Enterprise, Innovation and Networks Committee

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Title: The Severn Barrage - Friends of the Earth Briefing

This briefing sets out why Friends of the Earth maintains its opposition to the construction of a Severn Barrage after reviewing recent calls for a new appraisal at the scheme

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Introduction

The tidal range in the Severn Estuary is one of the highest in the world, reaching over 13 metres. So ideas for taking advantage of the Severn's high tidal range for energy generation have long been talked about by the public and energy specialists alike.

Numerous studies focussed around an electricity generating barrage were carried out between 1974 and 1988 following which a scheme was drawn up. It was called the Severn Barrage project and is essentially the design which has been proposed since. Yet the scheme was then and has since been widely considered as economically unattractive and also gave rise to environmental concerns.

The Government's recent energy review sparked renewed public debate about the construction of this Severn barrage scheme following further publicity by barrage supporters. This was perhaps unsurprising as the urgent need to address global climate change by reducing fossil fuel use is becoming widely understood.

Barrage supporters have cited new reasons for a re-examination of the barrage: rising world energy prices, 'low carbon' energy security, global warming related flood defence and coastal protection benefits, the potential for new habitat creation and the inevitable habitat changes due to sea-level rise, improved waterfront amenity, and a road and possible rail link between south Wales and the west of England.

Perhaps more surprisingly, the Welsh Assembly Government in its ‘memorandum’ response to the energy review said that it supported a new feasibility study into the barrage scheme. This call flew in the face of widespread calls over a number of years for a strategic comparative assessment of all potential large scale tidal energy generating technologies, or combinations thereof in the Severn Estuary (ie tidal lagoons, tidal fences, barrages, and underwater turbines in the deeper waters to the west).

In July the Government announced its review findings in a document called ‘The Energy Challenge’. It stated that the government will work with 'key interested parties to explore the issues arising on the tidal resource in the UK, including the Severn Estuary, including potential costs and benefits of developments using the range of tidal technologies and their public acceptability'(1).

Friends of the Earth welcomed the decision for an inclusive study of the range of tidal technologies, particularly as tidal lagoons appear to have the potential to extract tidal energy from the eastern part of the Severn estuary in a cost-effective and environmentally friendly way.

Section One - The Estuary and the Barrage

The Severn Estuary

The Severn Estuary is an ecologically rich and rare environment of international importance for birds and wildlife habitats. The extremely high hyper-tidal range caused by the funnelled shape of the estuary, globally one of the highest, has created niche and unique habitats in an environment which changes greatly by the hour.

In recognition of its international importance the estuary is currently being proposed for designation as a Special Area of Conservation (SAC) the highest protection in European Union law.

The fast flowing tides cause major sediments movements daily in the main heavily scoured channels. The resulting muddy waters severely limit the growth of small waterborne life in some areas. Yet adjacent areas of the Estuary are very biologically rich. Beneath the surface, there are around 10 billion shrimps and millions of fish living on worms and other tiny creatures within the mud.

Inter-tidal mudflats and sandflats, totaling around 77 square miles, have been created by the huge, twice daily tides. These flats provide a source of food and undisturbed refuge for thousands of water birds, some resident, many more over-wintering on major migration routes. Most bird species feed on the inter-tidal mudflats. The Severn is in the top 20 of the most important estuaries in the UK for wintering wildfowl and waders. It is one of the vital food refuelling stations for species breeding at high latitudes and spending winter in southern or western Europe, the Mediterranean and Africa. This is especially so when severe weather affects other UK sites further north and on the east coast.

The Estuary regularly supports over 20,000 birds and the over-wintering peaks have reached about 65,000 in the last 5 year, down from around 80,000 in the 1990's. Around 100,000 birds were recorded in the winter season of 1994-95. This includes several species whose numbers currently reach levels of international importance (1% or more of that species): shelduck, teal, pintail, dunlin, redshank, and in recent years, Beswick's swan and gadwall. Other species include European white-fronted goose, pochard, curlew, tufted duck, lapwing, wigeon, shoveler and grey and ringed plover.

The Bewick's Swan, found in important populations on the upper reaches of the Estuary, is listed as a species in danger of extinction. It feeds on the salt-marsh and nearby meadow grasses and uses the mudflats as a refuge when disturbed.

The huge tidal range has created extensive areas of salt-marsh, around 350 hectares in Gloucestershire. The salt-marshs are a roosting areas for birds and some species feed on the seeds of salt-marsh plants. Areas called Atlantic salt meadows are of international significance.

Within the fast moving, turbid waters 110 species of fish have been recorded, more than any other UK estuary including 7 species of migratory fish, also more than any other in UK. Stocks include tens of millions of young sea bass which form a basis of the Irish Sea fisheries.

The migratory species, which move between salt and fresh water to complete their breeding cycle, are salmon, sea trout, allis shad, twaite shad, river lamprey, sea lamprey and eel. The rivers Wye and Usk are important migratory destinations. Elvers eels migrate 2,000 miles from the mid Atlantic.

Other species, such as the abundant shrimp which are the basis of a complex food web, migrate within the estuary on a seasonal basis. Over the course of a year shrimp and their predators range from the mouths of the sub-estuaries seawards to Bridgwater Bay. They use the whole estuary system as a breeding area, nursery and food resource.

Several habitats have been prioritised in the UK Biodiversity Action Plan. The Severn and its ten sub-estuaries represent 7% of the UK's total estuary resource.

The estuary's narrowing coast and upward sloping bed forms a funnel shape which generates a pronounced wave called the Severn Bore as spring flood tides travel the 20 miles upriver towards Gloucester. The largest bores occur on about 25 days per year, can reach 2.5 meters high or more, and can travel at over 12 miles per hour.

The Severn has always been a highly dynamic estuary and the position of the shoreline has changed markedly in prehistoric and historic times. This process explains the extraordinary richness of the archaeology of the Severn and the surrounding wetlands.

The Severn Barrage

A range of 'tripartite' barrage studies were made between 1974 and 1988 which cost millions of pounds of public and private finance (2). From these studies a Severn Barrage Project was drawn up by the Severn Tidal Power Group (STPG) in 1989 (3). A revised 'New Appraisal' report was published in 2002 by the STPG calling for a re-examination of the Barrage Project (4).

The barrage scheme proposed would stretch nearly 10 miles from Lavernock Point west of Cardiff to near Brean Down in Somerset. The scheme wall would pass close to and just east of Steep Holm Island and two miles west of Flat Holm Island.

The barrage would impound an area, called a 'basin', of around 185 square miles of the estuary. A 140 mile stretch of coastline would border the basin. The Barrage would incorporate lock gates to allow shipping and smaller craft to access the port at Bristol, other docks and the River Severn.

The installed capacity, or maximum output, of the Project proposal would be 8,640 megawatts (MW) or 8.64 gigawatts (GW) and would have a load factor of about 23%. Generation would occur on the ebb tide. Output may be augmented by pumping additional water from sea to basin when the flood tide is near its peak (known as 'flood' pumping). The proposed barrage would generate about 17 tera-watt hours per year (TWh/y) in an average year or about 4.3 % of current UK electricity demand which was close to 400 TWh/y in 2005.

Some over-estimation in the public mind of the actual scale of the barrage output has been caused by failure by some in the media and elsewhere to distinguish between the terms electricity and energy. Electricity demand is about 18% of UK energy consumption. The barrage output would be equivalent to about 0.75% of current UK 'final' energy consumption which was around 2,250 TWh/y in 2005 (5).

Construction of the 13 mega tonne structure comprising 370 reinforced concrete caissons would take place at numerous locations around the UK and even Europe. Around 18 million cubic meters (around 30 million tonnes) of seabed material would have to be moved to create a level foundation. The caissons would then be carefully located in position during good weather and neap tides at a rate of about two caissons per month. This would take about 84 months if all went well. The barrage could probably be built by around 2017.

Why the barrage would be environmentally damaging

The barrage's 'ebb flow' mode of operation would require the permanent impoundment of the lower half of the existing tidal range to create a 'head' of water from which to generate electricity. Consequently, the tide in the 185 square mile basin would vary over the top half of its current 11 meter range at Lavernock Point. This would result in about 60% of the current inter-tidal area being permanently submerged, an area of around 46 sq miles.

Not only would the spring tidal range in the basin reduce from about 13 meters to 5 meters the tidal cycle would also be altered to maintain high water levels to create the head of water. This would reduce the time that the remaining inter-tidal zone is exposed by an hour or more.

So a significant part of 77 square mile inter-tidal habitat, feeding grounds for tens of thousands of birds, would be lost, only around 30 square miles would be left. Among the 65,000 birds that typically winter on the estuary are six species of international importance which are protected.

The incoming tidal surge eventually bores up river and on spring tides salty water inundates exposed low-lying areas which have become salt marshes. The barrage would moderate this tidal surge by up to nearly two meters and alter the frequency and extent of inundation of this rare and protected habitat. Substantial erosion and loss would almost certainly result. The Severn Bore would be significantly reduced in height and strength.

The barrage would also significantly alter the energy of current flows in the estuary, which would impact on the sediment regime, on silt deposition, and to some degree salinity. Tidal current speeds would be reduced by half and the 4 - 30 million tonnes of sediment scoured and carried on the neap to spring tides would substantially reduce.

The reduced energy in the water column would result in mud deposition and the reduced turbidity would allow greater sunlight to enter the waters generating more marine life. The 1989 barrage studies indicated that some changes caused by the barrage could or would bring benefits to some habitats and some species as the remaining inter-tidal area would become more biologically rich.

It could be that the basin water and the remaining inter-tidal flats would become more biologically productive, possibly supporting as many, if not a greater number and species of birds. Yet the RSPB says that the habitat changes would likely result in a change of species composition, away from the acknowledged conservation features and species of the site. The 1989 tripartite studies identified that three important bird species would not only be displaced but would not be able to find alternative sites elsewhere in south western England or Wales.

More specific studies since that time have not fundamentally altered the 1989 findings. A recent study on redshanks following the building of the Cardiff Bay barrage did find that displaced birds had poorer body condition and lower survival rates (6). Other studies have found reductions in numbers of some migrating bird species occurring since about 2000. This may be caused by birds finding favour and ‘short-stopping’ at sites around a warming North Sea. Yet climate change will further affect all these sites over time and it would not be a good strategy to incrementally encroach on any or all protected habitats on the basis of what could be short or medium term trends in bird behaviour.

The STPG agree that further studies, albeit more focused, would need to be done.

Impacts on fish

The effect of fish species of conservation interest (particularly lampreys, salmon and shad) also has to be further studied. The barrage wall and turbine operations could have a significant impact on any of seven migratory species in particular.

Migratory fish would have to pass through the sluices, turbines or fish passes. Migrating fish spawn in fresh water and outmigrate to salt water before returning to spawn close to the location of their birth. Consequently, such species would be instinctively required to pass through the barrage structure at least twice. The mortality rate for fish passing through low-head turbines is about 6%. Fish ladders can also have a similar mortality rate, depending on the success of the design, and also fish may avoid them. Those species which migrate within the estuary may also have to cross the line of the barrage.

Those fish that successfully negotiate the barrage structure, would then pass into the calmer basin where the change in current flows, sedimentation directional clues and predation could either benefit or dis-benefit differing species.

Sea level rise

The STPG say that sea level rise due to global climate change will adversely affect the existing habitats and that has to be included in future decisions about conservation. Yet, whatever adverse effects there could be, it hardly compares with the ‘sea level’ changes in the basin area that the barrage would cause.

Sea level is likely to rise incrementally by around 1 metre or so over the next century resulting in gradual habitat changes. This would allow species and UK flood defence strategies decades in which to adapt. The barrage would result in a sea level rise of around 5 meters or more within one year, submerging 60% of the inter-tidal area almost instantaneously, allowing species no time to adapt.

The draft Severn Coastal Habitat Management Plan (CHaMP) predicts a 10-20% loss of inter-tidal habitat over the next 100 years. This is likely to exacerbate the waterfowl population changes seen from other factors but the Severn will continue to be an internationally important destination for migrating birds.

Protection from an increasing rate of coastal erosion caused by increased climate-related storm intensity and frequency in combination with sea level rise has also been cited as a benefit by the STPG. However, the Environment Agency has stated that ‘claims of tangible flood defence benefits are therefore marginal to the overall case for a barrage’ (7).

Barrage effects westward of the structure

Any investigation should also include the potential erosion effects caused by the barrage on the westward coastlines. The diversion or reflection of tidal and wave energy back on to the very vulnerable coastline of Bridgwater Bay is a particular case in point (see Flood avoidance section below). The barrage structure would resist tidal movements. Even though the basin area remains about half full permanently, resulting in much less basin volume to fill on the flood tide, the tidal height would be less than currently is the case, by one meter or so at Newport.

Flood pumping would be required to raise the basin level further (see Fig 1).

All told, the features which comprise the conservation interest of the estuary would be significantly adversely affected by a Severn barrage. It is difficult to compare new habitats that would be created by the barrage with the current habitats, or the habitats modified by climate change, in the coming decades.

La Rance barrage

Positive impacts have also been cited with reference to a barrage across a narrow, rocky estuary at La Rance in France. However, the various studies of barrage schemes and potential sites generally indicate very site specific effects.

The 240 MW La Rance barrage, which operates in both ebb and flow mode, is around 20 times smaller than an 8,640 MW Severn scheme. It is barely half a mile long, compared to nearly 10 miles, impounds just 9 rather than 185 square miles, and generates around 0.64 TWh per year, less than 4% of what the Severn barrage would.

The ecology, the geography, and the scheme design itself are all different between La Rance and the Severn and comparisons are of limited relevance. There has also been a lack of pre and post barrage studies at La Rance on which to base authoritative conclusions about ecological effects.

Law and Policy considerations

The Severn Estuary and its tributaries are protected under a range of national and international designations. The estuary has three Site of Special Scientific Interest (SSSI) designations for various habitats and species (Upper Severn Estuary, Bridgwater Bay and Severn Estuary). It is also designated as a Wetland of International Importance (Ramsar) and a Special Protection Area (SPA). The inter-tidal area is protected as an SPA under the Wild Birds Directive and two tributaries, the rivers Wye and Usk, are designated Special Area of Conservation (SAC's), the highest protection, in part because of migratory fish. The UK nature conservation agencies and JNCC have recommended to the UK Government that the Severn Estuary be put forward as a SAC.

The estuary is part of the Natura 2000 network of sites of European importance for wildlife and habitats. These sites, which are recognised for the interlinked nature of their species and threats, are the cornerstone of the EU's nature protection policy. Member states are required in law to protect them.

If a barrage were to be built it would have to be assessed for compliance under the EU Birds Directive and Habitats Directive. Adverse impacts, or risk of impacts, particularly on the identified species and habitat 'features' would have to be identified. It would have to be assessed against alternatives in terms of energy generation and flood protection as climate change will result in changes, probably disturbance and loss.

Any adverse effects or risks would then have to be justified for ‘imperative reasons of overriding interest’. It would have to be demonstrated that alternative solutions are not available either in the area or wider afield.

Under the Habitats Directive, compensatory measures would also have to be proposed for habitat losses if the scheme were to be considered further. Yet the New Appraisal report notes that ‘within the basin formed by the barrage the hyper-tidal nature of the estuary would alter significantly and no measures to compensate for the loss of this particular feature could be engineered’. This is a crucial point, which was further clarified by the government’s decision to refuse the application for a deep water port at Dibden Bay in agreement with the inquiry inspector’s recommendation. There is doubt that the coherence of Natura 2000 could be secured if the barrage scheme were to go ahead.

The proposal would also have to be considered under the Water Framework Directive which requires that there is no deterioration of water quality and restoration of water quality.

The government’s own statutory advisers state that ‘a Severn Barrage development would not be possible within the current legal framework provided by the EU Habitats and Birds Directives. Adverse effects on the integrity of the habitats and species of international importance appear inevitable’ (8).

Section Two - The Case Against the Barrage

In this section the case put forward by the STPG, particularly in their New Appraisal report, is critiqued by Friends of the Earth. The value of barrage power claimed is looked at in detail and alternative solutions in terms of energy generation, emission reductions and flood defence are proposed.

New Appraisal Report

The construction cost of the barrage has always been considered a major hurdle to its viability. Construction estimates currently vary between ?10 - 14 billion (at 2005 prices) depending on a number of factors ranging from the cost of finance, to the provision of road and or rail link, and the size of the lock system required for future shipping.

In the 2002 New Appraisal report a barrage cost of ?55 - 65 /MWh (at 2001 prices) was estimated using a discount rate of 6% and other variables. Around a further ? 5 /MWh reduction would depend on who pays what for the substantial grid connections.

The STPG proposed this cost would be covered by the sales of power (estimated at ? 20 - 27 MWh), plus a credit for avoiding carbon dioxide emissions (?30 /MWh), plus a value for avoided future flood damage (?20 /MWh).

However, Friends of the Earth Cymru consider that various cost benefits have been overestimated:

- the 6% discount rate is a subsidised rate and is considerably less than the conventional 10% (8 – 15%) market rates which, if used, would put the kWh cost into double figures. Mega-construction projects also have a history of over-running, which also increases costs.
- the value of emissions avoided figure (for reasons set out in ‘The value of avoided emissions’ section below – which considers more cost-effective carbon dioxide reduction strategies and electricity generation technologies which can harness indigenous resources).
- the value of flood avoidance (for reasons set out in ‘ The value of flood defence’ section below - which considers alternative flood defence strategies) the value of barrage power (for reasons set out in ‘The value of barrage power’ section below)

Accounting for what Friends of the Earth Cymru conclude as the likely overestimates, the value of barrage power may well be more like ? 40 /MWh rather than up to ? 77 /MWh put forward by the STPG in the New Appraisal report. This compares with the STPG’s costs estimate of around ? 55 - 65 /MWh (in 2001 prices) at a 6% discount rate.

Note that a generating cost of ? 55 – 65 /MWh equates to 5.5 – 6.5 pence/kWh. A generating cost of around 7 pence per kilowatt hour (p/kWh) has been put forward by the STPG in 2006 (9).

The value of avoided emissions

The New Appraisal report estimated that the barrage would avoid emissions of around 17 million tonnes of carbon dioxide per year (mt CO2/y) worth ?30 /MWh. This figure is based on about one tonne of CO2/MWh avoided from the very dirtiest coal power stations operating today (emitting up to 1 mt CO2 per 1 TWhr) in 2001, and a carbon trading price of ?30 / tonne of CO2 (€ 45 / tonne).

Yet by the time a barrage could be built, probably 2017, the specific emissions from modernised or new coal power stations are almost certainly likely to be much lower due to significant efficiency advances and policy requirements. So a re-evaluation is needed.

New super-critical boilers can burn (co-fire) up to 20% biomass. With moderate co-firing (9%) modernised coal plant may well be emitting around two thirds of the figure used by the STPG (0.65 mt CO2 /TWh). By 2017 the barrage would probably displace about 11 mt CO2 per year if displacing coal-fired generation. So the value of emissions avoided by a barrage would be equivalent to more like ?20 /MWh or less rather than ?30 /MWh estimated by the STPG.

It could be that the emissions avoided may be even less than 11mt CO2 per year. The daily variations in UK electricity demand are currently met by coal power stations varying their output to match the national grid demand. This is known as load-following. However, by 2017 there could well be more gas power stations (CCGTs) and less coal power stations in the UK. So some CCGTs may also be needed for load-following duties and emissions from CCGT plant would be around 40% lower than modernised coal plant.

Gas generated electricity is forecast by the DTI at 55% of total UK electricity demand by 2020 and nuclear power may account for another 20% of the baseload *. Such a scenario would leave only around 25% of demand to include all the non-barrage renewables (16% by 2020) plus the twice daily tidal ‘pulses’ of power from the barrage (4 %) plus all the remaining coal capacity. The largest coal station, Drax in Yorkshire, is 4 GW, which even at a low load factor of 60% would provide 5 % of annual demand.

The barrage pulses last of between 2.5 – 6.5 hours. The peak level of the pulses would be between 3 - 8.6 GW, rising from zero by a huge 1.5 - 8 GW per hour. The peak level would reach between 8% - 21% of the average daily grid demand of 40 GW in winter. It would be even more in summer. In such a scenario it does not look possible for what little coal capacity that remained to load-follow the twice daily pulses.

The emissions avoided by a barrage may be further reduced because a rising proportion of coal and gas power stations may also be fitting carbon capture and storage (CCS) equipment after about 2015. Drax may be one such station.

Consequently the barrage output may only avoid 11 mt CO2/year at most by the time it could be built. This would be worth ? 20 /MWh at best in the STPG example depending on the mix of coal and gas power taken off load to balance the barrage output (assuming a price of ?30 /ton CO2).

Such issues considered, the value of barrage’s avoided emissions would probably be less than ? 20 / MWh rather than the ? 30 /MWh estimated by the STPG in the New Appraisal report.

note : Friends of the Earth response to the energy review showed in detail that much greater low-carbon, load following capability, and numerous other benefits, could be realised by fitting CCS to existing and or new coal stations as opposed to building new nuclear power stations (10)

The value of flood defence

In 2001 the International Panel on Climate Change (IPCC) published their Third Assessment Report which projected that the global average sea level would rise by between 9 and 88cm between 1990 and 2100 depending on various scenario assumptions. The average figure is about 45 – 50 cm by 2080.

Also in 2001 a DEFRA study into flood damage around Severnside estimated that the annual average damage cost associated with flood risk at ? 1,000 - 5,000 per hectare (11). It stated that costs could rise over 100 times by 2075 due to the effects of global warming and sea level rise. This valuation was based on an absence of mitigating measures.

Based on the DEFRA study the 2002 New Appraisal report calculated a cost associated with the flood ‘risk’ area at ?40 - 200 million per year rising at least ?4 billion per year by 2075. Such figures were derived using a 40,000 hectare estimate for the area of land below the 2001 flood defence standards which the barrage could protect. The STPG then valued the barrage’s average flood protection at ?20 MWh/y, or ?350 million per year, over its 50 year payback period.

There is doubt that the low lying areas around the Severnside region are at risk of increased flooding due to the effects of climate change. However, it would not require what would amount to an ongoing ‘payment’ of ? 350 million per year, which is what ?20 MWh would represent, to prevent such flood risks.

Since 2001 additional flood protection measures have and are being put in place by the Environment Agency and a new Gwent Levels protection strategy is expected in early 2007. Indeed, increased funding for the Severnside area could be very cost-effective. Damage to the tune of anything like ? 40 - 200 million per year would otherwise amount to ?1 billion within the ten years before a barrage could be built. The current annual budget for flood risk management in England and Wales is currently about ?600 million per year.

The IPCC working groups will also report back in 2007 in their Fourth Assessment Report (FAR). The forthcoming assessment is aiming to give more accurate forecasts of likely effects and risks. It will include revised sea level rise forecasts, which are likely to be higher, and which will inform future defence needs and protection techniques and strategies.

New techniques in coastal protection and management

New flood defence, habitat creation and coastal realignment techniques (managed retreat or forward building) are being developed around Europe and may well start to play a role in the Severn. The use of geo-textile bags filled with dredged material has also been used successfully. UK company HR Wallingford have carried out studies of such techniques for MAFF (12).

In recent years the requirements for disposal licences has resulted in a number of ports within or near marine SACs considering using dredged material for inter-tidal recharge schemes and saltmarsh restoration schemes (13). Around 4.5 million tonnes a year of silt is dredged from the shipping channels of the Severn for maintenance reasons most of which is disposed at sea. Some of this material could be used for coastal protection (see Annex A).

So much has and is being done, and more could cost-effectively be done, in terms of building a high degree of flood defences even before a barrage could offer any further protection.

Westward of the barrage

There is also a question of who would be accountable if the barrage itself caused coastal erosion and or flood risk on its seaward side as the energy of the incoming tide and wave action is partly diverted or reflected back off the barrage structure. The barrage studies identified potential problems around the highly vulnerable eroding coastline around Bridgwater Bay, an important habitat with a high bird density.

It may be that the use of coastal defence strategies outlined above, including use of dredged material and geo-textile bags, could provide sea defences in Bridgwater Bay. However, this begs the question that they could also be used along other stretches of the Severn.

Rail link possibility

In the coming decades, should the need arise, there may be an opportunity to provide additional flood protection for low lying Gloucestershire using a transport link in a different location to the barrage. The possibility of a new rail tunnel to replace the ageing, leaking but still serviceable Severn Tunnel route has been discussed recently. One new concrete lined single-track tunnel would be built and the existing tunnel, opened in 1886, would be used to accommodate a second concrete lined, single-track tunnel.

Alternatively it may be possible and cost-effective to build a new rail link on a bridge incorporating a retractable flood barrier. Such a rail bridge / barrier could be built on the English Stones, a rock reef lying just east of the Second Severn Crossing, as this would be the likely location for smoothest connection to the existing route. The estuary is about 2 miles wide at this point and at low tide 1.75 miles of the Stones are exposed, Such a construction could preclude or impede barge access to the small port of Sharpness but this would be small disbenefit relatively.

Similar ideas are not new. In 1933, a committee recommended the construction of a hydro-electric power station on a barrage located at the English Stones reef, which would utilize the tidal flow of the Severn. This plan, which was interrupted by World War II, was revived in 1945, when engineers confirmed the practicability of the scheme and projected an output of 2.2 TWh per year.†Any decision to build a hydro-electric barrage rather than, or even in addition to, a retractable barrier would again depend on environmental assessments of this sensitive area.

There is also a flood risk to low-lying Gloucestershire from storms and heavy rainfall in the River Severn catchment area causing high water levels to travel down river. The barrage would reduce this risk by moderating basin levels. Alternatively, a combination of flood defences and land management techniques along the course of the river, which reduce the rate of run-off, could also moderate this flood risk.

The value of barrage power

Tides occur twice in about 24 hours and 50 minutes, each high tide advancing by about 25 minutes following the lunar cycle. So the barrage's huge pulses of power, which follow after each tide, would generally not be well timed to the usual daily variations in grid demand.

Some power stations have to vary their outputs so that changes in demand on the grid can be met. This type of operation is called 'load-following' and is mainly performed by the UK's large coal power stations.

The New Appraisal report indicates that the barrage's output timing could be varied or 'retimed' between one and two hours, with some loss of power, to achieve a better fit with the demand on the grid. The report estimates this capability could or would add ?7 /MWh to the value of the barrage output.

Yet the huge pulses of barrage power would often add greatly to the variations on the grid and would require a significant degree of load-following themselves. This would likely cause wear and tear on the load-following power stations and would incur costs.

The figure below shows a typical winter day’s demand on the grid. The barrage’s pulses of power could reach the height of the blusection (over 8 GW) twice a day and would last for a few hours each time.

There would be times when the barrage’s pulses of output are moving, or could be moved, in line with the changes in grid demand. Yet this may only delay the time when fossil fuel-fired plant has to come on line anyway, so any cost benefits would probably be marginal. There would also be occasions, probably daily, when the barrage and grid outputs would be moving in opposite directions. This would require retiming to avoid major adverse swings in load.

Altering the optimum output timings to match grid movements or minimise adverse situations would likely incur some loss of power, estimated at between 0-25% per cycle (14). Yet even an average loss of 6% would result in a 1 TWh per year reduction, a loss in emission savings and potentially net income.

During the morning ‘switch on’ and evening winter peaks UK electricity grid demand can rise by around 5 GW per hour, falling off at a rate of around 3.5 GW per hour. In meeting this, coal plant ramps up by 4.5 GW per hour on winter mornings and 2 GW per hour during the evening peak. Gas-fired plant and pumped storage meet the reminder of the demand increase. The New Appraisal report indicates possible swings in barrage output of between 1.5 GW - 8 GW per hour depending on tide times and retiming decisions.

The New Appraisal report notes that highest spring tides in the Severn estuary lie within the period from 6–9 am and 6.30–9.30 pm. Yet such times are less than helpful for barrage operations. On these powerful spring tides maximum energy extraction is achieved if generation begins three hours after high tide. Although generation could be brought forward by one hour or delayed by two hours, at up to 25% power loss, the retimed spring tide outputs would still not coincide with the daily surges in grid demand which begin around 6 – 8 am am and 3.30 - 5 pm.

Load-following plant, typically coal power stations rather than gas power stations (CCGTs), is required to meet the large swings in daily grid demand. This is because steam turbines are significantly better than gas turbines at load-following. However, the thermal cycling and thermal shocks to coal plant, and more so to gas-fired plant, result in less than optimum efficiency and increased maintenance spend.

The rate of change of barrage output, averaging possibly over 4 GW per hour, would be comparatively very large (the largest UK coal station is Drax at 4 GW). If repeated up to 3 times a day, it would likely put the load following coal and gas stations under considerable strain. Such costs, which accrue to the load following generators, do not appear to have been considered in the barrage calculations.

A storage capability, such as a suggested secondary basin of 9 square miles, could also be added but this too would incur additional costs (15). So it would require further detailed study to identify what such output and timing changes may have on the ‘headline’ 17 TWh/y annual output, or the resulting annual income, or the costs to other load-following plant.

Predictability versus Variability

Much is made of the barrage’s ‘predictable’ power output and energy security. Yet it would not compare at all well with a significantly greater output of ‘variable’ wind power.

A recent study into renewables ‘intermittency’ estimated that the cumulative output of widely distributed windfarms around the UK would likely vary by less than +/- 2.5% of their overall capacity per hour, and by +/-20% per hour about once a year (16).

Consequently, even if all the 20% by 2020 renewable electricity aspiration (80 TWh/y) were generated by windfarms, a massive 26 GW of capacity supplying nearly five times more annual power than the barrage, the likely hourly swing would be much less the barrage’s (see Annex B).

The windfarms would likely experience an output swing of less than 0.65 GW per hour, albeit up or down, which is much less than the barrage’s ‘water limited’ minimum of around 1.5 GW per hour even on a neap tide (17). A swing in wind power output of 5 GW per hour would happen about once per year. Barrage output swings of over 4 GW per hour could happen potentially up to 3 times a day for a significant part of the year.

Coincidentally, about 80 TWh/year could potentially be generated by wind power by 2020, with roughly 30 TWh/y from onshore farms and 50 TWh/y offshore (18). Indeed, 11 GW of onshore wind farms could provide twice as much power annually than the barrage with only a fifth to a tenth of the likely hourly load change.

Large power pulses could be moderated if re-timing towards ‘water limited’ operation were routine but this would incur power loss. Large pulses to the grid could also be reduced by using barrage power in electrolysers to generate hydrogen, or using other potential fuels or energy storage systems instead. As electolyser prices fall hydrogen production may become a cost-effective solution, as may the use of future inter-connectors.

Inter-connectors

The use of the 2 GW capacity inter-connector to the European mainland has also been suggested by the STPG to help dissipate the output pulses over a much larger network. The STPG claim that because the annual flow through the inter-connector has been almost entirely into the UK, swings of 4 GW could be accommodated.

By 2020 and beyond, due to the increasing renewable electricity capacity and variable output both in the UK and in Europe, it would be reasonable for UK grid operations to move to a net inter-connector flow around zero to help balance swings of up to 1 GW in either direction. So the capacity of the existing inter-connector could be required for general balancing duties limiting is flexibility to around 1 GW swings. Indeed, the inter-connector could then help balance a massive 40 GW of cumulative UK wind farm capacity, which would have a likely swing of less than 1 GW per hour.

However, it is possible that the first UK link, of what could become a European electricity ‘super-grid’, of high voltage, direct current (HVDC) links may be in place by 2015 and so could be used to export barrage power. Such links would be designed to carry very large power flows very long distances to distribute and balance Europe’s various renewable energy and hydro storage resources, and also link to vast Saharan solar and wind resources (19).

Airtricity, the developers of a proposed very large 10 GW wind farm in the southern North Sea propose to connect it to both the UK and continental Europe via 5 GW HVDC links (20). So it would be possible to export some power in the 0–5 GW range via this link when the windfarm would not itself be generating. As windfarms typically generate power at some level for 70% of the time, even this link would probably be of limited usefulness for the barrage.

However, by 2025, there may be other HVDC super-grid links between the UK and continental Europe, possibly importing renewable electricity to the UK most of the time. Such links could enable barrage power to be subsumed on the wider EU grid.

Effect of a barrage on other generating technologies

If a barrage were built it is probable that some other generating schemes would not get built. The STPG say that its output could comprise nearly one third of the Government’s 2015 renewables target. It is unlikely that it could be built by 2015 but it could generate a fifth to a quarter of the Government's 20% by 2020 renewables 'aspiration'. So it could displace the deployment of other electricity-generating technologies including other renewables.

The STPG also say that the scheme could be financed by private capital, if long-term carbon credits become available(though it also appears that other forms of public funding are also being sought). Yet there are finite funds for capital allowances and Renewables Obligation (RO) support, and a limited number of carbon credits within a trading scheme. So, depending on how policy is formulated following the energy review, the barrage is bound to displace other schemes and technologies.

The review signalled that there would be moves to greater reliance on carbon trading to encourage the most cost-effective low carbon technologies, along with the possible 'banding' and 'extension' beyond 2015 of the RO to achieve the 20% by 2020 aspiration. Consequently, the barrage could end up directly competing with other renewable energy schemes for a limited pot of carbon credits, capital funding and or 'ROC' certificates up to the obligation's final year in 2027.

Renewables currently supply around 18 TWh/y, the much-touted 'aspirational target' of 20% by 2020 may equate to around 75 TWh/y and the barrage would supply 17 TWh/y. This would leave around 40 TWh/y from all other renewables. Yet the BWEA in its submission to the energy review estimated that on and offshore wind farms, plus a small contribution from tidal and wave devices, alone might generate around 75 TWh/y by 2020.

The 20% by 2020 aspiration is not necessarily very aspirational as it is, especially if technological advances enable faster deployment and higher output, so a barrage could further compromise the development of other renewables.

To counter such unhelpful potential conflicts the barrage could be excluded from the RO, as are large hydro schemes. Alternatively, the renewables target could be revised upwards by including an 'impoundment band'. Without such provisions, the barrage could adversely affect the investor confidence needed for the construction of offshore windfarms, tidal stream devices, wave arrays, biomass and co-firing schemes, carbon capture and storage infrastructure, and other low carbon and renewable technologies. This is especially so in the 2015 - 2020 period as ageing UK power stations are required to close.

Any diversion of RO certificates, carbon credits and or capital allowances and possibly other resources, to one site specific construction could damage technological leads that UK industries have in aspects of these developing technologies. This could have implications for technology transfer, exports and hence UK business, manufacturing and jobs.

Investment in tidal stream and wave technologies where the UK has an advantage in natural resources and technological lead are a case in point. Initial schemes will have capital and revenue support from the Marine Deployment Fund. Generating costs will hopefully fall quickly as production scales up. So it would not be helpful if the barrage then crowded out further larger scale commercial deployments.

Similarly, even if a clash with other renewables were avoided, the barrage could still squeeze the development of other more cost effective low carbon technologies (ie CCS and CHP) as there would be finite public funds for capital allowances for major programmes and or credits for CO2 emission reductions.

In terms of cost-effectiveness, it is reductions in carbon dioxide emissions in the next twenty years rather than the next 120 years which are most needed to tackle climate change. The barrage's construction emissions (13 mega tonnes of concrete) may also affect such effectiveness.

'Overriding public need' in meeting electricity demand

It would be a requirement under the Habitat's Directive to consider alternative ways of meeting any identified benefits of the barrage to assess if there is an 'overriding public interest' for the scheme. Yet, depending on forthcoming energy policies, the barrage may have a significant adverse effect on the development of other renewable or low carbon technologies and schemes around the UK which could also provide low carbon electricity.

The barrage would also physically preclude the development of other renewable technologies in the basin area of the Severn estuary or possibly effect marine turbine deployment on the seaward side. For this reason it is appropriate that the energy review stated that a study of energy technologies in the estuary would be of a comparative nature.

Other impoundment technologies

The construction of the barrage would preclude renewable energy generation from other tidal impoundment technologies east of Lavernock Point, namely rubble mound tidal lagoons and or possibly even concrete-walled tidal fences. These structures could also have a lifespan of in excess of 120 years and could be cheaper and or less environmentally damaging to build. So even in terms of renewable power output over 120–200 years the barrage may not claim any unique advantage. Furthermore, these technologies are ebb and flow generators so the problems of pulsed power are roughly halved and lagoons could also avoid the problem by using a 'multipool' design.

Tidal Lagoons

Tidal Electric Ltd, the company promoting tidal lagoons say schemes impounding an overall area of around 50 square miles in the basin area of the Severn could generate as much annual power as the barrage (impounding 185 square miles) (21). This is partly because the barrage would impound the less productive inter-tidal areas. Lagoons would also have to prove that they would not cause unacceptable harm to the estuary's conservation interests and there have been no cost studies for very large lagoons in the Severn. So further verification of the power output of lagoons per unit area, the areas where they could be built and construction costs, would inform public debate and should form part of any forthcoming study.

A detailed engineering study by consultants WS Atkins of a tidal lagoon proposal in Swansea Bay, which could be the world's first scheme, estimated a generation cost of 3.4 pence/ kWh (22). The scheme would impound 1.9 square miles and would generate an estimated 0.187 TWh/year.

Photomontage of Swansea Bay tidal lagoon (courtesy Tidal Electric Ltd)

Lagoons would typically be built about a mile off the coast and would not impound the inter-tidal feeding areas, or impede fish or navigation along the estuary. Unlike the barrage, lagoons would not provide a flood defence role against high tidal surges and sea level rise. A lagoon's rock walls may provide significant coastal defence against wind-driven wave action, and new habitat, depending on their size and location. Specific lagoon schemes, given the uncertainties of putting any large structure in coastal waters, could cause adverse coastal and or sedimentation effects or damage shallow submerged sandbanks which are protected by the Ramsar designation.

However, it appears possible that lagoon schemes could be constructed sequentially to reach the optimal overall capacity for energy extraction from the estuary without incurring significant harm to the range of conservation interests. Initial estimates by Tidal Electric Ltd suggest that lagoons could generate possibly as much power as a barrage though an environmentally benign optimum may be much less. A great strength of the lagoon system however is that it can be developed in a modular fashion, so that impacts of one scheme can be monitored and understood before building more, or larger, lagoons. With a barrage it is all or nothing.

The concept of concrete walled tidal fences, which impound an area by building out from an adjacent shoreline, has not been studied in terms of Severn estuary potential (23). They could be built completely offshore to avoid inter-tidal areas but they then effectively become a lagoon type impoundment. Alternatively, they may have a capability to protect vulnerable sections of coast. Again site specific studies would be needed to assess their feasibility and viability, and their energy potential or flood defence role in the Severn.

Effect of renewable technologies seaward of the barrage

The barrage would permanently retain an enormous volume of water in the basin area (roughly 185 square miles by 5 meters deep). The structure would also resist flow into the basin area reducing spring tide levels in the basin area by about a meter. These factors would moderate the tidal current flow in the narrow part of the channel on the seaward side of the scheme where there is the possibility of locating marine current turbines of one form or another. Changes in flow rate may prove to be small or negligible but are as yet not well understood. Consequently, even if the tidal stream energy available may not be affected, investor confidence in building tidal stream schemes there may well be.

Carbon Capture and Storage

In terms of low carbon power generation, carbon capture and storage (CCS) technology could well provide a less damaging alternative. At a price of ?30 / tonne for CO_2 it may be significantly more cost-effective to fit CCS equipment to coal and or gas power stations which would reduce their emissions by around 90%. Such technology in itself would strongly challenge the case for a barrage on the grounds of 'overriding public need' which would be required under the Habitats Directive.

Generation cost estimates for coal and gas-fired power stations fitted with CCS are just below the 4 p/kWh mark. The DTI is currently considering funding a CCS demonstration project to test the technical feasibility and cost viability of commercial scale CCS fitted to coal or gas power stations. The cost of carbon dioxide at which CCS is currently considered by industry experts to become viable is around ? 30 /tonne.

Section Three - Other Perspectives

Energy Security

The barrage is being promoted in terms of its indigenous power and hence to future UK energy security. Such a benefit needs to be placed in context for informed consideration.

Cost effective efficiency reductions and lifestyle choices may reduce UK primary energy supply (currently approaching 2,900 TWh/y) by up to half over the next few decades, even with a growing population. After that time the affordability of zero carbon power coupled to more efficient use could well moderate further consumption reductions. So UK energy demand could level out at around 1,450 TWh/year by 2050, half of current primary energy supply.

If built, the power generated by the barrage in such circumstances would provide around 1.2 % of 2050 UK energy demand. Its output would perhaps be around 2% of power supplied from indigenous sources.

A comparison is informative, about 1,000 offshore wind turbines or 3,000 onshore turbines would generate the same annual output as the barrage. Germany, with a land area 40% greater than the UK but very similar population density, has to date deployed nearly 18,000 onshore wind turbines, half of built within the last five years. So a reasonable capacity of onshore UK wind farms could provide probably more than double the barrage's annual output.

A 1.2% contribution to the assumed 2050 UK energy demand is, while useful, not substantial from a security point of view (24). This is in no way to decry such a contribution, it is to show the barrage in context given some public over-estimation of its potential.

Climate change contribution

The New Appraisal report estimated that the barrage would reduce emissions by 17 mt CO_2/year. This figure is impressive and would be accurate if the barrage were opened this year replacing dirty coal stations. Yet, year on year as UK CO_2 emissions fall, the emissions avoided by all renewables would reduce, so the emission savings also need to be set in context.

The barrage would generate essentially carbon free electricity for a design period of 120 years and probably considerably longer, excluding emissions arising from a 13 million tonne concrete construction. On opening, around 2017, the barrage would reduce UK carbon dioxide emissions from the electricity generating sector from probably between 9-11 mt a year if replacing a mix of fossil fired generation.

By 2020 with good progress on carbon reducing policies across all sectors UK emissions should have fallen to below 60% of 1990 emissions (1990 emissions were 577.7 mt CO2/year). A 60% reduction would result in around 330 mt CO2/year by 2020.

So by the time a barrage would be fully operational in say 2020, it may reduce UK annual CO2 emissions of around 3 % if displacing a mix of coal and gas fired generation. Emission savings would fall to very little if the barrage simply displaced other forms of very low carbon generation, such as CCS, or if it was built instead of other renewables, including other tidal technologies in the Severn.

Longer term considerations

Low cost power has been cited by the Assembly Government as a reason for the barrage and so needs to be considered in the wider context to assess its value.

The longer term value of the barrage output once it has paid back its debts around 2070 would arise from the difference between the cost of generation from the low carbon technologies in operation in 2070 and beyond, minus the barrage's annual costs. Such barrage costs comprise operation and maintenance (O&M) and 'off barrage' costs which were jointly estimated at ?112m per year (at 2001 prices) in the 2002 New Appraisal report. This suggests annual costs of around 0.8 pence /kWh at most at current prices.

The overall cost of other renewables and low carbon technologies may average around 3 - 4 pence/ kWh (at 2006 prices) so there would be a saving for the investors from that time. Yet it is likely that the owners would charge the market rate for power and there would be no direct benefit to the public.

So, in terms of economic benefit after the debt was repaid, for a scheme generating 1.2% of 2070 UK energy demand, the effect would amount to about a 1% saving in UK energy costs if the benefits were in some way to fully accrue to 'UK plc' (see Annex C for calculation). Such a saving is welcome but marginal.

Economic development

The STPG say that the barrage would contribute significantly to regional economic development which would therefore be included as part of any sustainable development assessment. Yet any assessment should also compare the economic development potential of alternative strategies.

Direct jobs would be generated in barrage construction, operation, and technology export could follow. The STPG say the region would also benefit indirectly from inward investment due to the road and possible rail link, increased land and property values and new recreational opportunities.

However, spending ? 11–15 billion on any UK energy generation technology would give rise to significant employment, regional development (albeit around the UK) and export opportunities. Indeed, the barrage would displace other and cheaper alternative low carbon or renewable energy technologies in which the UK may have a technological lead.

Direct jobs in construction, operation and maintenance may also accrue to the Severnside area itself if alternative renewable technologies were built in the estuary. Indeed, the barrage could significantly damage the prospects of some Severnside ports as larger shipping may be impeded. The 1989 Severn Barrage Project design incorporated a lock system for vessels of 70,000 dwt. Shipping size has since increased to 120,000 dwt and might rise further. Whereas for example, tidal lagoons would not impede shipping of any size accessing the established ports, infrastucture and hinterlands.

Barrage proponents say increased recreational use of the Severn would be an economic benefit. Yet the disturbance to birds, habitats and some existing recreational activities would have negative consequences too. Any inward investment generated by the barrage or its road link would tend to focus development around the major road junctions. This may then have negative consequences on the Gwent Levels SSSIs especially if the planned M4 Gwent Levels motorway is built.

The barrage road would also generate additional traffic on the existing road networks around Lavernock and Cardiff airport and cause various development pressures in rural Somerset. The setting of the National Trust owned headland at Brean Down on the Somerset coast would be hugely impacted by the close proximity of the barrage embankment

So the net economic effect at UK level, and even around Severnside, is unlikely to be more than marginal at best and potentially negative.

Summary

Friends of the Earth Cymru has revisited the case put forward for the construction of the Severn Barrage project and remain unconvinced about its claimed benefits. We consider that there are less environmentally damaging ways to minimise existing and forecast future climate related flood risk around Severnside. We consider that there are various alternative ways to generate renewable or low carbon power in the timescales in which the barrage may operate. We consider that the are much more cost-effective ways in which to spend the large capital sums required to generate power, reduce emissions and bring economic benefits to the UK

Friends of the Earth Cymru acknowledge that the Severn Barrage would avoid future climate related flood risk to the Severnside area east of the points at which it adjoins the coasts. However, we believe that there are other ways to significantly reduce the flood risk to the area even considering current forecast sea level rise and increased storm and wave intensity over the next century. We are also concerned that the effects of the barrage on its westward coasts may be adverse and not yet well understood.

New techniques in flood defence, such as managed retreat or forward building using dredged material, possibly in conjunction with silt-filled geo-textile bag constructions, are being developed. We believe that developing sea defences using new flood defence techniques can avert significantly adverse coastal erosion and habitat changes in the estuary that could result from global warming. This would protect the highly designated conservation interests of the Severn estuary and its tributaries and their part of the wider network of Natura 2000 European sites.

If necessary in the coming decades a replacement rail link for the ageing Severn tunnel could be constructed as a rail bridge integrated into a retractable flood defence barrier on the English Stones just east of the Second Severn Crossing. Such a barrier would protect low lying areas of Gloucestershire while maintaining unimpeded shipping access to Avonmouth and other Severn ports further west.

A barrage would retain a body of water 5 meters high permanently submerging much of the inter-tidal mudflats which are important feeding grounds for thousands of birds including important and threatened bird species. It would alter protected habitats, disrupt the passage of migratory fish and moderate the Severn Bore.

The barrage, which could be operational by around 2017, would generate very large pulses of electric power for a few hours on each tide. Such pulses of power would not be easily integrated onto the national grid and would require significant and probably very unwelcome load following operations by other UK electricity generators.

Power swings of up to 8 GW per hour, albeit in a known direction, would greatly exceed the likely hourly swings in the cumulative output of a major windpower programme generating 20% of 2020 UK demand, five times more power annually than the barrage. Power integration problems could be minimised, albeit at further cost, by the construction of new low loss direct current inter-connector links to continental Europe, and or hydrogen generation, or other storage technologies which may become cost effective by the 2020’s.

Depending on the details of emerging energy policy, the barrage would probably displace the construction of other renewable energy technologies and or low carbon combined heat and power (CHP), and carbon capture and storage (CCS) technologies. This would likely breach the Habitats Directive as the barrage scheme would have to be of overriding national interest which could not be addressed in alternative ways.

If the barrage attracted any form of government financial support, which it would probably have to, it is difficult to see how this would not also impact adversely on other renewable or low carbon energy technology development and deployment. This could have negative consequences for developing UK manufacturing and employment.

The barrage, which may generate just over one percent of 2050 UK energy demand, would also preclude the development of alternative potentially large scale, long lasting tidal impoundment technologies in the Severn estuary east of the scheme. Tidal lagoons in particular appear to have the potential to generate power more cost effectively, without direct impoundment of the inter-tidal areas or impediment to shipping. Schemes could be built sequentially to achieve the maximum environmentally benign energy extraction. Lagoons could have a coastal defence role, as distinct from the barrage’s flood and coastal defence role, by shielding coastlines from storm wave action.

It is for these reasons that Friends of the Earth Cymru maintains its opposition to the construction of the Severn Barrage and supports the government’s energy review statement for a comparative assessment of the potential of all tidal technologies in the Severn estuary, not just a barrage.

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Note: UK 'primary energy' demand (around 2,900 TWh/y) is actually much greater than final energy consumption but includes conversion loses (eg thermal loses at power stations, refineries, etc) in generating electricity or transport fuels. Many renewable technologies generate electricity directly, including barrages, so do not incur any such conversion losses.

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Annex A

The volume of silt dredged from the Severn estuary is around 2.5 million cubic meters per year. A flood defence wall of silt filled geo-textile bags 3 meters high covering of width of 10 m at its base, tapering to 5m, would require only 25,000 cubic meters of material per kilometre. Hence there would be more than enough material dredged in one year to build many miles of wall if needed.

Tidal Electric Ltd has indicated that silt filled geo-textile bags could be used in lagoon construction, as part the core of the impoundment wall. This could significantly reduce aggregate requirement.

Annex B

‘The most likely change in power output from a diversified wind power system from one hour to the next is less than +/- 2.5% of the total installed wind power capacity. Larger changes from one hour to the next do occur - a change in hourly output equal to +/- 20% of the installed wind capacity is likely to happen about once per year. Over the long term, around 99.99% of all the hourly changes in wind power output from a diversified system will be less than +/- 20%.’

80 TWh/y = 24 GW x 8.76 x 38%

Wind output rate of change less than 600 MW per hour likely (2.5% of 24 GW = 0.6 GW)

Wind output of 4.8 GW rate of change of per hour would occur about once per year (20% of 24 GW = 4.8 GW)

Annex C

(98.8 energy units x 4 pence + 1.2 energy units x 0.8 pence) / (100 units x 4 pence) = 0.990

This draft Final briefing was written by Neil Crumpton, campaigner, Friends of the Earth Cymru

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