Tidal power from the Solway Firth; barriers, impacts and capacity.

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Abstract

The Solway Firth has been assessed in the past as a potential site where tidal energy can be captured. Schemes of different scales and form have been proposed, but economic, environmental and cultural issues have always prevented them being implemented. The use of a medium to small scale barrage scheme (approximately 2.5 km in length, enclosing a basin area of about 45 km^2) could generate over 300 MWe of power. Options of linking with other smaller barrage schemes and offshore wind turbines such as those under construction at Robin Rigg offer potential for a sizeable and economically robust development. The Solway is a world renowned area for nature conservation with several national and international designations. Any development would have to be sensitive to their status and condition. Details of a research proposal are presented that seeks to integrate a number of disciplines and identify and circumvent barriers to development.

Introduction and background

Estuaries are dynamic multi-functional parts of our environment that provide beneficial materials, commodities and services but with associated risks and costs. The Solway Firth on Britain's' west coast, separating England and Scotland has a long history of supporting and limiting the local economy. The Solway is the third largest estuary in UK and has a published tidal range of 5.5 metres. The shore area comprises mainly of soft low raised beach cliffs, dunes and beaches with some sand banks and salt marsh. More recent deposits include sandstones and mudstones laid down in Triassic deserts around 200 million years ago, deposits of sands and mud of recent marine origin and tills laid down during the last ice age.

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The floor of the Solway Firth is comprised of glacial drift deposited over Triassic sandstones. From Bowness-on-Solway to Torduff Point on the Scottish side there are two distinct 'terraces' of marine warps consisting of heavier, more fertile soils and patches of alluvium concentrated around areas of salt marsh (White, 1996).

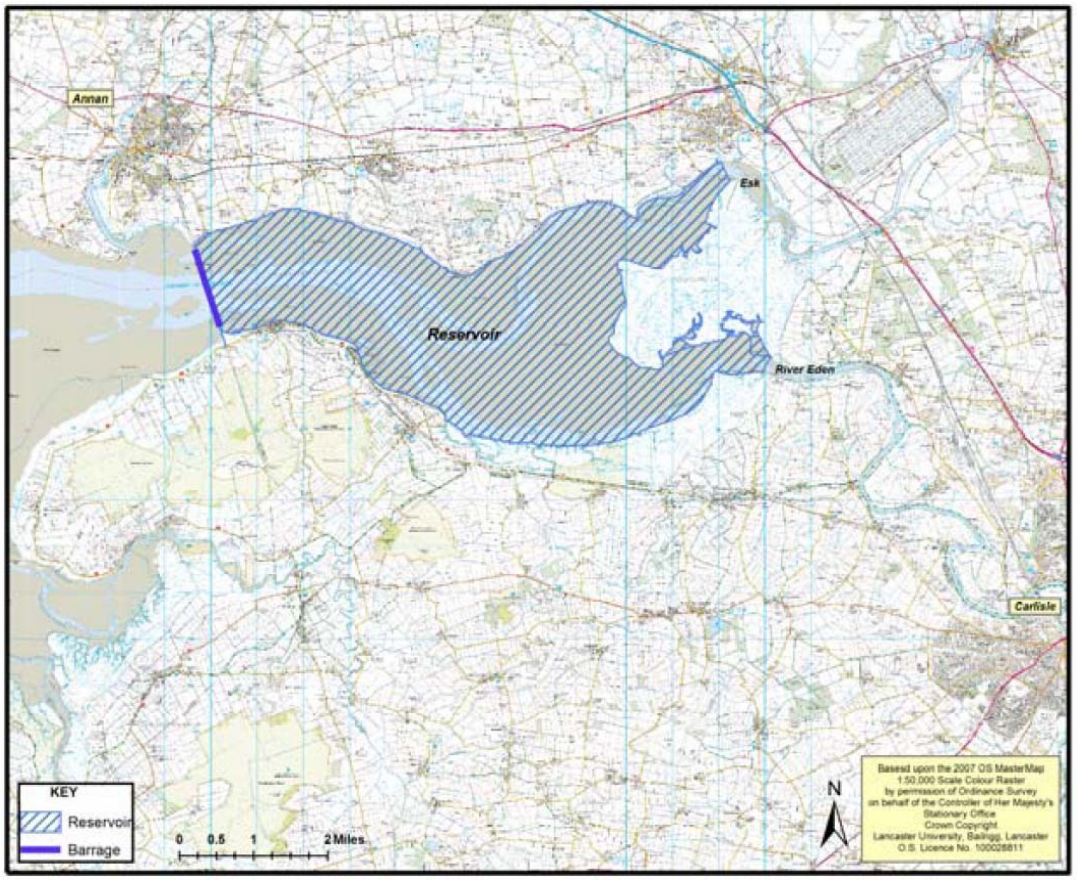
The estuary and its surrounds are nationally and locally highly valued for conservation, especially for shore birds, fish (including sea and brook lamprey and lampern (*Petromyzon marinus, Lampetra planeri* and *Lampetri fluviatalis*) and amphibians (such as the Natterjack toad (*Bufo calamita*)). The area's protection status includes a RAMSAR site, Special Protected Area (SPA), Special Area of Conservation (SAC), Area of Outstanding Natural Beauty (AONB), Sites of Special Scientific Interest (SSSI) and National Nature Reserves (NNRs).

History of investigations on tidal power generation from Solway Firth

In the mid 19th century a rail bridge or viaduct was built between Seafield and Bowness on Solway to allow freight to be moved from mines in Cumberland to steel works in Lanarkshire; after only a short period of operation the bridge was damaged by large ice flows and despite being repaired was dismantled in the 1930s on the grounds of health and safety. As other potential needs appeared, the same location was investigated for the siting of a barrage to provide drinking water (Babtie et al., 1966), collecting from a catchment of approximately 3,750 km^2 (75% in England 25% in Scotland). The proposal was shelved when the Kielder Water reservoir was built.

The same line of construction was reviewed in the 1980s in an attempt to guarantee supply of power at an acceptable price. A national study examined 118 small estuaries on Britain's west coast (the east coast does not have as effective tidal range) and identified the Solway initially as clearly the most cost effective (Binnie and Partners, 1987), but later as one of the most cost effective schemes.

Figure 1 The location of the original rail viaduct and proposed reservoir and barrage schemes at Barnik



A desk top study estimated that the installed capacity would be over 330 MW and could be produced at a cost of 3.7p kWh^{-1} (Binnie and Partners, 1989). The potential of development was compared to that of larger estuaries (Binnie and Partners, 1980) and matched the most cost effective of those (Severn – inner line). However, the raise in price of oil on the world market and investment in oil and gas exploration and harvesting in the North Sea meant investigations were shelved.

Table 1 Estimates of power generation and cost for the Solway (Binnie and Partners, 1987, Binnie and Partners, 1989)

Scheme	*Basin Area* *(km^2)*	*Head* *(m)*	*Length* *(m)*	*Turbine diameter* *(m)*	*No. of turbines*	*Installed capacity* *(MW)*	*Annual energy* *(GWh)*	*Capital cost* *(£M)*	*Cost of energy* *(p kWh^{-1})*
Outer	860.00	5.64	30,000	9	180	5580	10,050	7,480	4.9
Barnik	44.70	9.8	2,500	3	92	331	629	331	3.7
Barnik	44.70	7.0	2,500	3	98	342	625	300	2.1

Table 1 shows the detailed presentation from Binnie's report showing the sensitivity of the estimates to different parameters. In their provisional report the Barnik Point development was the most cost effective in the UK (by over 1 p kWh^{-1}). The cost nearly doubled by

reducing the number of turbines (and installed capacity) at the same time increasing head and estimated capital costs.

Proposals have occasionally be revisited in the intervening period (e.g. (White, 1996), but none produced a convincing economic case for development. One limit recognised for capture of power from tidal systems is the daily cycle of tides which provides the maximum output at the high and low tides at different times each day. A design has been developed and patented for installation initially on the Solway (Mounsey, 2004) that uses an air compression system to hold water until power generation is needed.

Local needs and constraints

As demonstrated by the history of the site, a crossing of Solway offers a number of opportunities that are recognised by the local population (Powell and Dyer-Smith, 2006). A tidal power scheme can provide some or all of these functions, but at a possible additional cost during construction, or through altering the power generating schedule. The major opportunities are described briefly below.

Sustainable Power

There are a number of opportunities for tidal power extraction within the Solway, ranging from large scale long barriers, through tidal pool systems to smaller installations such as Barnik Point and finally on to even smaller developments such as those on the Esk or Eden closer to Carlisle. These developments could work as an integrated system maximising power extraction but would require careful planning to minimise environmental damage. A double-skinned barrier at Barnik, with a mixing-pool between, could harness tidal power as well thus yielding more power.

There are other renewable energy opportunities such as wind-turbines that would operate with shared infrastructure such as grid connections. The wind farm at Robin Rigg in the Solway is currently under construction with a rated output of 180MWe (Scottish Parliament, 2002). It is being built by the German power company E.On and is the UK's largest offshore wind farm. Its estimated cost is £325 million and will consist of three 60MW offshore wind farms having a total of 60 wind turbines. The scale and costs of such a scheme suggest that a similar tidal scheme could also gain commercial support. The scheme has not been without

controversy[5] or mishap[6], but along with tidal power schemes can utilise the existing Chapel Cross Power station connection to the National Grid.

Communications

Different styles of scheme could support either a road and/or rail link that would connect two underdeveloped economies of southern Scotland and north Cumbria. The original rail link was primarily for iron ore, but more recent proposals (Babtie et al., 1966) specifically considered the traffic in timber between the Galloway Forest and the paper factories of north Cumbria. The link would shorten the journey to Northern Ireland via Stranraer (128 km to the west of Annan). The benefits of shortened journeys is seen not only in reduced transport costs and time saved, but also increased safety, avoiding all significant centres of population. If the UK reconsiders nuclear power, an ample supply of freshwater for a new power station at Chapelcross could be a significant factor; and this may increasingly become an issue for north Cumbria. Safe movement of nuclear waste to Sellafield could also be a significant factor, as a recent leak of nuclear waste (Feb 2006) onto a public road emphasised the public interest here.

Freshwater Lake

The barrage could be designed as a reservoir creating one of the largest expanses of freshwater in Britain, larger than any other lake in the Cumbrian or SW Scotland. Freshwater is seen as an issue of growing importance associated with climate change and a reservoir would be of national importance. With global changes a guaranteed supply of freshwater would benefit both the local communities and industry.

Flood control

On 8th January 2005 Carlisle experienced its worst flooding for 182 years. The events were the culmination of high rainfall in the catchment and particularly high tides in the Solway. Although counter-intuitive, a barrier restricting tidal movements could have been used to mitigate the surge. The traditional solution of protective dykes is no longer seen as a sensible strategy.

[5] http://news.bbc.co.uk/1/hi/scotland/2342811.stm

[6] http://news.bbc.co.uk/1/hi/scotland/south_of_scotland/6998281.stm

Using figures from earlier studies (Babtie et al., 1966) the levels of exceptional flood-rates from all rivers entering the upper Solway estuary could reach 3400 m^3/sec. If a barrage were closed at low-tide when the catchment is empty, then in the 7 hours of tidal flow the water in the impoundment would rise by 4.2m, well below the normal highest tide level of 5.1m. The absence of any tide effect whatsoever in the rivers should increase the speed of their outflow. The detailed management of such a system has not been fully modelled and would rely on effective and timely forecasting of flood surges.

Tourism

Dumfries and Galloway and north Cumbria are increasingly important tourist destinations. A barrier with crossing would provide an alternative route for the pleasure traveller between attractive tourist destinations in western England and Scotland, avoiding the motorway. National Cycle routes N7 (Loch and Glens Cycleway - Annan to Stranraer and Glasgow) and N72 (Hadrian's Cycleway at Bowness) would be joined, and an attractive new circular route created around the lake.

The lake itself would be an attraction in its own right, with new habitats for wild-life. It would become a boating centre with potential for development of national water-sport facilities, within 2 km of the M6 motorway at Gretna. It would be attractive to power-boat enthusiast who frustrated by the restrictions of the National Park Lakes. It would appeal to cruising sailors, providing protected winter fresh-water storage and sailing, yet with access to the sea via a lock. Gretna, Annan, Bowness and Port Carlisle would all attract marine servicing and construction work. Other ports, Maryport, Silloth, and Kirkcudbright would profit from additional marine commercial and pleasure traffic.

Current work at Lancaster University

There are a number of projects underway at Lancaster University directly relevant to the potential of tidal power generation on the Solway. Vicky Smith has been studying the ecological and environmental implications of a barrage scheme.

The thesis provides an inventory of the Solway Firth and surrounding areas describing internationally, nationally and locally designated for its habitats, populations of migratory, breeding and non-breeding birds and for other rare species such as the large heath butterfly

(Coenonympha tullia). Two options are examined, one permanent flooding of the intertidal mud and sand flats and associated secondary impacts such as the changes in the salt marsh environment would essentially remove all the qualifying features for these designations and if the development were to proceed it would undermine all purpose of the designations.

The second is a proposed tidal barrage which is a more viable option for development. As the barrage would be two-generation (operating on both the ebb and flow tides), there would be less disturbance of the tidal regime and so intermittent flooding of the inter-tidal zones would still take place albeit exposing these areas for a reduced period of time. This would result in less feeding time available for birds and a lesser area of mudflats that are exposed. However, it is possible that post-barrage conditions could be engineered to have characteristics of the best inter-tidal areas and so maintaining bird populations. There will still be residual impacts as birds are likely to be disturbed during construction which could last up to six years and so other mitigation measures may be required such as restricting the hours of operation of machinery or avoiding construction during the breeding season (if this was feasible). A tidal barrage would not require dredging or reclamation to take place either which reduces costs and impacts these processes have on the ecosystem.

The tidal barrage would not have the reservoir for recreational facilities and so less visitors likely with less permanent employment compared to proposal one. However, La Rance Barrage in Brittany, France, attracts 300,000 to 400,000 visitors a year and although the Solway would be unlikely to attract these numbers, a tidal barrage is still capable of being a tourist attraction and so could boost the local economy. La Rance is the only large scale functioning barrage in Europe and is still contentious; some feel that the barrage has improved habitats by increasing sedimentation, species diversity and invertebrate populations while others argue that the reduction in inter-tidal area has significantly impacted wading bird populations.

All forms of large-scale power generation have effects on the environment. It is unrealistic to assume that our energy consumption will dramatically reduce and so if we are to consider how to produce more electricity from renewable sources then difficult decisions will have to be made about how much environmental damage is acceptable to reduce greenhouse gas emissions (Clark, 2006).

David Robinson has examined the engineering options for a barrage scheme and has carried out an investigation into the feasibility and effects of the concept of a tidal barrage system to be incorporated on the Solway Firth. New and future technologies to be incorporated in the barrage system to provide benefits to the local economy as the production costs of electricity may be reduced. With the local environmental benefit as to the reduction of the risk of

flooding and the added national environmental benefit to the reduction of carbon emissions with the incorporation of electricity turbines powered by the tidal currents. Thus allowing the possibility to help the government reach the energy white paper targets set by 2020. The incorporation of the barrage into the local and national economy and the possibility of the creation of a 'Green theme park' for the education of the population on green issues such as power conservation, heating and energy losses through ineffective housing and the impact of fossil fuels on the environment with the barrage providing the main attraction. Also with the added benefit of a new transport link being created along the barrage allowing for a connection between Bowness on Solway on the north Cambrian coast and Annan on the south Scottish coast.

Other projects include an examination of the informatics associated with barrage development and question the quality and 'fit for purpose' nature of the widely available datasets. The projects link strongly with the work being carried out at the University of Liverpool under Professor Richard Burrows, who with support from the Joule Centre[7] is leading a project 'Tapping the tidal power potential of the eastern Irish Sea'.

The case for further research support

Man's use of energy is recognised as the dominant driver of climate change and, as our demand continues to grow, we are looking for renewable sources of power that will release less greenhouse gas. The energy crisis in the 1980s created interest in the use of barrage schemes across Britain's major estuaries and ITE and IH were both involved in assessing the potential and impact of installations on all major sites. As Britain discovered the North Sea's oil and gas, renewables were forgotten, but the current state of uncertainty about security of energy supply and the Government's commitment to reducing GHG emissions has led to all renewables being reconsidered. It is important that all potential benefits from a development are weighed against anticipated costs taking the whole system into consideration.

We propose to examine the environmental implications of a number of different barrage options for the Solway. The Solway has a high conservation status (RAMSAR, SPA, SAC, AONB and a number of nature reserves), accepts the outflow from the Eden in Carlisle (a high flood risk location) and has been used as a military test range (consequently contains depleted uranium). The project will test the hypothesis that an installation can have a positive

[7] http://www.joulecentre.org/

environmental impact, but maximizing the benefits may significantly reduce its power generating capacity. The work will require a whole system analysis with inputs from a range of disciplines.

Although the project will study the Solway, it is intended that it will develop a generic approach to evenly assess the benefits and costs of a barrage development by considering the interaction between each function and all the ecosystem services. The work has the benefit of the studies carried out in the 1980s as a baseline, but new approaches and concepts have developed since then; a protocol for rigorous and equitable assessment has to be defined. There is already renewed interest in barrage schemes for the Mersey and the Severn with energy capture from Morecambe Bay bridge a firm proposal. The Solway shares issues with these but is a more practical site for study.

Method: The project will identify the interaction between technical installations (and their modeled impact on water depth, flow, salinity and siltation) and ecosystem services (assessed through examination of biodiversity, hydrology, habitat change, land use change and flooding). An assessment protocol will be developed that will for each barrage option (structure – dam, retractable barrier, floating lagoon, etc., location and cost) assess the impact on ecosystem services related to each economic return.

The tasks carried out in the study will involve co-ordination of existing published and unpublished material (including use of CS, LCM and impact assessments led by Alan Gray), modeling the temporal and spatial dynamics of different schemes, field assessment to update EIA and evaluation of information to generate measures that can be combined with knowledge of their uncertainty and confidence. A framework for assessment will be employed as shown below.

Matrix framework for assessment, land use function and ecosystem service.

	Power generation	***Flood control***	***Local economy***	***Conservation***	***Freshwater capture***
Provisioning					
Regulating					
Supporting					
Preserving					
Cultural					

It is hoped that the project will expand into future research projects with links to electricity transmission, transport studies, freshwater storage, leisure activities, etc.

Outputs: These will include evaluation of different schemes on different issues, proposals for further work (including targeted monitoring) and scientific publications.

Conclusions

This paper discusses the feasibility and effects of the concept of a tidal barrage system to be incorporated on the Solway Firth, its barriers, impacts and capacity. It provides a brief background and the history of studies and investigations on tidal power generation from the Solway Firth and highlights the local needs and constraints, like sustainable power, communications, freshwater lake, flood control and tourism.

Describes briefly the current work and projects underway at Lancaster University directly relevant to the potential of tidal power generation on the Solway including the study of the ecological and environmental implications of a barrage scheme and the examination of the engineering options current and future for a barrage scheme investigating the feasibility and effects of the concept of a tidal barrage system to be incorporated on the Solway Firth. Other projects include an examination of the informatics associated with barrage development and question the quality and 'fit for purpose' nature of the widely available datasets. These projects link strongly with the work being carried out at the University of Liverpool under the Joule Centre project 'Tapping the tidal power potential of the eastern Irish Sea'.

Finally it makes a case for further research support as the next step for this investigation. It is important that all potential benefits from a development are weighed against anticipated costs taking the whole system into consideration and proposes to examine the environmental implications of a number of different barrage options for the Solway, testing the hypothesis that an installation can have a positive environmental impact, but maximizing the benefits may significantly reduce its power generating capacity. This work will require a whole system analysis with inputs from a range of disciplines potentially expanding into future research projects with links to electricity transmission, transport studies, freshwater storage, leisure activities, and other.

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