an ecologically sustainable tidal power exploitation option with minimum environmental damage and reliable energy output ability. The implementation of tidal fence in the Severn Estuary will provide UK with a long-term clean energy source and make reference for other tidal power resource development.

1. Introduction
The Severn Estuary always takes a place on UK's and the world's key protected objects list because of its large wetland areas, abundant diversity of species and corresponding habitats, which has great importance on ecosystem and energy transport. But at the same time, some people also want to remodel and utilize the estuary by carrying out tidal energy generation projects due to the world's second highest tidal range at Severn Estuary, which obviously conflicts with the former purpose of protecting the ecosystem from artificial interference. Actually detailed designs for tidal energy generation proposals had been raised since 1980s, which were put aside due to temporary difficulties like financial problems. Today these designs are put forward again because of the energy problems and necessity for sustainable development. This report reviews the physical environment and importance of the ecosystem of the Severn Estuary and the ecological asset may be affected by tidal power structures and recommends a most ecologically sustainable tidal power generation option that called Tidal fence, it focuses on the rationale and the advantages of the recommended option, trying to reach a balance between ecosystem and tidal power generation.

2. Demand for tidal power
It is widely considered that the River Severn, the longest river in the United Kingdom which is about 354 kilometers, becomes Severn Estuary after the Second Severn Crossing near Severn Beach, South Gloucestershire. It is actually at the mouth of three major rivers being the Severn, Wye, Usk and Avon and other smaller rivers, then forms a natural boundary between Wales and England in this stretch.

As is known to the public, tidal power can generate a tremendous amount of clean energy without creating dangerous climate change emissions or nuclear waste at the same time. With one of the world's highest tidal ranges(about 15 meters) and the high level of surrounding industrialization and
population, the Severn Estuary has always been the best choice for the site of renewable energy proposals regarding tidal energy. Though UK has drawn great attention on sustainable development, it is still facing a number of challenges. For example, increased energy need coming from renewable sources to meet European commission targets (generate 15% of the total energy from renewable sources). According to estimations, if an integrated exploitation plan of the estuary is approved (such as the Severn barrage), it could provide UK with up to 5% of its total required electricity, let along the other energy sources, such as wind and solar power (though not stable), which will significantly contribute to the European Union renewable energy targets as well as UK climate change goals (such as reducing UK CO2 emissions by 60% by 2050) [3]. Such plans have been raised continually since 1980, but they were always put aside due to various concerns like financial difficulties, today the government is currently conducting an Energy Review to assess progress towards meeting the goals of the 2003 Energy White Paper and calls for a barrage have resurfaced both in Wales and in England, but this time the problem lies forward is environmental issues.

3. Ecological importance of Severn Estuary
The special location of Severn Estuary determines the complex and comprehensive ecological environment at the estuary site comprising mudflats, sand flats, rocky platforms and islands. Which helps it to earn international importance with reputations like a Ramsar site for its wetland area, Special Protection Area for conservation for wild birds and Site of Special Scientific Interest. Actually the estuary can even affect the global energy balance, not just acting on local ecosystem, by spreading its energy and productivity via millions of birds and fish for years by years, this cumulative effect is astronomical in regions like Atlantic Ocean and Arctic tundra. The local ecosystem of Severn Estuary works as a gigantic reprocessing plant rather than simply driven by green plants and the sun, using as its raw material plankton and flotsam washed in from the sea and tributary rivers, as well as churned-up sand-dwelling microscopic plants with billions of bacteria and invertebrates convert this debris into protein in mud and silt of the inter-tidal zone [4], that means actually this system is very vulnerable and sensitive to any artificial interference on any link of this process, which is the basis of the whole estuary. More specifically, with one of the most extensive catchments in Britain and large freshwater inputs, Severn Estuary has considerable diversity and large numbers of wild birds supported by 22,000 ha of inter-tidal areas with largest aggregation of salt mash in south and south western UK [5](As shown in Table 1). So any tidal energy project would not be totally within the current legal framework provided by the EU Habitats and Birds Directives (Europe's environmental organizations) [6].

| Table 1. Vital Statistics of The Estuary Ecosystem |
|-----------------------------------------------|
| Tonnes of sediments | Visiting birds | Hectares of mud and sand flats | Hectares of salt mash | Species of fish |
| 10,000,000 | 69,000 | 20,958 | 1,400 | 100+ |

4. Potential Impacts
As a result, adverse effects on various aspects of the ecosystem of the estuary appear inevitable if tidal power projects come into service. For example, tidal power structures may cause a reduction of sediment supply to the coast and an increase of sedimentation in the sub-tidal area, which will lead to some degree of erosion of the coast. So instead of bringing flood defense benefits, tidal energy structures are likely to make the coast less resilient in the face of sea level rise and cause a decline in waterfowl populations due the reduction of sediments on the foreshore as their food (As an experience of the similar cases of surge-tide barrage across the eastern Schelde in The Netherlands and the tidal power barrage at Annapolis Royal in Canada). In addition, fishes like salmon, Eel, shad, lamprey and sea trout, some of which are designated as species of community importance by the Habitats Directive must move between fresh and salt water to survive and breed, though tidal energy generation devices are popular...
and indispensable for sustainable development, the turbines in those devices will bring risk to fish migration by increasing mortality and further impact the local fishery and ecosystem. Severn Estuary has been famous for providing refuge for various kinds of birds from Canada, Africa and Russia\cite{4}, they regard the estuary as an essential refueling stop for long distance migrants or a heaven for food and breeding, but with the former two potential impacts that may caused by tidal energy structures, the mud can no longer be the power source for the estuary with poor nutrient and the decreasing number of fish can hardly meet the bird's demand for food, which means the estuary will become unable to serve as a refuge for birds and it will definitely cause a decline in the species and number of birds. At the same time, without these little creatures as pollinator, the seed or pollen transmission of local plants will be affected as well, which, for the worst, seems to possibly cause irretrievable loss to the whole estuary in multi-access and significant interference on the global energy budget\cite{6}. However, there are significant uncertainties about the effectiveness of most of these impacts, all of them would require further investigation to determine their feasibility or to quantify their possible effects.

5. Rationale and advantages of Tidal Fence

So far, there has been various options for the tidal power generation, but as mentioned above, each of them will affect the estuary's protected species and habitats. What we can do is to choose the most appropriate option that has the least environmental damage from the available proposals. Take different factors into account, the tidal fence proposal would be the most ecologically sustainable option for the exploitation of tidal power at the Severn Estuary. The Severn tidal fence consortium is led by IT power, this scheme is a dual row fence with tidal stream turbines stretching across the Estuary from Minehead to Aberthaw\cite{6}. These turbines are special designed to take advantages of cross flow instead of axial flow, when the flow comes from the front side of the turbines, it will actuate turbines by pushing the fan blade, which is not efficient because the flow force is distributed to too many turbines, but when the flow direction is from the lateral side of the turbine, flow force is generated on one huge and special axis of the fence, which looks like a long and twisted spinning wheel with reversible blade design, the fence can produce electricity both as the water enters the basin and when it leaves\cite{7}. Moreover, it is practicable to combine tidal power generation and wind power generation into one device by installing wind driven generators on the top of the long fence to push the turbine together. These innovative technologies proposed within the tidal fence could be a blueprint for tidal power, providing incentives for tidal fence schemes all over the UK and the world.

With this design and the strong ebb and flow of the local tide, the tidal fence is claimed to be able to provide energy for around 8 hours every tidal cycle, which would be a predictable and reliable energy output accounting for 5% of the UK's total output and realize the pressure of reaching the target of producing 15% of the UK's energy from renewable energy by 2020 and reducing greenhouse gases by 80% by 2050. In addition, the tidal fence is designed to allow ships to pass between Cardiff and Bristol via a 650km gap in the fence, and will be continuously accessible at all stages of the tide. While ensuring the daily transportation of human beings, gaps above and below the tidal fence and the slow rotation of turbines will reduce disruption to fish migration and stress, which can offer better conservation to fish species than other proposals such as barrages. As shown in Table 2, though the temporary claimed power is only 1.2GW, lower than the capacity of massive tidal barrage proposals, but noticeably, it also covers a much smaller area than those productive projects and is totally outside protected areas like cSAC and creates a considerable reduction in CO2 emission. At the same time, because of the porous nature of the fence, the power generation devices will not affect the tidal characteristics so the mudflats will remain intact maintaining the habitat for inter tidal migratory birds. The tidal fence can not only bring harmony to energy generation and ecosystem, but also benefit the community, as estimated, The construction, operation and maintenance of the tidal fence could provide 8000 direct job opportunities to the South West and 1300 indirect job opportunities. However, as any other artificial devices, tidal fence also has some shortcomings in certain opportunities. For example, the noise and footprint due to construction could scare the wading birds or occupy their habitats, and the disturbance to fish migration due to the underwater turbines, though not as severe as other projects like barrages, still need to be taken into consideration.
serious consideration. In addition, the amount of green energy the tidal fence can generate is still less than people's expectation, once the further private sector funding to the project was even withdrawn because some feasibility study conclude the tidal fence to be unable to produce sufficient electricity to make the project cost effective. but as the IT Power claimed, new technology is under research and is expected to bring a great improvement to this number.

Table 2. Statistics of Tidal Fence

| Habitat loss | %within protected area | Claimed power | Construction costs | CO2 savings per year | Cost per unit of energy |
|--------------|------------------------|---------------|-------------------|---------------------|------------------------|
| 2,800ha      | 0%                     | 1.2GW         | £6.5-6.9bn        | 1.4mt               | 22.72p/kWh             |

6. Reasons for not choosing other options

Tidal fence is a new-raised proposal while there are other popular motions for the energy generation which, as far as I am concerned according to related statistics, may cause serious impacts to the ecosystem. One of them is the proposal of the Severn Barrage, once the idea of building a barrage at Seven Estuary is the mainstream of the government such as Beachley Barrage, Shoots Barrage and Cardiff-Weston Barrage( As shown in Table 3), but they are claimed to have adverse effects on ecology by environmental agencies. A barrage in the proposed location would have a direct impact on protected sites like SPA and cSAC, which are important for a wide range of species and habitats. Moreover, a barrage would directly impact the water quality by modifying nutrient flux, sediment regime and other important water quality components and also fundamentally alter the basis for setting appropriate limits for discharges to and abstractions from the estuary and the rivers that feed into it, and may require changes to existing authorizations for such activities[2]. Though a barrage can provide some protection against tidal surges to some degree, the flood defending task can also be handled by existing defense structures, timely forecast and strategic preparation in the medium term. But at the same time, as mentioned above, there may be a downstream vulnerability to tidal surges and foreshore erosion due to reflected tidal waves at the barrage face and the reduction in sediments for deposition, which will have opposite effect on flooding defense.

Table 3. Statistics of Cardiff-Weston Barrage

| Habitat loss | %within protected area | Claimed power | Construction costs | CO2 savings per year | Cost per unit of energy |
|--------------|------------------------|---------------|-------------------|---------------------|------------------------|
| 20,000ha     | 95%                    | 8.64GW        | £20.9bn           | 7.2mt               | 12.9 p/kWh             |

Another popular option for tidal power generation is the Severn lagoon, which is supported by a number of people like Friends of the Earth, who opposes the proposals for a barrage. Lagoons are man-made enclosures, similar in appearance to harbors or marinas, which would impound a body of sea water and separate it from the natural ebb and flow of the tides to create a sufficient difference between the water levels inside and outside the lagoons, then gates will open, letting water drain through turbines to generate energy[8] . Compared with a tidal barrage, a lagoon is more environmental friendly such as Fleming lagoon( As shown in Table 4) and Bridge water lagoon, which occupies much less areas of protected regions but also generates less energy[9]. Besides, similar to but not as severe as a barrage, the Severn Lagoon will also have adverse effects on water levels and estuary geomorphology which will result in risks to internationally designated conservation sites and displacement of designated bird species. But at the same time, quantified impacts on water quality and flood risk is still uncertain because the lagoon proposal is also a new-raised plan after the barrage proposal is set back[10]. Though it may have better performance on power generating than a tidal fence, for example, 1.36GW of the
Fleming Lagoon with the cost of 15.5p/kWh for per unit of energy against 1.2GW of the Tidal Fence with the cost of 22.72 p/kWh, but standing on the point of sustainable development, a Severn lagoon is no match to a tidal fence.

| Habitat loss | % within protected area | Claimed power | Construction costs | CO₂ savings per year | Cost per unit of energy |
|--------------|-------------------------|---------------|--------------------|---------------------|------------------------|
| 6,500ha      | 100%                    | 1.36GW        | £4bn               | 1mt                 | 15.5 p/kWh             |

### 7. Conclusion

Severn Estuary is a site of international importance with comprehensive and sensitive environment against human activities and that is the reason why this tidal power generation project is still unharnessed. On the other hand, the Severn Estuary has the potential to provide UK with a sustainable, renewable, reliable and long-term energy supply and help to reach renewable energy targets and aid the UK's energy security, of course with acceptable and predictable impacts on both ecosystem and communities\(^\text{[11]}\). From the aspect of ecological environment protection, the proposal of tidal fence is the best choice for the energy generation without any doubt, but this has always been under questioning because of the high cost for per unit of energy it generates and inefficiency and many people seem to prefer the proposal for barrages, which is more reliable according to past construction experiences. Given the likely scale of the impacts of such a development, and the associated environmental and social risks, an approach like the tidal fence proposal which focuses on smaller-scale deployment, sited and designed to maximize energy output whilst minimizing environmental impact, is more likely to deliver an acceptable solution in a timescale compatible with the urgent need to address climate change and maintain electricity supply. Meanwhile, the UK with enormous tidal power resources waiting for appropriate exploitation, tidal fence will be a new solution in this area and lead the way people harness tidal power and Severn Estuary will be its first success.

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