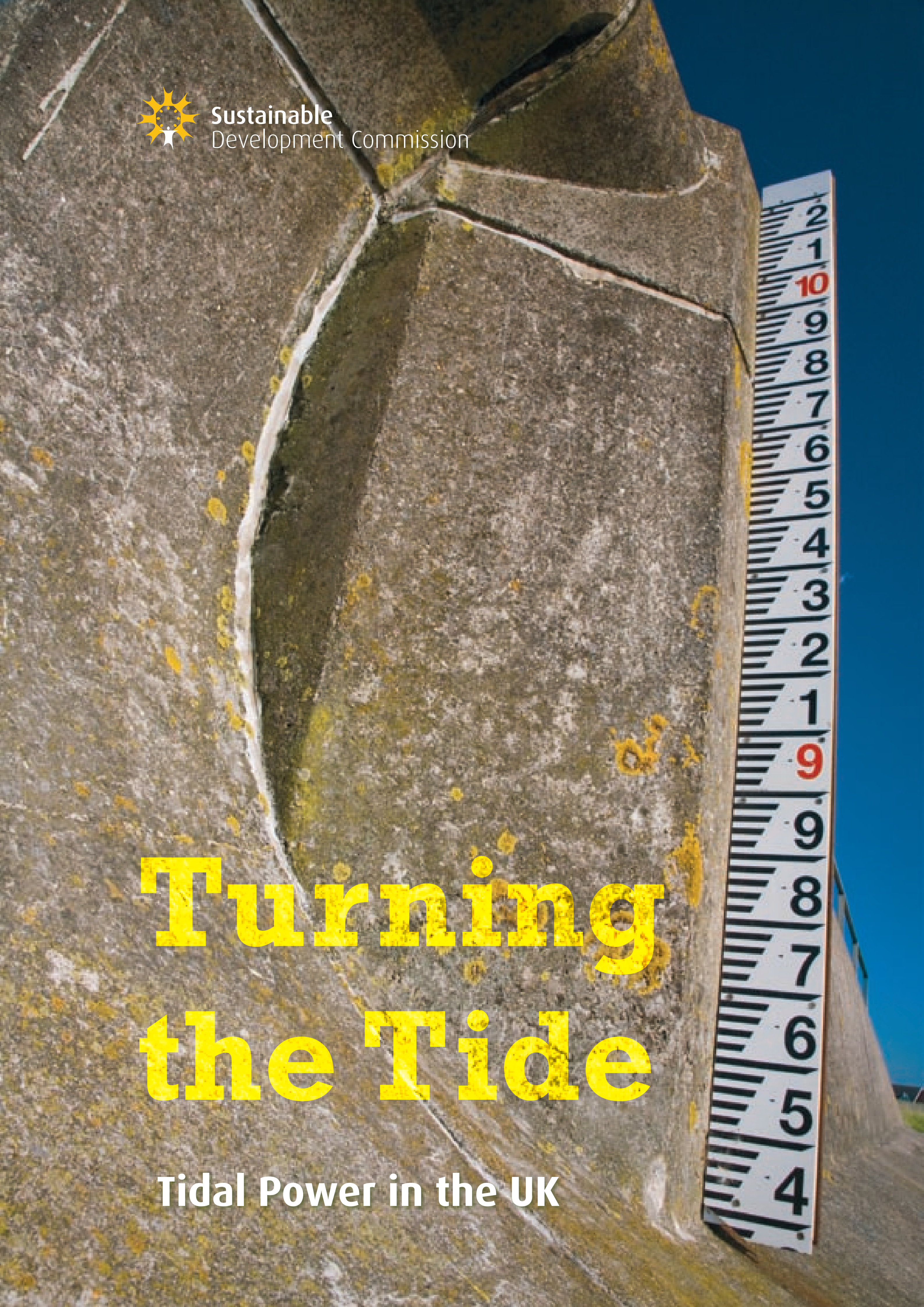

Sustainable Development Commission

Turning the Tide

Tidal Power in the UK

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Contents

Executive Summary

The UK has the potential to generate large amounts of clean and secure electricity from the tides. Using both types of tidal resource – tidal stream and tidal range – we could supply at least 10% of the UK's electricity if fully exploited, around 5% from each resource. Such a substantial prize deserves very close attention as part of much wider action aimed at tackling the twin challenges of climate change and energy security.

This report discusses both tidal stream and tidal range technologies, and considers a wide range of research, including the results of a public and stakeholder engagement programme. It presents the Sustainable Development Commission's position and recommendations on proposals for a Severn barrage which, if built, would utilise a very large proportion of the UK's tidal range resource, and could generate large quantities of low carbon electricity for over 120 years.

There is minimal conflict between the exploitation of tidal stream and tidal range resources, or between the technologies that might be deployed. The best tidal stream sites are in the north of Scotland, with significant potential also around north Wales, Northern Ireland, and the Channel Islands. The tidal range resource is concentrated in the estuaries off the west coast of Britain, including the Severn, the Mersey and the Humber.

Exploiting our tidal energy resources will require concerted action on a number of fronts. The tidal power technologies that could be deployed are very different in both design and level of development. Tidal stream devices are currently at the demonstration stage, and will require many years of targeted support to reach commercial maturity. Tidal barrages, on the other hand, are a proven, but highly capital-intensive option that would require a strong lead by Government to be built. With tidal lagoons, a lack of evidence means that the priority should be filling information gaps through practical, on-the-ground experience so that long-term viability can be better assessed.

However, all tidal technologies have a number of environmental, social and economic impacts that need to be considered. In particular, the impact of a Severn barrage on internationally protected habitats and species, is of great concern.

In this report, the Sustainable Development Commission (SDC) lays out a series of recommendations for Government on how to develop the UK's tidal power resources. On the issue of a Severn barrage, we consider the conditions under which such a scheme would be consistent with the principles of sustainable development, and issue clear advice to Government on how this should be taken forward.

Tidal stream technologies

In addition to having an excellent tidal stream resource – one of the best in Europe – the UK is currently leading the world in the development of a wide range of tidal stream devices. The long-term potential for this new industry – both in terms of its contribution to UK electricity supply, and its export potential – is considerable. The UK's success so far can be attributed to the ingenuity and perseverance of the device developers combined with the commitment shown to date by the UK and Scottish Governments.

However, this nascent industry still has a long way to go, with all the devices in the demonstration and testing stage of development. Taking the successful technologies on to full commercial deployment will require sustained Government support – both financial and practical. Innovation, and the development of new low carbon technologies such as tidal stream generators, needs to be a fundamental part of the UK's response to the challenge of climate change. The Government must increase R&D expenditure and become less risk-averse in supporting innovation.

As a result of the Government's plan to introduce technology banding to the Renewables Obligation, there is now an opportunity to build on the success of the Scottish Government's marine energy support programme by changing the focus of the UK Government's Marine Renewables Deployment Fund (MRDF) from revenue to grant support. This could better serve the needs of the tidal stream industry by providing access to funds aimed at encouraging pre-commercial demonstration.

The successful European Marine Energy Centre (EMEC) in Orkney, which provides a testing site for wave and tidal devices, must be used to its full potential. The centre could benefit from additional funding to offer a wider range of services, including certification of devices, baseline environmental data, and an expanded marine energy research role.

Furthermore, Government should explore the opportunity to develop a regional tidal stream cluster, or 'hub', around the Orkney islands and parts of the Caithness & Sutherland coastline. This could make good use of the less challenging conditions in these locations to develop a coordinated pre-commercial testing programme. There is potential for a new interconnector to the Orkney islands, and a need for better coordination to decide how to make use of available capacity between Dounreay and Beauly. The SDC recommends that work developing a regional 'hub' is led by the Scottish Government, in conjunction with EMEC, the Nuclear Decommissioning Authority, and Highlands & Islands Enterprise.

Finally, the SDC is very concerned over the long-term ability for tidal stream generation to connect to the electricity transmission system due to a lack of capacity. There is a real absence of long-term thinking on the part of Ofgem and the Government on the solutions necessary to overcome this constraint, which is a particular threat to the development of tidal stream in the north of Scotland.

In summary

- **The UK should 'stay the course' in supporting new tidal stream technologies**
- **Innovation funding in the UK must rise, with a commitment to support the development of tidal stream devices at every stage of the innovation chain**
- **Government should consider the potential for EMEC to become a tidal stream development and research hub to build on the success of this resource**
- **Ofgem and Government must urgently increase the capacity of the electricity transmission system to accommodate renewables over the long term.**

Tidal range technologies

As yet there has been no attempt to exploit the UK's large tidal range resource, despite numerous project proposals going back many decades. Virtually all of these have focused on the construction of tidal barrages, which use similar technologies to hydropower dams and are therefore relatively mature. However, the high capital cost and concerns over environmental impacts have prevented a barrage ever being built in the UK, despite examples in France and Canada operating successfully.

Likewise, the concept of a tidal lagoon is not a recent proposition. Not one has ever been built anywhere in the world, and although the technologies used would themselves be classed as mature, the concept itself is unproven due to a number of remaining uncertainties over design, construction methods and physical impacts. This means there is a lack of evidence with which to assess the long-term potential of tidal lagoons, despite a potentially significant resource in shallow water areas around the UK.

To help fill this information gap, the SDC believes there is a strong public interest in developing one or more tidal lagoon demonstration projects in the UK. We recommend that the Government takes this forward by providing financial support to encourage private sector or joint initiatives – either through increased support under the Renewables Obligation or by announcing a one-off competition. There should be a requirement that the research that is conducted is placed in the public domain.

On tidal barrages, our analysis has focused on the issue of a Severn barrage, which is dealt with separately. But we have also looked at the extensive resource outside the Severn Estuary, including the well-developed proposals for the Mersey Estuary. We are supportive of selective further investigation of barrages outside the Severn, and our recommendations on a Severn barrage will also be relevant to other barrage schemes.

Our evidence suggests that there is no serious conflict between the tidal stream and tidal range technologies that could be deployed in the Severn. Tidal stream devices are unlikely to be viable in the Severn Estuary, but there are more appropriate conditions further out in the Bristol Channel. Small-scale tidal lagoon development could take place alongside a tidal barrage. The only option ruled out by a barrage would be large-scale tidal lagoon developments, as these would be directly competing for resource. We do not consider that large-scale tidal lagoon development in the Severn Estuary would offer any economic or environmental advantage over a barrage.

In summary

- **There is minimal conflict between the potential development of tidal stream, tidal barrages and tidal lagoons**
- **There is strong justification for the development of at least one tidal lagoon demonstration project**
- **Government should offer incentives to encourage the development of a demonstration project, with the results of any research undertaken placed in the public domain**
- **There should be further strategic investigation of barrages outside the Severn based on rigorous application of the five principles of sustainable development.**

A Severn barrage

A number of different barrage options have been proposed for the Severn Estuary. This report considers two of these in more detail. The Cardiff-Weston scheme is one of the larger options proposed, and would have a generating capacity of around 8.64GW. The Shoots scheme (which would run near to the two Severn road crossings) is a smaller, 1.05GW proposal, with an annual output of around 2.75TWh.

The SDC's public and stakeholder engagement programme showed that 63% of the public in a national opinion poll had no knowledge of proposals for a Severn barrage; 18% had only a little knowledge. After being given summary information on a barrage proposal, including the potential advantages and disadvantages, 58% of people across the UK were in favour of a barrage and 15% against. This support was mainly because of the perceived climate change benefits.

The results of the public workshops held in Bristol and Cardiff (where more detailed information was provided) were also in favour of a barrage, as delegates felt the benefits outweighed the disadvantages. However, stakeholders were far less positive over the net benefit of a barrage, with a large number of concerns raised over the perceived negative impacts, particularly those affecting the environment.

Power output and cost summary for the two main Severn barrage options

		Cardiff-Weston	Shoots
Length of embankments		16.1km	4.1km
Generating capacity		8.64GW	1.05GW
Annual average electricity output		17TWh	2.75TWh
Contribution to UK electricity supply (2006 data)		4.4%	0.7%
Estimated cost of construction		£15bn	£1.5bn
Estimated cost of output at various discount rates (high case scenario)	2%	2.31p/kWh	2.58p/kWh
	3.5%	3.68p/kWh	3.62p/kWh
	8%	9.24p/kWh	7.52p/kWh
	10%	12.37p/kWh	9.54p/kWh
	15%	22.31p/kWh	15.38p/kWh

Potential benefits

The assumption is that both barrages would be operated on the ebb tide, with the addition of 'flood pumping' to increase the total energy output. This means that they would be generating electricity for around 7-8 hours on each tide, and output would vary within this period. As a result, the annual output of each barrage is less than that implied by their size. If built, the Cardiff-Weston scheme would generate 17TWh per year, which is equivalent to around 4.4% of UK electricity supply. This is the same level of output as would be produced by just over two conventional 1GW power stations.

The high capital cost of a barrage project leads to a very high sensitivity to the discount rate used. At a low discount rate of 2%, which could be justified for a climate change mitigation project, the cost of electricity output from both barrage proposals is highly competitive with other forms of generation. However, at commercial discount rates of >8%, these costs escalate significantly, making private sector investment unlikely without significant market intervention by Government.

The timing of output from a Severn barrage, regardless of the scheme, is not optimal. On average, both proposals would produce more power at the times of the day when demand is lowest. Nevertheless, electricity from a barrage would displace output from fossil-fuelled power stations, and would make a genuine and sizeable contribution to meeting the UK's targets on renewable energy and on reducing carbon dioxide emissions. The SDC does not believe that the variability in output from a barrage, which is highly predictable, would raise any significant technical challenges for the operation of the electricity grid. As we showed in our 2005 report on wind power, variability is something that can be managed at very low cost.

As well as being an energy-generating project, a Severn barrage is often seen as a way to provide additional flood protection to low-lying land along the estuary, and additional transport links. On flooding, a barrage would provide some additional upstream benefit against the risk of coastal flooding (such as a tidal surge) and would counter the effect of rising sea levels. However, existing flood defences would still need to be maintained, and a barrage would provide no additional protection from fluvial flooding events.

The SDC's conclusion is that there would be substantial flood risk benefits from a barrage, but these are only marginal to the economic case for its construction. Without a barrage, it is very unlikely that the Environment Agency would seek to provide this increased level of flood protection when it is viewed against all the other competing priorities for limited resources. The flood protection benefits of a barrage should therefore be seen as ancillary to a primarily energy-generating project. Options for increased levels of flood protection through alternative barrage alignments or designs should be valued in a way that is consistent with existing policy on coastal flood risk and through a strict analysis of the additional costs and benefits that would result.

On the potential for new transport links over the top of a barrage, the SDC believes that these benefits may have been overstated. There is little evidence showing how a road or rail crossing would actually be designed, and we conclude that this would present a number of challenges due to the existence of one or more ship locks, and could be very costly. On the question of identified need, there is nothing to indicate a strong justification for an additional road link. The case is stronger for a new rail link, to replace the aging Severn Tunnel crossing, but this would need to be considered against the alternative option of building a dedicated rail bridge or a new tunnel, neither of which require a barrage project to go ahead.

In summary

- **Electricity from a barrage would displace output from fossil-fuelled power stations, making a significant contribution to the UK's renewable energy targets**
- **The variability in output from a barrage is not a major problem for the electricity grid and can be managed at very low cost**
- **There would be substantial flood risk benefits from a barrage, but these are only marginal to the economic case for its construction**
- **The case for new transport links over a barrage is unproven, and needs to be assessed looking at the net costs and benefits.**

Conditions for sustainable development

The SDC has approached the issue of a Severn barrage from a general position that favours renewable energy. We have then examined the conditions under which a barrage might be sustainable, focusing on a number of controversial, potentially 'deal-breaking' issues.

This approach neither signifies the SDC's unquestioning support for a barrage, nor proposes a set of conditions which we believe would make it impossible to develop. Instead, we have considered a Severn barrage within a framework that places a high value on the long-term public interest and on maintaining the overall integrity of internationally recognised habitats and species.

We do not take a position on the relative merits of the various barrage schemes but have instead considered the issues generically, with an inevitable focus on the larger Cardiff-Weston scheme due to the availability of more detailed evidence and the greater degree of impact it would have – environmentally, economically and socially.

In summary

- **The SDC has approached the question of a Severn barrage by looking at the conditions under which its development might be sustainable**
- **We have done this within a framework that places a high value on the long-term public interest and on maintaining the overall integrity of internationally recognised habitats and species.**

Energy policy context

The SDC has a number of concerns over how a decision in favour of a Severn barrage might impact on wider energy policy aims. There is a risk that the development of a barrage might divert Government's attention away from the other necessary solutions to the challenge of climate change.

A Severn barrage has a number of disadvantages that are similar to those of nuclear power, and developing such a large amount of electricity generating capacity in a single location would not of itself move the UK any closer to a more decentralised energy system. Furthermore, the SDC is concerned that development of a highly-centralised Severn barrage project could frustrate efforts to reduce energy demand, as consumers perceive a barrage to be a solution to climate change mitigation, relieving them of the need to act.

Despite recent progress with the Climate Change Bill and the 2007 Energy White Paper, the SDC believes that the Government does not yet have the policies in place to deliver the carbon savings that will be required to 2050 – and in particular, the delivery of emissions reductions over the next 15 years. As shown by the Stern Review, action to reduce carbon emissions needs to be 'front-loaded' to have the best chance of stabilising the average temperature rise to no more than 2°C. The new EU target for 20% of energy to come from renewable sources by 2020 will also be a major challenge.

Nevertheless, in the light of increasing public concern over climate change and a greater political willingness to tackle the issue head-on, the SDC believes that a Severn barrage could be pursued as part of a major drive to reduce emissions substantially over both the short and the long term. A robust climate change and sustainable energy policy is an essential pre-requisite for development of a barrage. If this exists, there is the potential for a Severn barrage to be used as a symbolic example of the scale of action that is required.

In summary

- **Development of a Severn barrage must not divert Government's attention away from much wider action on climate change, including the development of a more decentralised energy system and the reduction of energy demand**
- **There is increased public and political space for action on climate change – it is therefore possible for Government to deliver on a Severn barrage as part of a comprehensive and radical programme on climate change.**

Ensuring the public interest

If built, a Severn barrage would be designed to generate electricity for at least 120 years. It would be a major addition to the landscape, and would have fundamental environmental, social and economic impacts on the surrounding area. These timescales emphasise the need for any barrage project to be designed and delivered in a way that ensures the long-term public interest rather than a short-termist, profit-maximising approach.

The SDC has a number of concerns over the apportionment of risks and benefits for any barrage scheme, particularly one that is led and owned by the private sector. It is very unlikely that a proposal for a Severn barrage would ever come forward without significant Government intervention, and a substantial funding package to pay for the initial research and evaluation. Once construction begins, the Government effectively underwrites the project due to its size and political significance. This increases the risk of moral hazard – i.e. that underinsured risks will be picked up by the taxpayer.

Despite taxpayers and consumers taking on a high level of risk, a barrage project led and owned by the private sector would not result in a fair distribution of the benefits, and the public would lose out.

A project of this kind also raises concerns over short-termism. A private sector developer would require a high rate of return on any barrage project, leading to a strong incentive to maximise near-term revenues through inappropriate ancillary development. The SDC has identified a number of risks regarding the possibility of unsustainable development pressures as a result of a barrage – for example, housing development in green belt or environmentally sensitive areas, new transport infrastructure, negative impacts on local ports – and the implications of these on local communities and on the net carbon balance.

We are concerned that a profit-maximising approach would substantially increase these pressures, putting all the emphasis on the role of planning controls and regulation, rather than integrating sustainability into the barrage development itself. There is also the risk that a short-termist approach could lead to the use of sub-optimal construction methods and materials (possibly leading to higher levels of ongoing maintenance), as most commercial projects find it difficult to value adequately benefits that occur over the very long term.

Finally, development of a Severn barrage would require a highly coordinated, outcomes-based approach to strategic planning and consenting issues. The organisations involved would need to ensure that any project was integrated into local policy and planning frameworks. This favours an approach where such considerations are firmly embedded into the project developer's aims and objectives.

In summary

- **The long lifetime of a Severn barrage places a very high emphasis on ensuring the public interest in the design and delivery of any development**
- **The SDC has a number of concerns over the apportionment of risks and benefits for a Severn barrage scheme, particularly one led and owned by the private sector – taxpayers and consumers could end up with all the risks but none of the benefits**
- **Short-termism in the design and delivery of a barrage could lead to unsustainable ancillary development and possibly sub-optimal methods and materials used in barrage construction.**

Compliance with environmental legislation

The Severn Estuary is a unique and dynamic environment. It has the second largest tidal range in the world, combined with a high suspended sediment load, and has a number of special features, including extensive areas of salt marsh, and mobile sandbanks. It is an important site for migratory birds, and for fish movements in and out of the estuary's tributaries, such as the Wye and the Usk. For these reasons the Severn Estuary has been designated a protected site under national and international legislation.

The most important pieces of conservation legislation for a prospective Severn barrage are the EU Directives on Birds and Habitats (the 'Directives'), which protect sites designated as Special Protection Areas (SPAs) and Special Areas of Conservation (SACs). The total amount of land protected under the Directives is a very small percentage of the UK, and the identification of sites is a science-led process that is based on protecting important ecosystem types and threatened bird species. The Severn Estuary is a SPA and a candidate SAC. The aim of designation is to protect against biodiversity loss by conserving a series of important or at-risk habitats and species that make up the Europe-wide Natura 2000 network.

The Natura 2000 network is based on the need to conserve biodiversity across Europe, and internationally. Biodiversity is a measure of both quantity and quality, and therefore distinctiveness. An increase in the total quantity of plant or animal life living in a particular location may not in itself represent an increase in biodiversity if the species concerned are commonly found elsewhere.

The Severn Estuary is a relatively unproductive environment due to the harsh conditions; yet it is host to a number of highly distinctive features and species. Its sheer size ensures that while species density may be relatively low, total numbers of some bird populations, for example, are very significant. Therefore, while a barrage might result in an increase in biological productivity, any reduction in the quantity of rarer species might lead to an overall loss of biodiversity.

The SDC is convinced that the Severn Estuary will remain an important area for biodiversity, despite the impacts of climate change. Warmer weather may account for some of the current observations of bird species shifting to estuaries on the east coast of England, but there is no certainty as to how climate change impacts will manifest themselves over the long term. As a result, the Severn Estuary will remain an important future option for migratory bird species. Furthermore, the estuary may play host to new species that are forced to shift away from more southern locations – this illustrates the importance of considering the trans-boundary nature of biodiversity.

The Directives are intended to facilitate sustainable development, by ensuring that environmental conservation objectives are adequately considered when proposals are put forward that would negatively impact on protected habitats or species.

Any development that is proposed within a SPA or SAC must go through a series of tests, as outlined by the Directives. If an 'appropriate assessment' identified the likelihood of adverse impacts, then the process that must be followed is:

1. Consideration of alternatives: The first test then requires an assessment of the alternatives, including the 'zero' (no-development) option and ways to mitigate against any adverse impacts.
2. Overriding public interest: If there are no viable alternatives to the development, then a political decision can be taken to proceed on the basis of 'imperative reasons of overriding public interest'. This decision would normally be taken by a Secretary of State.
3. Compensation requirement: If this is the case, there is then a compulsory requirement to provide compensatory habitat to ensure the overall coherence of the Natura 2000 network. The practicality and cost of this requirement represents the final test of the overall viability of the proposal.

Providing habitat compensation could include the creation of new habitat, the restoration of existing habitat, or the recreation of habitats within the site, in other designated sites, or in non-designated sites (and then designating them). It may also be possible to designate other estuaries not currently designated as SACs. To compensate for impacts on fish, compensation could involve the artificial restocking of certain fish species to maintain overall numbers.

The SDC has looked closely at the relevance of the European conservation legislation in the face of climate change. Some commentators have argued for a relaxation of the Directives when they are applied to projects that would reduce carbon emissions. The SDC believes that applying the principle of 'living within environmental limits', which is one of the UK's sustainable development principles, must result in the creation of absolute limits and boundaries if the concept is to have any meaning. Biodiversity objectives become even more important in a world impacted by climate change, and economic development must take place within the environmental constraints imposed by both biodiversity and climate change objectives.

As a result, the SDC believes that the UK's legal obligation to protect habitats and species that contribute to the overall viability of the Natura 2000 network should be vigorously upheld. The Directives provide a clear and robust legal framework for achieving sustainable development and therefore compliance with the Directives is a central condition for a sustainable Severn barrage. The SDC would be firmly against moves to reform or derogate from the Directives, as this would send a dangerous signal to other European member states that could end up harming compliance with the Directives, and the biodiversity objectives that they uphold.

This means that proponents of a Severn barrage must be prepared to fully comply with the process laid out by the EU Directives, including the requirement for a full compensatory habitats package to be in place before a barrage is built. Providing compensatory habitat on this scale would be a very significant undertaking matched by an equally high cost, but it needs to be seen as a central part of any proposal which may eventually dictate whether or not it can proceed.

In summary

- **The Severn Estuary is a distinctive habitat that is protected by national and international designations – in particular, the EU Birds and Habitats Directives, which apply a series of tests to prospective developments**

- **A Severn barrage could lead to a loss of biodiversity, resulting in the need for a compensatory habitats package to maintain the overall integrity of the Natura 2000 network**

- **The EU Directives provide a clear and robust legal framework for achieving sustainable development and therefore compliance with the Directives is a central condition for a sustainable Severn barrage**

- **Providing compensatory habitat would be a very significant undertaking on a scale hitherto unprecedented in the UK – but this would have to be an integral part of any barrage proposal.**

Our advice to Government

The SDC believes that there is a strong case to be made for a sustainable Severn barrage, subject to the conditions we outline in this report. This is the consensus view of all 19 of the SDC's Commissioners. Our headline advice to Government is as follows:

A decision in favour of a Severn barrage should only be part of a major effort to deliver at least a 60% cut in greenhouse gas emissions by 2050, with action loaded towards the next 20 years.

A barrage should only be considered within the constraints imposed by the European environmental legislation. As a result, the provision of compensatory habitat should be seen as a core part of any barrage project, and there should be no attempts made to weaken or derogate from the Directives.

Providing compensatory habitat is not a burden on the project; rather, it represents an 'environmental opportunity' to use a revenue-generating climate change mitigation project to help fund a large-scale compensation package that is designed around the need for climate change adaptation. This could be linked to coastal realignment strategies, which can have a number of flood protection benefits. The Government should seek a progressive interpretation of the Directives that takes into account climate change impacts on the long-term integrity of the Natura 2000 network of protected sites.

Finally, the SDC believes that a barrage should be publicly-led as a project and publicly-owned as an asset to ensure long-term sustainability in its design and delivery, and a fair allocation of risks and rewards. We believe that a publicly-led approach would be the best way to ensure against unsustainable ancillary development as a result of a barrage, and the early integration of local and regional economic and social priorities.

A publicly-led approach would enable the use of a low discount rate, justified by the long-term climate change benefits and potentially facilitated by the Government's access to low cost capital. At a low discount rate, the cost of electricity output becomes highly competitive with other sources of generation, even if the cost of the compensatory habitat package is high.

The SDC is not advocating the nationalisation of the electricity sector, nor are we ruling out a strong role for the private sector in delivering and financing a Severn barrage. Instead, we recommend that Government considers a range of innovative financing mechanisms that would maintain overall public control and ownership of the project.

In summary

- **The SDC believes that there is a strong case to be made for a sustainable Severn barrage**
- **Much wider and stronger action on climate change is a pre-requisite for the SDC's support**
- **There may be an 'environmental opportunity' available by linking a compensatory habitats package to climate change adaptation**
- **A Severn barrage must be publicly-led as a project and publicly-owned as an asset to ensure long-term sustainability**
- **Government should consider a range of innovative financing mechanisms that would maintain overall public control and ownership of the project.**

Moving forward

The SDC's recommendations are a major challenge to current Government energy policy. However, the approach we prescribe would enable Government to deliver a significant quantity of new renewable energy without compromising our international obligations on conservation and biodiversity.

Proposals of this scale require a new approach to decision-making. Government must avoid a 'decide-and-deliver' approach, and not set off on a pre-determined course of action where important conditions and principles could eventually be discarded. Instead, it must reflect on the wider implications of such a decision, and engage widely with stakeholders and public to ensure that their concerns and opinions are taken into account.

A crucial first step will be to obtain an early indication of the feasibility of compliance with the European environmental legislation, and the cost of achieving this. This should include an analysis of whether there is an 'environmental opportunity' available for linking the compensatory habitat package to climate change adaptation policies, and this would require early discussions with the European Commission. As the SDC has clearly stated, if compliance with the Directives is found to be scientifically or legally unfeasible (which, in the light of our current investigations, we do not believe it would be), then proposals for a Severn barrage should not be pursued, as the development would fail to satisfy the principle of 'living within environmental limits'.

There is a strong need for a cross-Government approach to this issue. As energy policy is a reserved matter, it is appropriate for the UK Government to take the lead, with close cooperation required between BERR, Defra and, critically, the Welsh Assembly Government, as well as the relevant statutory agencies. There is also a distinct and important role on strategic planning and economic development issues that should fall to the South West of England Regional Development Agency as well as the Welsh Assembly Government.

The SDC's advice to Government is based on our assessment of the current evidence, and it is up to the Government to decide how to proceed. However, the SDC would be interested in working with Government and other key stakeholders to explore some of the substantive issues we raise, in particular the prospect of an environmental opportunity, and in scoping out innovative financing options that maintain overall public control.

In summary

- **Government must avoid a 'decide-and-deliver' approach**
- **An early priority is to ascertain the scientific and legal feasibility of compliance with the EU Directives, and the likely cost of this**
- **There must be a cross-Government approach to this issue.**

1

Introduction

This report by the Sustainable Development Commission (SDC) represents the first ever strategic overview of tidal power in the UK. It looks at the potential of a wide range of tidal power technologies to make use of the UK's unique tidal resources for the production of reliable, low carbon electricity over the long-term. It also includes an in-depth analysis of the tidal power resource in the Severn Estuary and the potential role of a 'Severn barrage' from a sustainable development perspective.

The report draws on a wide range of existing and commissioned evidence on tidal power, together with the results of a substantial public and stakeholder engagement programme. The SDC has used this work, along with the expertise of its Commissioners and specialist staff, to develop a series of recommendations for Government.[1]

1.1 Background to this project

During development of our work programme for 2006-7 the SDC identified the potential for a project on tidal power from a UK-wide perspective. At the same time, the Department for Business, Enterprise and Regulatory Reform (BERR)[2] was being asked to conduct a fresh assessment of the potential for a tidal barrage in the Severn Estuary.

This led to the announcement in the 2006 Energy Review[3] as follows:

> "...Together with the Welsh Assembly Government, we [BERR] will therefore work with the Sustainable Development Commission, the South West Regional Development Agency and other 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."

This commitment led to the formation of a wide-ranging SDC research project on tidal power and the production of this report. The SDC was always keen to ensure a UK-wide focus on tidal power, and the inclusion of a wide range of tidal technologies. We were therefore very grateful to obtain full UK-wide funding of this project from the following organisations (placed in order of their level of funding):

- Department for Business, Enterprise and Regulatory Reform
- Welsh Assembly Government
- South West Regional Development Agency
- Scottish Government
- Department of Enterprise, Trade and Investment (Northern Ireland)

The funding obtained was used to commission a series of evidence-based reports, to run our engagement programme, and for general project administration. However, the SDC's agreement with our funding partners stipulates that the SDC has full editorial control over this document, our final report. As a result, the views expressed here are those of the Sustainable Development Commission, and do not necessarily represent the views of our funding partners. In addition to securing external funding, the SDC has contributed its own resources directly to this project through the specialist policy and engagement expertise of our Secretariat staff and Commissioners.

The SDC has also sought input from a wide range of stakeholders, both through our engagement programme, and through stakeholder meetings, public events, direct contact and our in-house Stakeholder Panel. We are grateful to all those who have taken the time to assist us on this project. We would particularly like to thank our colleagues in the various statutory agencies[4] for all their time and assistance in helping to peer review the reports we commissioned, and in providing advice to us on an ad-hoc basis on a wide range of issues.

1.2 Our approach

The SDC announced the start of this project on our website in July 2006. We invited organisations and academics with knowledge or expertise in this area to submit information to the SDC for consideration, and received a large volume of material. Subsequent to this, we embarked upon a competitive tendering process for five desk-based research contracts, which were structured as follows:

Research Report 1 – UK tidal resource assessment: resource mapping of geographical and temporal distribution of the resource, potential electricity generation contribution, grid constraints, strategic policy and planning framework

Research Report 2 – tidal technologies overview: summary of tidal technologies (deployed and in development), including economics, environmental impacts and economic and social factors associated with the different technology categories

Research Report 3 – Severn barrage proposals: summary of various barrage options for the Severn Estuary, their compatibility with other options, assessment of environmental impacts and the environmental policy framework, flood and sea level rise management options and impacts, navigation/fishery industry impacts, economics (including financing options), electricity generation/grid implications (including consideration of peak output and variability), life-cycle carbon emissions, life expectancy, and implications for regional economic and infrastructure development and recreational opportunities

Research Report 4 – Severn non-barrage proposals: case studies on a number of non-barrage options for the Severn Estuary, their compatibility with other options, and an assessment of environmental, economic and social considerations and impacts

Research Report 5 – UK case studies: a review of a number of case studies and proposals for tidal power developments across the UK using a number of different technologies.

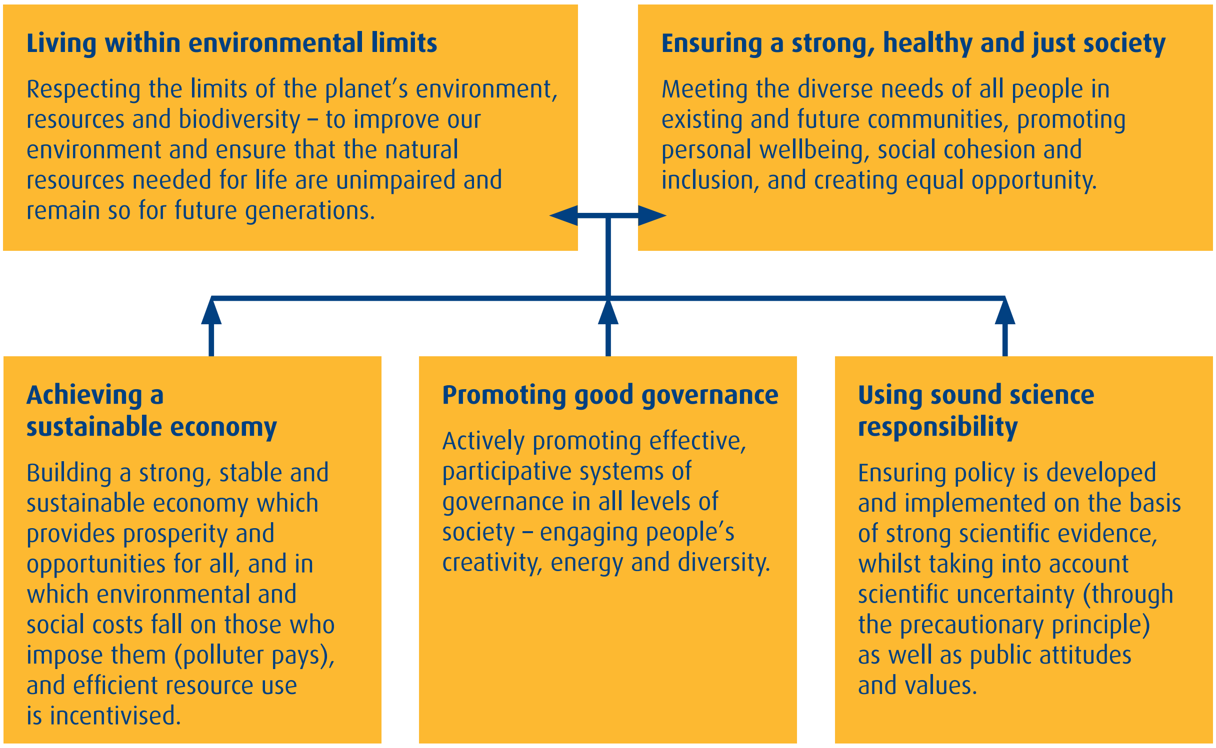
We have published the research reports on our website as stand-alone reports so that they may be used as a public resource. Each research report is referred to in this document by its shortened title (e.g. 'Research Report 1').

The SDC believes that effective engagement is essential to the development of truly sustainable policy-making. Engagement is particularly important for understanding new technologies such as tidal power, as new technologies represent an unknown quantity to many stakeholders and to the general public. It is also important when considering potential large-scale infrastructure development such as tidal barrages and lagoons, which have significant potential effects on the environment, economy and society at a regional and local level.

Although the SDC's work in this context does not aim to replace formal consultation (by Government or a project developer as part of a strategic environmental assessment or an environmental impact assessment, for example), engagement was key to this study, particularly in our review of specific proposals for the Severn Estuary. To better understand the implications and impacts of the proposed tidal technologies, the SDC commissioned a coordinated public and stakeholder engagement programme, the results of which can be found in a stand-alone report also published on our website. A short summary is provided in Section 1.5, and in Section 4.9 in relation to a Severn barrage.

After considering our commissioned evidence base, the results of our engagement programme, and the wealth of other information we obtained, the SDC began the process of assessing the various issues drawing on the expertise of our Commissioners and in-house specialist staff. As with all our work, the SDC is guided by the sustainable development principles agreed by the UK Government and the Devolved Administrations in 2005.[5]

Figure 1 **UK sustainable development principles**



We have used these five principles when considering tidal power development more generally, but also in relation to specific issues, such as the exploitation of the tidal resource in the Severn Estuary. Although each principle does not apply equally to the issues surrounding tidal power, the concept of sustainable development is particularly relevant when considering proposals that may have a wide range of environmental, social and economic effects, both positive and negative. It is for this reason that we believe the SDC, and sustainable development more generally, can add value in the consideration of such issues.

This report considers the tidal stream and tidal range resources separately (see below for an explanation), before going on to consider the issues surrounding a possible Severn barrage in some detail. Finally, we present our concluding analysis and our recommendations to Government.

The SDC is a non-departmental public body which was set up to advise the UK Government and the Devolved Administrations on sustainable development issues.[6] As such, it is not our role to recommend specific technologies or proposals for development where these are subject to an identified commercial interest. So, for example, we do not seek to make claims as to the benefits of one technology over another, and the actual performance and economic viability of different technologies will need to be determined under the framework put in place by Government. However, some of the issues surrounding tidal power require Government to make a number of strategic decisions, and these have been the focus of our work.

1.3 UK tidal resource

A detailed description of the UK's tidal resource is given in Research Report 1, which presents an overview of the current knowledge and research in this area. This section is based primarily on the findings from this work, unless otherwise stated.

Box 1 **What causes the tides?**[7]

Tides are caused by the gravitational attraction of the moon and the sun acting upon the oceans of the earth as it rotates. The tide-raising force exerted by the moon is approximately twice that of the sun. The relative motions of these bodies cause the surface of the oceans to be raised and lowered periodically, according to a number of interacting cycles. These include:

- A daily or half-daily cycle, due to the rotation of the earth within the gravitational field of the moon. This leads to the familiar occurrence of high and low water, which will be experienced at different times of the day depending on location. In the UK, high and low water occurs approximately twice daily (it is 'semidiurnal'), with the time of high water advancing by approximately 50 minutes per day.
- A worldwide 29.5-day cycle, resulting from the degree of alignment between the moon and sun. This results in 'spring tides' and, seven days later, 'neap tides'. Spring tides are those half-daily tides with the largest range (i.e. highest high water and lowest low water), while neap tides have the smallest range. Spring tides occur shortly after the full and new moon, with neaps occurring shortly after the first and last quarters. For any given location, the spring tide high water will always occur at the same time of day.
- A half-year cycle, due to the alignment of the moon's orbit to that of the earth. This gives rise to the largest spring tides, around the time of the March and September equinoxes, and the smallest spring tides, approximately coincident with the summer and winter solstices.

There is also a 18.6 year tidal cycle that results in larger than average tides, requiring estimations of tidal resource to be based on an 'average year'. The range of a spring tide is commonly about twice that of a neap tide, whereas the half-yearly cycle imposes smaller perturbations. In the open ocean, the maximum amplitude of the tides is about one metre. The law of energy conservation means that tidal amplitudes are increased substantially towards the coast, particularly in estuaries. This is mainly caused by shelving of the sea bed and funnelling of the water by estuaries. In some cases the tidal range can be further amplified by reflection of the tidal wave by the coastline or resonance.

In combination with the 'Coriolis effect' and friction effects, these factors mean that the tidal range and times of high and low water can vary substantially between different points on the coastline. They also result in a large variation in the energy that can be obtained from the tides on a daily, weekly, and yearly basis.

1.3.1 Two types of tidal resource

There are two quite distinct categories of tidal resource: tidal stream and tidal range. The **tidal stream resource** is the kinetic energy contained in fast-flowing tidal currents, which are generally found in constrained channels. The **tidal range resource** refers to the gravitational potential energy that can be found in estuarine areas that exhibit a large difference in water height (their 'tidal range') between high and low tides.

The technology used to exploit each of these resources is quite different. Tidal stream devices rely on capturing some of the energy contained in the currents passing by them, whereas tidal range devices seek to impound large volumes of water at high tide, and then release the water through turbines at low tide. Put another way, tidal stream devices make use of the kinetic energy of tidal currents, whereas tidal range devices rely on the gravitational potential energy created when water at high tide is kept behind an artificial impoundment.

There are a large number of prototype and demonstration tidal stream devices and two broad proposals for harnessing the tidal range resource – tidal barrages and tidal lagoons. The technologies will be discussed in more detail in Chapters 2 and 3, but a key difference is that tidal stream devices are modular (like wind turbines), whereas both tidal barrages and lagoons are large, single installations (more like hydropower dams).

The two types of tidal resource are generally found in very different locations. The majority of the UK's tidal stream resource is located in the north of Scotland in and around the Pentland Firth, although there are some significant resources around Alderney, Anglesey and the Strangford Lough area in Northern Ireland. The UK's tidal range resource is primarily focused on the western estuaries of Britain, with most of the resource concentrated in the Severn Estuary. Figure 2 and Figure 3 give an illustration of where the UK's tidal stream and tidal range resources are located respectively – the light colours indicate a high resource.

Figure 2 **UK tidal stream resource**

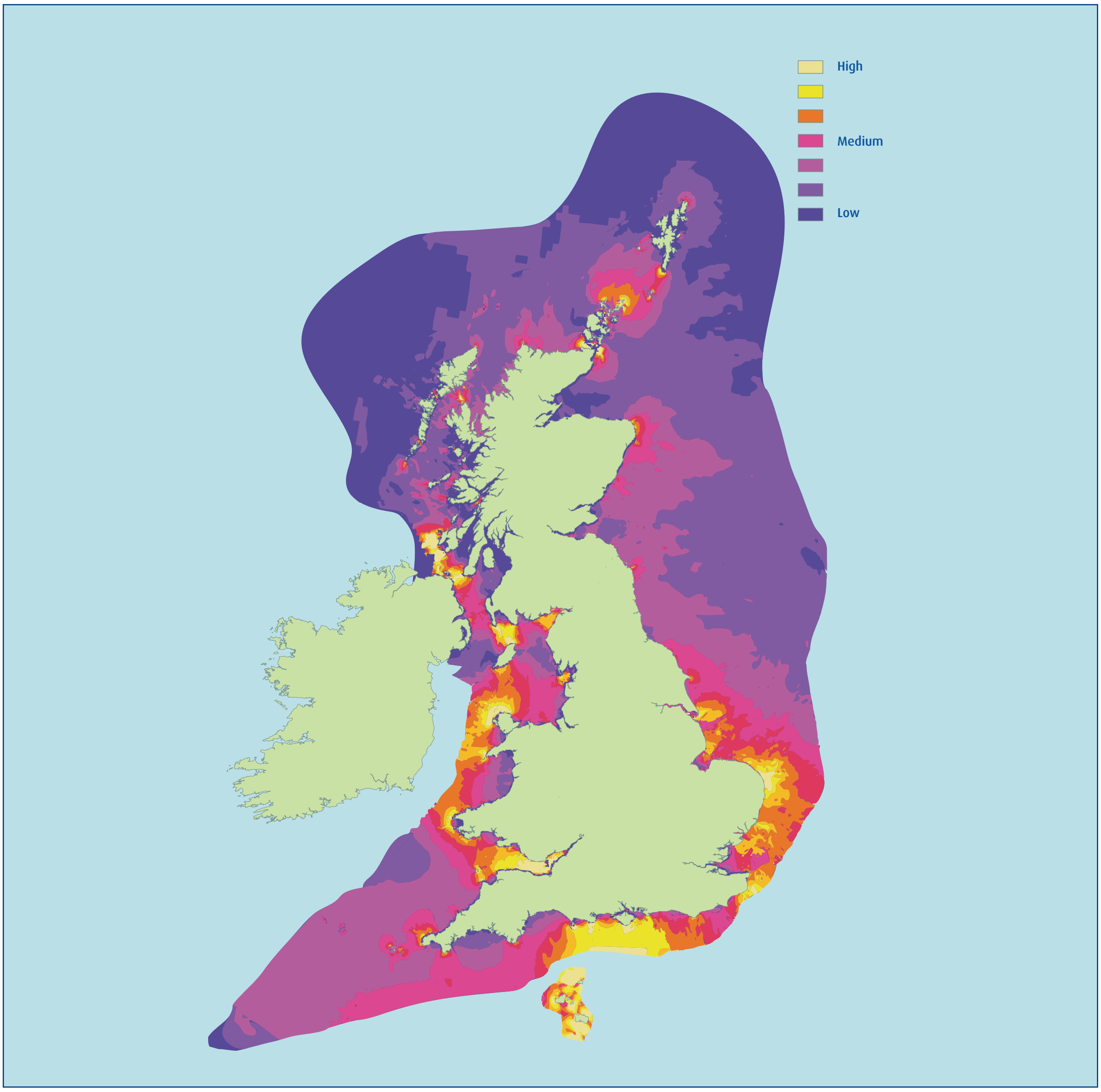
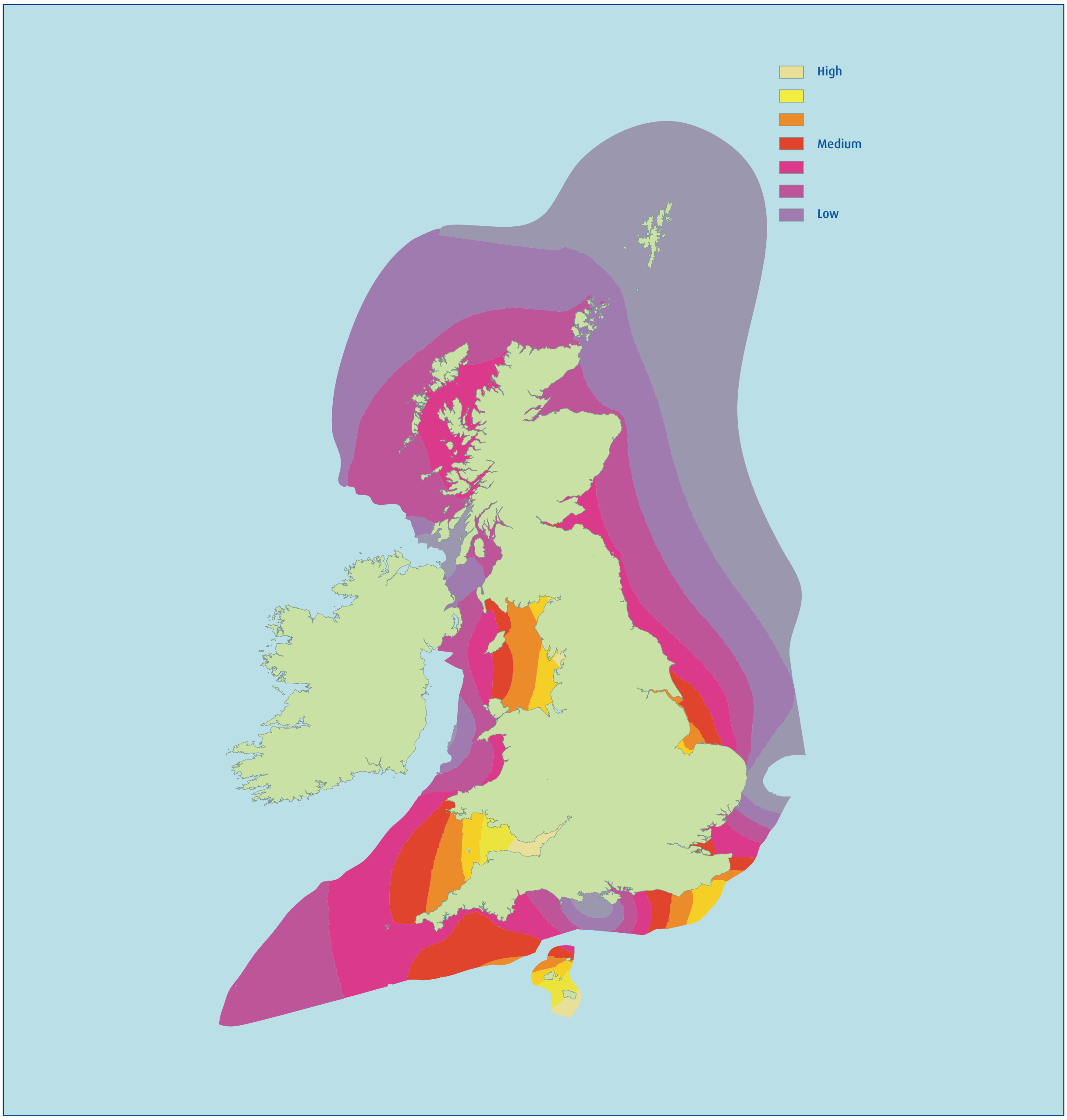


Figure 3 **UK tidal range resource**



Box 2 **Cube law for tidal stream resources**

The energy in a tidal current or stream is proportional to the cube of the water velocity. This means that the available power in a tidal current is calculated using the cube of the water velocity. This law means that even small changes in predicted tidal current velocity will lead to large changes in predicted power density. It also means that there is approximately eight times more tidal stream power during spring tides than at neaps.

As this report will illustrate, there are fundamental differences between tidal stream and tidal range resources and technologies. As a result, different policies would be needed to exploit these two resources in a sustainable way. For this reason, this report will look at each resource separately, before going on to look in more detail at proposals for exploiting the very large tidal range resource in the Severn Estuary – a 'Severn barrage'.

1.3.2 Electricity generating potential

Available estimates of the UK's tidal resource allow us to calculate the potential electricity generating output if all the best resources were fully exploited. Estimating the potential electricity output requires a number of assumptions to be made on the technical constraints of the device(s) installed, their efficiency, and the effect of resource extraction on the remaining resource. This means that there is a large degree of uncertainty in all resource estimates, an issue which is discussed below.

The top UK sites for the generation of tidal power are shown in Table 1. This illustrates the large percentage of the total UK resource that lies in the Pentland Firth and the Severn Estuary respectively.

Of course, it may not be possible to harness all the available resource due to wide range of potential constraints, but these figures do give an idea as to the high level resource and the prime locations.

Table 1: Top UK sites for tidal power

Tidal range sites		Tidal stream sites		
Site name	Resource (TWh/year)	Site name	Area	Resource (TWh/year)
Severn	17	Pentland Skerries	Pentland Firth	3.9
Mersey	1.4	Strøma	Pentland Firth	2.8
Duddon	0.212	Duncansby Head	Pentland Firth	2.0
Wyre	0.131	Casquets	Alderney	1.7
Conwy	0.06	South Ronaldsay	Pentland Firth	1.5
		Hoy	Pentland Firth	1.4
		Race of Alderney	Alderney	1.4
		South Ronaldsay	Pentland Firth	1.1
		Rathlin Island	North Channel	0.9
		Mull of Galloway	North Channel	0.8

1.3.3 Resource uncertainties

Estimating tidal resources is a complex task, and the methodology and data used to make these estimates is still in development. It is therefore highly likely that our understanding of the actual level of practical resource (i.e. the resource that is available after allowing for physical and technical constraints) will continue to evolve over time.

Box 3 **Quantifying the renewable energy resources**

Tidal resource assessments can be considered in three distinct stages:

Theoretical resource	A top level statement of the energy contained in the entire tidal resource.
Technical resource	The proportion of the theoretical resource that can be exploited using existing technology options.
Practical resource	The proportion of the technical resource that can be exploited after consideration of external constraints (e.g. grid accessibility, competing use (MOD, shipping lanes, etc.), environmental sensitivity).

So, for a tidal stream site, the spring tidal peak velocity (m/s) relates to the theoretically available resource, the area of water deep enough for the chosen technology relates to the technically available resource, and the potential impact on shipping lanes and general navigation relates to the practically available resource. A number of publications provide guidelines for site selection criteria.

One major factor in determining the resource is the scale of the assessment undertaken. Using a higher resolution will tend to give a much better prediction of localised current velocities, and therefore total energy output. However, most existing assessments have been done at a relatively low scale of resolution, leading to the potential for significant refinement over time.

A recent report commissioned by the npower Juice fund to assess the UK's tidal stream resource illustrates some of these uncertainties well.[8] It predicts a total extractable resource of up to 94TWh/year, requiring approximately 200,000 devices deployed across 11,000km^2 of seabed (not more than 40m deep). Both this work, and the Research Report 1, highlight a recent theory from the academic literature that suggests the UK's tidal stream resource has been under-estimated by a factor of 10 or 20.[9,10] These claims have not yet been supported by peer-reviewed papers, but they have understandably generated a lot of interest and seem deserving of further investigation.

On tidal range, it is worth noting that the estimation of resource presented in this report is related to the practical resource, and not the total theoretical resource. A report by the World Energy Council suggests that the UK might have up to 50TWh of electricity generating potential from tidal range resources "if all reasonably exploitable estuaries were utilised"[11] – this would be equivalent to around 13% of UK electricity supply from tidal range alone. Furthermore, previous calculations of the practical resource may not have considered the potential for electricity generation at shallow water sites, particularly those outside the west coast estuaries, which may have implications for the potential of tidal lagoons.

1.3.4 Timing of output from tidal sites

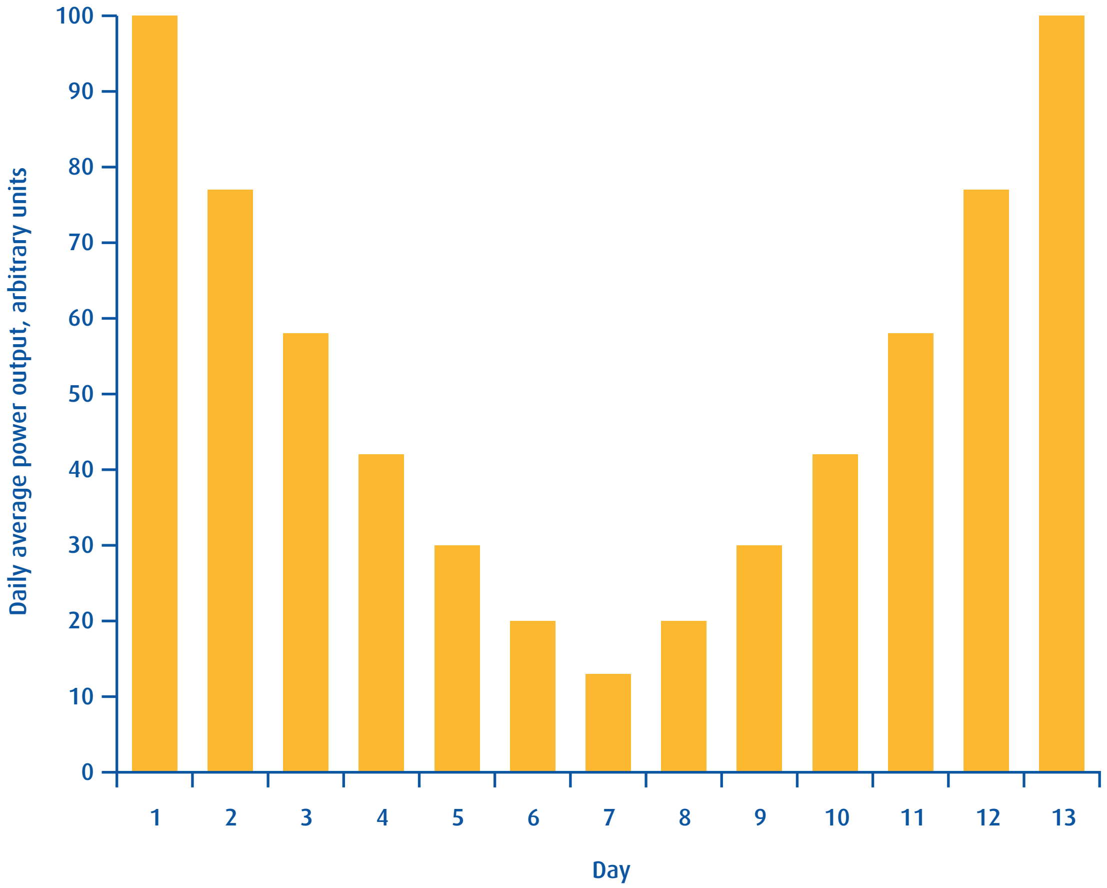
Tidal power is a variable and yet highly predictable resource. The biggest influences on the timing of the electricity output are the twice-daily tidal cycle, and the 14-day spring-neap cycle (see Box 1). However, the fluctuation in output of both tidal stream and tidal range devices can be accurately predicted over the lifetime of the installation.

These variations are discussed below, along with the temporal distribution (i.e. timing and location of output) of tidal generation if all good sites in the UK were developed to their potential. This information needs to be considered in the context of fluctuations in UK electricity demand, where demand peaks occur throughout the working day and particularly towards the early evening, with lowest demand in the early hours of the morning (this issue is explored in more detail, in the context of a Severn barrage, in Section 4.3.4).

Tidal stream

The magnitude of the tidal stream resource (which combines with wind effects to produce currents) varies sinusoidally, with the highest speeds occurring at mid ebb or mid flood, and with speeds approaching zero at the turn of the tide. There is also a very large difference between average power output during spring versus neap tides, as shown in Figure 4. This difference is accentuated at high velocity sites, such as those around the Pentland area. When combined with the daily tidal cycle, peak tidal output is around 90-100% of rated capacity on a spring tide, dropping to a 15-30% minimum, whereas peak output on a neap tide is between 15-40%, falling to a minimum of less than 10%. In essence the output is continuously changing, albeit in a predictable way.

Figure 4 **Typical variation in output from tidal stream power due to spring-neap cycle**



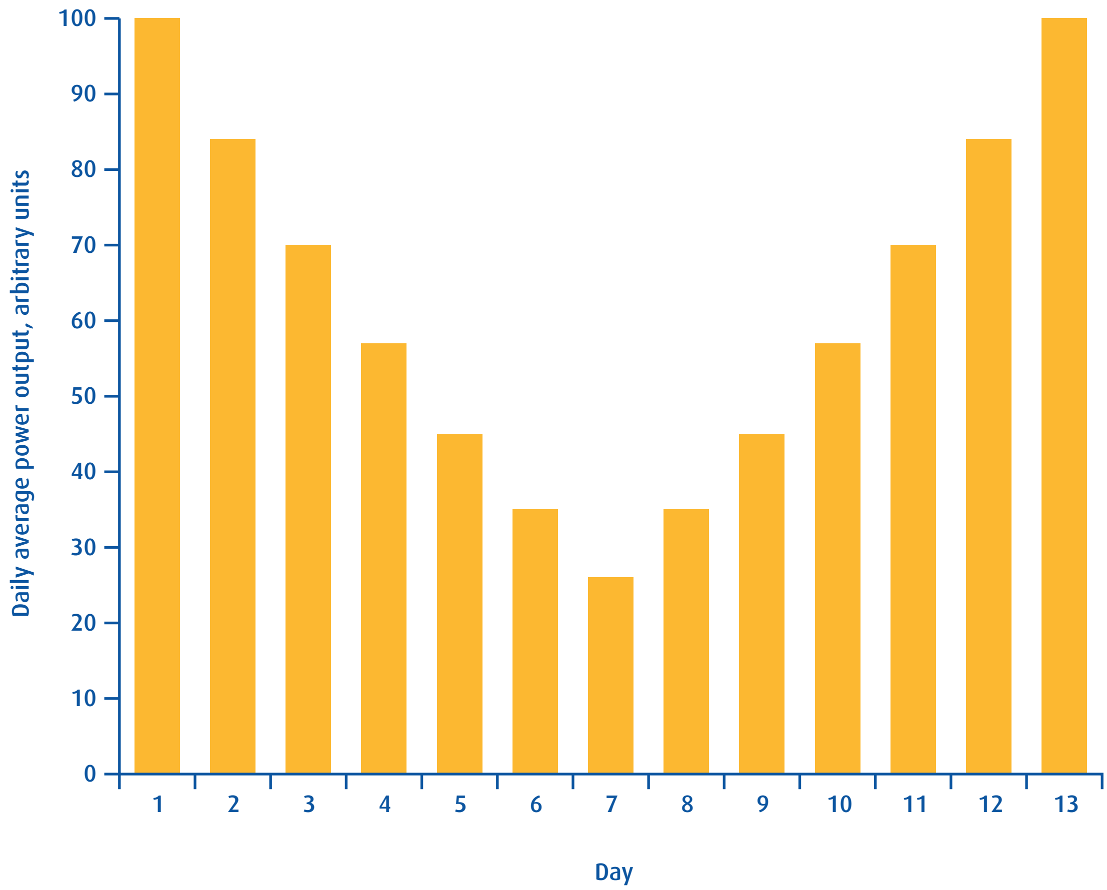
Temporally, spring tide peak generation for the Pentland (North Scotland) sites would occur at mid flood and mid ebb at around 9am and 3pm respectively, and then on the subsequent tide at around 9.30om and 3.30am. These timings would then shift by approximately an hour each day through the spring-neap cycle.

As a result, the Pentland resource is not ideally matched to UK electricity demand – although nor is it badly matched. The timing of output from the Pentland area would to some degree be offset by different timings from other UK locations; however, the dominance of the Pentland resource, along with the fact that spring-neap cycles are the same worldwide, means that it has the potential to outweigh any balancing effect from more dispersed tidal stream generation.

Tidal range

The timing of the tidal range resource is more dependent than the tidal stream resource on the operating regime used. For example, it is possible to operate a tidal barrage or lagoon in ebb or flood generation, or both, and flood pumping is also an option (to artificially increase the head). On the neap tide the electricity output is 25% that of a spring tide, as shown by Figure 5.

Figure 5 **Typical variation in output from tidal range power due to spring-neap cycle**



Maximum electricity output is thought to be achievable by operating a tidal barrage or lagoon in ebb generation mode, possibly with flood pumping. Generation times could be expected to occur around three hours after high water and continue for around four hours. As a result, a total generation time of just under eight hours per day could be expected.

Again, the dominance of the Severn Estuary resource means that the output regime from large-scale tidal power development in this location would have the largest effect on overall tidal range output. In general, the likely output characteristics of tidal range plant in the Severn are not particularly well-matched to UK electricity demand, although this is not a major barrier. A more detailed analysis of this issue in relation to a Severn barrage can be found in Section 4.3.

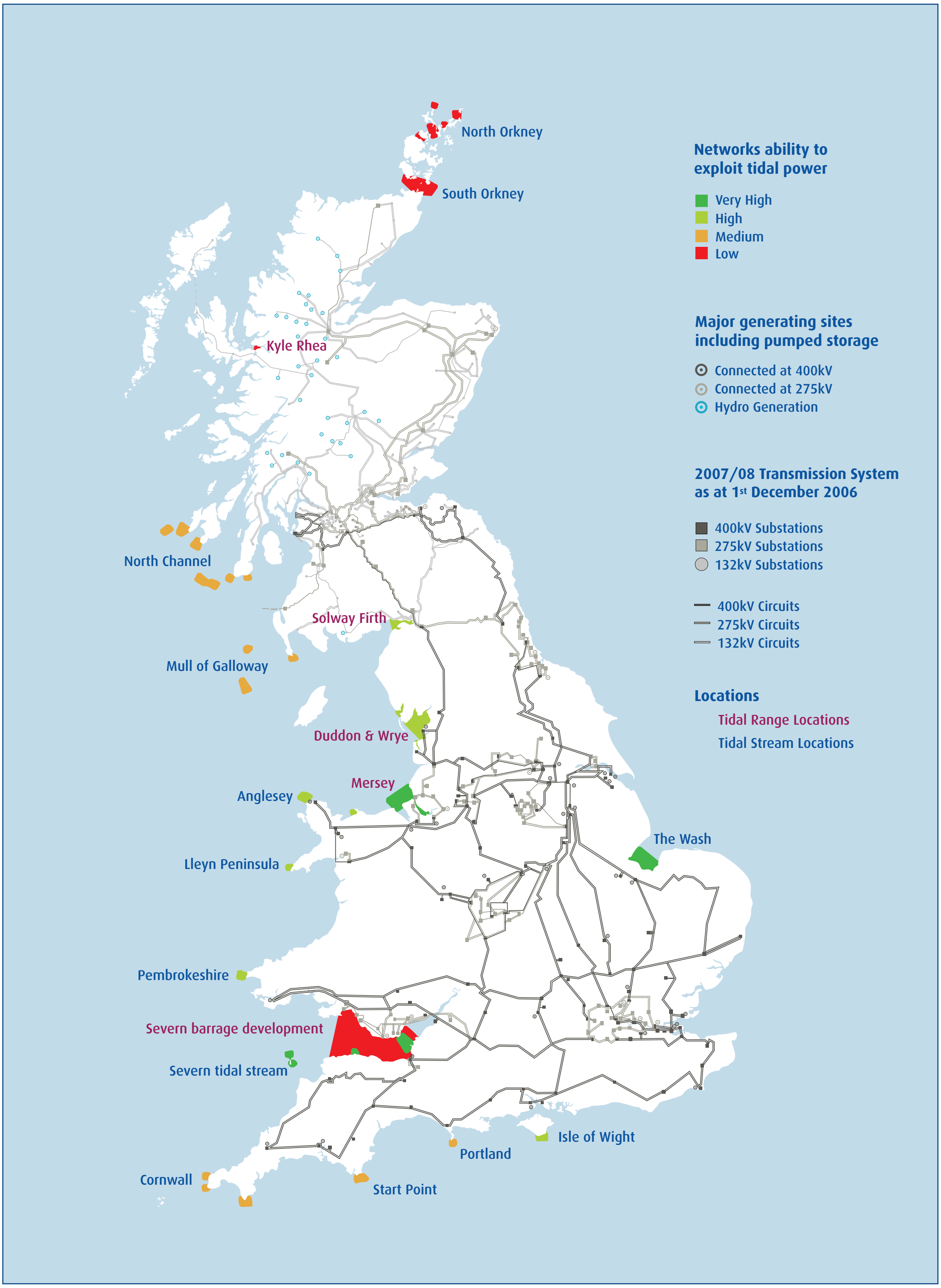
1.3.5 Transmission system constraints

Electricity transmission system

The transmission system in Great Britain is made up of the 400kV and 275kV high voltage transmission network (plus the 132kV network in Scotland), and has the responsibility for transporting large amounts of electricity around the country to where it is needed (see Figure 6). It is operated by National Grid Electricity Transmission (NGET) plc, who are also the owners of the transmissions system in England and Wales; in Scotland, the primary owners are ScottishPower Electricity Transmission Ltd and Scottish Hydro Electricity Transmission Ltd.

The transmission system feeds into the local distribution system, which is managed by the 14 Distribution Network Operators (DNOs) on a regional basis.

Figure 6 **Electricity transmission network in Great Britain[12], showing grid constraints on tidal power.**



The majority of generation plants in Great Britain are connected to the transmission system, with some 12GW of generation capacity connected to the distribution networks. The capacity of the transmission system to connect generation and manage the flows of electricity depends on the capacity of the network. The process of connecting to the network is based around the principle of matching the Connection Entry Capacity (CEC) (the generating capacity of the power station) with the Transmission Entry Capacity (TEC) (the capacity of the network to accept a new generator). Connection offers are made on the basis of an 'invest and connect' approach whereby CEC can never exceed TEC, so new lines must be built to connect new generation.

System constraints and upgrades

At present there are significant TEC constraints in the north of England and Scotland which are preventing the connection of new generation projects. In order to connect new generation, areas of the transmission network will need to be upgraded to higher voltage levels (measured in kV) to increase the TEC.

The 132kV transmission line between Beauly and Denny has been identified as requiring an upgrade to increase the TEC of the network in Scotland. Ofgem has approved the funding required to upgrade the line to 400kV line which would increase the TEC by around 6GW, allowing for the connection of 67 new renewable projects already in the pipeline. However, as a 400kV line will have a significant impact on visual amenity, consent for the upgrade has been delayed awaiting the conclusion of a public inquiry. Figure 6 shows the areas where TEC constraints would hinder the connection of tidal projects.

With the introduction of British Electricity Trading and Transmissions Arrangements (BETTA) in 2005, the Scottish network became an integral part of the GB network. In anticipation of this, many generators submitted bids to be connected onto the grid but most of these did not have planning permission, which can take many years to achieve. A total of 9.3GW of capacity is awaiting connection onto the grid in Scotland and this is known as the 'GB Queue'.

At the moment, connection onto the transmission system is dependent on spare capacity being available, but an alternative approach could be taken. As the SDC recommends in its report on the role of Ofgem in delivering a sustainable energy system,[13] there is the potential to free up capacity by operating a 'connect and manage' approach rather than a strict queuing system.

Implications for tidal power

These issues pose significant challenges for the connection of tidal stream projects, and this is discussed further in Section 2.4.2. Existing capacity constraints and delays to network upgrades will further delay the date by which tidal stream projects could connect. If the current approach to transmission connection and management is not modified, it is unlikely that the UK will see any significant level of tidal stream connection between now and 2020.

For tidal range the situation is less significant, for two key reasons. First, tidal range resources are generally located in areas where grid constraints are less pronounced, and are closer to high capacity transmission lines and to centres of demand. Second, tidal barrages and, to a lesser extent tidal lagoons, are likely to be larger, one-off projects when compared to a tidal stream array, making the incorporation of grid connection costs a smaller part of the overall project cost and therefore more manageable. Grid constraint issues related to a possible Severn barrage are discussed in Section 4.3.6.

1.4 Energy policy context

1.4.1 Current Government policy

Energy policy in the UK has risen up the political agenda in recent years due to the twin challenges of climate change and energy security. The UK Government has published two Energy White Papers and two Energy Review reports in the space of six years, and there are no signs that this increased attention and activity will subside. Indeed, many commentators now believe that energy policy is likely to remain under a state of constant review due to the growing realisation of the scale of the problems we face.

On climate change specifically, the UK Government has proposed a new Climate Change Bill,[14] which would bind future Governments to statutory targets for the reduction of greenhouse gas emissions, initially focused on carbon dioxide. This Bill, if successfully implemented, has the potential to fundamentally change the dynamics of climate change policy in the UK. Climate change legislation is also being considered for Scotland.[15]

The SDC strongly supports the focus on climate change and energy security, both of which have serious consequences for sustainable development if not urgently addressed. The two main aims of the UK Government's energy policy are summarised in the 2007 Energy White Paper[16] as follows:

- Tackling climate change by reducing carbon dioxide emissions both within the UK and abroad
- Ensuring secure, clean and affordable energy as we become increasingly dependent on imported fuel.

The UK Government believes that these energy policy goals should be achieved through private sector companies operating in liberalised energy markets. This means that Government's role is to set the policy and market framework for investment in new electricity generating capacity and associated infrastructure (including the framework for investment in renewable and low carbon energy sources), with energy companies responsible for investing in new capacity and for running the electricity grid. As a result, the Government does not directly build power plants or decide where or when they should be built.

1.4.2 The SDC's position on energy policy

The SDC has done a wide range of work on climate change and energy policy over the past few years, and we have continually stressed the need for an energy policy hierarchy: starting with energy conservation, moving on to using energy more efficiently, and finally the decarbonisation of energy supply. The potential for saving energy through behavioural change and investment in new energy efficient technologies is huge, and must be realised if we are to meet our climate change and energy security objectives.

In 2006, the SDC analysed a range of evidence looking at the UK's potential for meeting its energy needs from low carbon sources. This identified a very large renewable energy resource, and a number of scenarios that could deliver a 60% cut in CO_2 emissions by 2050, without the need for nuclear power. A number of more recent studies have also shown the potential of low carbon energy sources to deliver a sustainable energy supply.[18,19,20,21]

On climate change, we strongly support the conclusions of the Stern Review,[22] which identified three important policy elements for reducing emissions:

- Carbon pricing, through some combination of taxation, trading and regulation
- Technology policy, to support the development of a range of low carbon and high efficiency technologies
- Removal of barriers to behavioural change, which is particularly important in ensuring take-up of opportunities for energy efficiency.

This report aims to reflect Stern's recommendations, particularly in relation to innovation and the use of appropriate discount rates when considering climate change mitigation projects.

In the UK context, the SDC has consistently called for the early introduction of economy-wide emissions trading to provide an economic framework for other climate change mitigation policies, including taxes and regulation where appropriate. This would build on the preference of the UK and other European countries for a trading-based approach to carbon pricing, as demonstrated by the establishment of the EU and UK Emissions Trading Schemes over the last few years. However, we remain sceptical that emissions trading on its own will deliver the large-scale investments we need to move to a low carbon future, and this is a strong theme in this report.

In the energy and heat markets, we believe that Government policy must urgently seek to decouple energy use from economic growth, and we will work with Defra on proposals to set a cap on the energy that can be supplied to domestic and small business consumers,[23] and on further investigation into personal carbon trading. We have long been advocates for improved innovation funding, and for measures that encourage behavioural change. Further details of the SDC's recommendations on climate change and energy policy can be found on our website at www.sd-commission.org.uk.

However, it is clear to us that no matter how successful the UK is in cutting energy consumption through conservation and efficiency measures, or through action on transport or in other sectors, dramatic cuts in the carbon intensity of energy supply will still be needed over the next few decades. This will require a huge shift in investment towards renewable energy technologies, and to other low carbon options such as carbon capture and storage. Meeting new EU-wide targets for 20% of all energy to come from renewables by 2020 will be challenging for the UK, and it is against this backdrop that the SDC approaches the issue of tidal power, and its role in a low carbon economy.

1.5 Public and stakeholder engagement

As described in Section 1.2, a programme of public and stakeholder engagement was a major part of this project. This comprised the following key elements:

- A series of three one-day deliberative workshops with 20 members of the public (selected to form a broadly representative sample) in Bristol, Cardiff and Inverness
- A series of six focus groups at three locations that would be directly impacted by tidal power development: Brean Down, Lavernock Point, and Orkney
- Two one-day facilitated stakeholder workshops with a combined attendance of 72 were held in Aberdeen and Cardiff
- A national omnibus opinion poll comprising eight questions with a representative sample of 1010 members of the public
- An online forum debate with the Sustainable Development Panel, which is made up of more than 500 sustainable development stakeholders from all walks of life[24]
- A full and independent evaluation of the entire engagement process.

We have also engaged extensively with a wide range of individuals and organisations including the statutory conservation agencies, non-governmental organisations (NGOs), local authorities, trade associations, and other interested parties.

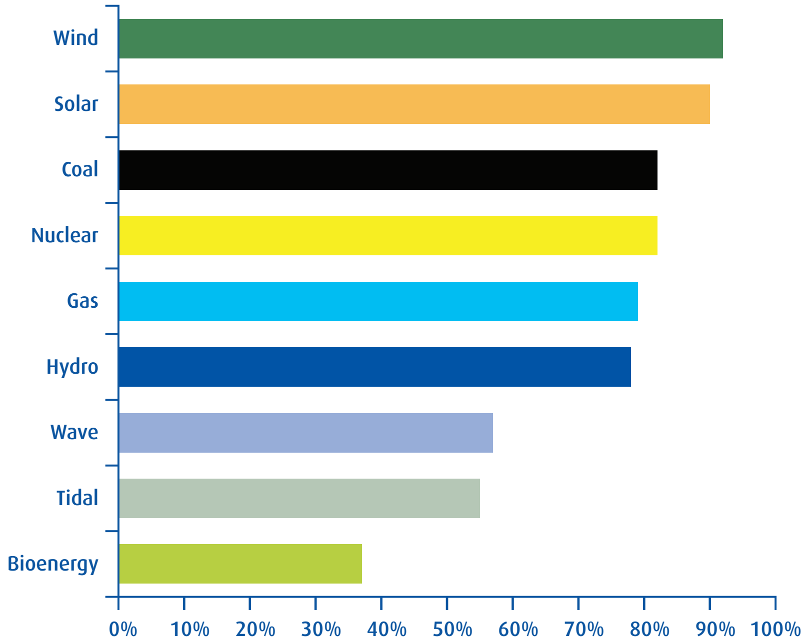
The results of our commissioned engagement work can be found in an independent report available from our website. A summary of the top level findings is provided below, and the work is also referred to throughout this report. The evaluation report will also be available from our website as soon as it is completed.

1.5.1 Tidal power and sustainable energy

The results from our public engagement showed a reasonably high awareness of climate change, although there are some differences in opinion on its importance as an issue. There was less awareness of energy security, but many people became concerned once they were made aware of this issue.

At a national level, only 55% of people had heard of tidal power, and the workshop results showed that some of these may be confusing it with wave power. This is much lower than the level of awareness for wind power (91%). Those with the most knowledge of tidal power seemed to be male, those from higher socio-economic groups, and those living closest to the sea.

Figure 7 **Awareness of energy sources which can generate electricity in the UK**



When asked about the UK's potential for generating energy from the tides, 76% of people felt that there was very considerable, or quite a lot of potential. However, many people felt that they needed more information before they could form an informed opinion of tidal power, with particular concern for further cost information and real-life examples.

All stakeholders at the workshops and within the 'SD panel' debate were aware of tidal power, although there was varying knowledge of the possible impacts, and widely differing views on the desirability of different technology options. There was generally strong support for tidal power; however, when explored in more detail within the workshops, there was a negative opinion overall when it came to a Severn barrage.

1.5.2 Tidal power technologies

Tidal barrages

There was a wide divergence of views between the public and stakeholders on tidal barrages. The public tended to be quite supportive of this technology, and were impressed by the large quantities of electricity produced, the long lifetime of a barrage, and some of the ancillary benefits such as proposed transport crossings (despite some of these being uncertain). They also believed that the disadvantages of tidal barrages, such as the level of impact they would have on the environment and local communities, and the high capital cost, were more profound than tidal stream and tidal lagoon technologies.

Stakeholders were more concerned over the disadvantages of tidal barrages than the public. Although they recognised a number of similar benefits, they emphasised a number of disadvantages, including the impact on habitats and biodiversity, the need for public subsidies, and the possible impact on ports and shipping.

> **"Tidal barrages have so many impacts on bird life and sea shore ecosystem, that they should only be considered in special cases of need."**
>
> SD Panel Member

Tidal stream

On tidal stream technologies, the public were more cautious in their support, and could not see as many advantages as for tidal barrages. This was due to the perception that tidal stream would not generate electricity at the same scale as tidal barrages (due to its modular nature), its unproven status, the comparatively short lifetime of the devices, and the currently high cost of electricity output. However, they also identified far fewer disadvantages, although there was some concern over visual impact.

Again, stakeholders took a rather different view, generally seeing tidal stream technologies in a much more positive light than barrages. They were particularly attracted by the comparatively low environmental impact and by their modular nature, making them more likely to attract investment. They were also aware of the UK's potential to be a leader in developing this technology, which was seen as a major benefit.

> **"Tidal flow technologies may be the most appropriate as they may have less impact on the environment on a day to day level and in circumstances where pollution may be a problem. It would be important to know how long they would operate for in assessing their benefit."**
>
> SD Panel Member

Tidal lagoons

The public felt that tidal lagoons had the least to offer out of the three options considered, with less energy produced than a barrage but with a higher environmental and visual impact. It is possible that much of this concern can be explained by the lack of information (particularly accurate visual material) on tidal lagoons, which led the public to feel that the technology was unproven.

Stakeholders perceived tidal lagoons more positively than the public, although with greater environmental impacts than tidal stream devices. They identified the potential for lower environmental impacts as a benefit when compared to a tidal barrage, along with the potential for local ownership and UK technological leadership. However, there were concerns over the sourcing of the construction materials, the loss of shallow water environment, and the potentially high costs.

> **"A recent study into tidal lagoon technology in Swansea Bay suggested it would have a minimal impact on local ecosystems and ecology, and may in fact create small refuges for birds! I think it is vital the DTI supports this technology as the UK could be a world leader in this sustainable solution. We shouldn't miss the boat as we did with wind power in the 70s and 80s. If proven environmentally acceptable then it should join wind, biomass and building integrated technologies in the provision of renewable electricity for the UK."**
>
> SD Panel Member

1.5.3 Conditions for acceptability

Any assessment of public and stakeholder opinion of relatively unknown technologies, such as tidal power devices, will suffer from a lack of information. This limitation may partially account for the lack of enthusiasm shown by some members of the public towards tidal stream devices and tidal lagoons, as the researchers were constrained by their inability to give real-life examples of what the installations would look like and how much they would cost in the longer term.

As a result, the SDC was keen to ensure that both the public and stakeholders were asked to identify conditions for acceptability for the deployment of tidal power technologies at scale. The public were most concerned about dealing with the environmental impacts related to a tidal power project, and minimising the visual impact. Meanwhile, stakeholders identified a more wide-ranging set of conditions, which have been summarised as follows:

- Full ecological/environmental impact study for all options
- Accurate, independent and centrally coordinated research and evidence base
- Clear government policy on energy, the role of renewables and tidal power
- Improved planning and consents systems
- Full consultation with marine users
- Reduced risk to developers and investors e.g. through a pilot scheme
- Proven economic viability.

When it came to the role of Government, the majority of respondents in the national poll (51%) felt that Government should take the lead on researching and supporting new tidal power technologies – see Figure 8. The broad view of stakeholders was that Government should be responsible for the 'top-down' direction and policy decisions, with regional organisations and the

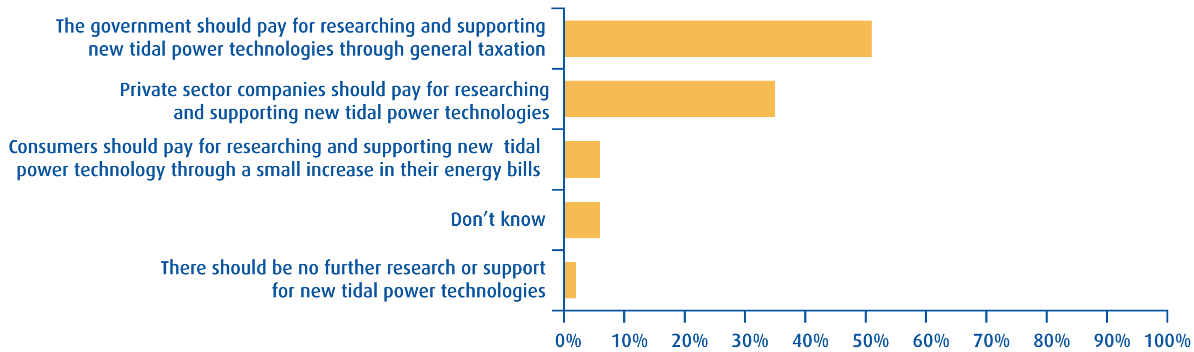
Devolved Administrations taking responsibility for implementation. Stakeholders also felt that while it was important for Government to promote new tidal technologies, they should also ensure they are focused on delivering greater energy efficiency and demand management, as well as other renewable energy sources.

In addition, many SD panel members felt that tidal power should be evaluated as part of a broader rethink of energy policy aimed at making the whole of the UK's energy consumption more sustainable.

> **"Tidal (and all other types of renewable energy sources) should not be developed and used unless they are done so as part of a more comprehensive renewable energy strategy that reduces the profligate demands on energy that our industries, economies, politicians, and the general consumer expects and demands."**
>
> SD Panel Member

> **"To pursue a truly sustainable energy policy we should prioritise reducing demand and encouraging a culture of energy conservation and efficiency. This must be accompanied by radical shifts in our attitudes and behaviours towards the use of energy resources."**
>
> SD Panel Member

Figure 8 **How should the UK best support tidal power technologies?**



1.6 Report structure

This chapter has summarised the UK's tidal resource and electricity generating potential, along with temporal factors and the grid constraint issues facing tidal power developments. It has also provided an overview of Government energy policy, and the SDC's advice on how this can be improved. Finally, the headline results of our public and stakeholder engagement have been presented.

The rest of the report provides more detail on each type of tidal power, with a particular focus on proposals for a Severn barrage.

The next chapter considers the potential for tidal stream development in the UK, looking at the technologies, funding regime, and environmental and socioeconomic impacts. This section concludes with a discussion of the opportunities and barriers facing the industry, and a number of recommendations for developing this industry.

Chapter 3 presents an overview of tidal barrages and lagoons, including a information on existing barrage developments in other countries, and a number of barrage and lagoon case studies. There is a short discussion over the cost estimates available for tidal lagoons, and a recommendation for further action. Issues related to the environmental, social and economic impacts of tidal range technologies are covered in Chapter 4 in relation to the specific example of a Severn barrage.

Chapter 4 presents the evidence the SDC has analysed on proposals for a Severn barrage, including an overview of the various barrage schemes that have been put forward, and a strategic analysis of potential conflicts in utilising the Severn Estuary tidal resource. It covers a wide range of issues, and presents a number of conclusions on the less contentious issues where the evidence is conclusive.

The final chapter summarises the SDC's recommendations on tidal stream and tidal lagoons, before considering the more fundamental, 'deal-breaking' issues raised by a Severn barrage. This concludes with the SDC's advice to Government, and with our recommendations on moving the debate forward.

2

Tidal Stream

As highlighted in Chapter 1, the UK has an excellent tidal stream resource that is presently untapped. A large number of tidal stream devices are in development, and there is a considerable degree of optimism regarding the long-term outlook for these technologies, and their ability to make a substantial contribution to combating climate change and improving our energy security.

This chapter begins with an outline of the different types of tidal technologies, their level of development, and their long-term potential. It then summarises the current UK policy context before considering the issues around the exploitation of the UK's tidal stream resource, such as the environmental and social impacts. Finally, it presents the SDC's analysis of the barriers and opportunities facing tidal stream technologies, along with some suggestions for their resolution.

The material below draws mainly on Tidal Research Reports 1 and 2, as well as the engagement work the SDC has conducted with stakeholders and the public.

2.1 Technology overview

2.1.1 Tidal stream devices

Tidal stream technologies work by extracting some of the kinetic energy from fast-flowing tidal currents and converting that kinetic energy to electricity. To do this they cannot completely block the path of the tidal currents, as otherwise there would be no energy to extract. Instead, they are designed to extract the maximum possible amount of energy whilst still allowing the sea to flow in a normal way – but with reduced energy.

Tidal stream devices are in general modular, stand-alone devices that would usually be installed in large arrays to maximise the potential electricity output. They are therefore similar in terms of deployment to technologies such as wind turbines, which rely on installations of multiple turbines to achieve a significant combined output. However, unlike wind turbines, tidal stream devices can only be installed offshore, and this poses a number of challenges. Some of the challenges are similar to those currently being tackled by the offshore wind industry but the tidal stream industry must develop and test the technology in and under the water in a challenging marine environment; the offshore wind industry could take technology that was developed, tested and proven onshore.

Due to being in the early stages of development, there are currently a very wide range of tidal stream devices with no clear sign of which will be the most successful in the long term. This situation mirrors the early development of the wind industry, where a variety of different designs were developed before horizontal axis turbines became the standard for large-scale installations. The large number of devices under development reflects the success of earlier Government policies towards tidal stream, where seed funding in the 1990s has encouraged the development of a large number of designs and prototypes.

There are several ways of categorising tidal stream devices, with overlap between categorisations. Probably the most obvious design element is the rotor configuration, of which there are three main categories:

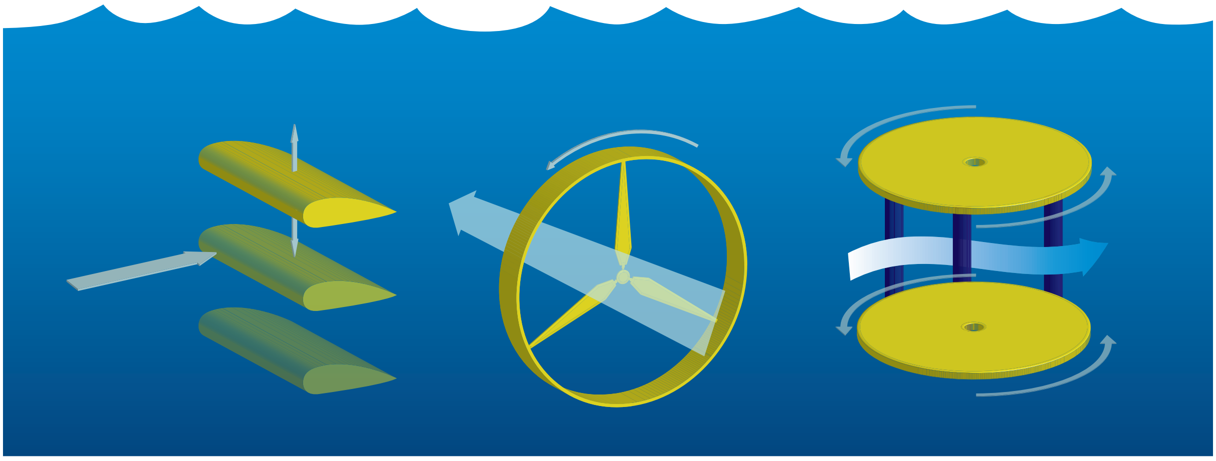
- horizontal axis
- reciprocating hydrofoil
- vertical axis.

These are illustrated in Figure 9.

In addition to rotor configuration, tidal stream devices can be categorised by their placement method, which can be fixed to the sea floor, weighted to sit on the sea floor, or floating (usually through the use of cables attached to land anchors). They can also be ducted, which is a way of concentrating the tidal flows from a larger amount of sea water into a smaller rotor area.

For further information on the types of tidal stream devices being developed, please refer to Tidal Research Report 2.

Figure 9 **Rotor configuration options for tidal stream devices.**



2.1.2 Current level of development

There are a large number of tidal stream devices in development, with a significant amount of this activity taking place within the UK. Research report 2 includes references to 24 known tidal stream technologies. Although these are inevitably at different stages of development, none of these devices has yet progressed beyond the prototype stage, with full-scale demonstration of some devices ongoing or imminent. After successful demonstration, each technology will need to progress to the installation of small (<5MW) and then large (<30MW) arrays, before looking to be installed as 'significant projects' on a similar scale to other renewable technologies such as wind power.[25]

Box 5 describes the installation of a demonstration device in Strangford Lough in Northern Ireland.

One of the success stories of recent years has been the establishment of the European Marine Energy Centre (EMEC) in Orkney, north Scotland – a case study of EMEC is provided in Box 4. EMEC is an impressive example of using public funds to create a generic resource to support and stimulate private sector investment.

Despite the relatively immature status of tidal stream technologies, there is growing enthusiasm over their long-term potential. In fact, most of the technologies surveyed have come about primarily as a result of concerted innovation funding during the 1990s, combined with a more recent injection of funding starting in 2001.[26] As a result, progress to date has been comparatively quick and there is strong potential for tidal stream technologies to replicate some of the growth seen in the early years of the wind industry. This is despite the fact that marine renewables in general have received far less R&D funding worldwide than other electricity generation and low carbon technologies.

There would be a number of significant benefits to UK leadership in the development of tidal stream technologies. These can be summarised as follows:

- Export potential in a relatively undeveloped market
- The transference of skills both into the tidal stream industry from the offshore oil and gas sector (which is facing long-term decline) and the offshore wind sector, and from the tidal stream industry to other marine renewables
- Development of a significant carbon-saving technology – both for the UK and for the world.

2.1.3 Future prospects

The most recent study of the long-term economic potential of tidal stream technologies was completed by the Carbon Trust[26] in 2006 as part of a wider review of marine energy, including wave power.

The Carbon Trust concludes that initial tidal stream farms could generate electricity in their early stages of development at between 9p/kWh and 18p/kWh, with central estimates in the sub-range of 12-15p/kWh. These figures are well above the base cost of electricity, but this is unsurprising considering the current level of technological development and the low level of deployment implied.

Future cost estimates are done on the basis of cumulative installed capacity, as this gives an indication of possible cost reductions as a result of learning. This analysis uses 'cost curves' to estimate this learning effect, and the results show that energy costs from tidal stream devices could fall to 7p/kWh with the installation of 1GW of capacity, and 5p/kWh with 1.5GW. These figures would bring tidal stream output close to, or within, the possible base price of electricity, particularly if fossil fuel prices are high in the future.

As a result, the Carbon Trust estimates that 1-2.5GW of tidal stream capacity could be installed across Europe by 2020, with the majority of this likely to be in the UK.

It is worth emphasising that these levels of capacity are well within the UK's identified tidal stream resource, meaning that the UK has the potential to develop its indigenous technologies in domestic waters, resulting in positive benefits for enterprise and employment. Beyond this, carbon pricing and incentives for renewables are likely to drive international demand for such technologies, presenting an export opportunity for UK-based developers.

2.2 Current Government policy

2.2.1 Tidal stream funding

There are a number of sources of funding for tidal stream devices, as follows:

EU Structural Fund (Wales): Funding is also available from the 2000-2006 Structural Fund Programmes, although expenditure can continue until mid-2008.

Marine Renewables Deployment Fund (MRDF): This £50m fund was set up by BERR (previously the DTI) in 2004 and has four components; the Wave and Tidal-stream Energy Demonstration Scheme, environmental research, related research, and infrastructure support. The demonstration scheme accounts for £42m of the fund and allows for the provision of capital grants and revenue support to technologies that are entering early commercial deployment.

Renewables Obligation (RO): The RO is a revenue support mechanism designed to facilitate the large-scale deployment of renewable electricity generation, thus leading to long-term cost reductions.

Research and Demonstration Programme (Northern Ireland): The Secretary of State for Northern Ireland announced £15.2m of funding in February 2006 to encourage and facilitate the demonstration of innovative renewable energy technologies over the following two years.

Technology Programme: Previously the 'New & Renewable Energy R&D Programme', funding from BERR is available under the Technology Programme to "further develop, evaluate and test wave and tidal stream device concepts and components". Eligible projects must be collaborative in nature and grants are made under a twice-yearly competitive funding round.

Wave and Tidal Energy Support Scheme (Scotland): A £13m fund set up by the Scottish Government to provide grants and support to businesses to support the installation and commissioning of pre-commercial wave and tidal stream devices at the European Marine Energy Centre in Orkney.

The Renewables Obligation works by placing an obligation on electricity suppliers to source an annually increasing percentage of their overall sales from renewable sources, reaching 15% by 2015. The effect of the RO is to create a premium for renewable electricity generators of around 4p/kWh, thus stimulating investment in the deployment of lower cost renewables such as onshore wind and landfill gas. However, the RO provides this premium to all renewable generators, and would provide an additional source of revenue for pre-commercial tidal stream devices. Furthermore, BERR and the Scottish Government now intend to introduce technology banding for the RO, meaning higher cost renewables will receive a higher premium. It is proposed that tidal stream devices would qualify for double the standard level of support under the RO, leading to a premium of around 8p/kWh.

Box 4 **Case study – European Marine Energy Centre (EMEC)**

Background

The European Marine Energy Centre was created to stimulate and accelerate the development of prototype tidal technologies and help them towards commercial deployment.

The site selection process considered 18 different criteria, with Orkney being selected as the ideal site due to an excellent wave and tidal resource combined with a national grid connection and access to the appropriate skills base.

Funding

Development of the EMEC site was led by Highlands and Islands Enterprise and was funded by a large consortium of public sector partners, including:

- Carbon Trust
- Department of Trade and Industry (now BERR)
- European Union, via the Highlands and Islands Partnership Programme (HIPP)
- Highlands and Islands Enterprise
- Orkney Islands Council
- Scottish Enterprise
- Scottish Executive (now Scottish Government)

The EMEC project was established as a result of a recommendation by the House of Commons Science and Technology Select Committee in 2001. To date, the funding consortium has invested over £15m in both capital start-up and development costs. This total funding forms part of the EMEC'S ongoing budget, although the centre is expected to begin recovering some of its operational costs by charging device developers for access to the facilities.

Facilities

The facilities of the centre comprise three sites in the Orkney Islands:

- the wave test centre at Billia Croo on the western side of mainland Orkney
- the tidal test centre in the fall of Warness off the outlying island of Eday
- the office and data facilities in Stromness.

The wave test facility became operational in 2003, with the tidal facility commissioned in 2006. EMEC is the first centre of its kind worldwide to offer monitoring, evaluation and grid connection to developers testing prototype marine energy devices.

The centre's tidal facilities comprise five tidal energy converter test berths, which are situated 2km offshore in water up to 50m deep. There are also five sub-sea cables linking the test berths to an onshore sub-station, and an observation point, a weather station and a data centre. Among the services available to potential device developers are access to a grid connection, space for monitoring, central office facilities and a limited environmental monitoring programme.

Projects

To date one tidal device (the Open-Centre Turbine by OpenHydro Group Ltd) has been tested at the centre, with around six devices in the pipeline. Despite a slow start, developers are now concerned that the centre will be at capacity within the next two years, meaning they may have to wait for spare test berths to become available.

2.2.2 Regulatory and planning framework

Planning and consenting regimes are in place across the UK for pre-commercial marine developments. Frameworks for commercial scale development are not yet in place. The planning and consenting regime is complex, with projects falling under a number of different regimes – further details are available in Research Report 1.

This section provides an overview of the current regulatory and planning framework. The SDC's recommendations on getting the regulatory framework right are discussed in Section 2.4.3.

England and Wales

Existing planning and permitting arrangements for demonstration phase projects in England and Wales are described in guidance published by BERR (previously DTI).[27] Consent is required under the Electricity Act 1989 for any installation with a rated capacity exceeding 1MW. Consents may also be required under the Coast Protection Act 1949, Food and Environmental Protection Act 1985, and the Town and Country Planning Act 1990.

The UK Government position is that a Strategic Environmental Assessment (SEA) will be conducted on the tidal stream resource once the industry reaches an appropriate stage of commercial development. This would probably occur in conjunction with a leasing competition for development rights to the seabed owned by the Crown Estate.

Scotland

Scottish Ministers have devolved responsibility for consenting requirements for tidal stream development. Consents are required under the Electricity Act, the Coast Protection Act, Food and Environmental Protection Act, and the Town and Country Planning (Scotland) Regulations 1997.

The Scottish Government carried out a Strategic Environmental Assessment (SEA) of marine renewables in the north and west coasts of Scotland during 2006-7. The aim of this work was to conduct a high-level assessment of the potential environmental effects of meeting the Forum for Renewable Energy Development in Scotland's (FREDS) estimate that 1,300 MW of wave and tidal energy capacity could be installed around Scotland by 2020.[28]

Northern Ireland

The Department of Enterprise, Trade and Investment (DETI) has devolved responsibility for consenting marine energy development under the Electricity Consents (Planning) (Northern Ireland) Order 2006. Again, consent may also be required under the Food and Environmental Protection Act, which would be considered by the Department for the Environment through the Environment and Heritage Service.

Renewable Energy Zone

The Crown Estate has powers to licence renewable energy generation on the continental shelf beyond the 12 nautical mile limit, in the area designated as a Renewable Energy Zone under the Energy Act 2004. The Scottish Government has responsibility for the zone beyond Scottish territorial waters.

2.2.3 European environmental legislation

The provisions of the European Directives on Environmental Impact Assessment, Birds, and Habitats, and the Water Framework Directive, as implemented in UK legislation, will also be relevant to the assessment and consenting of tidal stream developments across the UK.

In particular, the Habitats Directive requires the designation of European marine sites as special areas of conservation (SACs). Where development is being considered in a designated site (or a site that has been proposed for classification), additional regulatory requirements will apply. In particular, a high level of information on environmental effects will be required to demonstrate that protected features will not be adversely affected. There is extensive discussion of the European environmental legislation in Chapter 4 in relation to a Severn barrage.

2.2.4 Seabed licences/leases

Before deploying tidal devices, developers must obtain a site lease or licence from the Crown Estate, which has a business plan under which it will consider applications for demonstration-scale tidal projects. A further legal requirement will be the satisfactory decommissioning of tidal devices at the end of their consent period or operational lifetime.

2.2.5 Role of nature conservation agencies

The UK statutory conservation agencies have a role in advising Government on environmental and marine nature conservation issues as they relate to tidal stream development. The agencies are already actively considering the potential implications of tidal stream development for the marine environment, and are inputting on the evolving regulatory framework to ensure that any negative effects are identified, and avoided or mitigated. The SDC has received positive feedback on the constructive and proactive approach the agencies are taking on marine renewables, which has focused on the identification of gaps in our knowledge of the marine environment and the possible impact of renewable energy devices.

The Joint Nature Conservation Committee (JNCC), which is the Government's statutory advisor on UK and international conservation issues, has taken a strong coordinating role. The Countryside Council for Wales (CCW) has also been active, undertaking a high level assessment on the potential nature conservation and landscape effects of marine renewables development.[29] In its submissions to the 2006 Energy Review and the Welsh Assembly Government's Energy Route Map, CCW has advocated a process of strategic planning to help identify the most appropriate technologies and locations for the deployment of tidal stream and wave devices.

In Northern Ireland, the consenting process for the Marine Current Turbines SeaGen project has required the Environment and Heritage Service to deal with a specific test device project (see Box 5). English Nature had a general policy position statement on renewable energy, and Natural England (which is the new organisation that took over English Nature's responsibilities in 2006) has responded to the Energy Review in similar terms, advocating a process of strategic planning for renewable energy development. Scottish Natural Heritage also has a position statement on marine renewables.[30]

2.3 Environmental, social and economic impacts

Tidal stream development offers clear and potentially considerable benefits for securing a renewable energy source and producing low carbon electricity. As outlined above, tidal stream also offers the UK an opportunity to develop a potentially valuable export industry.

However, a sustainable development perspective considers these benefits within a framework that must also account for the environmental, social and economic impacts. These impacts will be a mix of positive and negative impacts and the way they play out in practice will vary according to the location and the scale of development. This section principally focuses on any impacts that might be negative, as these impacts will require the closest attention by Government, developers and communities to ensure that they are avoided or mitigated.

Tidal energy installations – whether deployed as a single prototype device or an array – will have varying levels of environmental impact that will require different levels of environmental assessment and monitoring for consenting purposes. The construction of tidal energy schemes will require some environmental baseline assessment (and subsequent monitoring) as part of an Environmental Impact Assessment (EIA), which will also indicate mitigation measures to reduce environmental effects.

2.3.1 Physical configuration of devices

The physical characteristics and configuration of devices will have implications not only for the economics and viability of the technology, but also for the nature and significance of potential environmental, social and economic impacts. At present, a large number of devices are at different stages of development and the long-term prospects of each device cannot be predicted with any accuracy. It is difficult to fully describe the impact one device might have when it is deployed in the sea and it is even more difficult to describe the cumulative effects of a number of devices deployed as an array.

One differentiator is the location of a device within the water column; a seabed-mounted underwater device may be more compatible with existing shipping routes and may have less of a visual impact. Another differentiator is the water depth at which a device can be deployed; some devices with fixed foundations may not be able to utilise high energy sites located in deep water. The marine environment itself poses significant technical and cost challenges, and developers are likely to test devices in more accessible and possibly less energy-intensive sites. Later developments may focus on more challenging sites. The Pentland Firth, for instance, offers the greatest concentration of tidal stream resource in the UK with some of the most challenging conditions – this is unlikely to be an early choice for tidal stream developers.

The interaction between the design of devices and their impacts will be iterative, as developers continue to test and deploy their devices. The environmental, social and economic impacts of early devices will play a part in determining their viability and success, along with other technical success factors, such as energy output and ease of installation and maintenance. This may incentivise developers to search out the low cost and low impact options as the technology develops.

2.3.2 Environmental considerations

By their nature, tidal stream devices are designed to extract energy from the water, and their presence will affect the physical, chemical and ecological features of the marine environment. This section provides an overview of the main environmental impacts and some of the key issues in dealing with the potential effects of tidal energy development on the marine environment.

Scale and locational factors

The scale of each installation (the number and size of the devices installed) and the total number of installations around the coastline will be the key determinants of overall environmental impact. Accordingly, given the relative immaturity of the industry, and the small number of devices being installed, the risk of any significant impacts is at present very low.

This is an important point for decision-makers to be aware of as consents are sought for new devices at the testing stage. However, taking a long-term view of the industry also requires that the potential impacts of large-scale deployment in the future are considered now and taken into account in evolving the regulatory framework and in the ongoing development of device designs. To date very limited environmental monitoring has been required for prototype devices, which means that opportunities to develop the baseline data on effects of devices could be missed. Nevertheless, the SeaGen test project at Strangford Lough will be subject to considerable environmental monitoring over the period of its five year consent (see Box 5).

The location of tidal stream development will be a further determinant of impacts. The desk-based research commissioned by the SDC has primarily considered the potential impacts of tidal stream technologies in generic terms. The impacts of a particular development will depend on site-specific factors ranging from the conservation interests of the site to its location in relation to towns and marine industries. Early tidal installations are most likely to be developed in the more accessible resource locations, with the challenging, high-energy resource locations developed once the technology matures.

These issues are explored in greater depth in Research Report 2.

Available information

To date very few tidal stream devices have been deployed as prototypes, and there is only limited environmental data available. However, these devices are not full scale, nor are they deployed in areas which are likely to be used for commercial generation of tidal power in the future. In addition, the environmental impacts of prototype devices cannot necessarily be taken to represent the potential impacts of generating power from an array of devices on a commercial scale. There are additional issues when the impacts of one prototype device are multiplied up to assess the cumulative effects of a tidal stream array.

Despite the lack of direct observational data relating to tidal energy, a considerable amount of information exists regarding the environmental effects of other marine developments. For example, the offshore wind, and oil and gas industries, provide information on the environmental impacts of drilling, piling and sub-sea cabling in the marine environment. This illustrates some of the synergies between both different categories of offshore renewables, and between offshore renewables (which are experiencing steep growth) and the UK's large offshore oil and gas industry (which is in long-term decline).

This is also a risk issue. At present, where single test devices are being deployed for a relatively short time (say 1-5 years), the risk that environmental damage will result is low, and the significance of any adverse consequences is likely to be low as well. However, as the industry develops and more devices are deployed, the risk and significance of any adverse effects will increase. Any information gaps will need to be progressively filled to avoid this scenario and allow the industry to expand.

There is an important exception, where even a relatively low level of risk needs to be recognised. For European marine sites, a very high level of information will be required as part of an 'appropriate assessment', and it will be necessary to show that development will not have an adverse effect on a protected site or feature before consent can be given.[31] This position will mean that these sites are unlikely to be attractive for early stage testing and installation of devices. Nevertheless, in the longer term, development will not necessarily be inconsistent with the objectives of marine conservation provided good information is available to make the case.

The implications of information gaps for policy makers is discussed in Section 2.4.4 below.

Box 5 **Case study – Strangford Lough**

Background

Following the demonstration of the company's SeaFlow concept turbine off the coast of Lynmouth, north Devon, Marine Current Turbines, a UK company, has developed SeaGen, a 1.2MW underwater, twin-turbine test device. The turbines are mounted on a vertically-moveable cross-arm on a single supporting pole, which is drilled into the seabed and is visible above the water. SeaGen is due to be tested at Strangford Lough, Northern Ireland. Further information is available from the project website: www.seageneration.co.uk.

Funding and investment

The DTI's Technology Programme has provided around £4.27m in grant support to develop the technology. The company has indicated that this has covered around half of the project cost. Marine Current Turbines has secured investment from EDF Energy, BankInvest and Guernsey Electricity, and more recently, from Triodos Bank and AM2 (Bermuda Limited).

Site selection

The Strangford Lough project was initiated in late 2003. The company selected the site for its wave-sheltered environment, strong directional tidal flows, and proximity to the shore and local technical services. Once installed, the turbine will be connected to the local grid and generate enough electricity for approximately 1000 homes. The developer undertook consultation with regulators, statutory consultees, the Crown Estate, the local community and other stakeholders over the course of developing the project.

Environmental issues

The site is also acknowledged to be in an environmentally sensitive area and one of the key issues for the project has been predicting and assessing the potential environmental impacts. This has involved putting in place a comprehensive monitoring programme as part of the five-year consent that has now been granted for the project.

Strangford Lough is an important international site for nature conservation and is designated under EU Habitats and Birds Directives as a Special Area of Conservation, a Special Protection

Area for birds (see Section 2.2.3), as well as being a Ramsar site for internationally important wetlands. The SeaGen test site is in the Strangford Narrows, which connects the Lough to the Irish Sea. The area has important subtidal and intertidal rock, sand, mud, and horse mussel habitats as well as wintering waders, breeding terns and seal populations. An Environmental Statement (ES) was initially prepared in June 2005 to support the company's application for consent under the Food and Environment Protection Act 1985 (FEPA) and to assist the competent authority, Northern Ireland's Environment and Heritage Service (EHS), to fulfil its obligations under the Habitats Directive.

The ES prepared in 2005 recognised that the novel technology meant that there was some uncertainty about the potential impacts on seals and basking sharks. At maximum turbine speed the rotor blades would operate at around 12m/s, about a third of the average wind turbine speed according to the ES. A speed of 10m/s is more likely, which corresponds to around 12 revolutions per minute.

It was also recognised that the installation and presence of the device will have some visual impact on the seascape as the part of the structure that is above water will be visible from land and from the ferry crossing from Portaferry. Once installed, the effects will be more significant during maintenance as a result of increased activity and the cross-arm being raised above the water level.

Outcome and lessons

The EHS initially granted a FEPA consent for the project in December 2005. However, further investigations were necessary to fully support the 'appropriate assessment' process under the Habitats Directive. This process requires a very high level of confidence that internationally-important protected conservation features will not be negatively affected by development. The EHS granted a further consent for the five-year demonstration in February 2007.

The project now has a comprehensive monitoring programme in place for birds, habitats, seals, and basking sharks. The conditions of the consent also give the EHS some options for stopping the operation if significant adverse effects occur, including the ability to require further monitoring and assessment, or even early decommissioning. The monitoring can be expected to generate useful information on the actual environmental impacts of the SeaGen device which will have application in future design modifications. It will also help in predicting potential environmental impacts at other sites or from the installation of multiple devices.

On the environmental issues, the ES indicated that, early on in the project, there was general support from stakeholders for the development of a new renewable technology but that there were potential issues around the international designation and impacts on protected species. The delay in the consenting process to fully address concerns under the Habitats Directive suggests that it might have been possible to avoid or resolve these issues earlier to ensure that the strict requirements were met without delaying the project. However, the case study also indicates that working in an environmentally sensitive area is a major challenge for a one-off demonstration project involving a new technology.

The testing and monitoring should nonetheless provide valuable information on the operation of a tidal stream turbine in the marine environment. The actual installation of SeaGen, which was most recently scheduled for the summer of 2007, has been further delayed because of a problem with the jack-up installation vessel but is due to go ahead shortly.

2.3.3 Summary of environmental impacts

The key environmental impacts from tidal stream development are those related to:

- ecology (habitats and species)
- landscape and seascape
- noise (airborne and underwater)
- seabed, sediments and currents
- water quality

Impacts on other users of the marine environment – such as fishing and navigation – will also need to be considered as part of an environmental impact assessment. In practice, these issues need to be considered much earlier at a strategic level and in site selection. The issue of conflicts of use in the marine environment is discussed in Section 2.3, which considers the potential social and economic impacts of tidal stream development.

Environmental impacts at the various stages of development will need to be considered, including:

- construction
- operation and maintenance
- decommissioning.

At the construction stage, the key impacts will be related to drilling and piling activities, increased levels of noise, and increased activity and pollution risk associated with construction boats and activity. Direct effects on the seabed are greatest at this stage. For tidal stream devices, construction of the device itself would usually take place onshore, followed by installation of the device and associated cabling at sea.

At the operation and maintenance stage, the device may have effects on water movements and sediment, as energy is extracted from the tidal flows, and underwater noise and the turbine operation have the potential to affect ecology, fish and marine mammals.

Tidal stream devices, once developed to full scale, can be expected to have a lifetime of around 20 years. At the decommissioning stage, similar effects to those identified for commissioning can be expected. Further effects at this point may include disturbance to any new community of marine organisms that has become established on the device.

The environmental effects of associated onshore infrastructure, in particular power cabling, will also need to be taken into account, and can often be a significant practical issue during consenting (as separate planning consent must be sought).

Ecology (habitats and species)

A number of marine species and habitats in UK coastal waters have the potential to be affected by tidal energy schemes. These include birds, fish, marine mammals, plankton, and benthic communities on the seabed. Terrestrial habitats may also be affected by infrastructure works to accommodate the landward transmission of electricity.

The main issues affecting habitats arise from changes to the physical environment – for example, changes in water flow and tidal mixing, wave action, tidal inundation, patterns of sedimentation and erosion, and disturbance of the seabed by construction and cabling. These changes can alter the character of marine communities, or lead to the displacement of species from feeding or breeding areas.

Fish and marine mammals may be particularly affected by the generation of underwater noise, and the electromagnetic fields generated by sub-sea transmission cables. Collision risk is another factor that will need to be considered for each device. Although the risk from turbines turning slowly underwater may be low, this risk, and the potential behavioural changes of these species, will need to be assessed with care, and monitoring of installed test devices will be needed.

There are also potentially positive effects from tidal stream development for nature conservation. A tidal installation may function as a refuge area for fish populations as a result of reduced fishing pressure from the creation of 'no-catch' zones. The potential benefits of this will depend on the specific impacts of a device, the scale of its deployment, and consideration of decommissioning implications, but this may offer an opportunity to integrate renewable energy generation (and a commercial activity) with nature conservation objectives.

Landscape and seascape

Many coastal areas have an important amenity and natural heritage value for communities, visitors, and recreational users. The placement of a tidal energy scheme in waters close to the shore may have an impact on the landscape and seascape of the area, particularly where the devices are surface-piercing structures. The level of impact will depend on the landscape character of the coastal area and the type of tidal energy scheme. Scottish Natural Heritage, for example, has suggested that development should be avoided in isolated or undeveloped coastal areas.[30]

Visual effects – both the appearance of a device and its visibility from land or from a vessel – and the impacts on landscape and seascape are often a key issue for local communities, and design and location will need to be considered. While tidal stream development is likely to have a lower impact than wind development, lessons can be drawn from that industry about the importance of early engagement on these issues with local communities. In the case of a new technology, this may mean providing good information to demonstrate the very low visibility of a device or development. The visual effects of supporting infrastructure – substations, pylons – will also be a key issue.

Noise

Noise and vibrations travel significant distances underwater. Increases to background noise during construction and operation may have serious effects on marine mammals and fish, depending on the level, frequency and duration of noise. Again, this is an area where there is insufficient information on the potential effects of noise levels from tidal stream devices.

Depending on the distance from shore, climatic conditions and wind direction, noise from construction, maintenance and decommissioning activities may also affect local communities.

Seabed, sediments and current

The placement of tidal energy structures and their associated cabling on the seabed will result in a change to the physical characteristics of the area, and may involve a loss of habitat. Fixed tidal stream devices will have a relatively small footprint for each individual device, varying in accordance with whether the device is fixed or floating. For an array of tidal devices, cabling arrangements will be complex, effectively increasing the footprint of an installation. Cabling may have a significant but short-term adverse impact on the seabed. At the decommissioning stage, cabling may be left in place to avoid further disturbance, or re-used with a new installation of devices.

The placement of a solid structure on the seabed in an area of strong tidal flows will effect patterns of sediment erosion, transportation and deposition. By extracting energy from the flow, a tidal stream device can reduce the downstream velocity of the turbine considerably, with the effects discernible some distance away. This is one of the key areas where the potential cumulative effects of deploying tidal stream devices in large arrays are unknown and further research will be required.

Water quality

The main issues for water quality from tidal stream development are the potential leakage of lubricants and hydraulic fluids, and the chance that increased volume of vessel traffic associated with the scheme may result in increased levels of fuel and oil leakage into the water.

Design and mitigation measures

Relative to tidal barrages and lagoons, tidal stream devices are expected to have relatively low effects on the environment.[32] This will depend on the type and number of devices deployed, as discussed above. The greatest environmental effects can be expected to occur where arrays, farms or a series of farms are deployed.

Possible mitigation methods for managing effects on the seabed, sediments and hydrodynamics include sensitive design of base structures and choice of location to minimise impact on sensitive sites. The design of devices will also need to consider their interaction with fish, birds and marine mammals. It may also be possible to time construction and decommissioning activities to minimise adverse impacts on sensitive ecological receptors (such as marine mammals affected by noise). Monitoring of test device installations will improve understanding of ways in which impacts can be avoided or minimised.

2.3.4 Social and economic impacts

As the tidal stream industry develops, the social and economic impacts (positive and negative) are likely to represent some of the more tangible effects for communities at a local and regional level. At this stage, there is very limited information to draw on, although it is likely that social, economic and environmental effects will be closely interrelated.

Economic effect from large-scale tidal stream deployment might include those related to:

- commercial fishing
- employment and income benefits from new industries
- opportunities for local industries
- ports, commercial and recreational shipping
- tourism
- wider economic regeneration and export potential.

Many of the impacts from tidal stream development could be economically positive for local communities and the wider economy. An important exception to this is navigation and fishing interests, which could be negatively affected by tidal stream developments due to restrictions on movement and access. The issue of conflict between marine users is discussed further below.

Community effects

In addition to the potential for local employment benefits, tidal stream developments may also have the following impacts or benefits for local communities:

- community benefit payments
- educational opportunities
- impact on historical or cultural heritage sites
- impact on the amenity value of the area
- seascape and visual impacts.

The SDC's engagement with local communities shows that new and unknown technologies can be a very emotive subject. There is a particularly strong need for accurate information on the likely visual impact to enable people to take a view on any proposed development. As with marine stakeholders, early and effective engagement with local communities is highly desirable.

The use of community benefit payments by renewable energy developers is common practice in the onshore wind power industry, and could be easily replicated by tidal stream developers.[33] There may also be the potential to encourage community investment in new tidal stream developments, which is a model that has been applied to some small wind farms in the UK, and on a much larger scale in Denmark.

Conflicts of use in the marine environment

Tidal stream development, particularly as the industry develops and becomes a stronger presence, is bound to come into conflict with other users of the marine environment. Other users of the marine environment include:

- commercial fishing
- commercial shipping and navigation
- dredging and mineral extraction
- Ministry of Defence activities
- navigational aids and lighthouses
- oil and gas industry
- other offshore renewable energy (wind, wave)
- ports
- recreational fishing
- recreational shipping
- tourism
- undersea cabling and pipelines.

The SDC actively sought to ensure that marine users were invited to participate in its stakeholder workshops, and a number of representative organisations from the marine sector attended the SDC's stakeholder workshops. The strong message from those who participated is that this industry must actively engage with and take account of the interests of the marine sector.

As a new activity and form of development, tidal stream development will sometimes conflict with other activities and interests, whether commercial or recreational. This issue of compatibility and conflict is one of the key challenges that a 'marine spatial planning system', as proposed in the Marine Bill, may help to address so that multiple, cumulative, and potentially conflicting uses of the sea can be managed in a sustainable way – see Section 2.4.3 for further discussion. It should not be assumed that the impacts of new developments on other users will be negative. While safety zones around offshore renewable energy installations may affect fishing operators, the wider and potentially beneficial effects on fish stocks should not be ignored if a safety zone is able to function as a refuge.

Various marine users have already started to respond to the developing marine renewables industry. Most organisations responded initially to the development of the offshore wind industry but their awareness of the issues is being extended to wave and tidal energy. A number of organisations have position statements on offshore renewable energy. In general, the marine sector seems to be supportive of tidal energy in principle but there are strong calls for early engagement by renewable energy developers with the marine sector.

One potential issue will be around overcoming assumptions of 'first-come-first-served' for access to the marine environment. The challenge to existing marine users must be that the marine environment is a common resource. While important commercial and recreational interests must be maintained, some flexibility might be required to accommodate new activities. Space must be created to allow new activities to use that resource, considering the pressing need to develop alternative, low carbon energy sources and the considerable UK potential to do so in the marine environment.

The SDC's view is that there is sufficient space for different users of the marine environment to co-exist. A strong strategic overview by Government and relevant stakeholders can assist in avoiding and resolving conflicts. At a project and site-specific level, it is clear that developers will need to engage early and effectively with other users. A model of stakeholder liaison groups, such as those used in the development of offshore wind, may also assist in ongoing engagement, as well as research and coordination issues.

2.4 Opportunities and barriers

This section presents the SDC's view on the opportunities and barriers facing the tidal stream industry, focusing on the role of Government. Drawing on our engagement with industry stakeholders, we look at a number of areas where Government policy could be improved to have the best chance of creating a viable tidal stream industry. The SDC's high level recommendations on tidal stream are presented in Chapter 5.

2.4.1 Funding regime

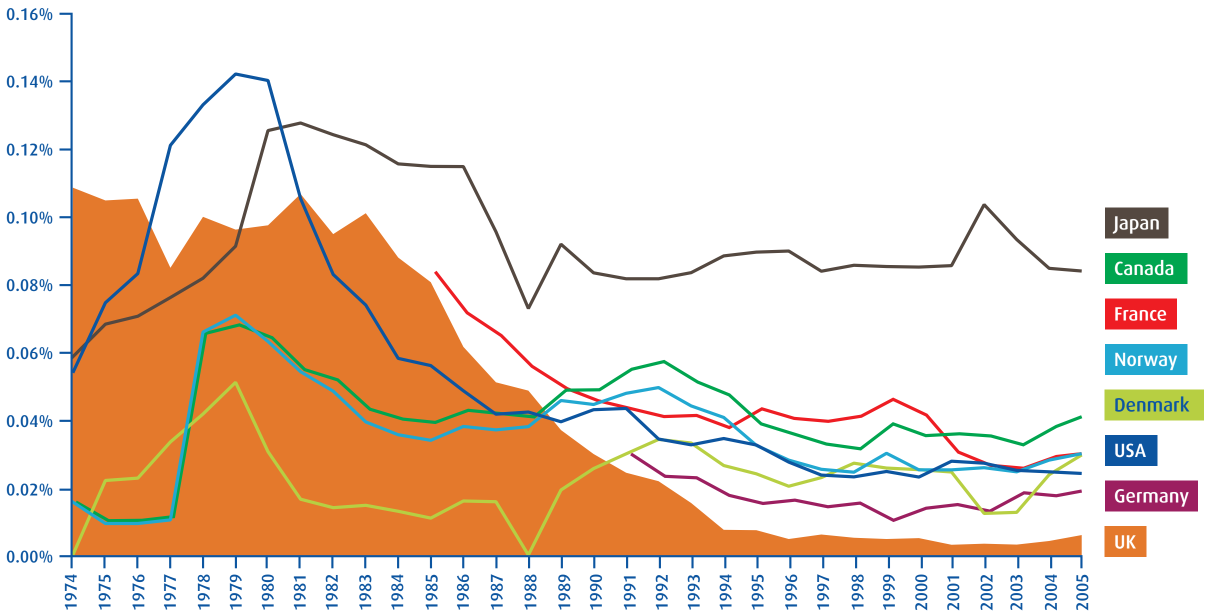
The importance of innovation funding

Experience from the wind industry demonstrates the importance of Government subsidies in the early stages of development. Generous subsidies in a number of European countries helped to drive growth, which led to convergence on a standard three-bladed horizontal axis design, followed by significant learning effects and cost reductions over time. Wind power costs reduced from over 20 Euro cents per kWh in the early 1980s to around 7c/kWh in the early 1990s with only a few gigawatts of installed capacity.[26]

The lessons from the wind industry point to the importance of viewing early subsidies as high risk, state-sponsored venture capital, with even higher levels of risk for each individual 'investment' that is made. Although Governments are often wary of taking such a gamble with taxpayers' money, there is a strong consensus that the role for Government-funded innovation support is to take the risks that the private sector is unwilling or unable to bear.

For example, the Stern Review highlights the role of publicly-funded research and development, and recommended that global public energy R&D funding should double, to around US$20bn. And the International Energy Agency (IEA) states that "it is unlikely that the technological challenges facing the energy sector can be addressed without significant increases to R&D budgets in IEA member countries".[34] Despite this advice, the UK has one of the lowest public expenditures on energy R&D of any developed country – see Figure 10.

Figure 10 **Publicly-funded energy R&D expenditure as a share of GDP**[35] Source: IEA



The Stern Review also highlights the fact that innovation is a process over time and goes far beyond the invention stage. The main steps in the innovation chain were summarised as:

Basic R&C ➔ Applied R&D ➔ Demonstration ➔ Commercialisation ➔ Market accumulation ➔ Diffusion

Despite the obvious simplification of what is actually a highly complex process, it is clear that each of these stages requires a different mix of policy interventions ranging from direct research grants, to partnership funding, to revenue support, and most likely action to remove non-market barriers.

Analysis of current policy

Although the sums of money available to tidal stream technologies are quite small, the SDC received generally positive feedback from stakeholders on the support being given to the industry. However, we did hear a number of concerns over the assumptions behind the establishment of the MRDF, which appears to be slightly ahead of its time in aiming for early commercial deployment. With devices still at the research and demonstration stages, the Scottish Government scheme has been roundly welcomed in helping to fill a gap in the support landscape by providing support linked to the highly successful EMEC (see Box 4). This conclusion is supported by the fact that the MRDF has not yet had any applications for funding, against the nine projects (both wave and tidal) that have been awarded funding from the Wave and Tidal Energy Support Scheme in Scotland.

The banding of the RO is certainly a positive development for tidal stream technologies, but is unlikely to stimulate increased activity in itself as the level of support available is insufficient at current levels of development. The RO is a relatively blunt tool that was put in place to deliver the UK Government's target for 10% renewables by 2010, and the more recent target of 20% by 2020. It was originally justified as a policy measure to deliver long-term reductions in the costs of these technologies, but it was never intended to provide start-up support to new technologies. Its importance to tidal stream devices over the next 5-10 years is therefore limited, though its introduction provides the opportunity for BERR to reassess how to use its MRDF funding scheme in a more targeted manner.

A less risk-averse approach

Overall then, although the current funding regime may be sufficient, the Government must be prepared to make new funds available over the next 10-20 years in a flexible way that responds to the needs of devices at different stages in the innovation chain. This may require an increase in total levels of support over time.

While the UK Government's MRDF sought to provide revenue and grant funding, the proposed introduction of banding in the Renewables Obligation provides Government with the opportunity to redirect the MRDF solely towards direct grant funding to help support further project development. The RO itself will provide the longer-term signal to help stimulate commercialisation.

The success of the Scottish Government's marine funding highlights the fact that there is capability in the tidal sector to develop test sites and early stage demonstration projects. With ongoing support these companies will be able to install initial tidal arrays and pre-commercial schemes.

The SDC recommends that the UK Government uses the existing MRDF funding in a flexible way to facilitate similar developments, whilst also being ready to provide additional funding in the future. The Scottish and Northern Ireland governments will also need to review current funding schemes at the appropriate time and consider successor funding to ensure ongoing learning and development in the tidal energy sector.

There is a strong justification this expenditure. The UK urgently needs to increase its R&D expenditure on low carbon energy technologies so that it can play a lead role in the low carbon economy of the future. Tidal stream is a good example of a potentially new industry where the UK has a well-developed competitive advantage.

Current Government policy towards technologies is very concerned over being 'technology blind', and avoids 'picking winners'. Although this may not always be put into practice, there is a general presumption against taking risks with public money by putting large amounts of money into single projects, in case they fail. However, this aversion to risk may need to be weakened if Government is going to be pro-active in supporting low carbon innovation. As private sector venture capital activities show, it is sometimes necessary to back a large number of innovations in the hope that one or two will be a big success.

The UK Government's Technology Programme has played an important role to date in funding research, device development and testing. This funding needs to continue, but Government must give consideration to (a) the timeliness of awarding funding so that development timelines are not dramatically increased by delays in funding decisions and (b) how such funding can be used alongside other sources such as the MRDF.

As well as central Government funding (from the UK Government or the Devolved Administrations), there are a number of additional ways in which Government could increase funding to tidal stream technologies. The Carbon Trust has a number of technology support programmes, and is well placed in the industry. And the newly established Energy Technologies Institute could be well-placed to make riskier decisions as a result of its strong links with (and part-funding from) the energy sector.

2.4.2 Grid constraints

As noted in Section 1.3.5 and in the SDC's recent report on the role of Ofgem in delivering a sustainable energy system,[13] the availability of transmission capacity is a major issue for renewable generators. This is particularly true for tidal stream developers, as the best resources are in many cases found in locations where there is a severe lack of grid capacity.

Grid capacity at tidal stream locations

For tidal generation technologies to connect to the electricity system there needs to be sufficient capacity on the grid to manage the flow of power that they generate – see Section 1.3.5 for an overview of general transmission issues. The capacity of the grid to connect new tidal generation differs by location. At present, there is capacity for new tidal generation to connect in areas such as the Severn, the Mersey and the Wash, where the Transmission Entry Capacity (TEC) is above the Connection Entry Capacity (CEC). However, the grid in the north of Scotland, where there are significant tidal resources, is heavily constrained with little spare capacity for new generation.

In Orkney North, for example, there is only sufficient capacity to allow the connection of 15MW of generation. To connect a greater quantity of generation a new sub-sea cable to the mainland, at either 33kV or 132kV, would be required. It is possible that this would necessitate an upgrade of the line between Dounreay and Beauly, which could itself trigger further reinforcement of the grid.

Similarly for Orkney South, any project over 10MW would require grid reinforcement. If the total resource of over 2GW were to be exploited this would require a new 400kV double circuit line from Dounreay at least as far as North Yorkshire. The situation is similar for the Shetland Islands in that a new 600MW wind farm has required Scottish Hydro-Electric Transmission Ltd (SHETL) to plan for the construction of a new high-voltage direct current (HVDC) sub-sea cable to connect the islands to the mainland. Once this is built the Shetland distribution network will become part of the GB transmission system and be subject to the same rules.

These examples suggest that there is still some capacity in the north of Scotland for very small generation projects, but that larger projects will trigger reinforcements in other parts of the grid for which the construction timelines are lengthy – ultimately delaying the connection of new tidal stream generation.

In other areas of the UK these issues are apparent but less pronounced. In Anglesey, north Wales, generation of up to 100MW could be connected without triggering additional reinforcement of the grid. However, much of this capacity will de taken up by new wind projects, meaning that although the capacity constraints are less onerous it is still likely that tidal projects would trigger further grid reinforcement which could delay connection until after 2012.

Other capacity issues

There are a number of factors which exacerbate the problems faced by tidal generators as a result of a shortage of capacity on the grid. The first is that there are a number of projects which are awaiting connection already. The upgrade of the Beauly-Denny line in Scotland will allow for an increase in capacity; however the projects currently in the GB queue will account for the capacity increase, meaning that any future tidal stream technology that wishes to connect will require a further upgrade to the grid infrastructure unless it is small enough to connect to a local network. These triggered reinforcements could mean that projects would not a have a firm connection date until after 2015.

The issue of the GB Queue is compounded because a proposed major transmission line in Scotland, the Beauly-Denny line, is subject to planning appeals, as it will affect a large swathe of land across Scotland, including designated landscapes. Decisions on the potential for 'under-grounding' (i.e. running some of the transmission line underground, rather than over conventional pylons) have not yet been taken. If consent is granted, would mean construction would not start until 2012. It is possible that the upgrade of other lines to a 400kV line will meet with similar objections.

An additional issue is that some of the projects in the BETTA queue do not have the necessary consents or financial backing to proceed, but because the queue is managed on a first-come-first-served basis, the projects at the front of the queue which do not have the necessary consents are delaying the connection of projects at the back of the queue which do. The energy regulator, Ofgem, and NGET are working on ways to better manage the BETTA queue but at present the current regime is resulting in significant delays to connection timelines.

The second factor relates to the way in which the queue of generators awaiting connection is managed. At present places in the queue are given on a first come first served basis; this has resulted in some more viable projects being delayed whilst projects at the front of the queue seek planning permission or financial support. New tidal projects wishing to connect would have to join the back of this queue. As recently proposed projects are being offered connection dates as far off as 2019, a tidal stream project could expect to have to wait beyond that for a confirmed connection. However, the recent changes to the final sums liability in addition to the National Grid Company proposal to allow any spare capacity to be utilised by the "most suitable projects" should help with the management of the queue, and bring forward some projects. The SDC believes that over the long term the regime will need to give greater certainty to renewable generators and offer shorter connection times.

The SDC's report into the role of Ofgem[13] noted the potential for adopting a 'connect then manage' approach as an alternative means of managing the GB queue. Under this scenario the TEC could be exceeded, but with the output of generators being managed so that any increased generating capacity resulting from new renewable projects would displace output from conventional power plants.

The third exacerbating factor is uncertainty around the offshore regulatory regime for transmission infrastructure. Ofgem and BERR expect to agree a regime by late 2008; however the process to date has been characterised by indecision on the part of BERR which has led to some delays. The decisions taken over the next year will have an impact on the costs faced by offshore generators for connecting to the grid and as such it is unlikely that significant project proposals will come forward until there is certainty around the regime.

These factors together present considerable uncertainty and delay around the connection of new renewable energy generation technologies and tidal stream projects in particular, which will need to be addressed by Ofgem and Government if tidal power is to play a part in achieving the UK's renewables targets.

2.4.3 Getting the regulatory framework right

As the industry grows and develops, it is clear that the framework for strategic planning and consenting must be robust. The existing position described in Section 2.2.2 will only take the industry so far, and a long term view needs to be taken for the regulatory framework, alongside the innovation support that will be required. Certainty around timeframes as well as regulatory requirements will be one factor necessary to attract investment into the technologies and projects as the industry grows.

Marine Bill and planning

The Marine Bill is a major policy development that will have an impact on tidal stream technologies.[36] The bill makes a series of significant proposals:

- a new UK-wide system for marine spatial planning
- a streamlined, transparent and consistent system for licensing marine developments
- a flexible mechanism to protect natural resources, including marine protected zones with clear objectives
- improvements to the management of marine fisheries in relation to England, Wales and Northern Ireland and the ability to share the costs of management with commercial and recreational sectors
- a new Marine Management Organisation delivering UK, England and Northern Ireland functions.

Of these proposals, marine spatial planning seems likely to be of central importance for contributing to sustainable development in the marine environment, and to managing conflicts between marine activities. The marine environment is traditionally under-regulated and often under-protected. As a result, the SDC is, in principle, very supportive of the bill being taken forward as a policy option, consistent with the principles of sustainable development and with the aim of providing a workable regulatory framework.

The new Scottish Government recently indicated that it intends to introduce a Scottish Marine Bill.[37] The Advisory Group on Marine and Coastal Strategy has recommended that a system of marine spatial planning be introduced, integrated as far as possible with UK and international marine planning systems. The group also recommended a Scottish marine management organisation and improved provision be made for marine nature conservation.[38] This consistency of approach will be welcomed by marine users.

The Planning White Paper may also introduce a further change to the planning framework in the future with proposals that would affect consenting for major infrastructure projects of national significance and would cover large electricity generation in England and Wales. The potential implications for onshore cabling and grid requirements will also be relevant. However, as these issues are not yet resolved and it will be some time before tidal stream technology reaches that level of commercial development, this issue is not explored further here.

Strategic environmental assessment

The decision of Scottish Government to take forward an SEA on marine renewables is indicative of the strong developer base, potential resource and political support to develop a world leading industry in Scotland. The environmental report of the marine energy SEA was published in 2007 and it estimated between 1,000MW and 2,600MW could be developed in Scotland based on current environmental data.[39] The SEA also outlined key mitigation measures which would minimise the environmental impact of wave and tidal devices. The results of the SEA will be used to inform the Scottish Government's marine energy strategy and provide a wide range of data to developers and regulators.

The SEA examined the Northern and Western coastlines and major island areas of Scotland using the FREDS estimate[28] that 1,300MW of marine energy capacity could be established around Scotland by 2020 as a basis for the assessment. It examined the effect that wave and tidal energy devices could have on a range on environmental factors, including bird, mammal and fish life, and also the effect that shipping, fishing lanes and military practice zones could have on the deployment of marine devices. The results of the SEA indicate that between 1000MW and 2,600MW could be developed around the North and West coast with acceptable environmental effects. The SEA concluded it is possible to meet a generating capacity of 1,300MW with only minor environmental effects.

The UK Government position is that a SEA will be undertaken once the industry reaches the appropriate stage of commercial development, probably in conjunction with a leasing competition for development rights to the seabed owned by the Crown Estate. However, they believe it is important that a SEA is carefully timed to avoid a situation where the absence of a SEA begins to hold up the industry, or prevents good decision-making on consent or locational issues.

In the absence of good information and data, it is crucial that policy is structured in a way that recognises and accounts for the limitations of the information that is available. A useful approach advocated by the UK statutory conservation advisor, JNCC, to the Scottish Government, is that a marine renewables strategy needs to be developed using adaptive management techniques.[40]

The suggested approach is intended to account for gaps in our knowledge of the marine environment by allowing environmental learning from demonstration and early commercial projects, while providing a clear signal to the market that significant tidal stream resource may be developed over the longer term. The process would involve several stages, including a gap analysis on environmental information, provision of comprehensive environmental impact assessment guidance to developers, targeted field survey work, and coordinated and collaborative data collection and monitoring. These stages would inform both individual developers' environmental impact assessments as well as a strategic environmental assessment (SEA).

Role of the Crown Estate

Alongside the strategic planning and consenting framework set by Government, the Crown Estate has an important role as the owner of the seabed. The Crown Estate's marine interests cover more than half of the UK's foreshore, the beds of tidal rivers and estuaries, and almost the entire seabed out to the 12 nautical mile limit around the UK.[41] Apart from the usual regulatory requirements, tidal stream developers will also need to secure seabed leases from the Crown Estate.

In offshore wind, the Crown Estate has taken a role not only in granting leases but also in supporting an environmental data collection and research programme – Collaborative Offshore Wind Research Into The Environment (COWRIE). Although it is an organisation run along commercial lines, the Crown Estate's special status enables it to take a long-term view of its estate, and it can therefore be supportive of pre-commercial projects that can prove their viability. The nature of its interests in the marine environment means that the Crown Estate works closely with government departments and agencies, including BERR on energy policy and Defra on marine policy.

2.4.4 Dealing with information gaps

A real issue facing the tidal stream industry and Government is that there is a lack of baseline information on the marine environment and on the impacts on the marine environment of installing tidal stream devices and extracting energy from the tides.

The implication for policy makers is that we need to take care making assumptions or looking for definitive answers as what we know about tidal stream devices and their interaction with the marine environment continues to develop. Policy needs to be structured to take account of the immature state of the evidence base, so that it can respond as we learn more about the marine environment and the interaction of tidal stream development.

Some information will be on 'generic' issues related to the extraction of tidal energy from the marine environment and may draw on experience from other marine sectors such as offshore wind, and oil and gas. Basic information on the effects of drilling, piling and cabling in the marine environment has some application to early stages of environmental impact assessment/starting point for assessing effects). In addition, data sets on marine ecosystems in certain areas will be useful in assessing the potential effects of a tidal device on those ecosystems. A gap analysis on environmental information will need to focus in particular on seabirds, marine mammals, benthic ecology and cumulative impacts.

However, much information will be specific: to a device and to a site. There is an obvious cost attached to obtaining this information, particularly where field work will be required to obtain data from a location. The marine environment is a particularly difficult and expensive environment to operate in, and it will not always be possible to predict in advance whether a site might contain important biodiversity, habitats and species. The best approach to obtaining this information in the most cost effective way will often be to ensure that environmental baseline data is obtained wherever possible at the same time as other primary data. For tidal sites, modelling of the tidal currents and energy potential at a particular site will require such field work.

The Government, in supporting innovation of these new devices, will also have a role in filling gaps with strategic and generic research. The adaptive management approach outlined above can assist. This research will help inform the planning and consenting framework. It will also support developers to make sound decisions and by reducing some of the costs. The Scottish Government's Strategic Environmental Assessment had a specific objective of putting available information into a framework that developers can use. The Welsh Assembly Government is considering a Marine Renewable Energy Strategic Framework.

Information gaps cannot be addressed only by Government. Developers will need to address environmental considerations upfront. Taking a long term view of the potential of a technology under development, its environmental impacts and compatibility with other marine activities will influence its success, if only by making consenting for large scale deployment more straightforward.

A key issue is developing priorities for research. One example is the COWRIE research programme for offshore wind, which is starting to consider other marine renewables. Baseline ecological data on marine sites is also needed and may come from different academic and government research sources, not necessarily related to marine energy. A SEA would be a critical opportunity to draw this information together. Similarly, any competitive tender round for seabed leases from the Crown Estate could consider how data can be centrally held and made available in recognition that, whether for practical or commercial reasons, datasets may be difficult to access, and there are considerable benefits to be gained from good coordination and information-sharing.

The SDC believes that Government and the Crown Estate should ensure that marine energy research needs are dealt with through COWRIE, as this is a well-developed structure for shared learning.

2.4.5 Utilising the EMEC resource

The decision to set up EMEC, at a cost of £15m, is a good example of public funding being used to stimulate private sector investment in an economically and environmentally efficient way. The provision of a single site for testing significantly reduces the need for each developer to find and construct their own testing site, and allows for the minimisation of environmental impacts and for the impact of different devices to be compared in similar conditions. Furthermore, Orkney is an excellent site at which to test tidal devices, as it has a good resource without the harsher conditions found in the Pentland Firth.

But there is a risk that the full potential of EMEC will not be realised. The centre has a very small staff, and is therefore not able to offer the range of support services that might be more efficiently delivered from a central resource. If the UK is to maintain a strong lead in the development of tidal energy, then the position of EMEC needs to be strengthened.

For example, there is minimal budget available for environmental baseline studies to assess the impact of devices on the environment, and the centre does not offer a certification scheme to enable devices to have their results independently monitored and recorded. EMEC has already produced the first Assessment Standard for Wave Energy Convertors,[42] a standard that aims to set out a uniform methodology that will ensure consistency and accuracy in the measurement and analysis of power performance of wave energy devices. There is a need to look at the development of standards for tidal energy devices, as well as other aspects of site installation and management. Providing EMEC with sufficient funding to support work on standards and certification would strengthen its international standing as a test facility whilst also providing the industry with valid, impartial information that will be vital in building investor confidence in the technologies.

There is also a strong case for funding core research and academic staff at the centre, using existing ties with Heriot Watt University, the UHI Millennium Institute as well as other UK higher education bodies.

2.4.6 Creating a development path

Despite the significant interest from communities around the coastline of the UK in tidal stream development, initial demonstration projects are likely to cluster around key locations because devices are some way from commercial deployment. In Northern Ireland, test developments are likely to cluster around Strangford Lough and the northern coastline. In Scotland, developments are likely to grow out of an initial cluster now developing from EMEC.

While our study has identified the excellent resources in the Pentland Firth for tidal stream developments, first and second generation devices are unlikely to be located here due to the challenging conditions. Therefore, support will be needed for development of devices in lower energy areas that provide better testing and development conditions, before the industry is ready for larger-scale deployment in the most energy intensive sites. Around the Highlands and Islands, but in particular in Orkney and parts of the Caithness & Sutherland coastline away from the Pentland Firth, suitable sites do exist. It therefore seems sensible for the UK and Scottish Governments to support the development of a regional tidal energy cluster, or 'hub', between Caithness & Sutherland and the Orkneys for initial tidal development.

EMEC would be in a natural position to offer support and research services, and the Scottish Government has already used its Wave and Tidal Energy Support Scheme to good effect to allow schemes to develop out of initial testing at the EMEC site. This approach could be extended, if additional grid capacity is provided. Alongside EMEC, the Nuclear Decommissioning Authority (NDA) has identified the economic potential of tidal to the Caithness & Sutherland area, and Highlands & Islands Enterprise (HIE) is a long-time supporter of tidal energy.

Within the Orkneys there is only limited capacity for further deployment. However, there is available capacity in Caithness & Sutherland currently being utilised by Dounreay nuclear facility and the capacity of the existing transmission line from Dounreay to Beauly could be increased by adding an additional string of wires to the existing pylon line. By adopting the SDC's recommendations on the way that NGC manages the transmission network, new tidal capacity could be accommodated.

There is a strong case for the Scottish Government to coordinate the work of EMEC, the NDA and HIE to develop a strong regional tidal energy hub, and for one of these bodies to lead on the development of additional transmission capacity, including a strengthened link to the Orkneys. However, due to the Orkneys' status as a Registered Power Zone (which has allowed for additional expenditure by the Distribution Network Operator on network management), connection of the first 15MW of capacity would be possible without any constraints.

The SDC's recommendations focus on tidal stream, and care would need to be taken in managing any synergies or conflicts towards wave power or other marine renewables. In the longer term, it may be more helpful to consider these technologies separately (rather than as 'marine renewables'), as they are likely to have different needs that Government policy will need to respond to. Government should seek to minimise any potential overlap between competing facilities (for example, between EMEC and the proposed 'Wave Hub'[43] in Cornwall) to ensure that public money is spent in the most efficient way.

3

Tidal Range

As with tidal stream, the UK has an excellent tidal range resource that is currently unexploited. A large percentage of this resource is located in the Severn Estuary, but there is also potential for energy extraction in other western estuaries, and potential from shallow water areas with a reasonably high tidal range.

This chapter considers some of the generic issues related to tidal barrages and lagoons, and contains a number of tidal range case studies from around the UK. A more detailed discussion of the issues raised by the exploitation of the tidal range resource – in particular, the environmental, social and economic impacts – can be found in Chapter 4 in relation to a Severn barrage. This reflects the site-specific nature of tidal barrages and lagoons, the sheer scale of the Severn Estuary resource, and the SDC's remit for this project.

The material below draws mainly on Tidal Research Reports 3, 4 and 5, as well as the engagement work the SDC has conducted with stakeholders and the public.

3.1 Tidal range technologies

The tidal range resource refers to the 'gravitational potential energy' that is created as a result of impounding a large volume of water on the high tide. This water is then passed through low-head turbines once a height difference is created on either side of the impoundment, generating electricity.

There are two principal concepts for the design and placement of a tidal impoundment, as follows:

- Tidal barrage: A hard barrier is placed at a strategic point in an estuary with a high tidal range, thus creating an impoundment upstream of the barrage in conjunction with the banks of the estuary
- Offshore tidal impoundment, or 'tidal lagoon': A tidal lagoon is a completely artificial impoundment that would be constructed in shallow water areas with a high tidal range.

According to the limited evidence available, there is not necessarily any major conflict between the simultaneous development of tidal barrages and tidal lagoons, due to possible locations for lagoons outside the major estuaries. There is also very minimal conflict between the development of both these technologies, and the deployment of tidal stream devices, as the resources are in general found in different locations. This issue is discussed in more detail in Section 4.2.4 in relation to the Severn Estuary.

3.1.1 Tidal barrages

The concept of generating electricity from a tidal barrage has existed for over 100 years. In the UK, a series of government-commissioned studies since the 1920s have looked at the potential for a barrage across the Severn Estuary, and since then a number of proposals for other estuaries have surfaced. Despite this activity, no proposal has ever been pursued further, mainly due to high capital cost of constructing a barrage and, more recently, environmental concerns.

However, there is some limited overseas experience with tidal barrages. The largest and oldest energy-generating barrage in the world was constructed at La Rance in France, and began operating in 1966. This 240MW barrage, which generates around 540GWh per year, has a very good operating record, whilst also providing a road link across the estuary. It demonstrates well the feasibility of tidal barrages and has provided some useful information on how they can be operated. Unfortunately, due to a lack of baseline data and the features of the estuary, it provides very little data that might help to illustrate the effect of a barrage on the estuarine environment, and the impact on species and habitats.

The Annapolis Royal tidal generating plant, located in Canada, is a much smaller, 20MW barrage that was commissioned in 1984. It utilises the tidal resource of the Bay of Fundy, which has one of the highest tidal ranges in the world. There are also a number of very small tidal barrage projects located in China and Russia, and there are well-developed plans for at least two medium-sized tidal barrage projects in South Korea.

As Chapter 4 explains in relation to proposals for a Severn barrage, tidal barrages are major civil engineering projects that have very high capital costs. This factor, along with the length of time needed for project development and construction, and the subsequent risk of cost overruns, has limited the private sector's interest in developing such schemes. However, increasing concern over climate change and energy security is leading some to reappraise tidal barrage projects, which have the potential to provide large amounts of low carbon energy for over 100 years.

Environmental concerns remain one of the biggest obstacles to the development of tidal barrages. Estuaries are often home to a number of unique habitats and species – particularly those with a very high tidal range, as this results in particularly harsh conditions that only some species can endure. As with hydropower dams,[44] tidal barrages could have a major impact on local environments, with concerns raised over wider biodiversity objectives. This issue is covered extensively in Chapter 4 in relation to a Severn barrage.

3.1.2 Tidal lagoons

The concept of a tidal lagoon probably originates in proposals from the 1981 Bondi Committee report, which considered a concept called the Russell Lagoons (discussed further in Box 6). The proposal was for a series of three bunded enclosures that would be constructed against the banks of the Severn using dredged material to build artificial embankments in shallow water areas. These would operate in a similar way to a barrage except that they would not fully obstruct the estuary; instead, they would create a narrow channel running in-between the three lagoons.

Figure 11 **La Rance tidal barrage**

More recent proposals are for completely offshore impoundments to be constructed (i.e. not connected to the shore) in shallow water areas from conventional embankments created by dumping sand and rock on the seabed. This would be protected by a rock armour to dissipate wave attack and maintain the integrity of the structure. The pre-fabricated generating units would be positioned on the seaward side of the structure and floated into place as caissons. The SDC is aware of suggestions for possible tidal lagoon developments in Swansea Bay, Liverpool Bay (which is the subject of a theoretical study in Research Report 5 and is also studied as part of a recent report on the tidal resource in the Mersey Estuary), and in the Thames Estuary.

Currently there is no example of a tidal lagoon development anywhere in the world, and this makes evaluation of the technology difficult. The various technologies and methods that would be used are not individually innovative; any innovation that exists is in the concept and its construction.

Tidal lagoons are generally thought to be achievable from an engineering perspective, but there are some differences of opinion on how they might be constructed, and the resulting costs. Most of the differences relate to the design of the structure, such as the gradient and height of the embankments, which in turn may be site-specific (e.g. the ground conditions for some sites may allow for a steeper gradient than others). Using different assumptions on the gradient and height of the embankments leads to different estimations of material requirements, and therefore capital cost. There is also some disagreement over the likely electricity output from tidal lagoons, which rests primarily on whether they are able to achieve a higher load factor as a result of ebb-flood generation, rather than ebb-only generation. The latter is often assumed as the optimum method of operation due to output modelling done on a Severn barrage and from experience at La Rance tidal barrage.

Box 6 **Tidal lagoon proposals in the Severn Estuary**

Various tidal lagoon proposals have been put forward for development in the Severn Estuary, including the Russell Lagoons concept, re-evaluated as part of Research Report 4, and the Swansea Lagoon proposal being promoted by the company Tidal Electric.

Our research suggests that the Russell Lagoon concept for three land-bordered tidal lagoons in the Severn Estuary (see Figure 12) is unlikely be viable when compared to the alternative of a barrage. The energy captured would be considerable at around 6,480GWh per year, but this is less than half the estimated production from the Cardiff-Weston barrage scheme. Meanwhile, the costs appear to be higher due to the longer barriers that are required. It is also possible that a Russell Lagoon-type development would have a similar or even more disruptive impact on the estuarine environment and possibly shipping, due to the channelling effect it would have on tidal currents passing between the three lagoons. Such impacts would put the Russell Lagoons in a similar category to a Severn barrage in respect of the environmental legislation – this is discussed in more detail in Chapter 4.

The much smaller 50MW proposal for a tidal lagoon in Swansea Bay (see Figure 13) is possibly more realistic, although there are a number of uncertainties over the economics as discussed below. Estimates for annual electricity output for such a scheme range from 124-187GWh per year, putting it on a similar scale to a medium-sized onshore wind project.

Figure 12 **Proposed position of the three Russell Lagoons**

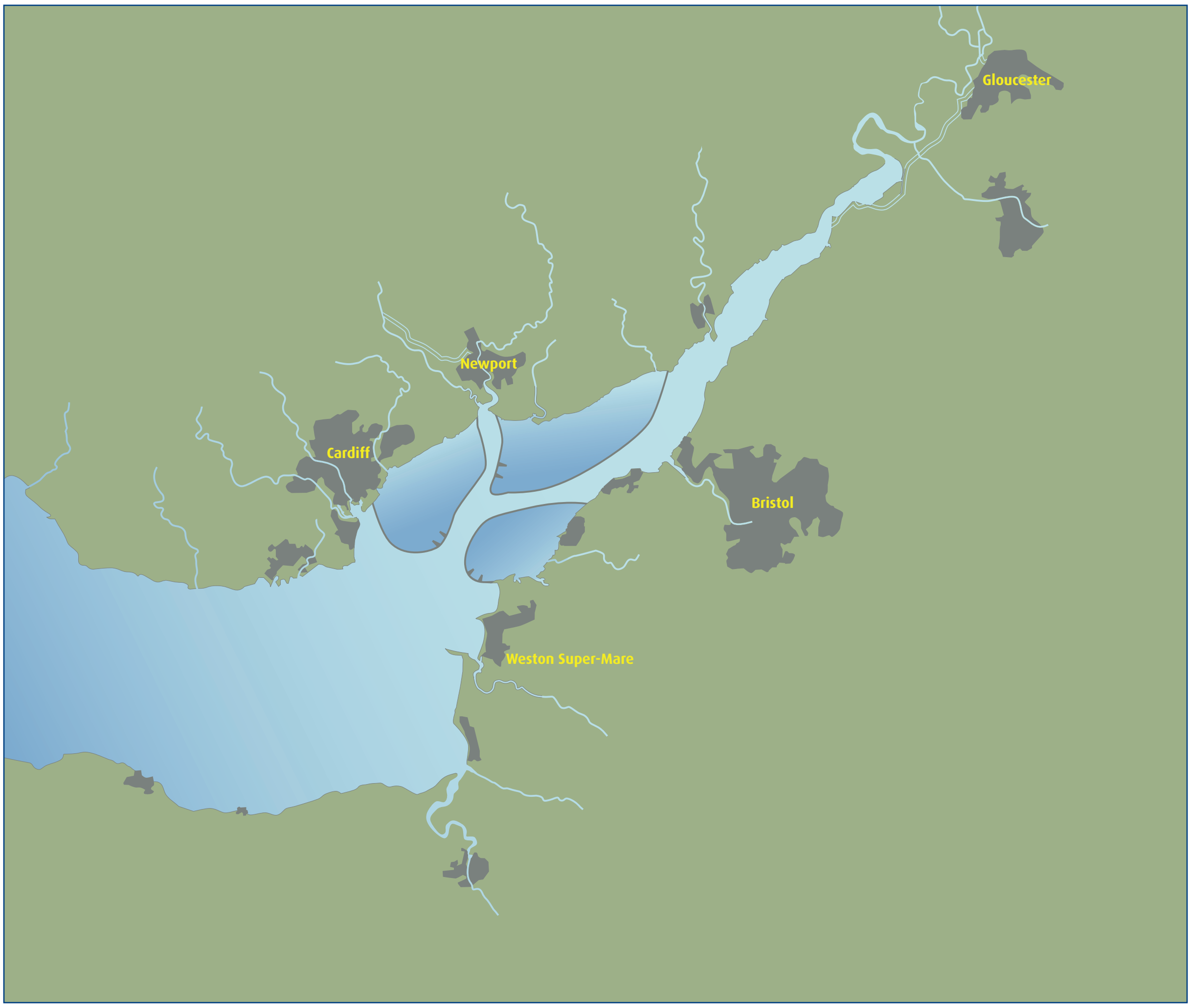
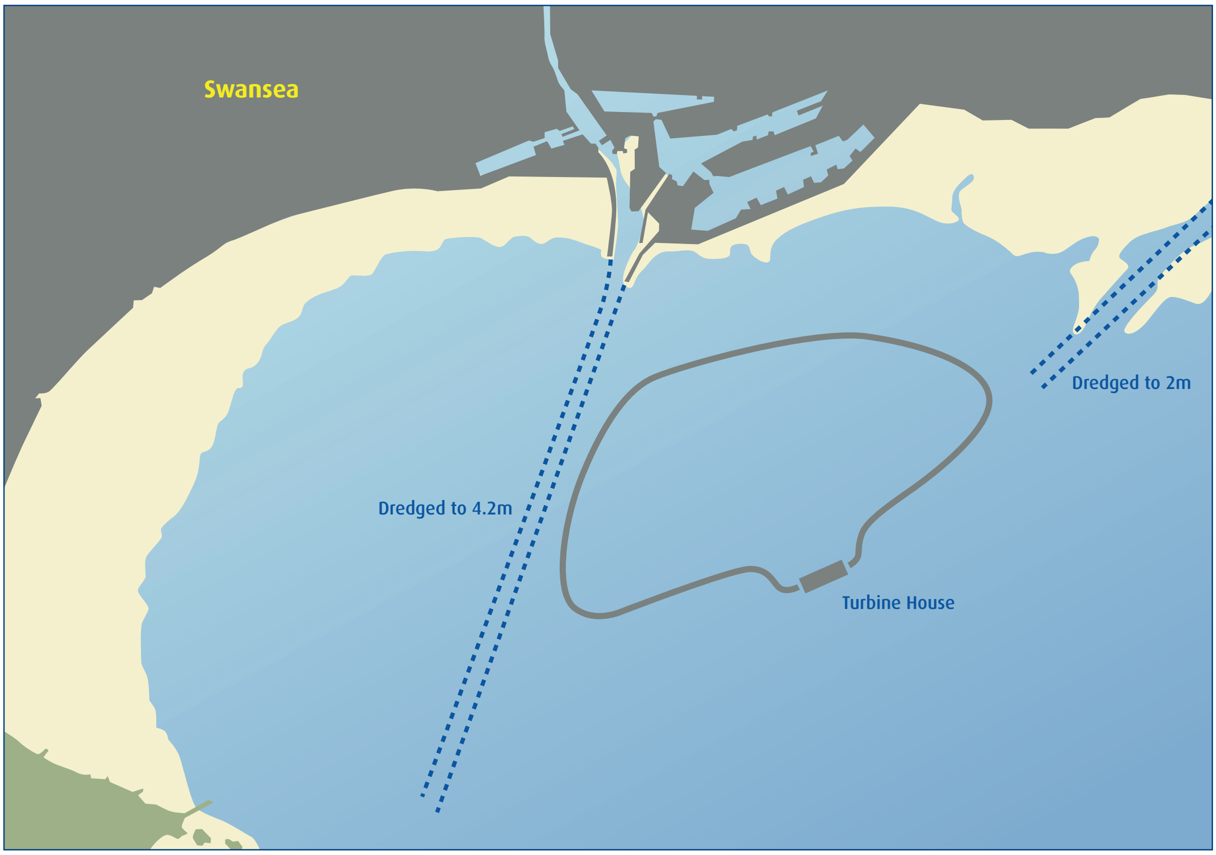


Figure 13 **Proposed position of the Swansea Bay tidal lagoon**



The impact of these assumptions is illustrated well by comparing estimates of the capital cost of a tidal lagoon in Swansea Bay, as proposed by Tidal Electric Ltd (see Box 6 for further information). The developer estimates a total capital cost of £81.5m, compared to the £255m estimate given by a DTI-funded study. A more recent estimate by RWE npower[45] for a similarly-sized scheme in Liverpool Bay has a capital cost range of £108m-£135m.

Such differences in capital cost estimates lead to very large variations in estimates for the unit cost of electricity output – see Table 2.[46]

Table 2 **Unit cost of output estimates for proposed Swansea Bay tidal lagoon project**

Unit cost of output (p/kWh)	**Capital cost** (£m)	**Annual output** (GWh/y)	**Discount rate**			
			3.5%	**8%**	**10%**	**15%**
Tidal Electric Ltd	£81.5m	187	2.05	4.15	5.13	7.67
DTI-commissioned review	£255m	124	8.7	18.39	22.91	34.63

The SDC does not believe there is enough information to determine which cost estimate for this first-of-a-kind project is most accurate due to the lack of any practical experience. Although the potential for cost reductions over time as a result of innovation are limited (the technologies utilised can be classified as 'mature'), there could be substantial opportunities for 'learning by doing'.

3.2 Funding regime

There is no explicit Government support programme for tidal barrages or lagoons. However, as renewable sources of electricity, a developer looking to construct a tidal barrage or lagoon would qualify for support under the Renewables Obligation (see Section 2.2.1 for further details). This provides revenue support once the project is commissioned and is generating electricity, and therefore tends to favour technologies with a low risk profile and comparatively low capital costs.

As a result, it is debatable whether the RO (along with the low carbon premium implied by the EU Emissions Trading Scheme and the Climate Change Levy) would provide enough of an incentive to stimulate private sector investment in tidal barrages or lagoons on its own. Although the funding available under the RO is due to be banded according to technology type, it is currently unclear whether barrages and lagoons will qualify for additional support once the bandings are announced.

For very large schemes, such as a Severn barrage, there is a strong case for providing support outside the RO, as the level of output represented by such schemes could have a detrimental effect on the rest of the renewables sector due to fears of a collapse in the price of Renewables Obligation Certificates (ROCs). Smaller schemes may find it possible to raise finance under the current funding regime, despite the constraints imposed by such capital-intensive technologies. However, the economics of barrage and lagoon schemes are likely to improve with scale, making larger (and less easy to finance) schemes potentially more viable than smaller ones.

A lot depends on the perceived risk of a technology, which relates to concerns over obtaining development consent (and in particular, uncertainties over the cost of compliance with any environmental designations), but also uncertainties over design and construction methods, and concern over possible delays. This is likely to affect tidal lagoon proposals more than tidal barrage projects, as there is no existing evidence to draw on and the concept remains unproven.

3.3 Exploring the policy options

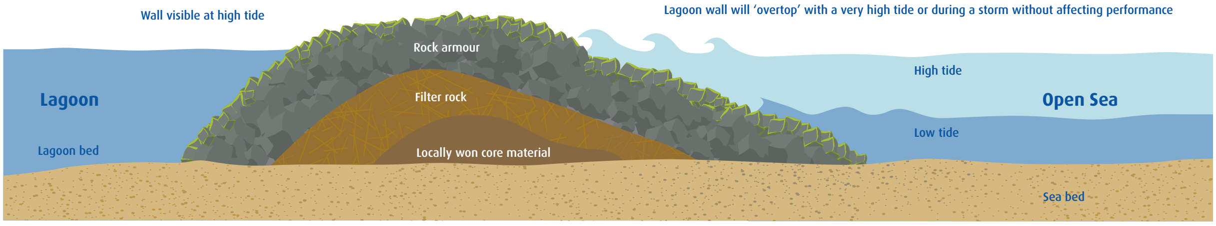
For tidal barrages, there is good justification for some limited further investigation of options outside the Severn Estuary, particularly where there are ancillary developments (such as a transport link, or for floor protection) that could be a major component of any proposal. The SDC has not considered non-Severn barrage options in enough detail to comment on the need for any changes to Government policy to stimulate potential interest. However, our conclusions on a Severn barrage may be relevant to the consideration of some of these schemes, particularly those on compliance with the environmental legislation and on ownership models.

If one or more barrage options are developed in the UK, then a strategic overview will be needed to ensure that there is no conflict between them. This is particularly important where habitat compensation is required (see Section 4.10.4 for further details), as the compensation required for one scheme may rely on other estuaries remaining undeveloped.

For tidal lagoons, the main issue is a lack of hard evidence, particularly on construction methods, costs, and environmental impacts. The SDC believes that the only way to fill these information gaps is through the construction of one or more demonstration projects. As there little, if any, research activity on tidal lagoons elsewhere in the world, there is a very good case for the UK to lead on developing a more robust evidence base that can be used by governments and the private sector to decide whether tidal lagoons are an economically and environmentally viable way to generate low carbon electricity.

Experience suggests that a tidal lagoon demonstration project is unlikely to come forward without some form of additional support. This could be achieved by placing tidal lagoons into a higher band within the revised Renewables Obligation, possibly combined with grant funding. However, an alternative option would be to announce a competition to develop one or more demonstration projects, similar to the process being proposed for carbon capture and storage.[47] The SDC believes that there are a number of parallels between the two technologies that would favour a comparable approach. Finally, any publicly-funded research that is conducted on tidal lagoons should be placed in the public domain.

Figure 14 **Artist's impression of the construction of a tidal lagoon wall**



3.4 Tidal range case studies

As discussed in Section 1.3, a large percentage of the UK's tidal range resource is concentrated in the Severn Estuary. Due to the scope of the SDC's project, and the complexities of the issues involved, the option of a Severn barrage, which could capture a large percentage of the Severn resource, is discussed separately in Chapter 4.

This section takes a more detailed look at other potential options for capturing the UK's tidal range resource, with an overview of tidal lagoons, and a summary of proposals for barrages in the Mersey and Thames estuaries.

Mersey Estuary

The Mersey Estuary has a mean spring tidal range of 8m and a potential resource of 1,400GWh per year. It has been the subject of a number of studies looking at the potential for a tidal barrage, and culminating in a report by the Mersey Barrage Company in 1992. However, the proposal was never progressed further, although there is now renewed interest as a result of a recent study commissioned by Peel Environmental Ltd in association with the North West Regional Development Agency (NWDA) and the Mersey Basin Campaign.[48] The SDC has considered this new work, along with the summary of existing proposals provided in Research Report 5, in preparing this brief summary.

Figure 15 **Map of the Mersey Estuary showing study zones for used in NWDA study**

Source: Peel Environmental Ltd.

As highlighted by NWDA study, there are a number of potential options for harnessing energy from the Mersey Estuary. In order to assess the options, the estuary was divided into study zones, as shown in Figure 15. The only viable option for Zone 1 was considered to be a tidal lagoon, which could be operated independently from the other options. For the remaining zones, the most productive options were two tidal barrage options (one termed as a 'tidal gate'), although several tidal stream options were also studied.

The capacity and estimated electricity output from each option is shown in Table 3. The most recent previous estimate for electricity output from a Mersey barrage was for 1,450MWh per year, but this included gains from flood pumping, which the more recent studies do not. The construction costs of a Mersey barrage have been estimated at £1.5bn (inflated to 2006 prices). This results in a unit cost of output ranging from 12.27p/kWh to 15.79p/kWh when a commercial discount rate of 8-10% is applied. Section 4.8.2 discusses the impact and appropriateness of using commercial discount rates in relation to a Severn barrage. However, even after allowing for cost reductions and the benefits of carbon-free electricity, these costs are unlikely to be commercially competitive under current market conditions.

Table 3 **Comparison of main tidal power options for the Mersey Estuary**
(source: Peel Environmental Ltd)

Technology option	**Rated capacity** (MW)	**Annual electricity output** (GHh)
Tidal lagoon (Zone 1)	350	650
Tidal barrage (Zone 2)	700	1,200
Central reservation (Zone 2)	20	40
Constrained channel (Zone 2)	50	100
Tidal fence (Zone 2)	35	80
Tidal gate (Zone 3)	380	700
Water wheel (Zone 3)	200	500

Like the Severn, the Mersey is a highly protected estuary, and has international designations as a SPA and Ramsar site and a number of national designations – see NWDA study[48] for further details. Liverpool Bay, Mersey Narrows, and the North Wirral Foreshore are all proposed SPAs. The estuary houses a number of intertidal and subtidal habitats that support populations of invertebrates, although these habitats are less pronounced in the Mersey narrows, where the tidal stream resource is strongest. The Mersey has seen considerable growth in fish and bird species as changes to industrial practices have made the river less polluted, and there are over 40 species of fish, and large populations of waterbirds, which could potentially be displaced by any proposed project.

The NWDA-commissioned study identifies the barrage proposals as the most disruptive in terms of environmental impact, but detailed up-to-date analysis has not been conducted in relation to how a scheme would impact on the protected features and species.

The Mersey is also an important shipping corridor, and although a barrage could be constructed upstream of Liverpool port, it would impact on access to Garston, Eastham Locks, the QEII Oil Lock and the Manchester Ship Canal. The studies done by the Mersey Barrage Company involved a detailed analysis of ship movements based on shipping traffic from 1990, which included conditions predicted by the hydraulic model. The results of this showed average increases in voyage times of around 40 minutes, resulting in cost increases of around £1.5m per year (1992 prices). In addition, maintenance dredging requirements were estimated to increase by up to 60% in comparison to pre-barrage conditions. Naturally, this data would need to be updated to take account of current and future shipping requirements if a barrage option was to be developed further.

One of the major drivers behind investigations into exploitation of the Mersey's tidal resource has been the potential for a variety of non-energy benefits. The Mersey Barrage Company conducted an economic valuation of these benefits, concluding that a barrage would result in additional benefits of between £90m and £213m. The potential for a new road link is seen as one of the main non-energy benefits, as well as increases in tourism and amenity. However, the analysis uses a very low valuation of the loss of intertidal habitat, and this may not take account of the protected nature of these sites, and the resulting requirements to provide compensatory habitat for protected bird species.

It is not clear at this stage whether the recent study commissioned by NWDA and others will result in further work, or indeed a full project proposal. However, there does seem to be real enthusiasm for harnessing the tidal resource in the Mersey, and a consortium of interests that might be willing to take this forward.

Loughor Estuary

The Loughor Estuary in Wales has an annual mean spring tide of 3.9m, with the upper estuary being identified as a potential site for a small tidal energy barrage of 5MW. The proposed barrage would extend from Burry point at the entrance of Carmarthen Bay to Pontardulais, a point where there is already a natural constriction where a railway line and the A484 cross the estuary.

A major incentive to the construction of the barrage is the potential for a marina upstream of the barrage for recreational use. The barrage has the potential to generate 15.1GWh/year if allowed to operate all year round. However, the use of the scheme for amenity purposes (i.e. the marina) would reduce output to around 9.7GWh/year, as the output would be limited during the summer months to retain high water levels upstream; the exact output penalty would depend on the operation of the marina. Whilst the inclusion of an amenity element may reduce the output of the barrage, it also improves the economic justification for a barrage by spreading some of the construction costs to the businesses developing the marina.

The unit cost of electricity where the barrage is generating all year round compared to when it is running at lower output during the summer months depends largely on the discount rate used. At higher discount rates, the unit cost of output is lower when there is reduced output during the summer months (due to amenity use), but at lower discount rates the unit cost of output is lower if the barrage generates all year round. The small scale of the project would mean it could connect easily to the united utilities 11kV distribution line.

As with many barrage proposals, the quantity of mobile sediment and its propensity to rapidly erode and accrete is a serious concern, which may in turn change the hydrodynamic regime. The Loughor Estuary inlet provides nursery areas for whiting, plaice and sole, and has three designated production areas for cockles and mussels. A barrage in this location is also expected to disturb bird and invertebrate populations, as the mid-shore mussel beds are important bird feeding areas and major wildfowl roosts are present on the salt marshes at Whiteford. The impact on these habitats and species would be more pronounced during the construction period.

The mouth of the Loughbor Estuary overlaps part of the Carmarthen Bay and Dunes Special Area of Conservation (SAC), which is a designation under the EU Habitats Directive. The estuary is also contained within the Bury Inlet Special Protection Area (SPA) for avian features under the EC Birds Directive. Additionally the Burry inlet is identified as a Ramsar site for wetland features under the Ramsar Convention.

The Loughor Estuary has a small power generation capacity compared to the Mersey Estuary or the Severn. This has a negative impact on the economic viability of the proposals, notwithstanding the environmental concerns that would need to be overcome for any project to proceed.

Duddon Estuary

The Duddon Estuary, located on the Cumbrian coast, has a relatively high mean tidal range of 5.8m, and interest in its potential for generating tidal power was first identified in 1988. The local authorities were interested in the potential of a barrage both for energy capture and a new road crossing, which would improve the region's transport infrastructure.

The proposed alignment of a barrage extends from the mouth of the estuary just west of Haverrigg to Sandale Haws dune system, spanning a total of 4.4km. This location was seen as favourable as it offered the greatest energy potential. The proposed design for the Duddon barrage would include ten 10MW double-regulated turbines with an expected annual energy output of 212GWh/year.

The existing distribution network around the Duddon Estuary does not have capacity to allow connection of the project. For connection to occur, a new 132kV line would need to be constructed from the connection point near Barrow, to Hutton, a distance of 45km. The capital cost of this line connection would be about £5m, roughly 1.4% of total project costs. The project would need to receive the appropriate consents and financial backing before construction could begin on the line, meaning that connection would probably not occur before 2020.

The proposed project would include a road between Barrow and south Cumbria, which would reduce the journey distance by approximately 20km, equal to around 40 minutes. This would allow better transport connections to Millom and Haverigg, which are not well served by the existing road network because of their relative isolation.

The major industrial towns in the area have suffered as the core manufacturing economy of the region has declined. The proposed project could involve a workforce of some 1,200 employees during construction, with a further 300 jobs supported by indirect requirements such as accommodation. About 30 people would be required to operate the barrage when commissioned.

The area is recognised as an area of national conservation value and forms part of a larger Special Area of Conservation under the EU Habitats Directive. Additionally, the entire estuary is a Site of Special Scientific Interest, and is designated under the Ramsar Convention.

The estuary supports spawning grounds for sprat and a nursery area for herring, whiting, plaice and sole, with cod bass and rays commercially exploited in the area. It is also a designated production area for cockles, and there are regular sightings of harbour porpoise. As a result, there would need to be in-depth analysis of the environment impact of the proposal, and steps taken to compensate for the damage caused.

Wyre Estuary

The Wyre Estuary in Lancashire has a high mean tidal range of 6.6m, which makes it an attractive location to generate tidal power. There are two possible sites which are being considered for the location of a barrage. The barrage would have an installed capacity of 60-64MW (depending on the alignment) and would be expected to generate 123-133GWh/year. There is also the potential for it to provide a new road crossing at the mouth of the estuary; this would require a link road to be built across an existing golf course. Although the road link is not regarded as central to the scheme, it may be viewed as an opportunity to improve local infrastructure.

The total project cost is estimated at around £138m, resulting in a unit cost of output ranging from 5p/kWh to just over 19p/kWh depending on the discount rate used. The relatively small scale of the project would allow connection to the existing distribution system via a 11kV line.

The Wyre Estuary has important conservation designations, and is a Site of Special Scientific Interest. The estuary is a spawning ground for sprat and a nursery area for herring, whiting, plaice and sole. Virtually all the rivers draining into Morecombe Bay are important for salmon and sea trout, so the construction of a barrage would affect these species, in addition to a potential impact on the commercialised cockle industry. The estuary is also important for wintering wading birds and wildfowl.

Although the impacts to the environment have not yet been accurately quantified, there is a concern that with the change in the estuary's profile there could be localised erosion and loss of saltmarsh habitats. Subsequently the area to the west of the estuary is densely populated and there are numerous other uses of the coastline, including tourism, fishing, and oil and gas developments, all of which could be affected by the construction of a barrage.

Thames Estuary

The current Thames Barrier, which was completed in 1984, is a major component of London's flood defences. Due to the impacts of climate change, such as sea level rise and increased storminess, it is likely that London will need to consider building new flood defences to protect it over the long-term. This issue is currently being studied as part of a large-scale project called 'Thames Estuary 2100' to develop a tidal flood risk management plan for the estuary.[49]

It is suggested that a new flood protection barrier could be designed to incorporate energy generation (possibly up to 800MW), and a new river crossing. The cost of a new flood protection barrier is already estimated at around £20bn, so incorporating additional features would help improve the economics of any scheme, and could potentially generate economic development and climate change mitigation benefits for London.

No further details are currently available, but the SDC believes that there is significant potential in energy generation from the Thames, and this merits serious consideration.

4

A Severn Barrage

4.1 Background

This chapter will focus on proposals for a Severn barrage[50] from a sustainable development perspective. This focus is in recognition of the SDC's remit for this project, which specifically calls on the SDC to consider the resource in the Severn Estuary and the issue of a Severn barrage. A Severn barrage, if developed, would be just one renewable energy project among the many that will be required. However, the SDC believes that our approach on this issue is justified by the high concentration of tidal range resource, the unprecedented scale of the proposals, and the need for Government to take a strategic decision on whether or not further investigation should take place.

The need for a strategic decision to be made on this issue is based on our recognition that a number of factors are at play. The 2006 Energy Review referred in particular to concerns about the environmental impact of a Severn barrage, and this issue has been a key criterion in our review. The Severn Estuary has the second highest tidal range of any estuary in the world, and the unique hypertidal habitats it supports are protected by UK and international law. These important protections point to the need to give careful consideration to alternatives and the competing public interests between conservation and biodiversity, and the provision of secure, low carbon energy supplies. A Severn barrage project would represent a major infrastructure project on an international scale. At a regional level, such a large-scale project would have profound implications for the economy and for society in the south-west of England and south Wales.

In the context of climate change and renewable energy targets, there is renewed interest in re-examining a Severn barrage. But the costs and risks would be significant, and development is unlikely to occur without some form of Government support, both political and financial. These factors mean that Government needs to develop a long-term position on this issue. The SDC believes that this position must be informed by the principles of sustainable development.

This section draws primarily on Research Report 3, which goes into more detail on many of the issues discussed here.

4.1.1 Chapter outline

Our analysis begins with a strategic overview of the Severn estuary tidal resource, including a summary of the various barrage options, followed by a look at the alternatives to a barrage and the conflicts in resource utilisation that emerge. We then consider the contribution that the two primary barrage options might make to UK electricity supply, and the characteristics of electricity output and the implications for grid management. This is followed by a summary of the evidence we have collected on the carbon payback of the two barrage options, and the estimated contribution they could make to reducing carbon dioxide emissions.

The report then goes on to consider the physical effects of a barrage development, including consideration of data uncertainty, sound science, tides and currents, morphology, and the sedimentary regime. These conclusions are used to determine the possible impacts on the environment and conservation status of the Severn Estuary, and economic and social impacts at a regional level. A separate section deals with the estimated costs of a barrage scheme, and looks at financing options and how these fit within current energy policy.

Finally, the report summarises some of the results of our public and stakeholder engagement work before commenting on the policy process going forward and issues of good governance.

4.2 Strategic overview of the Severn Estuary resource

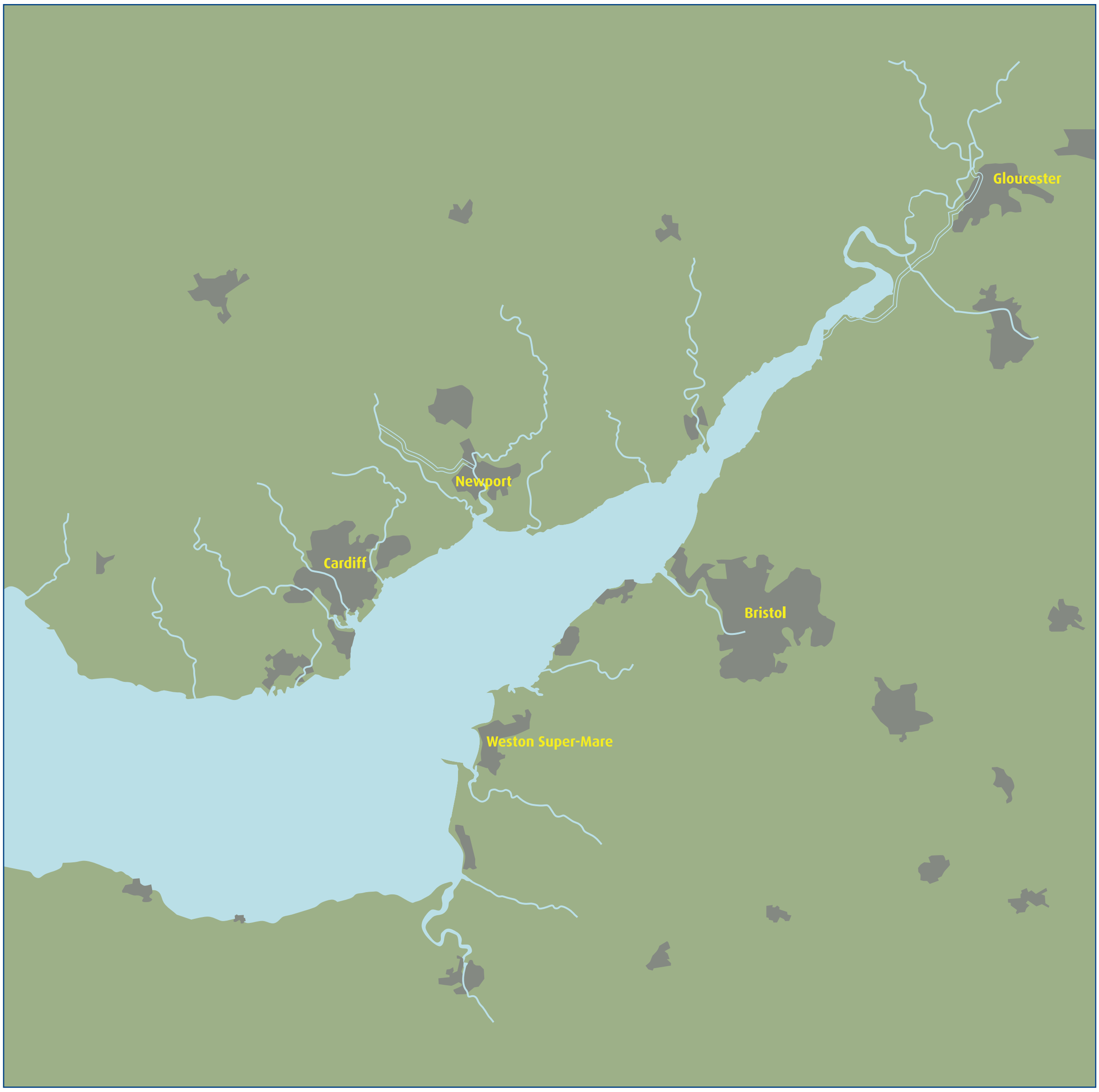
As the shown in Chapter 1, the Severn Estuary stands out as the UK's largest single concentration of tidal range resource. This section summarises the main barrage options proposed for capturing this resource and looks at any potential conflicts between the development of a tidal barrage and tidal stream devices or tidal lagoons. It also considers the compatibility of more than one tidal barrage.

4.2.1 The Severn Estuary

The Severn Estuary is located on the west coast of Britain, where the river Severn meets the Bristol Channel, between south west England and south Wales. In addition to the river Severn, which is the longest and has the highest water flow of any river in Britain, the estuary is also fed by the rivers Wye and Avon. The estuary supports a number of major cities, including Bristol and Cardiff, and is the site for a number of industries, including port installations, chemical processing plants, and nuclear power stations.

The Severn Estuary is a hyper-tidal estuary system as a result of having the highest tidal range in the world after the Bay of Fundy in Canada, with a mean tidal range of 8.2m at Avonmouth. This has resulted in around 200km^2 of inter-tidal area and a highly dynamic sediment regime that is in a constant state of flux.

Figure 16 **The Severn Estuary**[51]



Source: Severn Estuary Partnership

4.2.2 Severn barrage options

The consideration of a Severn barrage has had a long and chequered history, with a number of different studies and proposals surfacing over the past 80 years or so, along with the reports from two Government-backed Committees. The first of these was the Bondi Committee report in 1981 which favoured an ebb generation barrage scheme on the Cardiff-Weston alignment. A subsequent two year study was funded and carried out by the Department of Energy, Central Electricity Generating Board, and the Severn Tidal Power Group (STPG) between 1987 and 1989 (Energy Paper 57, The Severn Barrage: General Report. 1989).

The schemes identified by the SDC's research are as follows:

- **Cardiff-Weston scheme**: often known as the main 'Severn Barrage' proposal, this would run from Lavernock Point, west of Cardiff, to Brean Down, south-west of Weston-super-Mare

- **Cardiff-Weston scheme with second basin**: similar to the Cardiff-Weston scheme above, but with a second basin on the seaward side, thus enabling utilisation of nearly the full estuary resource and also providing some flood protection benefits to the Somerset Levels

- **Dawson continuous power scheme**: a barrage in the outer estuary from Minehead (see above), but with an embankment extending to Brean Down, thus creating a second basin and enabling continuous power output

- **English Stones or Shoots scheme**: the currently proposed alignment would run close to the two Severn Crossings and has been designed to facilitate a high-speed rail link to replace the aging Severn Tunnel

- **Hooker scheme**: similar to above but with a second basin to seaward, enabling out of phase operation on both the ebb and flood tides

- **Minehead-Aberthaw scheme**: often referred to as the 'Outer Barrage', this alignment would make maximum use of the Severn Estuary tidal resource, and is the longest barrage proposal because of its downstream location; this option is being explored by Somerset County Council on flood protection grounds
- **Severn Lake scheme**: a 1km wide barrage in the same location as the Cardiff-Weston scheme, designed to allow the construction of a number of additional features, including a wave farm on the seaward side, and four marinas

- **Shaw two-basin energy storage scheme**: similar to the above, but with deep-set pump turbines to enable significant pumped storage capacity.

The cost of a Severn barrage is to a large degree dependent on the length and scale of the embankments, while energy output is dependent on the number of turbines and location within the estuary. In comparing construction cost estimates to the estimated electricity output, the SDC's review of previous work indicated that the two most cost effective schemes are the Cardiff-Weston and the Shoots alignment and, for comparative purposes, decided to focus on these in more detail and as a starting point for reviewing Severn barrage options in terms of sustainable development. The Cardiff-Weston scheme is the most well studied scheme, and the updated Shoots concept is based on an earlier scheme which was also studied in some detail.

The SDC's starting point in considering these schemes is as renewable energy schemes, and not, for instance, as flood defence barriers or regional development projects. However, the overall sustainability assessment will depend on a holistic and integrated assessment of the schemes, having regard to their impacts, costs and benefits. The SDC strongly supports renewables and the decarbonisation of the energy from a policy perspective (see Section 1.4). However, we started this project with no previous position on a Severn barrage and our objective has been to review the available evidence and test the arguments for and against a barrage against the principles of sustainable development.

It is clear that if a Severn barrage were constructed, regardless of the option chosen, it would be a huge civil engineering project that would have a major effect on the surrounding landscape and environment, and on the regional economy. This is mainly as a result of the scale of a Severn barrage. The Cardiff-Weston and Shoots options are summarised in Table 4.

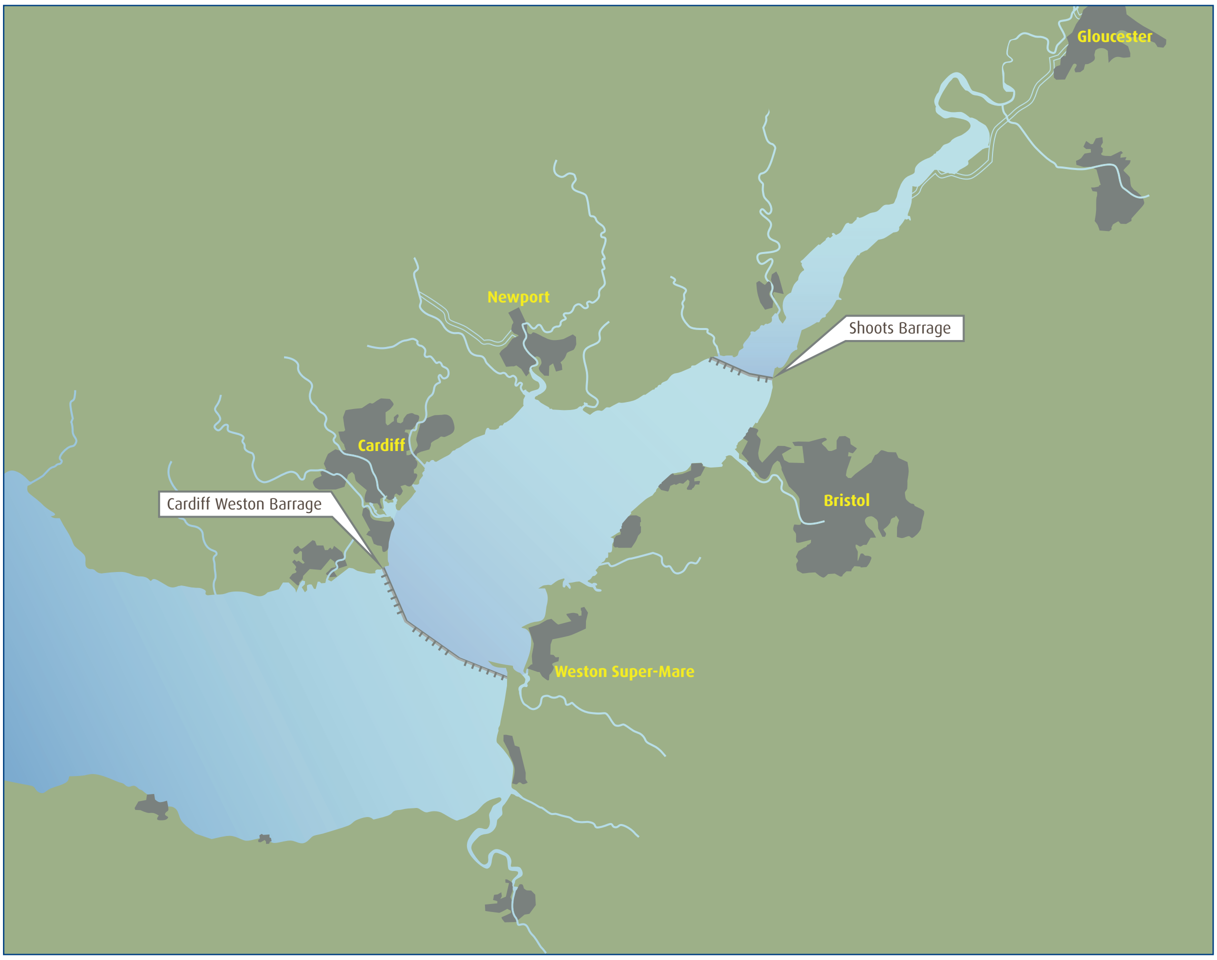
Table 4 **Comparison of the Cardiff-Weston and Shoots barrage options**

	Cardiff-Weston	**Shoots**
Length of embankments	16.1km	4.1km
Generating capacity	8.64GW (8,640MW)	1.05GW (1,050MW)
Annual average electricity output	17TWh (17,000GWh)	2.75TWh (2,750GWh)
Number of turbines	216	30
Number of sluice openings	166	42
Ship lock size	360m x 50m (x2)	225m x 37.5m

As this overview shows, the Shoots barrage is significantly smaller in terms of size and output than the Cardiff-Weston barrage due to its location much higher up the estuary (see Figure 17), where the volume of water impounded is much less.

The landfalls of the proposed barrage schemes should be treated as indicative rather than precise, and the potentially significant effects on the environment and communities living in those areas should be recognised as issues that would require substantial further investigation.

Figure 17 **Proposed layout and location of the Cardiff-Weston and Shoots barrage**



4.2.3 Alternatives to a barrage

In order to properly consider a potential Severn barrage it is important to first consider the other options for exploiting the tidal energy resource in the Severn Estuary and Bristol Channel. Although the evidence on this subject is high level and in some areas incomplete, a number of conclusions have emerged from Research Reports 3 and 4.

4.2.4 Compatibility of options

In order to take a strategic overview of the Severn Estuary resource, it is important to consider the compatibility of the different options available. This includes both the compatibility between tidal barrages, lagoons and tidal stream devices, and also between different tidal barrage options.

Tidal stream

Due to the nature of the resource and the technologies, there does not appear to be any major potential conflict between the utilisation of the tidal stream resource in the Severn Estuary and tidal barrages or lagoons. This is because the tidal stream resource is concentrated in deep water channels, which, along with large sedimentary deposits in the estuary, would present a number of engineering difficulties for most devices as well as being a navigational hazard for shipping.

Tidal stream devices are more likely to be sited further downstream from a barrage, in the Bristol Channel. This location has a number of potentially favourable sites that are near the shore and outside the deep water channels.

However, if a Severn barrage were built then (regardless of the engineering constraints) it would not be commercially viable to deploy tidal stream devices within the basin of a Severn barrage, due to a 50% reduction in tidal currents. A Severn barrage would also reduce the tidal range (and hence the tidal current velocities) on its seaward side by about 10% for the Cardiff-Weston barrage, reducing progressively with distance downstream; the effect on the output of tidal stream devices is more pronounced due to the fact that output is proportional to the cube of the current velocity.

Nevertheless, the effect on tidal stream devices in the Bristol Channel from a Severn barrage is likely to be minor, with a reduction in output of less than 10%; for devices installed after a barrage was developed, this could be mitigated to some degree by optimising their design. Conversely, the large-scale exploitation of the tidal stream resource in this area could have an adverse affect on a potential Severn barrage by reducing the available tidal range. However, based on current resource information, the tidal range resource (used by a barrage) would be much greater than the tidal stream resource, which has many preferable locations in other parts of the UK (see Section 1.3).

Tidal lagoons

The level of conflict between tidal lagoons and a barrage depends to a large extent on the scale and location of any lagoon development that is proposed. A direct conflict would occur where tidal lagoons are being proposed in an area very near to, or within the basin of, a tidal barrage scheme. This is because both technologies utilise the tidal range resource. For example, a tidal lagoon behind the Cardiff-Weston barrage would have its output reduced by around 75% of its normal value due to a 50% reduction in the tidal range; this would make tidal lagoons here uneconomic in combination with a barrage. There would also be a 10% predicted reduction in tidal range just outside the Cardiff-Weston barrage which would reduce the output of a tidal lagoon in the Bridgwater Bay area by around 20%; the effect further downstream would be less pronounced. It is not considered possible to place a tidal lagoon upstream of the proposed Shoots barrage due to a lack of an appropriate site.

For small-scale tidal lagoon developments, such as the proposed project in Swansea Bay, conflict between these two options would be limited, with only a small reduction in output expected at this location due to a barrage. The conflicts would obviously increase with the scale of any proposed lagoon development and its proximity to a barrage. The impacts could also be two-way, with a potential reduction in the output of a barrage if tidal lagoons were to restrict the flow of water further upstream.

The effect of the Shoots barrage on potential tidal lagoons would be less than for the Cardiff-Weston barrage, with development of tidal lagoons possible in all the locations identified above.

Tidal barrages

Compatibility between barrage options also needs to be considered in any strategic assessment. If the Shoots barrage were built first, then it could theoretically be followed at a later date by the construction of the larger Cardiff-Weston barrage in order to develop more of the tidal range resource. The Cardiff-Weston barrage would reduce the tidal range in the basin to around half its normal value, leading to a reduction of output in the Shoots Barrage of possibly 75%. The Shoots Barrage would also have an effect on the level output from the Cardiff-Weston barrage (and the timing of combined output from both schemes), but much of this would depend on the method of operation and would need further investigation.

Although it is conceivable that the Shoots Barrage could be followed by development of the Cardiff-Weston scheme, it seems highly unlikely that this would occur in reverse order as the marginal benefits of the Shoots scheme at this stage would be significantly reduced. However, it is possible that more of the tidal resource could be developed following development of the Cardiff-Weston single basin scheme by constructing a second basin extension across Bridgwater Bay. This option is discussed in more detail in Research Report 3.

4.2.5 Dealing with data constraints

The desk-based research has allowed some of the substantial evidence base on Severn barrage options to be updated, and for some new work and thinking to be developed. However, it was not within the scope of this project to conduct a comprehensive re-evaluation of a Severn barrage. A large number of uncertainties remain, particularly in relation to detailed modelling of environmental impacts, the cost of the proposed schemes, and the potential effects on the local and regional economy.

On environmental impacts specifically, while a huge volume of data already exists, the studies carried out in the 1980s predate the Habitats Directive and the UK regulations giving effect to the Habitats and Birds Directives (see Section 4.6.2 below). The impact of a barrage on protected features and the implications of the Directives' requirements for development were therefore not considered in previous studies.

Despite these uncertainties, the SDC believes that there is enough evidence to take a strategic decision on whether or not a Severn barrage warrants further investigation, bearing in mind the cost and effort likely to be required to do this. This report will be the SDC's contribution to this debate; the final decision is the responsibility of Government.

4.3 Electricity output and characteristics

This section considers the contribution that the two Severn barrage schemes under consideration would make to UK electricity supply, their method of operation, and the implications of this on their load factor and the timing of their output. It then looks at the implications of a barrage on grid management, and transmission constraints.

Table 5 **Contribution of Severn barrage options to UK electricity supply**

	Cardiff-Weston barrage	Shoots barrage
Annual average electricity output	17TWh (17,000GWh)	2.75TWh (2,750GWh)
Percentage of UK electricity supply (387TWh in 2005)	4.4%	0.7%
Percentage of UK energy supply (247Mtoe in 2005)	0.6%	0.1%

Source of UK energy data: Digest of UK Energy Statistics, 2006.

4.3.1 Contribution to electricity supply

Table 5 shows the potential contribution of the two Severn barrage schemes under consideration to UK electricity supply. Figures are also provided for their contribution to UK energy supply, which takes account of all the energy used in the UK economy, such as for heat and transport. As one would expect, the contribution to total energy supply is much lower, which illustrates the importance of reducing heat and transport carbon emissions in addition to those from electricity generation.

To put these figures in context, the annual output of the Cardiff-Weston barrage would be equivalent to the output of around 2.2GW of conventional baseload plant, such as combined cycle gas turbine (CCGT) plant or nuclear (assuming a 90% load factor – see Section 4.3.3 below). With a typical 1GW plant size, this is equivalent to just over two large power stations. The Shoots barrage would be equivalent to the annual output of a 350MW conventional power plant.

The impact on the UK's targets for renewable electricity would be more pronounced. The UK Government has an aspiration for 20% of the UK's electricity to come from renewables by 2020. More recently, the UK has also agreed to an EU-wide target for 20% of all Europe's energy consumption (including heat) to come from renewables by 2020.[52] The Cardiff-Weston barrage would make a big contribution towards the 2020 aspiration, assuming it could be built in time. Even the Shoots barrage would make a sizeable contribution, equivalent to that envisaged by a large offshore wind project such as the London Array.

Most of the research on tidal barrages assumes a working life of 120 years, although it is conceivable that electricity could be generated well beyond the design life if structural integrity could be maintained, and if siltation did not significantly impair operational efficiency. These conclusions are well supported by experience with large hydropower dams, and with the barrage at Rance in France, which is in good condition after 40 years of operational service. Within the lifecycle of the structure there would need to be periodic maintenance and replacement of some of the plant and equipment, which would most likely occur every 40 years or so.

4.3.2 Method of operation

Tidal barrages and lagoons can be operated on the ebb or flood tide, or both, and with the optional addition of flood/ebb pumping to increase/decrease the level of water in the basin to further increase output. These options are explained in more detail in Research Report 3.

Modelling work on the Cardiff-Weston barrage indicates that the method of operation with the highest potential electricity output would be ebb-generation with flood pumping, with the pumping contributing to a net gain in output of around 3%. The corresponding data on the Shoots barrage is incomplete, but the results are likely to be in a similar range.

The research on output calculations has so far been from an engineering perspective, and takes little account of the realities of the UK's liberalised electricity market, although there is acknowledgment of a degree of flexibility in how a barrage might be operated. This is largely because the existing work was completed in a different era, when electricity generation and the operation of individual power plants was under the control of the Central Electricity Generating Board. Under this scenario, the aim of maximising theoretical electricity output for plant with very low variable costs (such as nuclear, or a tidal barrage) makes sense, as the system operator is likely to schedule conventional plant to fit in with the resulting output schedule.

However, this is no longer the case, and it is now likely that the operator of a Severn barrage may seek to operate the plant on a sub-optimal output regime to take advantage of more attractive wholesale electricity prices. Integrating such economic factors into future electricity output models is a vital consideration. The figures on output presented here should therefore be viewed as theoretical rather than as what might occur in operation.

4.3.3 Load factor

Tidal power is by its very nature intermittent but highly predictable. This is because it is not reliant on weather systems, but on tidal cycles that can be calculated hundreds of years in advance.

The terms 'load factor' or 'capacity factor'[53] are used to describe the average output of an electricity generator over a year in comparison to its rated capacity. No generator has a load factor of 100%, as there will always be some down-time required for routine maintenance, and the occasional fault.

Conventional thermal generation (e.g. from coal, gas and nuclear) will in general have a maximum load factor of around 80-90%, although the actual figure will depend on whether the plant is used to provide baseload power, or to generate intermittently. Onshore wind power has a lower average load factor of around 27%, although individual wind farms in good locations may record load factors that are much higher than this UK average.

Taking the installed capacity figures shown in Table 4 above, the Cardiff-Weston barrage would have a load factor of 22.5%, with the Shoots barrage at just less than 30%, although the actual figures would depend on the method of operation, as discussed above. Although low, a load factor at this level is not a problem in itself; it simply feeds through into the cost of electricity output.

4.3.4 Output profile

The intermittent but predictable nature of tidal barrage output is well illustrated by the output profile. This is a highly complex subject which is briefly summarised here – further details can be found in Research Report 3.

The timing of tidal range devices, as already described in Section 1.3.4, is primarily related to two tidal patterns: semi-diurnal tides, and the spring-neap tide cycle. Semi-diurnal tides are the regular daily tides, with two full cycles within a period of 24 hours and 50 minutes. The spring-neap tide cycle is the 29.5 day cycle that affects the extent of the tidal range within each daily tide, with a wide variation between spring tides (maximum output) and neap tides (minimum output).

As already explained, a Severn barrage operated in ebb-generation mode will impound the water at high tide and then allow the receding tide to create a height difference between the basin water level and the sea level before releasing the water through turbines. The optimum time for generation occurs between 2.5 and 4 hours after high tide, with electricity generation occurring for 7-8 hours after commencing. However, within this period, output from a barrage would not be constant, particularly at the beginning and end of the generation cycle.

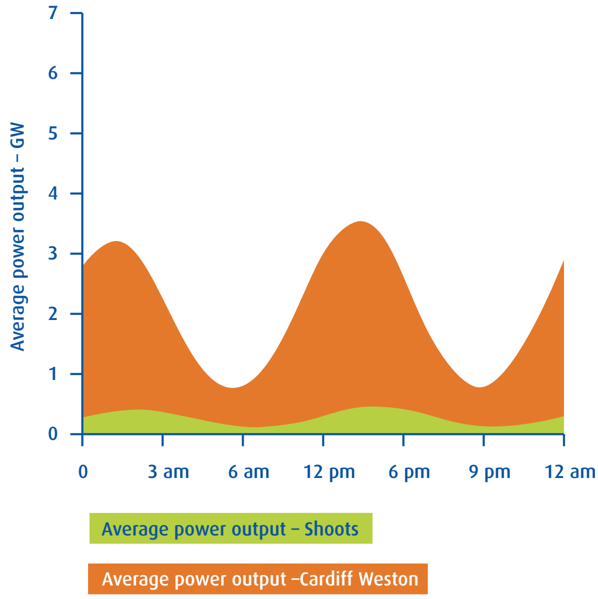
Over a seven day period, the timing of generation from a Severn barrage will advance by approximately six hours. This, along with the variation in output due to the spring-neap tide cycle, means that there is a complex relationship between the output of a barrage and electricity demand. Peak electricity demand in the UK occurs during early winter evenings (approximately 6pm), with high demand occurring throughout the day from around 7am onwards. Lowest demand is experienced in the early morning hours, particularly in the summer months.

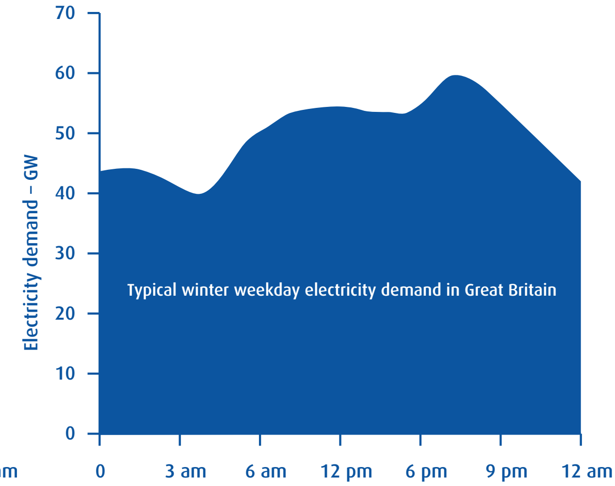
On some days, peak barrage output will coincide with peak electricity demand, but the average output from a Severn barrage is not ideally matched to UK electricity demand. On average, greater output from the Cardiff-Weston barrage would occur in the early afternoon (1-3pm) and the early hours of the morning (1-3am), with minimum production occurring between 7-9pm and 7-9am. As a result of being slightly upstream, the Shoots barrage experiences high tide, and therefore peak output, around an hour later than the Cardiff-Weston proposal, putting maximum output at around 2-4pm and 2-4am. These results are illustrated in Figure 23 (note different scales).

Expressed another way, average power output during the peak electricity demand period (5pm to 7pm) would be around 37% of the maximum hourly average for the Cardiff-Weston barrage, and around 55% of the maximum hourly average for the Shoots barrage. The higher figure for the Shoots barrage is explained by the fact that output at this location occurs one hour later, which on average puts it closer to the peak demand periods on a greater number of tides.

However, average figures will also tend to understate the differences between spring and neap tides, and the variation in output that will occur during one generation cycle. Figure 19 (a & b) illustrates this using actual data compared to a typical electricity demand profile.

Figure 18 **Average output from both Severn barrage proposals in comparison to the UK winter electricity demand profile**





Overall then, both barrage proposals would make a substantial contribution to UK electricity demand, but one that is sub-optimal in terms of helping to meet peak electricity demand periods, when carbon savings would be highest.[54] Furthermore, the wide variation in output both during and between generation periods (from 0GW to 8.6GW for the Cardiff-Weston proposal) combined with the daily changes in the output profile of a Severn barrage pose a number of serious questions relating to grid management and transmission capacity. These are explored below.

Figure 19a **Spring tide power generation profile from Cardiff-Weston barrage over a 24 hour period during spring and neap tides**

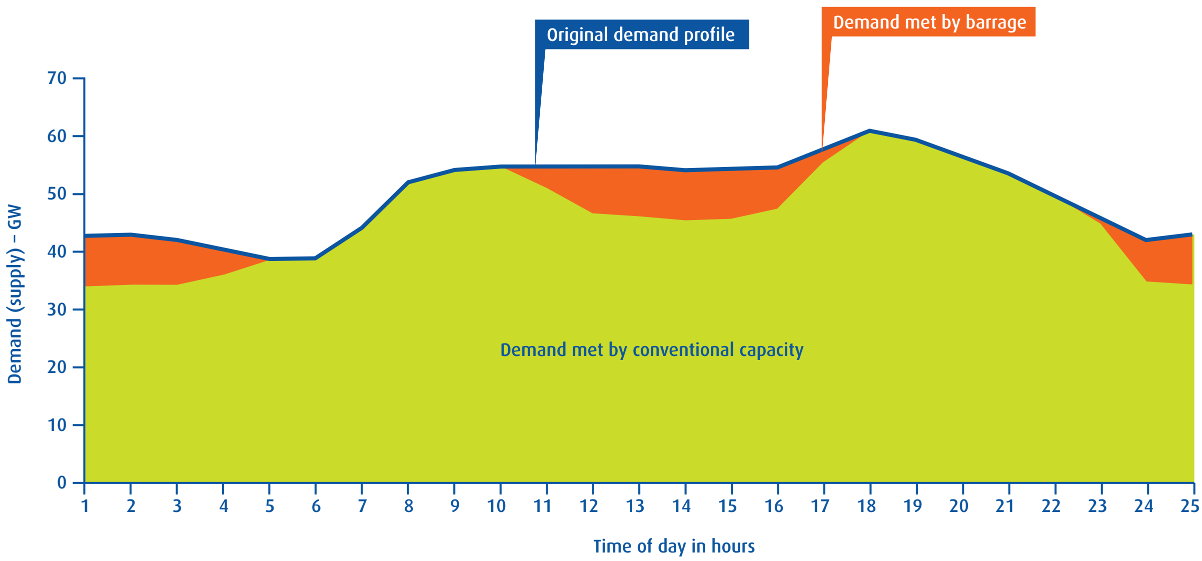
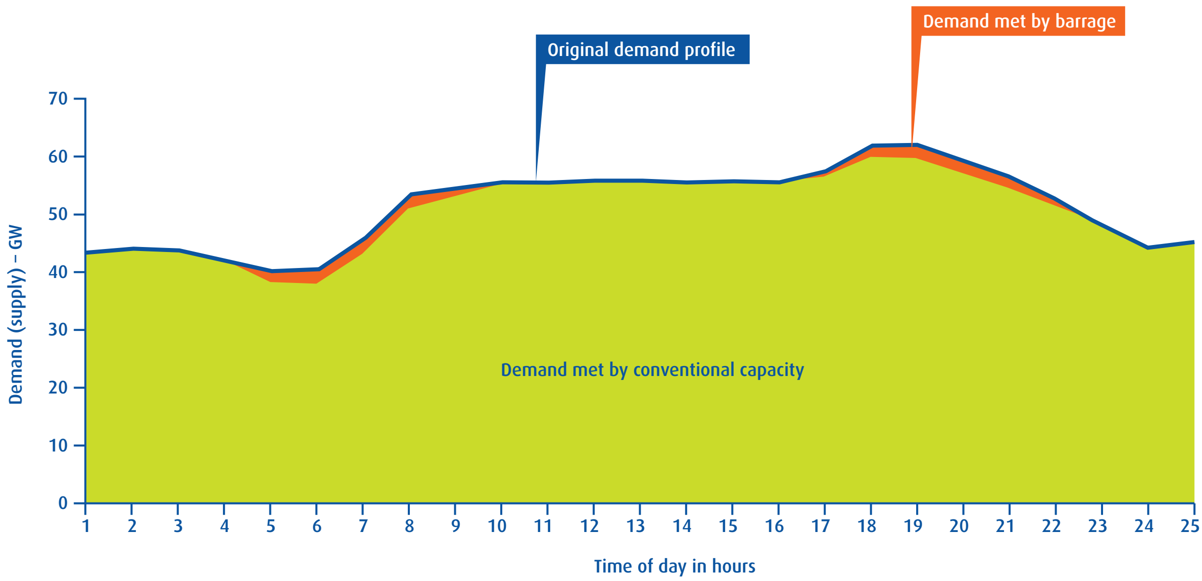


Figure 19b **Neap tide power generation profile from Cardiff-Weston barrage over a 24 hour period during spring and neap tides**



4.3.5 Implications for grid management

Misconceptions over intermittency

As described in the SDC's 2005 report on wind power,[33] there are a number of misconceptions surrounding the integration of renewables into the national electricity grid. It is commonly assumed that intermittent output, such as that from tidal or wind power, causes a problem for the grid operator, and that such output requires dedicated backup, thereby offsetting some of its benefits.

Both the SDC and the UK Energy Research Centre (UKERC)[33,55] have shown that such claims are unfounded, and are based on a number of inaccurate assumptions regarding grid management. First, both the supply and demand of electricity are constantly changing, even under a system based entirely on conventional thermal generation, with large changes in both variables throughout the day. For example, major sporting events result in a rapid demand surge from the simultaneous boiling of kettles during breaks, whilst at exactly the same time an unexpected fault could cause the loss of over 1GW of supply from a large power plant. The grid operator has tools and strategies in place to deal with these eventualities, and the addition of intermittent renewables to the grid needs to be considered in this context.

All electricity generation plant is intermittent to some degree, and in many respects several renewable technologies are actually less prone to unexpected outages than thermal generation plant. This is because no technology is 100% reliable, so even baseload thermal plant (such as CCGT plant or nuclear) will be out of service for some of the year, either for scheduled or unscheduled maintenance. When this is unscheduled, the grid operator must cope with an instantaneous loss of up to 1.3GW of supply, or possibly more if there is a transmission failure. Most renewables, including tidal and wind power, can have their aggregate output predicted several hours in advance of generation, or in the case of tidal power, years in advance. Furthermore, in the case of modular renewable generators (such as wind turbines or tidal stream devices), a fault in one device will be insignificant in terms of overall output. Finally, a fall in output from these renewables is unlikely to occur instantaneously – as explained below for tidal power.

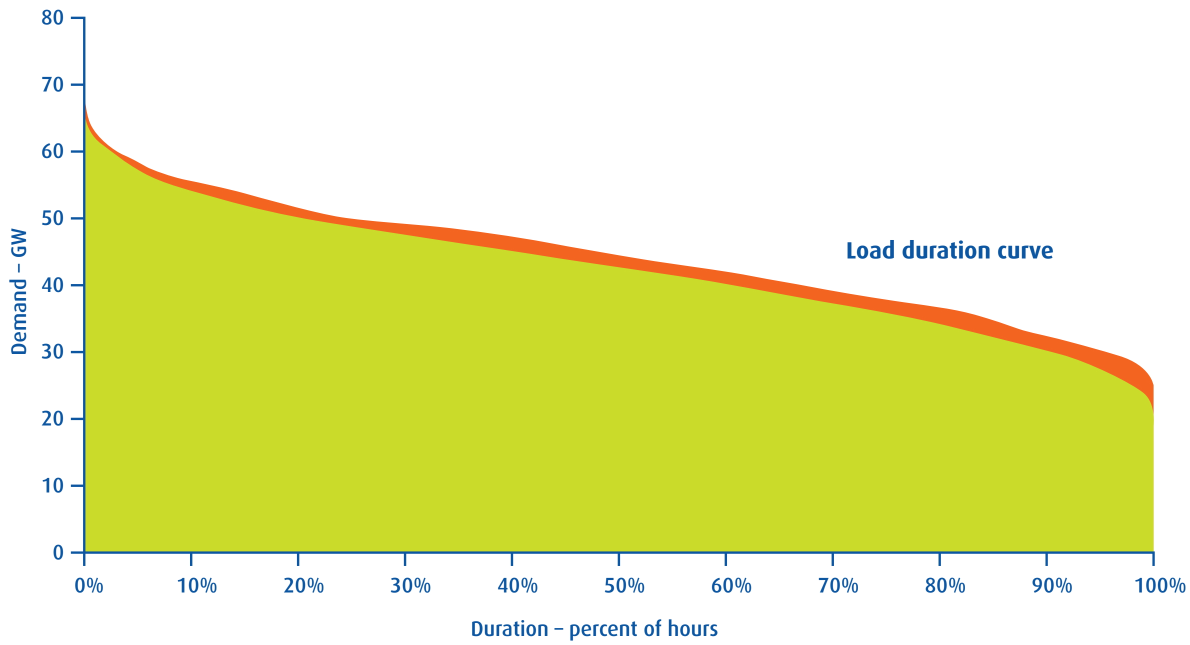
The integration of a large volume of one renewable technology does present a number of issues for grid operators, but there is no need for dedicated backup plant. What is more likely is that due to the lower capacity value[56] attributable to some renewables, they are unable to displace conventional capacity on a megawatt-for-megawatt basis, so the plant margin rises.[57] This is an economic consideration rather than an operational barrier.[33,58]

The capacity value of a Severn barrage

This is particularly true of a Severn barrage. Because of the regular mismatch between the timing of greatest barrage output and peak electricity demand, along with a low load factor, the capacity value of a Severn barrage is low. This is illustrated by the demand duration curve for the Cardiff-Weston barrage shown in Figure 20, which shows minimum electricity demand being met by conventional capacity dropping from 25GW to 19GW, whereas peak electricity demand falls from 70GW to 68GW. The effect for the Shoots barrage would be proportionately smaller.

This implies that the Cardiff-Weston barrage is able to displace 2GW of conventional capacity in the year modelled, giving it an average 'capacity value' of around 20-23%. The equivalent data does not exist for the Shoots barrage, but following from the conclusions of Section 4.3.4, its capacity value might be somewhat higher.

Figure 20 **Demand duration curve with and without the Cardiff-Weston barrage** (data from a single year)



When peak barrage output (8.64GW from the Cardiff-Weston barrage) coincides with times of minimum electricity demand (25GW), the type of generating output displaced is an important consideration from a carbon-saving perspective. This depends on the grid mix, and at present, the Cardiff-Weston barrage would not displace any low carbon output (e.g. output from nuclear or renewables), as the total capacity of such output is less than the net capacity requirement after the barrage output is subtracted. In the longer run, with more renewables and/or other low carbon capacity, it is likely that tidal output would occasionally be competing for demand with low carbon output during low demand periods.

Overall, a Severn barrage operated for maximum electricity output would reduce the number of hours that experience small changes in demand for power from conventional generation, cause a small increase in hours that experience a moderate level of demand change, and increase the extreme hour-to-hour fluctuations in demand that would need to be accommodated. This means that the conventional capacity would need to be more reactive and better able to respond to very large changes in demand (either positive or negative).

Implications for system balancing

From a grid management perspective, the predictability of these variations lessens the impact these changes would have on the stability of the grid. There would be a requirement for increased load following capability from other generators – often termed as 'system balancing' requirements – but this would be provided from existing capacity, and there would be no need for dedicated reserve (or backup) plant. This conclusion is consistent with the finding that the Cardiff-Weston barrage would displace up to 2GW of conventional capacity, and is also consistent with the SDC's previous work on wind power.[33]

An increased need for system balancing carries an economic penalty. Under the current market framework this cost is unlikely to fall to the generator responsible for causing the increase, and is therefore shared between all market participants. As a result, it is important to consider the likely scale of these costs in any economic evaluation, as they will eventually be passed on to consumers.

Overall then, the SDC does not feel that the variability or sub-optimal timing of output from either Severn barrage scheme are factors that undermine their potential contribution to climate change or energy security objectives. While the Cardiff-Weston scheme would undoubtedly require more active grid management, we view this as an economic rather than a technical constraint.

It is also important to consider the possible contribution that increased energy storage and demand management might make over the long time period that a barrage would be operating. Future advances in large-scale electricity storage technologies, and developments in automated demand response (sometimes referred to as 'dynamic demand'),[59] could lead to a much more dynamic and sophisticated electricity grid – and one that is better able to accommodate intermittent or variable supply.

As our research shows, there are a number of potential ways that a barrage could be designed to provide some level of storage itself, through sequential release of water into multiple basins for example. Our analysis of this is that such a scheme would need to be economically (and environmentally) justified based on the net benefits it could provide. Therefore, any modification of the basic design would need to be treated as an energy storage project, and evaluated in comparison to other ways of providing such storage capacity.

One possible variation of a multiple basis design would be if construction of the Shoots barrage was followed at some later date by construction of the Cardiff-Weston barrage. As this would create a basin within a basin, there may be the potential for improved dispatchability of the combined output of the two schemes.

4.3.6 Implication for the transmission system

The Severn Estuary area has significant network capacity for new generation, with negative transmission network use of system (TNUoS) charges currently in force for generators in the south-west of England due to a shortage of generation there to meet local demand. However, any assessment of network capacity is only ever a snapshot in time, as the situation can change rapidly through a combination of new capacity (some of which may only be at the conceptual stage), network reinforcements, and the decommissioning of existing plant.

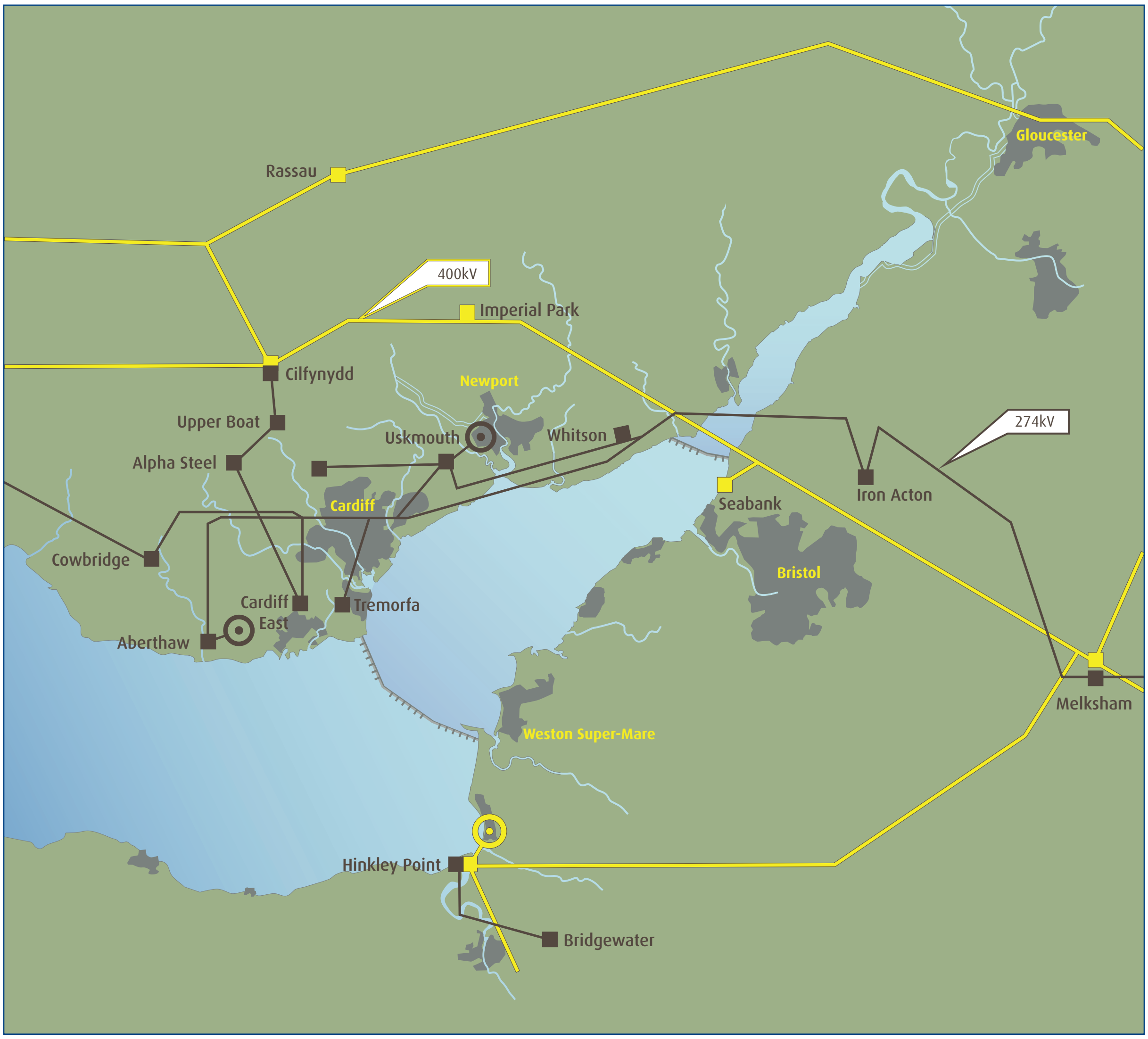
The current financial incentives through TNUoS charges to connect new capacity in the south-west and, to a lesser degree, in south Wales, could have a positive effect on the economics of any barrage proposal. However, the TNUoS system is highly dynamic, and it is likely that the connection of a large amount of new capacity in the form of a barrage would reduce or even reverse this situation for all generators in these TNUoS zones, including the barrage itself.

In addition to having sufficient spare capacity in the connection zones, any new connection to the grid must be able to identify a suitable connection point to the wider transmission system. For high capacity projects, there are a number of constraints in place that are intended to ensure system reliability and stability, with limits on the amount of capacity that can be connected to a single point.

As shown in Figure 21, the transmission network around the Severn Estuary is quite developed, with possible connections at both 400kV and 275kV on both sides of the estuary, not far from the potential landing points for a barrage.

The implications for a Severn barrage are very different for the two schemes under consideration here. For the larger Cardiff-Weston scheme, our research indicates that two connections into the 400kV network would be required at both the south and the north sides of the barrage (i.e. four

Figure 21 **Electricity transmission network (400 and 275kV) around the Severn Estuary**



connections in total), as the 275kV network on the north side is near to capacity and there is very limited capacity on the 132kV distribution network on the south side.

Due to the much smaller rated capacity of the Shoots scheme, the research indicates that all of the connection options seem to have sufficient capacity to accommodate this through just one connection. A connection to the Hinkley Point – Melksham 400kV double-circuit is considered the most appropriate due to a high demand for new capacity here, which could further increase with the decommissioning of the nuclear power station at Hinkley Point.

These conclusions show that both schemes would require some new transmission infrastructure to connect into the existing network, but that this requirement is far higher for the Cardiff-Weston scheme due to its higher rated capacity. There may also be a requirement for additional grid strengthening in other parts of the transmission network if such a connection were to be made, although such requirements would need further detailed study.

There is also the possibility that equipment may be required to allow this additional output to be used in southern England to substitute for capacity presently provided by the French interconnector to avoid congestion in the central England network. This would have a negative effect on the carbon savings achieved by a Severn barrage, as electricity imported from France has a low carbon intensity due to the high percentage of nuclear power that is installed there.

4.4 Carbon emissions

This section assesses the embedded carbon emissions that would come from building a Severn barrage (the 'carbon payback') before going on to look at the estimated carbon savings over the lifetime of the scheme.

4.4.1 Carbon payback

The work commissioned as part of this project included an assessment of the embedded carbon emissions from the construction phase of a Severn barrage project. The assessment excludes emissions from the transport of materials to site, which could be significant, and emissions from operations and decommissioning. On this basis, it is not a full lifecycle carbon analysis. However, construction emissions are likely to outweigh significantly these other emissions. Emissions from operations and decommissioning are also likely to decrease over time due to the progressive decarbonisation of the wider economy.

The long lifecycle of a Severn barrage has a positive impact on the carbon 'emissions factor', as the embedded emissions from construction are counter-balanced by 120 years of zero emission electricity generation. The emissions factor for the Cardiff-Weston barrage is estimated to be 2.42gCO_2/kWh, with a figure of 1.58gCO_2/kWh for the Shoots scheme (based on figures for the English Stones scheme). This translates into a carbon payback of around 5-8 months for the two schemes.

The emissions factor for a Severn barrage puts it in the very lowest category for power generation, and it compares well against other low carbon technologies such as nuclear power (16gCO_2/kWh).[17] There seems little doubt that, despite a number of emissions that remain unaccounted for in this analysis, a Severn barrage would be a low carbon technology. However, a full sustainable development appraisal requires us to consider the carbon impacts of resulting development in the surrounding region, and other effects such as the displacement of cargo movements. This is considered in Section 4.7 below.

4.4.2 Carbon reduction potential

One of the main arguments for building a Severn barrage is its potential contribution to reducing carbon dioxide emissions, and therefore its ability to help the UK meet its national and international obligations on renewables and emissions of greenhouse gases.[60] It is therefore important to know what the likely benefits of a barrage would be on the UK's climate change mitigation efforts.

The reduction in carbon dioxide emissions from a Severn barrage depends heavily on the assumptions made on the carbon intensity of the displaced electricity. As the output from a tidal barrage is intermittent, highly predictable, and has a very low operational cost, it is likely that this would be treated as baseload generation by the electricity market, in a similar category to nuclear power.

As a result, tidal barrage output is most likely to displace the output from large, centralised, fossil fuel plant. There are two ways to think about the carbon impact of plant displacement: a) that new capacity will displace the output of existing plant, or b) that it will displace the need for some other form of new capacity, and the associated emissions.

It is assumed here that a Severn barrage would displace the need for some other form of new capacity, which would most likely be CCGT plant as this is currently the preferred choice for new-build baseload generation. The reason for this is that a Severn barrage is unlikely to be operational for at least 10 years, during which time much of the UK's coal capacity will be taken out of service due to the Large Combustion Plant Directive. This, along with the continued retirement of the UK's nuclear capacity, will create the need for substantial amounts of new-build capacity, to which a barrage would contribute. Assuming that a Severn barrage would displace the output of CCGT plant is consistent with the SDC's analysis of nuclear power[17] and wind power.[33]

Official figures show that average emissions for gas-fired plant are 100 tonnes of carbon[61] per gigawatt-hour (tC/GWh).[62] However, it is more appropriate to assume that a Severn barrage would displace new-build gas-fired plant, which has a carbon intensity of around 90tC/GWh.

Using this figure, along with the 'average gas' and the 'grid mix' figures for comparison, Table 6 presents the likely annual carbon savings (as both carbon and carbon dioxide) from the two Severn barrage proposals being discussed.

Although it is possible from this data to calculate the lifetime carbon savings (over the 120 years expected life of a barrage), these figures are unlikely to be realistic because over this period it is likely that the generating capacity being displaced will be progressively less carbon intensive as society is 'decarbonised'. As a result, the contribution, in percentage terms, to UK electricity supply (as described in Section 4.3.1 above) is seen as more useful than calculating the total lifetime carbon savings.

Table 6 **Potential carbon savings from a Severn barrage**

	Cardiff-Weston		Shoots	
	MtC	$MtCO_2$	MtC	$MtCO_2$
Annual carbon savings (based on 90tC/GWh)	1.53	5.60	0.248	0.91
Percentage reduction in UK carbon emissions (1990 baseline)	0.92%		0.15%	
For comparison				
Annual carbon savings based on 'average gas' displacement (100tC/GWh)	1.7	6.22	0.275	1.00
Annual carbon savings based on 'grid mix' displacement (131tC/GWh)	2.23	8.15	0.36	1.32

4.5 Physical implications of a barrage

The construction, presence and operation of a Severn barrage would involve major physical changes to water levels, geomorphology, and sedimentary processes. These physical changes underlie and have significant implications for:

- the **environment** – the estuarine ecosystem, intertidal and wetland habitats, birds, fish
- the **economy and society** at a local and regional scale – ports and navigation, land drainage and flooding, water quality, infrastructure and transport, employment, industry and recreation.

A Severn barrage would be a very large structure across the estuary with a significant physical footprint. The Cardiff-Weston barrage is about 16km long and a Shoots barrage is about 4km. However, the changes that a barrage would cause extend well beyond the direct physical footprint of the structure, and involve physical changes to the estuary as a result of reducing the tidal range and changing the water levels within the barrage basin ('upstream') and outside of the barrage ('downstream'). The physical barrier across the estuary, together with the changes to water levels, the tidal currents and the wave regime of the estuary, also mean that the sedimentary and morphological characteristics and processes of the estuary would be significantly altered. This section summarises some of the key effects that are predicted to occur with development of a barrage. The issues of the lifetime of a barrage and decommissioning are also considered.

4.5.1 Sound science and uncertainty

This section addresses the physical changes that a barrage would have on the estuary and surrounding coast. These physical changes underlie not only the environmental and conservation impacts of a barrage, but also the implications of a barrage for the economy and for society. As outlined above, the SDC considers that we have enough information to reach a high level view on the strategic question of whether a Severn barrage is an option that merits further investigation. However, we are conscious that there are gaps in the information available about the effects that a barrage would have, and the costs and possible options for mitigating any adverse effects. Further, we know that there is not enough information to take a decision to proceed with development or to satisfy commercial or regulatory requirements. Sound science and information are essential to good decision-making and to ensuring that we operate within environmental limits.

The 1980s studies provide a wide analysis of the physical and ecological regimes before and during the construction and operational phases of barrage development. The research was undertaken during the 1980s and early 1990s and focused on the Cardiff-Weston alignment of the barrage. However, those studies and the review that the SDC has commissioned identify a large number of unknowns, and a lack of certainty both as to the estuary as it is now (the environmental baseline) and, to a greater degree, the post-barrage scenario.[63] As mentioned above, the studies also predate designation of many of the conservation features. They may not have used the most advanced modelling techniques or applied the latest knowledge of estuarine ecosystems and processes, or international experience, to the effects of coastal defence structures.

For example, information on the effects of a barrage on currents is based on modelling from early 2-D depth-average predictions, which provide a limited basis for drawing firm conclusions. How morphological features of the estuary might respond, upstream and downstream of a barrage, is a complex issue and has not been studied in detail, and this considerable uncertainty makes predictions of the ecological response and the impacts on habitats and birds very difficult at this stage. Predictions of the loss of intertidal habitat, for example, are based mainly on estimated changes to water levels, as comprehensive predictions of changes to morphology are not available.

Changes of ecology and ecosystems involve a complex set of interactions between physical, chemical and biological parameters. For a scheme at the scale of a Severn barrage and the difficulties of modelling a dynamic and complex natural system, it is likely that some uncertainties will remain even after further detailed studies are carried out.

These areas of uncertainty also have implications for considering the effects of development on ports and navigation, and flood risk management, which are discussed further in Section 4.7. The function of the estuary in supporting economic and social structures, and the value of ecosystem services provided by estuaries – for example, as nurseries for fish, filters for waste, and assisting with flood management – should be taken into account.[64] This does not mean that any change to the system is automatically 'bad' or negative, but rather that a holistic approach needs to be taken. It also implies that we should attempt to understand the long term effects of any proposed development because the consequences will be felt over the long term, and the costs of dealing with problems of this nature are more likely to fall at a local level rather than as an upfront cost of development.

4.5.2 Water levels and currents

The high tidal range seen in the Severn is the product of the shape of the estuary and the velocity at which the tide wave propagates, which causes a resonance effect. This 'hypertidal' nature is what makes the estuary attractive for potential power development, but it is also responsible for creating a series of unique conditions and habitats, such as extensive mud flats and mobile sand banks. Extracting energy from this dynamic regime in the form of a tidal barrage would fundamentally change the nature of the Severn Estuary.

On the whole, a barrage would raise the average water level inside the basin by raising the low tide levels to around present mean sea level and by reducing high tide levels by up to 1m (up to about 0.5m for a Shoots scheme). The mean sea level in the estuary would be raised by some 2.5m to 3m for the Cardiff-Weston scheme. The overall effect is to reduce the tidal range by around 50%. For the Cardiff-Weston scheme, the range would decline from 11.5m to 4.5m on spring tides, and 5.5m to 2.5m on neaps. For the Shoots scheme, the result would be a similar reduction in tidal range, from 12.5m to 4.5m on spring tides, and 6.5m to 3.5m on neaps.

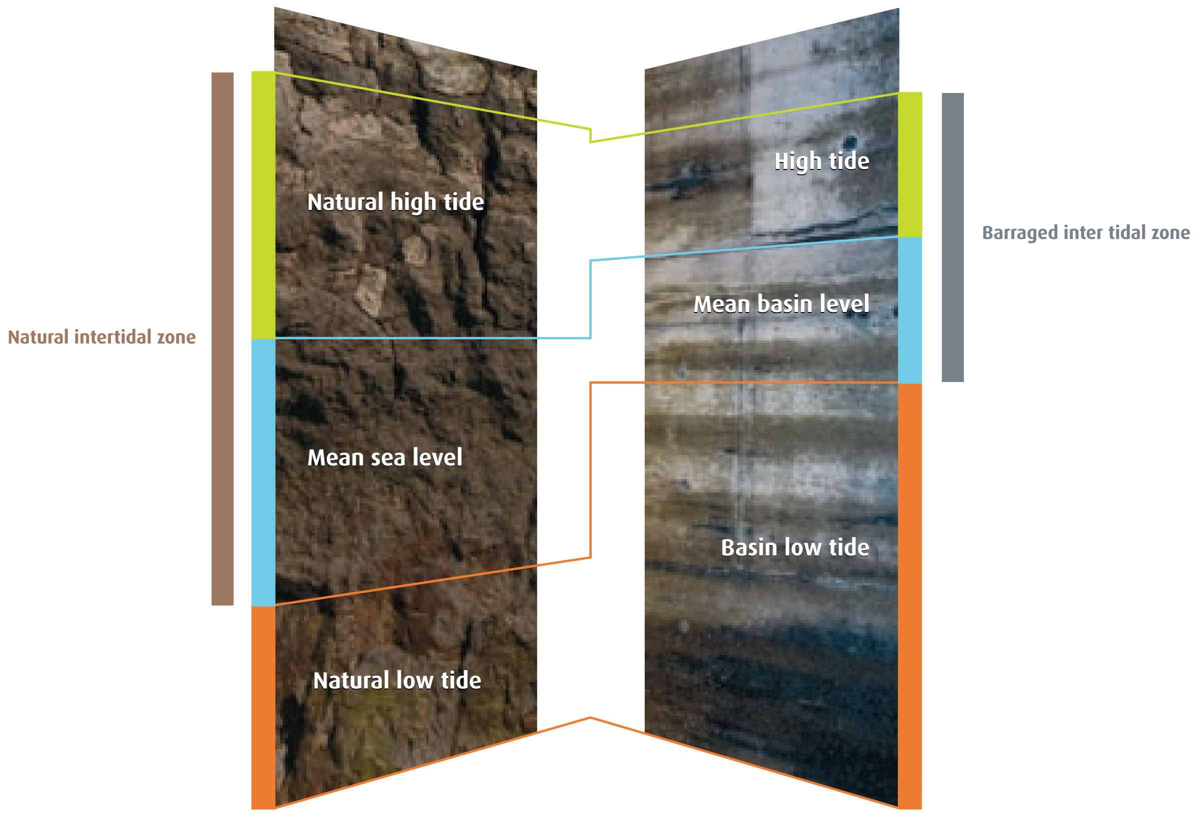
Downstream of a barrage, model predictions for the Cardiff-Weston alignment are that low water levels would be raised somewhat and high water levels would be reduced. These effects would decline with distance, although the models predicted that the decrease in high water levels could be detected up to 75km seawards. However, Research Report 3 notes that these modelled results are counter-intuitive, and that high water levels could increase due to water being held up against a barrage. Ascertaining the correct prediction using advanced modelling, which also considers sediment transport, would be an important factor in determining the risk of erosion downstream of a barrage.

The general effect of a barrage on the tidal range is shown in Figure 22.

The scale of change to the tidal range within the barrage basin is best illustrated by considering the loss of intertidal habitat. The intertidal area is the area between high and low tide that is regularly exposed to both air and water as a result of the tides. This is discussed further in Section 4.6.3 below.

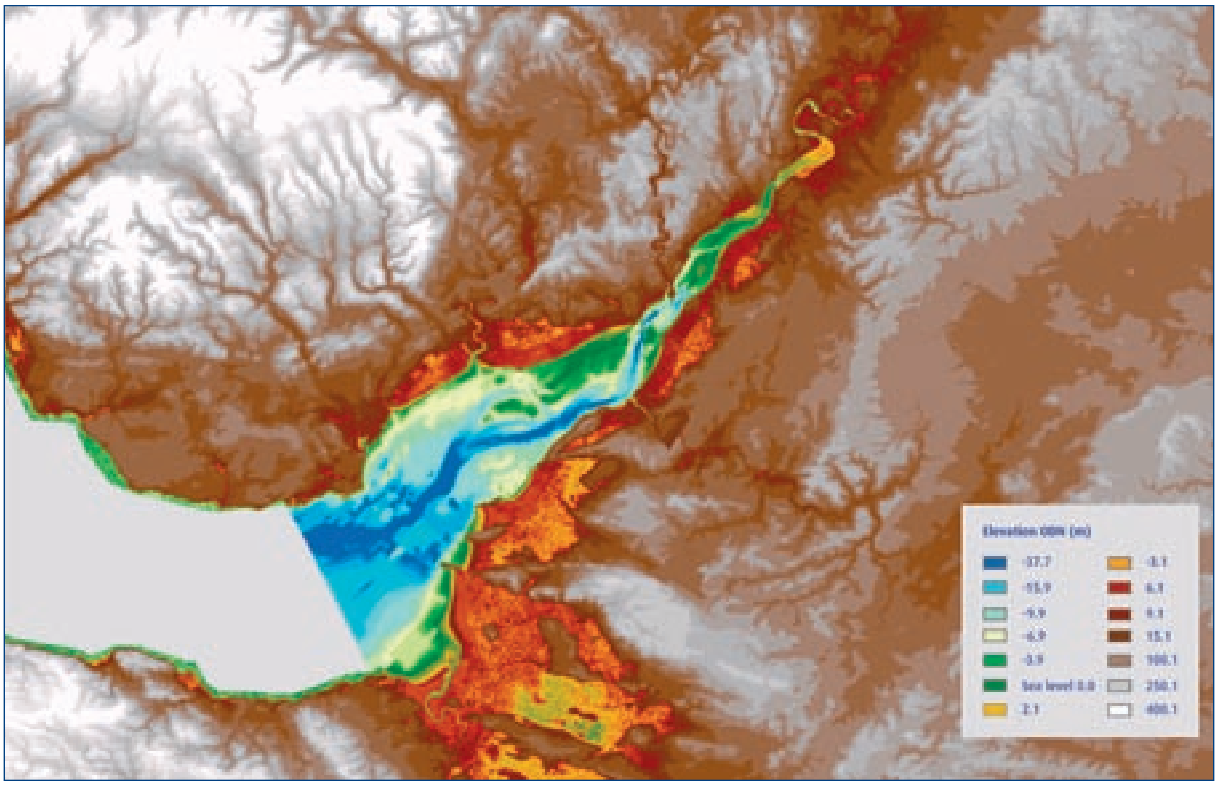
As a result of the huge tidal range, the estuary

Figure 22 **Relative position of tidal basin water levels under an ebb generation mode of operation**[65]



Source: Clark

Figure 23 **Elevation in and around the Severn Estuary**



also has very strong currents. The currents maintain deep channels and high loads of suspended sediment. The reduced tidal range would reduce currents in the estuary as a whole. Locally faster flows would be experienced close to the sluices and turbines in the barrage.

In addition to water levels and currents, changes to the wave regime of the estuary are also relevant to the Cardiff-Weston scheme. With water levels in the basin remaining more constant (from the reduced tidal range), waves might be generated on the surface of the estuary with the risk that increased wave energy could affect soft shorelines at the margins of the estuary.

4.5.3 Morphology

Morphology refers to the form and development of the landscape, in this case also referring to the underwater areas of the Severn Estuary. As Figure 23 shows, the estuary is characterised by deep channels running through more shallow waters, with a number of low-lying areas on both sides that would be inundated at high water if there were no flood embankments. This also illustrates the possible threat of sea level rise and storm surges to this region.

The Severn Estuary is a highly dynamic environment, with rapid (often daily) and longer-term changes seen in the depths and positioning of different features such as sand banks and channels. Recent evidence suggests that the addition of the Cardiff Bay barrage has resulted in the gradual split and migration of the Cardiff Grounds (a sand bar), which may give some indication of the impact of a much large Severn barrage.

Changes to morphology and the sediment regime have implications for the environment, the engineering of a barrage, and also at a social and economic level; for example, in relation to ports and navigation.

More detailed examination of the possible impact of a barrage, some of which is either highly contested or the subject of much uncertainty, is outlined in Research Report 3.[66]

4.5.4 Sedimentary processes

The muddy nature of the Severn Estuary is the product of a high suspended sediment load, which is maintained by the strong currents that pass through deep channels in the estuary, particularly on spring tides. The currents are also influenced by the pattern of the tides. The flood tide is stronger than the ebb tide, but this is countered by the ebb tide lasting for a longer period of time.

Although our knowledge of these sedimentary processes in the estuary is incomplete, it seems that these currents are the primary mechanism for sorting of seabed materials, leading to gravel and rocky patches in the channels, and muddy deposits in the inter-tidal areas. Other sediments present in the estuary include clay, sand, and shingle with sediment supplies from a number of sources, including rivers, cliff erosion, saltmarsh erosion, mudflat erosion, the seabed, and seaward inputs.

There are a number of large sand bodies in the estuary, such as the Middle Ground. These are deposited through a 'tidal pumping' mechanism, which sees marine sands brought up the estuary on the strong flood tides which the slower flowing ebb currents are unable to remobilise. Muddy sediments, on the other hand, appear to remain in suspension for most tides, having been introduced from upstream fluvial (river and stream) sources.

The construction of a barrage could be designed to limit the effects on the sedimentary regime until closure, although dredging for construction materials could have a significant direct effect.

Once constructed, a barrage would have a major effect on sedimentary transport by reducing the tidal force on the seabed outside the vicinity of the barrage by a factor of four during flood tides and a factor of ten during ebb tides. This would lead to a significant reduction in sand transport (with the freezing of currently mobile sand banks), and the likely deposition of mud sediments.

Close to the barrage structure itself, where the strong currents pass through the turbines and sluice gates, sediment transport would continue, with a net accumulation of sediment predicted on the basin side. This sediment accumulation, and its ability to significantly reduce the operating lifetime of a barrage, has in the past been of particular concern for the Shoots proposal, but design modifications (e.g. positioning the sluice gates higher up to avoid water flows with the highest sediment loads) have been investigated to attempt to tackle this issue. Further investigation would be required to ensure that these modifications were sufficient, as excessive sedimentation could have serious implications for the economic viability of the scheme.

Overall, a barrage might result in deposition of up to 85% of the mobile sediment load, which in turn may allow sufficient light to penetrate the water column to create a viable photic zone. The consequences of this decreased sediment concentration and its role in creating conditions for primary production within the water column are discussed further below in relation to ecology and birds.

4.5.5 Decommissioning

There is very little discussion of decommissioning in the existing research, and the general assumption up to now is that the structure would not be intentionally dismantled even if power generation were to cease. Despite the obvious cost of decommissioning (which could be as high as the construction cost in real terms), there may be a number of good reasons why this would be the preferred option, such as minimising disturbance to the environment and some of the benefits of additional flood protection (see Section 4.7.3 below).

As the barrage structure would be largely benign, and assuming the estuary systems would re-establish under the altered regime over the long lifetime of a barrage, decommissioning does not have the same significance that it might have with some other electricity generating technologies. The only possible exception to this is if the scheme turned out to have more serious environmental impacts than anticipated, and it was therefore decided that the estuary should be returned to its previous state. However, the feasibility of returning the estuary to its previous state is unknown, and the environmental impacts of decommissioning might themselves pose significant challenges.

It would be possible to plan for the costs of decommissioning by placing a levy on the sale of electricity which, due to the long lifecycle of a barrage, would have a very minimal impact on the cost of electricity, particularly if this were deferred until after any initial capital were paid back.

However, due to the long lifecycle of a barrage and the uncertainties over decommissioning, the pragmatic approach would be to view any potential development as a permanent addition, and to consider the resulting impacts as irreversible.

4.6 Environmental impacts

Based on this overview of predicted changes to the tidal range, morphology and sedimentary processes, the effects on ecology, habitats, birds and fish, and water quality are now considered. Many of the habitats and features of the Severn Estuary are designated conservation sites under international and UK legislation, and the key designations are outlined here.

An environmental impact assessment (EIA) would also require full consideration of a range of other potential impacts of a proposed development, including the landscape and visual effects of a Severn barrage which are also discussed below. The future evolution of the estuary system having regard to predicted sea level rise and climate change impacts is also considered.

Further detailed discussion of the environmental impacts and the policy framework can be found in Research Report 3. The following discussion also draws on a paper by Prater[67] on behalf of the Royal Society for the Protection of Birds (RSPB), and from the SDC's discussions with the statutory nature conservation agencies – in particular the Countryside Council for Wales (CCW), Natural England (NE) and the Environment Agency (EA).

4.6.1 Scope of environmental review

This review has focused mainly on the marine and coastal environmental impacts associated with the Shoots and the Cardiff-Weston barrage schemes. It is clear that a barrage would cause major changes in the physical and biological marine environment, upstream and downstream of the development, and that these changes would also affect coastal land.

More information is available for the Cardiff-Weston scheme than for the Shoots as a result of previous investigations. Many of the environmental effects of the schemes would be qualitatively similar but there are important differences in scale and, due to the respective locations of the two schemes within the estuary, the particular conservation features that would be affected.

The potential environmental effects of a barrage on the terrestrial environment have not been considered in any significant detail in this review or in past research. The land use planning aspects of the barrage schemes under consideration have not been developed in detail by the proponents to date, and the alignments of the schemes have been selected mainly on economic and engineering criteria. In addition, the impacts of extracting, producing and transporting construction materials (for example, the extraction of aggregates) have not been considered. All of these issues would need detailed investigation if any barrage proposal were to be considered further.

The discussion also focuses mostly on the implications of the expected changes in the presence of a barrage, rather than the construction and operating impacts of a barrage. Construction would itself have significant environmental impacts, directly from the physical footprint of the barrage as well as noise, dust, traffic and water quality issues which could affect habitats, fish and birds as well as local communities during construction periods of several years. The reason for focusing on the post-construction scenario is that these environmental impacts are more complex, long-term and, in many cases, might be irreversible. The direct habitat loss from construction would of course be part of the consideration of the impacts of the development on the integrity of the European site, and the whole construction sequence would need to be fully considered in terms of its impacts, with mitigation and management measures put in place.

While the La Rance barrage in France is a good example of the engineering, operation and energy output of a barrage, comparisons in environmental and ecological terms are less helpful, for two reasons: no baseline environmental data exists from before the barrage was built, and the estuaries are different types.

4.6.2 Protected status of the Severn Estuary

The Severn Estuary and the surrounding coastal areas are subject to numerous national and international designations which are designed to recognise and protect habitats and species as well as features of landscape, and of archaeological, geological and historic importance. This discussion focuses on the international designations, which are of central importance because of the strict legal tests that they set up to which a barrage proposal would need to comply in order to assess, reduce, justify and then compensate for any adverse impacts. Moreover, many of the same features that are protected in national legislation and policies are also protected in the international designations.

The Severn Estuary is classified as a Special Protection Area (SPA) for birds under the EU Birds Directive and, following its submission to the European Commission (EC) in 2007, is now a candidate Special Area of Conservation (cSAC) under the EU Habitats Directive.[68] The rivers Wye and Usk are already classified as SACs. The SPA area is also designated as a wetland of international importance under the Ramsar Treaty.[69]

Figure 25 provides further details on the areas covered. The sites, which together form part of the European Natura 2000 network (explained below), contain a range of protected species, including waterfowl, migratory fish and plants, as well as river, estuarine and intertidal habitats, and natural features such as sand banks.

The Severn Estuary and the adjacent areas also contain various sites of special scientific interest (SSSIs) and other reserve and heritage designations which are protected under national legislation[70] – see Figure 26. These designations include areas behind the existing seawalls such as the Gwent Levels as well as geological features such as Sully Island and Middle Hope. Further details of these designations can be found in Tables 6.2(1), (2) and (3) of Research Report 3.

Habitats Directive and Natura 2000

The Habitats Directive (92/43/EEC, 1992) addresses the conservation of natural habitats and of wild flora and fauna. The Directive expressly acknowledges the broader objective of sustainable development, and

Figure 24 **Natura 2000 network of designated sites across biogeographic regions**

The EC Natura2000 network across biogeographical regions

Natura2000 site

Biogeographical regions 2005

- Alpine
- Anatolian
- Arctic
- Atlantic
- Black sea
- Boreal
- Continental
- Macaronesia
- Mediterranian
- Pannonian
- Steppic
- Outside data coverage

Note: Natura2000 data for Cyprus and Malta are not included.

places the aim of maintaining biodiversity within that context. It stipulates that the maintenance of biodiversity should take account of economic, social, cultural and regional requirements, and recognises that in certain cases, the maintenance of biodiversity may require the encouragement of human activities. The Directive also highlights the continued deterioration of natural habitats and the increasing number of wild species that are seriously threatened.

The main method for securing the biodiversity objective is the creation of a coherent European ecological network of SACs: the Natura 2000 network (article 3). The network is intended to ensure that the natural habitats are maintained, and if necessary restored, at a favourable conservation status within their natural range. The Natura 2000 network also includes SPAs classified under the Birds Directive. At a European level, 18% of Europe's land area is designated under Natura 2000, illustrating the intention for selected sites to be unique or important in a European context.[71] In the UK, designated sites cover around two and a half million hectares of land and coastal marine areas.[68] The Severn estuary contains around 20,270ha of intertidal habitat, around 7% of the total intertidal habitat in the UK.[72] Figure 24 shows the extent of the Natura 2000 network as of 2005.

The Habitats Directive establishes a process whereby Member States must propose a draft list of sites, and the EC then adopts sites identified as of Community importance. In the UK, there are a total 611 designated SACs, cSACs, and Sites of Community Interest (SCIs) (which are sites that have been adopted by the European Commission, but not yet formally designated by the government of each country).[73] A further three estuaries, the Severn (as noted above), together with the Dee and the Humber estuaries, have been submitted as candidate SACs.

Member States may take only account of scientific matters in selecting sites for submission to the EC.[74] Once a site is classified, proposed developments that would adversely affect the integrity of the site must be considered through the process set out in article 6(4) of the Directive, as implemented UK law through the Habitats Regulations. This process, which contains a series of 'tests' and includes a requirement for compensation to be provided, is outlined in detail in Section 4.10.4.

Birds Directive

The Birds Directive is a long standing Directive (1979/409/EEC) specifically focused on the conservation of wild birds. Member States must take measures to preserve, maintain or re-establish habitat for wild birds, and for certain Annex 1 species, take special measures, including classifying Special Protection Areas (SPAs).

The Directive is less onerous in terms of the process for classifying SPAs, which is done by the Member States. There is no process for considering proposed developments within a SPA. However, the Birds Directive is now linked to the Habitats Directive, and SPAs are part of the Natura 2000 network. Furthermore, the Conservation (Natural Habitats &c.) Regulations 1994 apply the same tests that apply to a SAC to any proposed development which would adversely affect the integrity of a SPA.

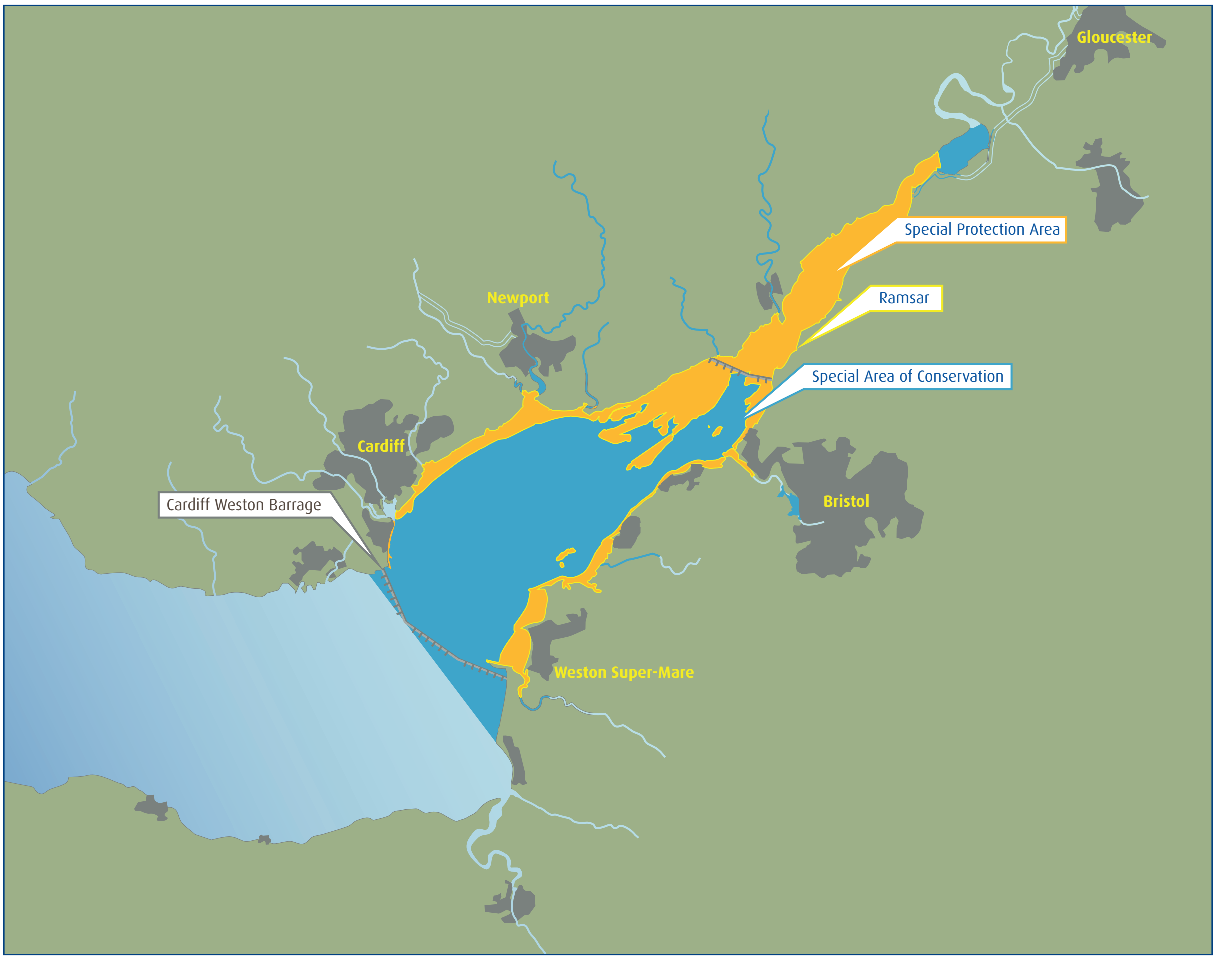
The SPA and SACs are considered together in this report as both would be subject to the tests set out in the Habitats Directive. They are referred to together as 'the Directives'.

Box 7 **Summary of key statutory designations in the Severn Estuary**

The Severn Estuary area is recognised through a number of international, national and local designations including:

- Special Protection Area (SPA)
- Ramsar Site
- Special Areas of Conservation (SAC) and a candidate SAC (cSAC)
- Sites of Special Scientific Interest (SSSIs)
- National Nature Reserves
- Local Nature Reserves
- Sites of Importance for Nature Conservation
- European Marine Site.

Figure 25 **Map showing international designations in the Severn Estuary**



Defining biodiversity objectives

The Directives seek to protect biodiversity by protecting certain habitats and species. Understanding the concept of biodiversity and how it fits within this framework is critical. At a global level, biodiversity loss continues to occur at a rapid rate due to human activities, and this loss is degrading the ecosystem services that we rely on for human wellbeing and development. In the past, Europe's ecosystems have suffered more man-induced fragmentation than those of any other continent. The Natura 2000 network of protected sites is one important way of protecting biodiversity at the scale of biogeographic regions across Europe.

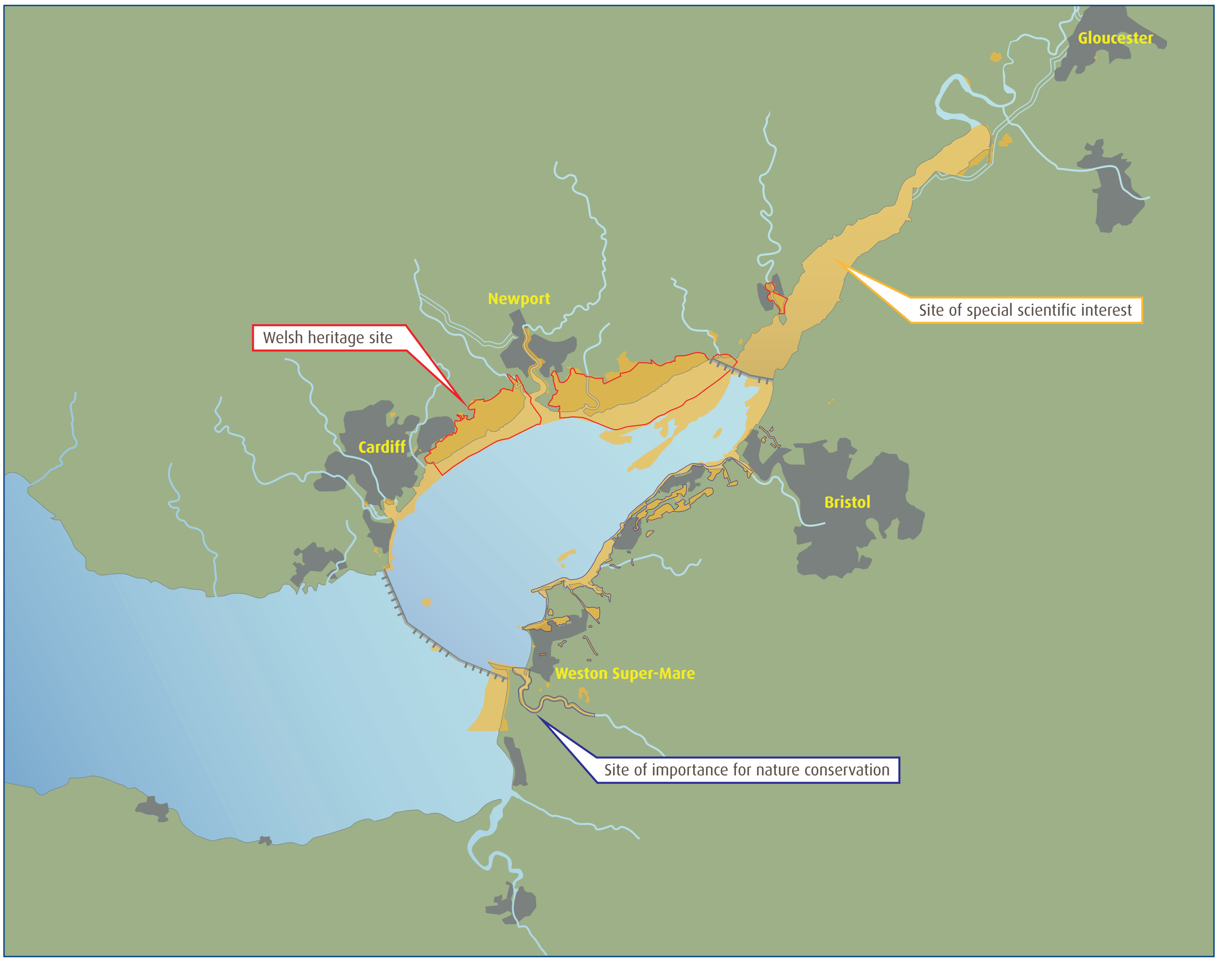
Biological diversity or 'biodiversity' is the variety of life on earth – comprising ecosystems, species and genes. The UN Millennium Ecosystem Assessment[75] defines biodiversity as "the variability among living organisms from all sources, including terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are a part. This includes diversity within a species, between species, and of ecosystems."

The definition is important because it shows that biodiversity has different dimensions. It is not simply about numbers of different types of species, or 'species richness'. Neither is it simply a measure of the biological productivity of an ecosystem. Compare, for example, an Arctic tundra which has very few species with the Amazon rainforest where the numbers of different plant species number in the tens of thousands. Both are important ecosystems.

The findings of the UN Millennium Ecosystem Assessment,[75] which was initiated in 2001 in order to assess the consequences of ecosystem change for human well-being, include the following advice for decision-makers, which is particularly aimed at avoiding these 'conceptual pitfalls':

> "Different interpretations of several important attributes of the concept of biodiversity can lead to confusion in understanding both scientific findings and their policy implications.

Figure 26 **Map showing national designations in the Severn Estuary**



Specifically, the value of the diversity of genes, species, or ecosystems per se is often confused with the value of a particular component of that diversity. Species diversity in and of itself, for example, is valuable because the presence of a variety of species helps to increase the capability of an ecosystem to be resilient in the face of a changing environment."

One of the messages from this work is the importance of identifying the geographical scale being studied, and to recognise that biodiversity refers to diversity at multiple different scales. In the case of the Severn Estuary, this thinking is behind the designation of features that may be important in the context of European or UK-wide biodiversity. The impact of a Severn barrage on species and habitats is considered in the following sections, with a summary of the overall impact on biodiversity provided in Section 4.6.10.

4.6.3 Habitats and ecology

The dynamic environment and large tidal range of the Severn Estuary give rise to a set of features and habitats that are, in a number of cases, unique to the estuary – that is, that are not typical of estuaries generally. Each component of the marine and coastal environment needs to be evaluated to build an overall picture of the likely environmental impacts of a Severn barrage, and Research Report 3 provides a more detailed ecological assessment that considers the baseline, predicted future evolution and potential impacts for the various components of the Severn Estuary environment. Here, the discussion summarises and highlights the key issues set out in that report. Again, as discussed in Section 4.5.1 above, this discussion is based on existing data and research, and considerable uncertainties remain as to the ecological response of the estuary.

The key ecological features in the marine environment are the intertidal mudflats and sandflats, saltmarsh, the rocky intertidal area, sand dunes, and subtidal habitats. These habitats would be directly affected by the changed physical regime under a barrage, as described above. In addition, a number of transitional coastal habitats such as wetlands, grazing marsh and reedbeds are present around the estuary above the high tide mark and beyond the existing seawalls. These habitats would be affected with less frequent inundation and by changes to land drainage and the water table. The populations of birds and fish within these environments are also a central aspect of the ecological picture. Marine mammals are less of a concern although some species such as the harbour porpoise and grey seal feed in the Bristol Channel and outer Severn Estuary.

Intertidal habitats

The most dramatic and noticeable change to habitats comes as a result of the reduced tidal range and new water levels in the post-barrage scenario, and the direct reduction of intertidal area upstream of the barrage. The Severn Estuary and Bridgwater Bay have extensive areas of intertidal mudflats and sandflats, estimated at some 23,000ha in total. Figure 27 shows the location of the two barrage schemes in relation to the intertidal zone.

The predicted change in intertidal area landward of each barrage is a loss of approximately 5,530ha on a spring tide and 3,372ha on a neap tide for the Shoots scheme, and 14,428ha and 5,842ha of the equivalent tides for the Cardiff-Weston scheme: see Table 7 below. This change is predicted on the basis of expected water level change alone. In reality, the distribution and extent of the intertidal mudflats and sandflats will also be influenced by the changes to the sedimentary regime of the estuary, as well as other factors including sea level rise and the operating regime of a barrage.

Figure 27 **Location of the two Severn barrage schemes in relation to the intertidal zone**

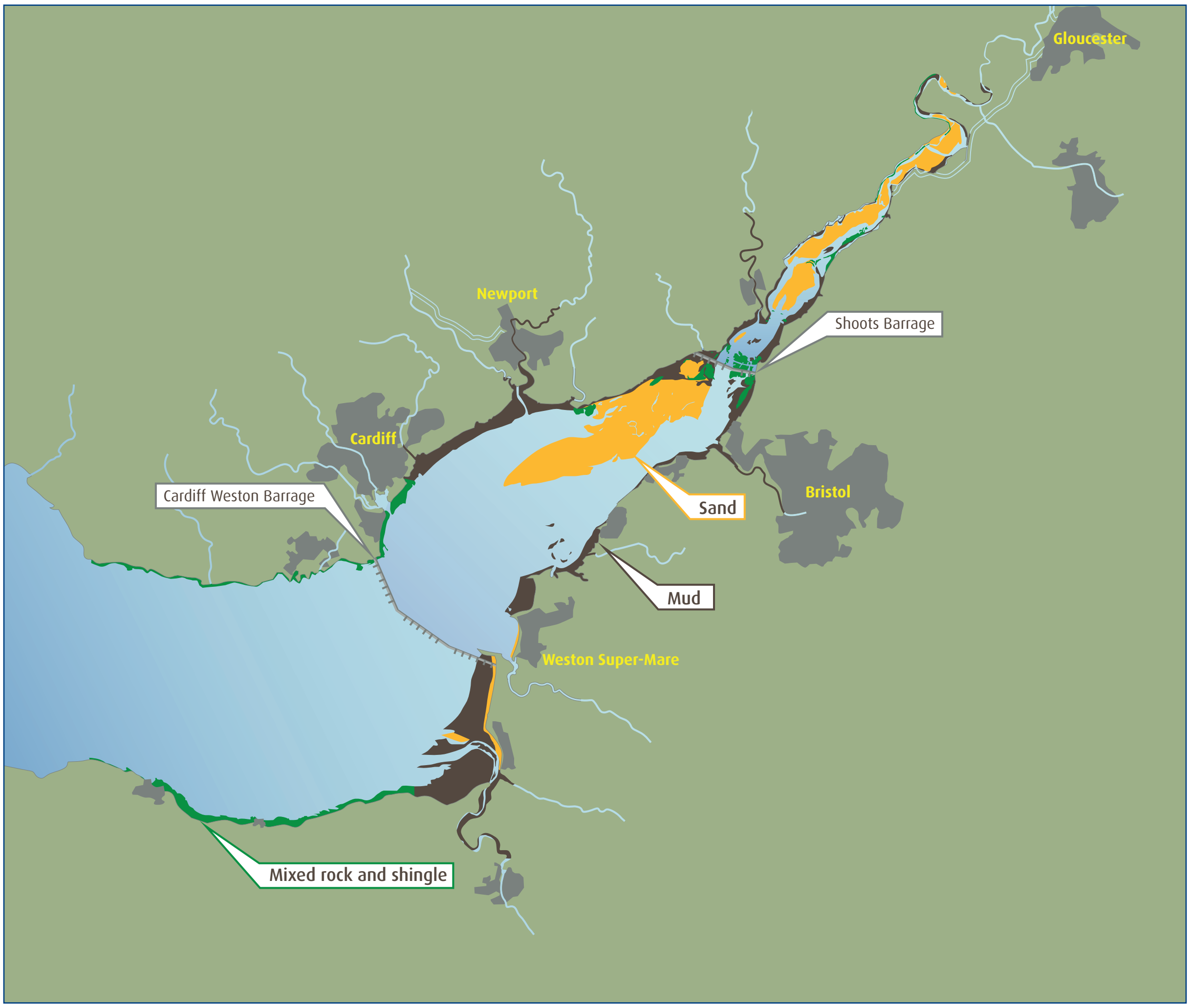


Table 7 **Predicted change in extent of intertidal area landward of the two barrage schemes based on predicted changes in water levels alone**

Scheme	Range	Current intertidal area (ha)	Predicted intertidal area	Change in intertidal area (ha)
The Shoots	Spring	7275	1745	-5530
	Neap	4815	1443	-3372
Cardiff to Weston	Spring	18898	4469	-14428
	Neap	9881	4039	-5842

In this dynamic environment, sediments are highly mobile and the extremes of physical stress mean that the intertidal habitats of the Severn Estuary are characterised by a species-poor assemblage of invertebrates (i.e. a low number of species). However, this does not necessarily mean a low biomass. The assembled species tend to exist in large numbers of relatively small individuals. The large tidal range, funnelling processes, strong tidal streams, and high suspended sediment loads create difficult conditions for the colonisation of benthic species (species that live on the sea floor such as invertebrates). In the sub-estuaries of the rivers Wye, Bristol, Avon and Usk, the benthic macrofauna is similar to that found in the soft sediments of the main estuary but in higher numbers.

Invertebrates and biodiversity

Changes in the physical regime and the intertidal area would have implications for the invertebrate communities present in the intertidal area. The 1980s studies pointed to invertebrate associations in the intertidal areas increasing in abundance and in biomass of species with a barrage. Species typical of hypertidal estuaries were predicted to decrease while other species might increase. The size distribution of individuals in these species would also tend to increase.

This prediction gives rise to one of the most critical – and controversial – questions about the impact that the significantly reduced intertidal area would have for ecology and birds, and the relationship between this reduction and the expected increase in biological productivity. There is broad agreement that these preliminary assessments are accurate as to the direction of change that would be expected. However, there are fundamental differences and disagreements between experts about the particular implications for birds and ecology in generation.

Saltmarsh habitat

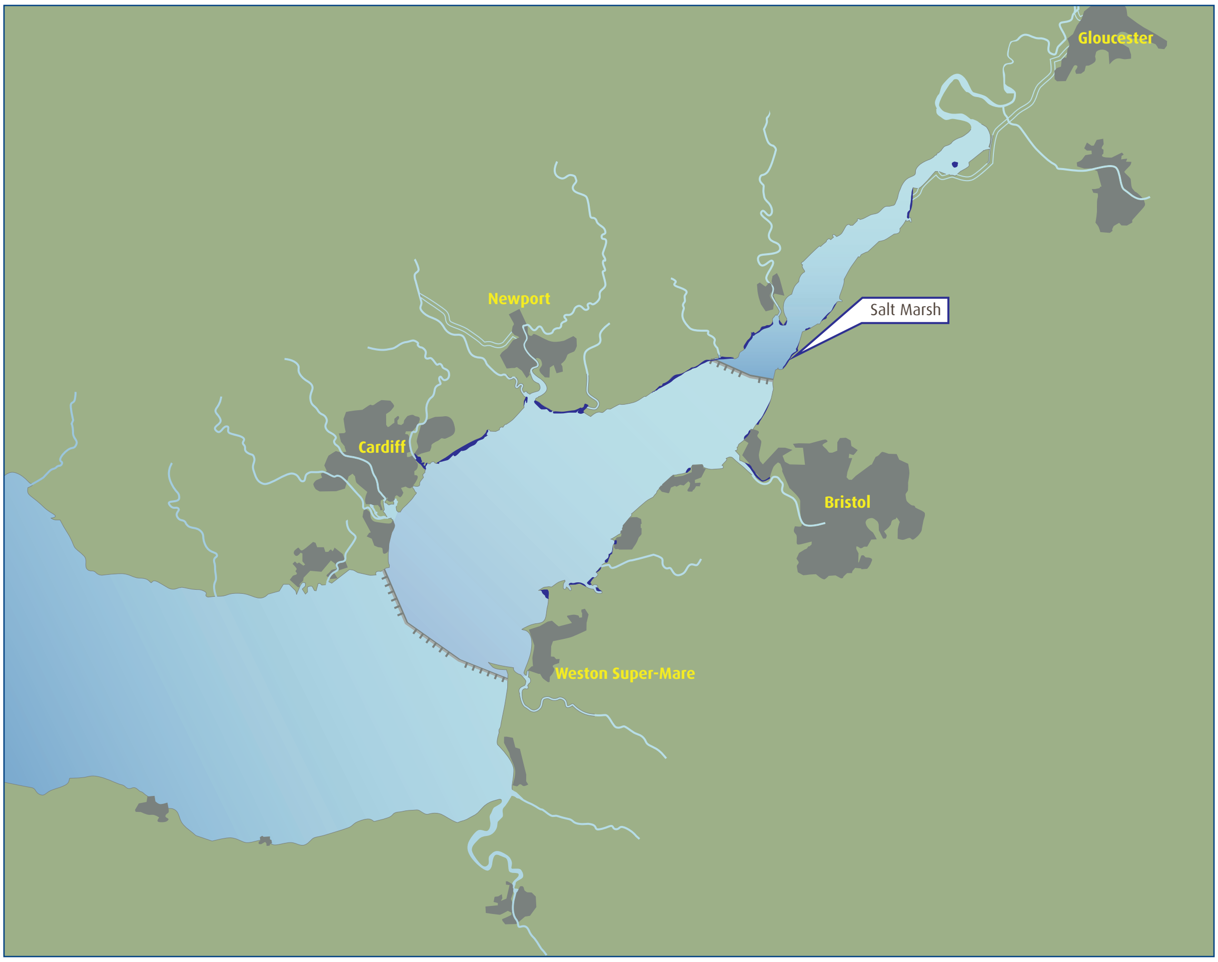
The Severn Estuary is an important location for saltmarsh, a resource that is in decline throughout Europe and the UK. Figure 28 shows the location of saltmarsh areas in relation to the proposed barrage schemes.

A marked contraction of saltmarsh habitat is also predicted in the presence of a barrage. This is principally because, with the change in tidal range and duration, existing estuarine saltmarshes would be inundated less frequently. However, changes to the hydrodynamic conditions, sedimentary regime and morphology of the estuary would also affect the saltmarsh.

For a Cardiff-Weston alignment, a reduction of around 540ha is predicted and for a Shoots alignment, about 133ha. These figures refer only to the expected reduction upstream of a barrage; reduction might also occur downstream. The total area of saltmarsh around the estuary and Bridgwater Bay is about 1430ha. Although the expected reduction is qualitatively similar for a Shoots barrage, the actual reduction is of a much lesser magnitude due to the relationship between the location of the saltmarshes and the barrage.

As the upper marsh zone becomes more permanently exposed, it would be colonised by more terrestrial vegetation. The predicted terrestrial vegetation is expected to include increased distribution of Spartina, which is a type of grass

Figure 28 **Saltmarsh areas in relation to the proposed barrage schemes**



often found in freshwater swamps and saltmarshes. The increased presence of Spartina on the upper tidal flats is of concern for birds. In particular, this raises concerns for one of the important migratory birds, the Dunlin because studies in other UK locations have found a correlation between the spread of Spartina and decrease in Dunlin[67].

Loss of saltmarshes through accelerated erosion would mean that even as the high water mark is restored with sea level rise over time, it is possible that re-establishment of former salt marshes would not be possible except over a very long time period (centuries to millennia).[76]

Subtidal habitats

The muddy and sandy subtidal habitats would increase in area as a result of the decreased intertidal area. The change in physical regime would affect particular species of honeycomb worm, Sabellaria, which forms reefs and is a protected feature of the estuary. Subtidal sandbanks would also change as the result of the morphological, hydrodynamic and sedimentary changes discussed above at paragraphs 4.5.3 and 4.5.4.

Rocks and shingles

In addition to the main mud and sandflats of the intertidal area, some rocky intertidal areas would also become subtidal under a barrage, and some geological features including wave cut platforms which rely on continued erosion for their maintenance would be lost.

The main shingle habitats in the estuary are the low shingle ridges in Bridgwater Bay. Changes to the sediment regime and physical processes within the estuary have the potential to affect the shingle habitats within the estuary.

Transitional habitats

Transitional habitats around the Severn Estuary include grazing marsh, reedbeds, saltings, drainage channels, wetlands, grassland and woodlands, rivers and standing open waters, and agricultural land and urban areas. As with the saltmarsh, these areas would be expected to experience less frequent inundation. The changes would affect the composition and structure of the habitats and the species they support. The overall picture for these habitats would need to be investigated in more detail to understand the implications of changes to water levels, land drainage, and the water table. For example, the expected increase in water levels would be generally expected to have a positive effect on freshwater wetland habitats. The early studies also indicated that reedbeds might develop extensively at the head of the estuary in areas that are presently intertidal.

Plankton and marine algae

There is little quantitative or qualitative information available on the plant communities of phytoplankton, microalgae, macroalgae, intertidal plants or detritus. In the presence of a barrage, the early studies indicated that there would be a general increase in species diversity, standing crop and productivity of these plant communities as result of reduced turbidity and greater substrate stability. However, the overall conclusion was that a substantial change in the productivity of the estuary was not predicted. This is in contrast to the predictions in relation to invertebrates discussed above.

4.6.4 Water quality

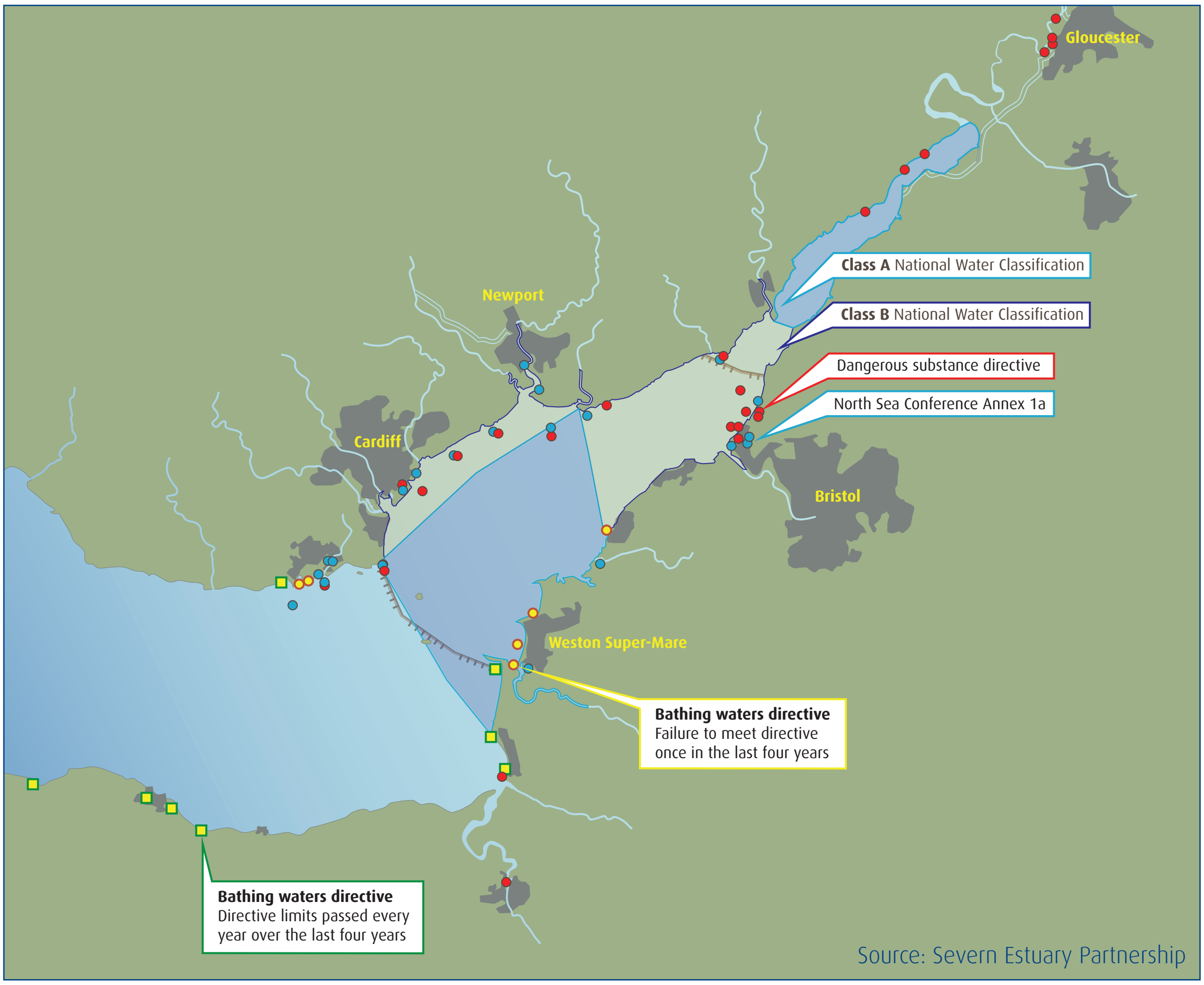
Water quality standards are set by UK legislation, although in many cases are determined by EU Directives or international conventions that have been implemented via UK regulations. The most important of these is the Water Framework Directive, which came into force in 2000, and requires all inland and coastal waters to achieve 'good status' by 2015. The Environment Agency is the primary regulator of water quality, and has responsibility for the licensing, monitoring and enforcement of sewage and industrial waste discharges. It is also responsible for monitoring designated bathing waters in line with the EC Bathing Water Directive (1976).

Water quality itself is dependent on a number of variables, including point source discharges of sewage and industrial effluent, diffuse agricultural run-off, highway drainage, spillage from industrial premises and marine vessels, and contaminants in rivers. The Severn Estuary is currently classified under the National Water Council classification system as good quality in the upper estuary and fair quality in the middle and lower estuary – see Figure 29. The evidence suggests there has been a continual improvement in water quality for the major contaminants. The high suspected sediment load in the estuary means that algal productivity is low, and eutrophication is not seen as a major threat.

The physical implications of a barrage on currents, water depths, and turbidity will all have implications for water quality. Unfortunately, available assessments are based on limited data and were preliminary studies undertaken sometime ago, and prior to the Water Framework Directive. For the Cardiff-Weston scheme, a few preliminary conclusions are available as follows:

- A barrage would reduce the dispersion of sea water up the estuary and the absorption of oxygen, which would lead to the freshwater/seawater interface moving seaward by 5-30km, depending on river flow
- The concentrations of conservative pollutants (that remain chemically unchanged in the water) such as nickel and cadmium could at worst double
- Concentrations of other, non-conservative pollutants behind the barrage were not predicted to change significantly. Similarly, the number of bacteria near sewage outfalls is predicted not to change significantly
- The oxygen status was predicted to be largely unaffected by the reduced tidal mixing and the system would tend to be capable of retaining more oxygen because of the reduced salinity
- The suspended sediment concentrations characterising the water column, landward of the barrage are predicted to reduce to those typical of other high tide estuaries

Figure 29 **Severn Estuary water quality and statutory monitoring sites**[51]



- It is predicted unlikely that eutrophic conditions would result, although there is some dispute over this finding.

For the Shoots scheme, variations on the above conclusions include a reduction in cadmium upstream of a barrage (due to the major sources being downstream of the proposed location), but a possibly inferior situation with respect to ammonia, BOD (biological oxygen demand), dissolved oxygen and some metal contaminants including nickel and copper.

Notwithstanding these initial predictions, and agreement that sediment levels would decrease significantly, water quality remains an area of uncertainty. The impact on water quality of a barrage, and even the question of whether there would be an overall improvement or deterioration in water quality is highly contested. An issue that would require further investigation based on updated predictions would be how the Water Framework Directive would apply.

4.6.5 Birds

The Severn Estuary is recognised as an internationally important estuary for birds, and international and national designations protect a number of bird species and their habitats. Five species are of international importance and nine or ten are of national importance. In total the estuary has an assemblage of some 65,000 waterbirds. An assemblage of birds is a measure of the abundance of birds using a site. The threshold for an internationally significant assemblage of waterbirds under the Birds Directive is 20,000.

The site was classified as a SPA based on the period 1988-1993; the species affected are shown in Table 8. Bird numbers are counted using a five year mean peak average (to avoid exceptional counts affecting the assessment of importance). Since classification, bird numbers have changed and work by the RSPB provides a good overview of the numbers, relative importance internationally and nationally, and how species numbers have changed since the SPA classification[67]. An environmental assessment of a barrage scheme would need to provide a more complete baseline picture of bird numbers and patterns of use in the estuary. The table below shows the key bird species and the assemblage of birds.

Table 8 **Bird species presented in the SPA citation (with numbers in brackets)[67]** Source: RSPB

Citation category	Species qualifying at citation (average numbers between 1988-93 in brackets)	Species qualifying 2000-2005 (average numbers between 2000-05 in brackets)
Internationally important populations of regularly occurring Annex 1 species	Bewick's Swan (289)	Bewick's Swan is just below the 'international' threshold (276)
Internationally important populations of regularly occurring migratory bird species	Shelduck (2,892) Dunlin (41.683) Redshank (2,013) European White-fronted Goose (3,002)	Shelduck (3.272) Dunlin (23,312) Redshank (2,566) Teal (4,450) Pintail (758)
An internationally important assemblage of waterfowl	Qualifies	Qualifies
Nationally important bird populations within internationally important assemblage of waterfowl	Wigeon (3,977) Teal (1,998) Pintail (523) Pochard (1,686) Tufted Duck (913) Ringed Plover (winter)(227) Grey Plover (791) Curlew (3,096) Whimbrel (246) Spotted Redshank (3)	Bewick's Swan (276) European White-fronted Goose (942) Wigeon (8,062) Shoveler Pochard (880) Ringed Plover (passage)(665) Curlew (2,545) Black-tailed Godwit Whimbrel (passage)(222) Spotted Redshank (10)

Existing bird population status

Two species have declined substantially in recent years: the Dunlin and the European White-fronted Goose. This decline is probably as a result of climate change, and reflects a trend for other sites in Wales and south western England where warmer winters mean that birds have been remaining in more eastern areas. Ringed Plover has also decreased, probably for the same reason. Grey Plover has decreased although the reasons are not clear. Decreases in Pochard and Tufted Duck have also occurred but for different, local reasons (possibly in response to improved local water quality or changes in food supply). Other species have increased considerably over this time. For example, several ducks (Pintail, Shoveler, Teal, Widgeon) as well as Redshank and Black-tailed Godwits. Pintail and Teal are now at internationally important numbers in the Severn.

Overall, if the estuary were classified as a SPA today individual species and total numbers would still be of international importance. The estuary is used as a feeding ground, roosting and loafing site and supports high numbers of birds on their migratory passage. The intertidal area is of particular importance, although usage of the area is not distributed evenly. So, for example, counts in the winter of 1987-1988 found that 50% of birds were feeding on just 13 sites which cover 12% of the total intertidal area, and six of these sites were downstream of the two barrage lines, in Bridgwater Bay and Parrett Estuary. The next 40% of birds were at another 43 sites. Most birds roost near the feeding areas on the upper intertidal area below saltmarsh and, during high spring tides, in the upper saltmarsh or in fields around the estuary.

Intertidal areas upstream of the Shoots barrage location are generally utilised less by overwintering birds. However, the intertidal, saltmarsh and coastal grazing marsh areas in the upper estuary (around Slimbridge) are also areas utilised by the Bewick's Swan, which can occur at internationally important numbers and is listed in Annex 1 of the Birds Directive.

Impact of a barrage

A number of studies have attempted to model and predict the potential impacts of a barrage on bird populations. However, as has been discussed above, predictions depend upon the physical and ecological response of the estuary. The two key factors are the reduced intertidal area, where the birds' prey resource is found, and a reduction in the time available to feed.

One of the key issues is whether the increased productivity of the estuary might offset some of the loss of intertidal area. This prediction is made by Kirby.[77,78] However, these predictions remain very controversial and uncertain in the absence of a greater understanding of basic physical, hydrological and operational information and advanced modelling of morphological change on which to base accurate predictions.[67,79]

Analysis as part of the 1980s studies concluded that prey density and size were the key variables rather than foraging time, and even assuming a 50% loss of feeding area, predicted increases in prey density were found to be of the order found in other estuaries.[80] However, the expected increase in bird densities (as a result of increased prey density) did not apply for some species such as Dunlin and possibly Shelduck – meaning the makeup of bird populations would change.

These conclusions can be seen as a broad indicator based on consideration of the existing mudflats and sandflats under the different water levels. The actual impacts would depend on other physical changes to morphology upstream and downstream of a barrage as well as bird behaviour in response to changes. Actual impacts would vary species by species, but with interactions between different species of birds. Some birds might use the reduced intertidal area in higher densities; others might move to less favourable areas with less food sources. A range of other parameters such as implications from the spread of Spartina, and disturbance effects on birds of significant infrastructure works would also need to be considered. Accordingly, the overall picture is very complex.

In relation to a Shoots barrage, the loss of intertidal area would be considerably less and the resulting impact on birds would be significantly less than for a Cardiff-Weston scheme. Many key areas of bird usage are seaward of the Shoots barrage line. Dunlin, for example, is rarely found above this line so the impact on this species would be minimal. Again, a more detailed assessment would be required.

4.6.6 Fish

The Severn Estuary supports a range of migratory and marine fish species. The migratory species of particular concern are salmon, twaite, allis shad, sea and river lamprey, eel and sea trout, which are designated features of the estuary under the EU Directives.

The estuary also provides feeding, spawning and nursery grounds for a number of marine species. For example, flounders, bass, whiting, sprat, mullet, pollack and sole are found in considerable numbers as high up the estuary as Oldbury.

A barrage would affect fish in a number of ways: principally as a result of it being a physical barrier in the estuary, and because of potential changes to water quality including dissolved oxygen, turbidity, and contaminants. However, a range of other factors would also come into play – increases in prey on juveniles by birds and fish, change in prey resources, changes to spawning and feeding grounds, as well as delays to migration and the movement of smolt (spawn) and the identification of natal rivers. Furthermore, fish would be sensitive to barrage construction, in particular noise and water quality.

For the barrage structure itself, the issues are its physical presence (the potential to delay or block migrations routes), the safety of fish passing through turbines, and the possible mitigation measure of fish passes. All these factors will vary depending on the type and age of the fish.

The effects on fish are very much influenced by the location of a barrage within the estuary. The Shoots barrage, higher up the estuary, would not 'block' the River Usk (a SAC in its own right) and so the impacts for fish (especially shad, lamprey and salmon) would be directly reduced and the overall reduction of leaving one of the key protected rivers 'open' could be material.

In relation to passage through turbines, a 2001 study cited in Research Report 3 involved simulations using specifically the turbine proposed by STPG for the Cardiff-Weston barrage and this predicted injury rates for species including salmon (adult – 40%; smolt – 10%), eel (28%) and shad (juvenile – 53%) with varying injury rates (as indicated in brackets). However, the Environment Agency's view is that salmon, sea trout and shad in particular, would potentially face high to very high mortality rates. Actual injury rates would be sensitive to precise turbine designs, rotation speeds, fish pass size and location and patterns of generation.

Large fish passes, possibly of different types to target different species, would be needed to try to mitigate the presence of a barrage by providing an alternative route for some fish. Further work would be required to consider options for fish passes.

Further detailed studies would be required of the possible impacts on species, especially those which are designated or of commercial or recreational importance. The implications of changes in water quality and the sensitivity of different species to change would also need to be considered.

International experience with fish passage at other barrages varies. The pilot barrage scheme in the Bay of Fundy resulted in a very high impact on migratory fisheries. The barrage at La Rance has been described as having had minimal impact on migratory fish species, although other reports suggest that the barrage has had an impact on migratory species such as Trout. A Severn barrage would use turbines more closely resembling the Rance barrage in terms of this aspect of operation, so the very high mortality rates experienced with turbines at Bay of Fundy would not be expected. Nonetheless, the adverse impact on fish populations could still be very significant, depending on the success of mitigation measures.

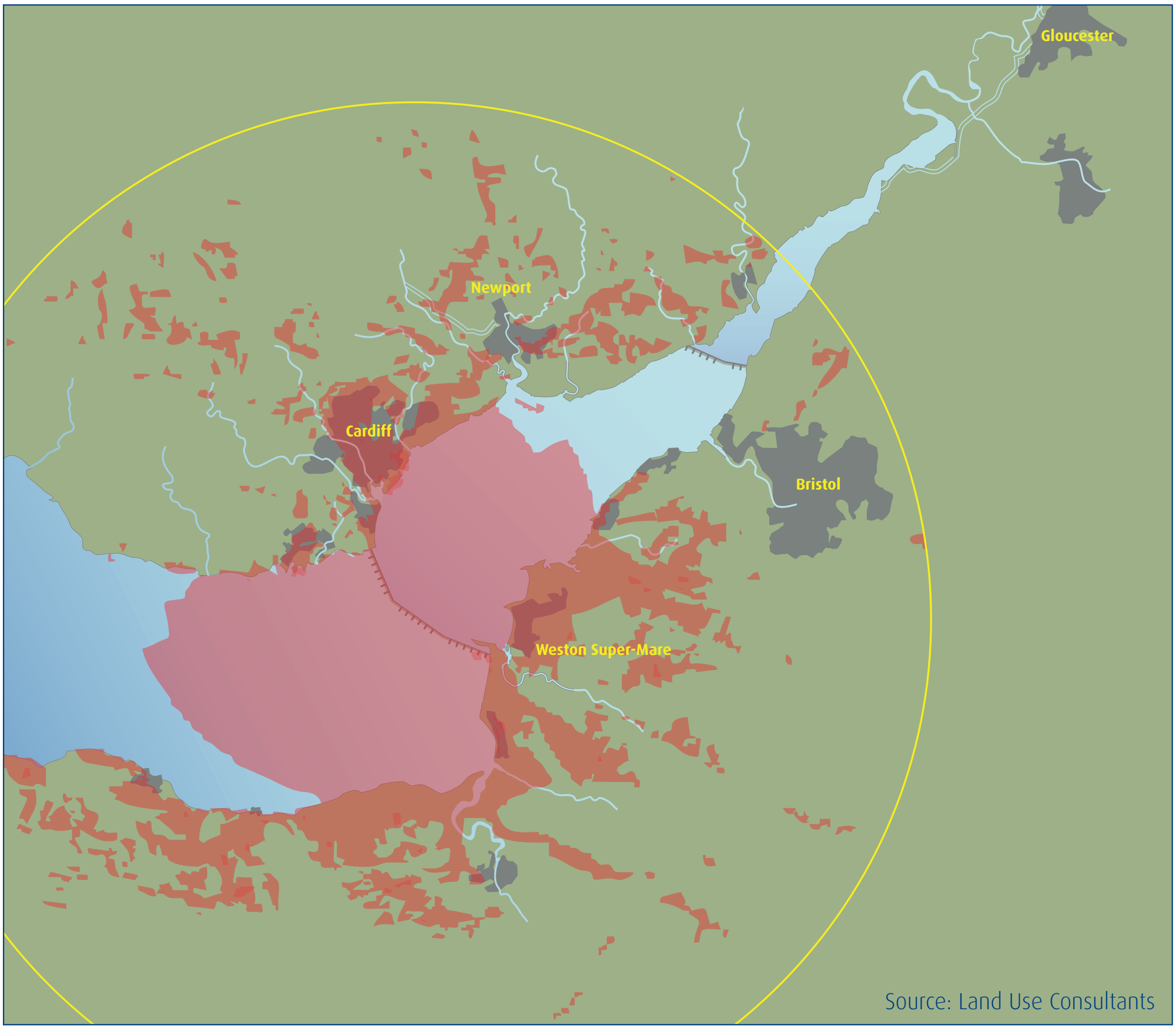
4.6.7 Landscape and visual

A report recently commissioned by Natural England[81] has considered the effects of the construction and operation of the Cardiff-Weston barrage on a range of landscapes and views. The landscape features considered were principally located on the English side of the Severn in accordance with the agency's remit, although the 'zones of visual influence' identified cover the whole of the estuary and surrounding areas. Figure 30 predicts the zone of visual influence up to 50km from the Cardiff-Weston scheme when no road link is included.

The conclusion of the report was that a Severn barrage at the Cardiff-Weston location would potentially have a significant effect on some aspects of the landscape and seascape character, national landscape designations, and views. Both the physical presence of a barrage and the physical changes to water levels and morphology would affect the landscape. In addition to direct impacts, the infrastructure associated with a barrage could have a range of indirect effects; in particular, road links and new power lines as well as possible new coastal development. The report includes suggestions for minimising or mitigating the impacts, and enhancing the landscape through location, layout and design.

Going forward, there would need to be a good understanding of public perceptions of the existing landscape and seascape, and attitudes towards a new built structure like a barrage. This would need to be considered in any future design work and for a comprehensive assessment to be made before, and as part of, an Environmental Impact Assessment. Accurate and realistic visual simulation images (static or video) are important for people's understanding of a proposal; the existing images are very dated and do not use modern techniques or reflect the existing landscape and seascape including, for example, the second Severn crossing. This type of assessment should be a priority to inform public and stakeholder debate and engagement if a Severn barrage were to be taken forward.

Figure 30 **Zoone of visual influence up to 50km from the proposed Cardiff-Weston barrage (with a road link)**[81]



4.6.8 Climate change and the Severn

The Severn Estuary is not a static system, and predictions for the evolution of the baseline estuary environment need to be considered in the light of sea level rise and climate change. Research Report 3 draws on recent work by the Environment Agency[82] to develop a coastal habitat management plan (CHaMP) for the Severn. There is also some other research considering the implications of climate change for the estuary although this is relatively limited and a developing area of research.[83]

The Severn CHaMP confirms that the estuary is changing and predicts that the change will continue, looking at timeframes of 20, 50 and 100 years. Sea level rise will create 'coastal squeeze' and eventually, some loss of intertidal habitat. The greatest percentage change is expected to be in saltmarsh. In 2025, changes in the upstream areas of the Severn estuary will be apparent, and by 2055, a change in the overall estuary bed profile can be expected. By 2105, this is likely to be further change to the profile of the estuary bed with an overall net loss to the intertidal area. The estimated changes compared to the current situation are presented in the table below.

Table 9 **Severn Estuary habitat changes as a result of climate change**

Total Estuary Change (As compared to 2005)	**Estimate of Area in 2005** (ha) (GIS estimate)	**20 year** % change	**50 year** % change	**100 year** % change
Intertidal Area	22,500	-7	-7	-11
Intertidal mudflat and sandflat	20,000	-6	-5	-9
Saltmarsh	1,600	-13	-41	-38
Transitional grassland	1,600	+13	+6	+6
Subtidal	46,000	+3	+3	+5

The predictions of the CHaMP will be used to inform decisions on coastal flood risk management, and will inform the shoreline management plan for the Severn Estuary. The aim is to ensure that potential habitat loss is taken into account in decisions on coastal defence works (maintenance of existing works and construction of new works) in a way that protects the integrity of the Natura 2000 network and Ramsar sites.[84]

In relation to birds, Prater[67] indicates that decreases in Severn Estuary bird numbers for several important species (Dunlin, Ringed Plover and European White Fronted Goose) are attributable to warmer winters – the trend has been for a shift to eastern estuaries (small species such as Dunlin would have been disadvantaged by a smaller body weight in colder eastern temperatures in the past). However, this trend could be reversed over time (as habitat availability and conditions change in other areas), and western estuaries could receive higher numbers in the future. This points to the position of the Severn within the wider network of protected sites and as part of the East Atlantic Flyway.

There will be winners and losers among the birds in the Severn Estuary from climate change. Sea level rise will have an impact on the estuary but it is not clear that the levels of sea level rise and habitat loss predicted until the end of the century will have a major negative impact on the current bird interest of the site.[67] Even bird species in the Severn that drop below the thresholds for international significance are expected to remain important in a UK context. Fish (in particular salmon), will also be affected by climate change, but again the direction of change (positive or negative) depends on a range of factors and varies under different climate change scenarios.

Overall, the picture is complex and involves a number of interacting factors related to sea level rise and an increase in average temperatures under various scenarios. Different habitats and species may respond differently to both factors at a UK and international scale over the medium to long-term, meaning that the relative importance of a site will vary for different species over time. However, the estuary, and conservation sites in general, will remain important for habitats and species as they adapt to climate change.

4.6.9 Impact of a barrage on protected features

The first stage in applying the Directives is that an 'appropriate assessment' must be made. An appropriate assessment for a scheme at the scale of a Severn barrage would require extensive further studies and analysis. The following gives an indicative assessment of the predicted impacts on the conservation features. This overview shows that features would be affected to various degrees by both of the two schemes under consideration. However, the scale of the different schemes, and hence the impacts, should also be kept in mind.

The conclusion of this preliminary assessment is that either barrage would have significant implications for the integrity of the sites. This means that the tests in Article 6(4) of the Habitats

Table 10 **Assessment of impact on designated SPA and pSAC features from both barrage schemes**

Receptor	Cardiff-Weston Scheme	Shoots Scheme
SPA Features		
• Annex 1 species – Bewick's swan	• No specific assessment available – possible impacts to population	• No specific assessment available – possible impacts to population
• Overwintering assemblage of waterfowl	• Species specific assessments generally lacking; broad overview studies suggest that overall populations may be relatively unaffected	• No specific assessment available; limited impact likely based on existing information on bird distributions
• Intertidal mudflats and sandflats	• Potential loss of up to c.14,500 ha of intertidal habitat	• Potential loss of up to c.5,500ha of intertidal habitat
• Saltmarsh	• Unquantified but substantial loss of existing 539ha resource	• Unquantified but substantial loss of existing 133ha resource
• Intertidal rock and shingle	• Unquantified loss of intertidal rock and shingle	• Unquantified loss of intertidal rock and shingle
cSAC Features		
• Atlantic saltmeadows/ saltmarsh	• Unquantified but substantial loss of existing 539ha resource	• Unquantified but substantial loss of existing 133ha resource
• Estuary	• Reduction in tidal range and flows u/s barrage; small local reduction in tidal range d/s of barrage	• Reduction in tidal range and flows u/s of barrage; small local reduction in tidal range d/s of barrage
• Mudflats and sandflats	• Potential loss of up to c.14,500 ha of intertidal habitat	• Potential loss of up to c.5,500ha of intertidal habitat
• Reefs (Sabellaria)	• Unquantified, but significant	• Unquantified but minor
• Subtidal sandbanks	• Unquantified change	• Unquantified change
• Fish (allis and twaite shad)	• Very high risk of very high mortality. Potential stock eradication.	• Very high risk of very high mortality. Potential stock eradication.
• Fish (river and sea lamprey)	• Medium risk of high mortality	• Medium risk of high mortality
River Usk SAC Features		
• Fish (allis and twaite shad)	• Very high risk of very high mortality. Potential stock eradication	• Low risk of impact
• Fish (river and sea lamprey)	• Medium risk of high mortality	• Low risk of impact
• Fish (atlantic salmon)	• High risk of high mortality	• Low risk of impact
River Wye SAC Features		
• Fish (allis and twaite shad)	• Very high risk of very high mortality. Potential stock eradication	• Very high risk of very high mortality. Potential stock eradication
• Fish (river and sea lamprey)	• Medium risk of high mortality	• Medium risk of high mortality
• Fish (atlantic salmon)	• High risk of high mortality	• High risk of high mortality

Directive must be applied.[85] In effect, given the major changes that a barrage would bring and the nature conservation importance of the estuary, any barrage development must make a very strong case to justify overriding the presumption of protection. The tests – no alternative solutions and imperative reasons of overriding public interest – as well as the requirement to secure compensatory measures are considered in Section 4.10.4 as part of the discussion on process and good governance.

4.6.10 Biodiversity impact of a Severn barrage

The Severn is notable in that it has a low number of species, relative to other estuaries. In fact, the Atlantic region as a whole has lower levels of biodiversity in pure species numbers than other regions within Europe – but it makes up for this in terms of animal abundance.[86] Similarly, in the Severn, the diversity and abundance of species found within the estuary may seem to be relatively poor in comparison with other estuaries. But the Severn estuary hosts very large numbers of individuals because of its sheer size, and also plays an important role as part of the overall network of estuaries in Great Britain and in the Atlantic biogeographic region of which it is a part (see Figure 29).

Moreover, the species in the Severn Estuary occur in different ways than in other estuaries; the invertebrates are an unusual mix and they are generally smaller than their counterparts in other estuaries but occur in larger numbers. Therefore, from a biodiversity perspective, any changes to the diversity of the Severn Estuary would need to be assessed both in terms of their impact on the estuary itself, but also in terms of the impact on national and international biodiversity.

On a geographical scale, the species that use the estuary – especially migratory birds and fish – fit into the wider biogeographic region and so it would be important to consider implications of a barrage for these populations within this wider context – for example, the East Atlantic Flyway for waders and the Atlantic for salmon, trout and other fish species.

The initial predictions give a strong indication that large-scale barrage development would have an irreversible effect on some protected features, reduce the area of certain habitat types (most notably the intertidal area), and that there would be a loss of existing biodiversity. An increase in the productivity of the estuary as a result of a barrage may not, in the latter case, be seen as desirable if this were to replace unique features with those that can be found in other ecosystems. There is also significant uncertainty based on available information of whether increased productivity in the estuary would translate into increased bird numbers.

4.7 Economy and society at a regional level

This section reviews the available information on the impacts that a Severn barrage would have on the economy and society at a regional level. Unfortunately, the available information is out of date, and in some cases incomplete, as the detailed studies done in this area mainly date back to the 1980s, with some updates from STPG's 2002 report, as summarised in Research Report 3.

These significant limitations make it difficult to draw definitive conclusions on a number of key issues. Further work, including new primary research, would be needed to address these gaps. A full sustainability appraisal of the regional and local impacts would provide a framework for enhancing positive impacts and for mitigating negative impacts. In particular, the impact on the region's ports is identified as a significant issue that would need further detailed consideration.

4.7.1 Ports and navigation

The Severn Estuary is home to four commercial ports: Bristol, Cardiff, Newport, and Sharpness/Gloucester. Of these, only Sharpness (which provides access to Gloucester via a canal) is upstream of the both proposed barrage locations, along with the heritage harbour facilities at Chepstow and Lydney. The estuary's major port operations – the Bristol Port Company facilities (which comprise Avonmouth and Royal Portbury docks) and the Associated British Ports (ABP) facilities at Cardiff and Newport – are located upstream of the Cardiff-Weston location but downstream of the Shoots location. The ports of Barry and Bridgwater are located downstream of both barrage locations in the Inner Bristol Channel.

The ports and the services they support are an important part of the local and regional economy, and are responsible for handling around 3% of UK trade (17.2 million tonnes of freight in 2004). It is estimated that the Bristol and south Wales ports generate over 15,000 jobs between them, with many more jobs held in port-based companies. With their close proximity to centres of population in the West Midlands, and good strategic transport links through road and rail, the ports in this area make an important contribution to the region and are in many cases successful businesses in their own right. The Severn Estuary is also used by fishing and leisure interests, whose needs may be very different to large commercial users.

In the case of Bristol port, there are existing proposals for a major expansion of the ports facilities at the Royal Portbury site in order to provide increased capacity for deep-sea container ships, which are expected to be an important component of future growth in the shipping industry. The new facilities would have berths for four ultra large container ships (often termed 'post-Panamax') of up to 16m draught to accommodate these vessels when they enter service.

A number of stakeholders from the marine and ports sectors have expressed concerns that navigational requirements are sometimes overlooked when marine infrastructure projects are carried out, and in the case of a Severn barrage, that the potential impacts on the region's ports have previously been downplayed as an issue. The message consistently passed to the SDC was of the need for early engagement and consultation so that any conflicts can be mitigated, and safety ensured.

The Marine Bill published by the UK Government should help to achieve a more integrated approach to the planning of marine developments.

Impact of a barrage

A barrage in the Severn Estuary will create a physical barrier to ship movements, requiring the installation of one or more locks in order to facilitate passage between the two different water levels. The operation of locks will inevitably have an impact on ship movements through any delays or restrictions on capacity, as well as adding a cost penalty as a result of the time taken to pass through the locks. The design of locks is also an issue, as current designs assume a maximum ship size that would be too small for the very large container ships that might dock at Bristol in the future.

No detailed studies have been carried out on ship movements in relation to barrage operations, and this remains as a gap in the evidence base that would require further work as part of comprehensive impacts assessment. For example, earlier studies on the proposed Mersey Barrage (see Section 3) included a detailed assessment of ship movements and the likely economic impact of a barrage. In relation to construction, previous studies have assumed that navigation would be maintained throughout the construction period, with the locks completed prior to barrage closure.

Changes to the tidal range as a result of a barrage could have mixed consequences for shipping, particularly upstream. The raising of low tide water levels could potentially be beneficial for the navigation of shallow draughted vessels as an increased period of time would be available for transit in the estuary. However, the reduction in high tide water levels could have serious implications for the navigation of large vessels upstream of a barrage, as this would reduce the amount of time and/or capacity for transit. This would exacerbate the current constraints at Sharpness, which would be upstream of both barrage proposals and can only be accessed by large vessels (6,500dwt) on the spring tides. The Cardiff-Weston scheme would also have an impact on the ability of very large container ships to access an expanded Bristol port, thus jeopardising this planned development.

Changes to the seabed geomorphology and the sediment regime (as described in Section 4.5) could have a direct impact on navigation in the whole estuary through changes to the location of existing features such as deep channels, and the possibility of much greater siltation. A direct impact would be greater requirements for dredging, an activity that may in future be more tightly controlled if the estuary is approved for SAC status under the Habitats Directive. It is important to note that this is another area that remains controversial, and more detailed studies would be required to better model the likely effects of a barrage scheme.

Implications and mitigation measures

There could be significant adverse economic impacts on a particular port, or set of ports, as a result of a Severn barrage due to a potential displacement of port activity or a limit on certain forms of expansion. There is a point at which the delays and inconvenience of having to pass through locks would affect the attractiveness and competitiveness of a port in an international market and therefore potentially to affect the long term viability of one or more of the ports in the estuary. This could result in a loss of trade and investment for the regional economy and the potential for increased carbon emissions, habitat loss, and other environment impacts as a result of port relocation or from a transfer of traffic to other (possibly less optimal) locations.

Mitigation measures might include increasing the size and number of ship locks, and requiring some degree of flexibility to the operational regime of a barrage to accommodate shipping traffic. These two measures could have a negative impact on the construction cost, or potential output of a barrage, which would need to be balanced against the long-term benefits. With regard to sedimentation, dredging has already been identified as a possible solution, but one that has its own negative implications, including a potential carbon cost as a result of increased activity. A reappraisal report produced by STPG in 2002 indicated that a new port downstream might be required to offset for the impact on ports upstream of a barrage. However, this would present a whole series of environmental, social and economic issues, and would need to be considered from a strategic level.

4.7.2 Transport links

Many of the proponents of a barrage point to the potential for new transport links – either road or rail – running on top of the barrage and thus gaining additional value from the structure. These proposals were raised during our public engagement programme, and there was strong interest in the potential for additional transport links, although some concerns over the possible impacts of improved access and associated development on existing communities.

The prospect of new transport links raises a number of key questions, which can be summarised as follows:

- Is there an identified need for new transport links at either of the two primary locations?
- Considering the needs of ships passing through the ship locks, how would a road or rail link be engineered into a fully-functioning barrage and which traffic would get priority?
- What are the possible impacts on local communities and the environment of building new transport links?
- Would public support for a barrage be any different if for some reason transport links were not a viable option?

Identified need

The SDC has not been convinced that there is any identified need for a new road link either at the Cardiff-Weston or the Shoots location, the latter now having two road crossings already. There are no existing plans that propose a further Severn road crossing, and in the case of the Cardiff-Weston barrage it is not clear that the volumes of traffic that a road link would displace would justify such a project. However, this view contrasts with the results of our public engagement work, where a road crossing at the Cardiff-Weston alignment was felt to offer significant job and leisure opportunities.

The most promising proposal seems to be for a high-speed rail crossing running over a barrage. The existing Severn Tunnel was completed in 1885 and provides a single-track rail connection between Bristol and Cardiff. According to Network Rail,[87] the Severn Tunnel is a serious constraint on enhancing services to and from south Wales, which include passenger and freight traffic. Some stakeholders are also concerned at the long-term viability of this strategic asset, which is of crucial importance to the economy of Wales.

Neither road nor rail options have been fully assessed and costed in previous assessments of a Severn barrage, so there is limited information on what the additional cost might be. Although a rail crossing could be added to either barrage scheme under consideration, the most logical (and least lengthy) option would be a crossing over the Shoots proposal, as this would follow the existing alignment of the Severn Tunnel, allowing easy connection to existing infrastructure. A rail crossing on the Cardiff-

Weston scheme would also be able to link into the national rail system, but would require much more new track and a number of new connections, thus increasing the cost.

Engineering uncertainties

In addition to limited information on cost, there seems to be a lack of information on how a road or rail crossing would be engineered. With the Cardiff-Weston scheme in particular, the existence of one or more ship locks and the high volumes of commercial shipping traffic that could be expected, present a number of challenges. A solution might be to completely bypass the locks altogether by building a viaduct over the barrage, but this is unlikely to work for a rail link as the gradients would probably be too steep. A solution for rail might be to build a link on both sides of the lock(s), thus switching rail traffic to the side that is not being used by the ship lock system. Of the two options, a viaduct would appear to be more expensive, would have a potentially large visual impact, and would not necessarily benefit from having a barrage as its foundation.

Comparing the two transport options, it seems that a road link could pose more difficulties than a rail link due to the more continuous nature of road traffic and the greater width requirement (assuming a road link would be dual carriageway or greater); a viaduct could be very expensive, although this would depend on its length, and whether it was only required for the lock section of the barrage. For a rail link, the Shoots alignment may be preferential on engineering grounds due to the lower volume of shipping traffic at this upstream location.

Community and environmental impacts

Any new transport infrastructure project can have significant impacts on existing communities and the environment, both positive and negative, although these differ considerably between road and rail.

For a new road link, the positive impacts can include improved access for local communities (and the wider region), reduced congestion, and shorter journey times as a result of more direct routes. These benefits, if maintained, can have positive benefits for the local and wider environment, with potential for reduced air pollution and carbon emissions. On the negative side, a new road link can spoil the local environment, cut off existing communities, lead to an increase in traffic, congestion and pollution, and increase carbon emissions.

The impacts of a new rail link may be more confined to the land-take of the infrastructure itself, and some of this may displace existing infrastructure. The benefits are likely to be inter-regional rather than specifically local, with the potential for shorter journey times and improved frequency on the Cardiff to London route. The local environmental impact is likely to be limited, although this depends to some degree on whether the new link is accompanied by electrification of the existing line.

Public support

The strong initial reaction among some members of the public to the potential for new transport links was based to some degree on a perception that this would represent greater value for the project – two benefits 'for the price of one'. If, however, it turned out that a new transport link was not viable for whatever reason, this may lead to a reduction in support for the barrage project as a whole. This is particularly true if the project is presented to the public with the transport option attached from the start. The conclusion from this is that proponents of a barrage may wish to postpone judgement on the merits of new transport links until the case for one is proven and the engineering uncertainties are resolved.

Valuing transport proposals

The provision of new transport links as part of a Severn barrage project would appear to be an 'optional extra' for which there are uncertainties both over the need, and the engineering practicalities. As a result, transport proposals should be evaluated as stand-alone projects based on the additional costs that they might add to a barrage scheme. For a rail crossing, this would necessitate an assessment of the comparative cost of building a link over a barrage compared to a new bridge link or tunnel that could be constructed in the most appropriate location.

4.7.3 Coastal defence and flood protection

The original proposals for a Severn barrage were not conceived or designed with flood defence in mind. But with the sea level rising and the prospect of increased storm surges – as a direct result of climate change – the flood management and risk profile of a barrage are now an essential part of the analysis. As the Foresight 'Future Flooding' report shows,[88] climate change is increasing flood risk, particularly from sea level rise and more stormy weather, and coastal flood risk is predicted to increase in proportion to flood risk from rivers.

Two aspects of coastal and fluvial (river) flood risk need to be considered:

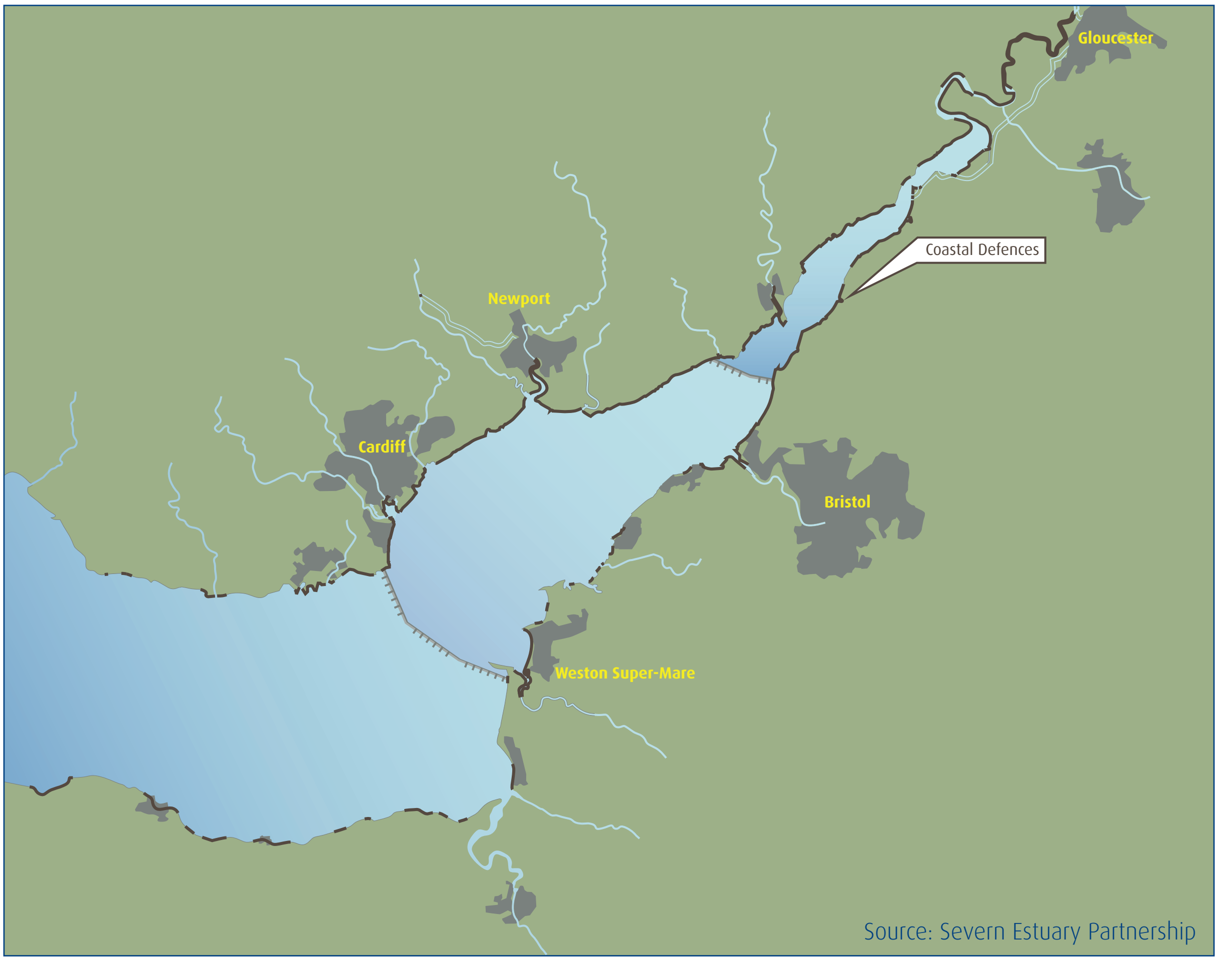
- Coastal defence and possible protection from sea level rise and storm surges for low-lying land around the estuary
- Flood risk from rivers that flow into the estuary

The discussion in this report is at a high level and flooding is an issue that would need to be considered comprehensively in any future studies. It is difficult to make definitive statements based on available information. In particular, more information would be needed on the operating and management regime for a barrage as well as how changes to the morphology of the estuary (discussed in Section 4.5.3) could affect management of coastal erosion and flood risk in the long-term.

Severn Estuary flood defences and land drainage schemes

The vast majority of the coastline along the Severn Estuary is already protected by coastal defences. Many of the defences have been built over hundreds of years, and some date back to Roman times. This has generally been a progressive process of land reclamation, with many low-lying areas now dependent on these defences to avoid inundation at high tide. In turn, thousands of people are now reliant on coastal defences to protect land and property. The extent of coastline protected by defences is shown in Figure 31.

Figure 31 **Existing coastal defences around the Severn Estuary**



The main coastal flood risk is from very high tides combined with storm surge events, which can occasionally cause water levels to increase by up to 2m. In upstream areas, there is a further risk of fluvial and surface flooding from high rainfall. In some instances, a combination of factors may increase the risk, for example, where river flooding upstream coincides with a high spring tide.

The very severe flooding experienced in central and western England in July 2007 was a result of heavy rainfall (rather than a storm surge), which caused high river levels and flash surface flooding. On this occasion, it appears that a Severn barrage would not have been able to prevent any flooding because it occurred during a period of neap tides, which means there was no impediment to river discharge into the estuary.

A further consideration is land drainage management. There is around 800km^2 of low-lying land upstream of the Cardiff-Weston barrage, including the Somerset, Wentlooge and Caldicott Levels; part of the Somerset Levels lie downstream of the proposed barrage location. Upstream of the Shoots proposal there are also large areas of low-lying land around Gloucester. These low-lying areas are in many cases drained by a large number of schemes, which help to provide land suitable for agriculture and human settlement in the region. Previous research identified well over 100 drainage schemes with outfalls into the Severn, and many of these use 'tidal flaps' (one-way drains) to allow discharge during low tide periods.

Flood risk and coastal erosion policy

The Department for Environment, Food and Rural Affairs (Defra) sets Government policy on flood and coastal erosion risk in England, and gives financial support to operating authorities for flood and coastal defence. These are the Environment Agency, local authorities, and internal drainage boards. In Wales, the Welsh Assembly Government has devolved responsibility for policy and funding. In England and Wales, the Environment Agency is the principal operating authority with responsibility for the main rivers and the sea.

Under the Government's strategy 'Making Space for Water',[89] the Environment Agency will take on a more strategic overview role for all flood and coastal erosion issues, and the role of Regional Flood Defence Committees will cover both coastal erosion and flooding.[90] Local authorities have powers to undertake some flood protection works for ordinary watercourses and some elements of coastal erosion. Internal drainage boards (IDBs) are independent bodies, created under statute to manage land drainage in areas of special drainage need. Planning policy also requires local authorities to take the risk of flooding and coastal erosion into account when considering new developments.

Funding decisions and strategic planning for new flood defences and the maintenance of existing defences are made through a system of prioritisation. Priorities are determined according to the cost effectiveness of the scheme being considered, where the benefits are weighed in terms of protecting existing assets, the value of those assets, improving public safety and ensuring the long-term sustainability of the scheme with respect to climate change and resulting sea level rise.

Across England and Wales, the Environment Agency is presently funded for an annual spend of approximately £600M for the construction and maintenance of flood defences. Although in the long-term this figure will no doubt rise, there are nevertheless limited resources that must be prioritised in order to achieve maximum value.

Implications of a barrage

It is important to note that none of the original barrage schemes were designed with flood protection in mind. However, due primarily to the threat of climate change impacts, this situation has now changed and, as noted in Section 4.2.2, flood protection is now viewed by many as a significant possible benefit of a Severn barrage. Concern over rising sea levels has led some to call for more detailed investigation into the 'Outer Barrage' or two-basin schemes (where a second barrage could be built from the Cardiff-Weston barrage across Bridgwater Bay), as these would offer flood protection for a much larger proportion of low-lying land than either the Cardiff-Weston or the Shoots scheme.

The main benefit of a barrage would be a significant increase in the level of coastal protection for low-lying areas upstream of a barrage. The immediate effect of a barrage would be to lower the level of the high tide within the basin. The Cardiff-Weston alignment would lower the high water level by around 1m. This reduction would effectively protect that area of coast from sea level rise with the expectation that as sea level rises over the next 50 to 100 years, the high water level would gradually increase to the pre-barrage level. For an Outer barrage (at Minehead), very large areas of land would be protected behind the barrage. It must be recognised that a barrage would not replace existing coastal defences around the estuary. The design and operation of a barrage would require these defences to be maintained. A barrage would also give some protection to the area upstream of a barrage from storm surges.

Downstream of a barrage, models indicate that high water levels would decrease. However, these results are somewhat counter-intuitive, and as discussed in Section 4.5.2, it can be seen that a barrage might be expected to increase water levels slightly. The correct position would need to be ascertained using advanced modelling techniques to predict more accurately the likely water levels and whether sediment would deposit in the area of Bridgwater Bay (as a result of decreased currents) or whether coastal erosion could occur downstream of the barrage, requiring remedial coastal defences.

A barrage could also allow high water levels in the upstream basin to be managed to some extent. This would on occasion require a change in the operating regime, and so there would most likely be costs incurred as a result of lost electricity output. This ability to manage a barrage would assist flood management in the event that peak river flooding was predicted to coincide with a spring high tide. In such an event, the aim would be close the barrage to prevent water entering the basin and to prevent the high tide reaching its maximum. This mode of operation would be similar to the Thames barrier which protects large parts of London. It is likely that a condition would be placed on the barrage requiring the operator to operate the barrage to prevent flooding if required.

As well as the possible benefits, there are concerns that a barrage may also have negative long-term impacts on flood risk upstream of a barrage. One risk that has been suggested is that changes in the sedimentary regime and morphology of the estuary could weaken the banks of rivers and streams by depriving them of sediment flows, thus causing erosion. The concern is that this could require expensive modifications and upgrades to flood defences upstream.

Land drainage is one further aspect that needs to be factored into consideration of a barrage. The original barrage studies indicated that the impact of an increase in low water levels as a result of a barrage, combined with the increased time at which water is held at high tide levels would mean that some existing drainage schemes will be adversely affected due to shortening of the time available for discharging. In addition, where sea defences are on pervious foundations, extra local drainage might be required to control saline intrusion. The previous research identified well over 100 drainage schemes with outfalls into the Severn, and many of these use ‘tidal flaps’ (one-way drains) to allow discharge during low tide periods. These drainage issues can be dealt with technically by a programme of remedial works to upgrade and add pumping stations to a number of existing outfalls. The cost of the estimated work is accounted for in the cost estimates for the Cardiff-Weston scheme at between £24.5M and £61.9M (1988 data escalated to 2006 prices); there is no equivalent data for the Shoots scheme.

Further investigation is needed to allow a full assessment of the possible benefits and risks for coastal defence, rivers, and land drainage. On balance, the objective would be that to ensure that there is, as a minimum, no net increase in flood risk to social and economic infrastructure from a barrage. This assessment would also need to be valued in economic as well as wider sustainability terms.

Valuing flood risk benefits

Flood risk is an emotive subject, and one that is bound to rise up the political agenda as the impacts of climate change become more pronounced. However, the UK’s coastline is extensive, and it would be very resource-intensive to attempt to protect all of it from flooding. As a result, clear prioritisation is required to ensure that the available resources are spent in a way that ensures the most benefit. It is also important to distinguish between coastal and fluvial flood risk, and the interplay between them.

Evolving UK policy on flood risk management is that physical, manmade structures are not necessarily an affordable, or even the best, solution for long-term adaptation to climate change.[89] In some cases softer options, such as improving the capacity of saltmarshes and floodplains, may be more appropriate. This may also need to be combined with a policy of ‘managed retreat’ or ‘realignment’ where the value of assets that would require protection does not justify expenditure on additional coastal defences.

These issues demonstrate that coastal defences and the adaptation response to climate change are linked with approaches to coastal and wetland habitat management. In the UK, the Essex Wildlife Trust project[91] is an example of a scheme linking coastal realignment and wetland habitat restoration: coastal defences were shifted inland to allow 84 hectares of farmland to become a natural tidal wetland and a sustainable flood protection mechanism. This project has been cited as an example of adaptation practice by the Working Group II of the Intergovernmental Panel on Climate Change (IPCC).[92]

Wetlands can play an important role in adaptation – literally making space for water, allowing natural processes to take their course, and absorbing the force of storm surges – but coastal and wetland habitats are themselves at risk from climate change (see, for example, a Defra-published guide on 'Conserving biodiversity in a changing climate').[93] Protecting these habitats or making new space for them can offer opportunities to achieve conservation and coastal and flood protection objectives. These links are starting to find a place at a policy level, but critically, they must be translated into practice.

In the case of the Severn Estuary, the view of the Environment Agency is that a barrage would not save any money because it would not remove the need to keep and maintain the existing coastal defences.[94] It is also clear that funding levels for coastal defence and flood protection in the UK are extremely unlikely to come even close to the cost of infrastructure represented by a barrage.

The most obvious exception is London, where expensive flood protection mechanisms such as the Thames Barrier can be contemplated because of the very high concentration of population and high value political, economic and social assets that would otherwise be at risk. Building capital-intensive civil structures to protect the UK's coastal areas on a large scale from sea level rise would be economically unrealistic, as well as potentially unhelpful and technically difficult or impossible to deliver. So when it comes to assessing the future risk and options for maintaining coastal defences to provide a similar level of protection in the future, a very large, expensive barrage would not be the top of the list of options as a coastal defence project.

This position leads to the Environment Agency's conclusion that any flood risk benefits from either the Cardiff-Weston or the Shoots scheme would be economically marginal. In effect, there is not substantial public money available for coastal defence which could be applied to part-fund a barrage. However, this position does not necessarily mean that a barrage would provide a marginal level of additional protection, as the level of protection could in fact be substantial.

The terminology used may instead be a reflection of the low asset value of some of these areas, rather than the level of protection provided. This points to another issue: that by providing a higher level of protection to land that would not otherwise be protected and might, without a barrage, be lost to sea level rise, a barrage would have the consequence of increasing the value of such land. This could increase development pressures in low-lying coastal areas around the estuary. This issue is discussed further in Section 4.7.5.

Accurately calculating the net flood risk benefit (after accounting for possible negative impacts and for the barrage operating regime) would be an important task. If such a benefit can be proven, then there may be a case for crediting this benefit to a barrage project in some way, although this would depend on how a barrage was financed. A scheme led by the private sector may seek a grant from Government to 'pay' for the flood protection benefits, whereas a public sector scheme would be able to treat such benefits as part of the overall scheme.

The flood risk benefits from the 'Outer Barrage' or a two-basin scheme would no doubt be greater than the Shoots or the Cardiff-Weston schemes, and would provide a greater degree of protection to areas such as the Somerset Levels. However, such benefits would need to be balanced against the additional cost of these schemes and, assuming that these costs would be met from public funds, consideration would need to be given to the wider pressures on the flood risk management budget in England and Wales.

It may be the case that some of the land that would receive additional protection would not normally be considered for coastal defences due to its low value in terms of protecting life and property. Implementation of softer options, including managed retreat, may be more appropriate in combination with a greater degree of protection for high value assets. It is also possible that a barrage developer may seek to use some of this land in formulating a compensatory habitat package, as required under the EU Directives.

4.7.4 Employment

A Severn barrage would result in the creation of substantial numbers of new jobs, most of which would be concentrated in the construction phase. Previous studies have made detailed estimates for the likely scale of new employment, but most of the data and assumptions for this work are now likely to be out of date, so the figures quoted both here and elsewhere need to be treated with extreme caution. For example, productivity gains may mean a 10-20% reduction in labour requirements, but this may be accentuated by any shift of production to other countries. It is also not clear from the previous studies how the indirect employment impacts were calculated, and there is no data on possible employment disbenefits as a result of reduced visitor spend at certain sites or from a reduction in port activity.

The most recent work by STPG (2002) estimates employment at 200,000 person years for the construction phase of the Cardiff-Weston scheme, peaking at 30,000-40,000 per year in Years 2 to 5 of the project. STPG also estimated that 50% of the jobs created would be in the Severnside region. This would most likely result in a substantial net migration of labour into the region from the rest of the UK and internationally. In the current European job market, a large percentage of this migrant labour could be expected to come from the new EU member states, or from the new member states of the future.

With any strategic assessment of employment impacts, consideration needs to be given to the net employment effect of any particular development in the context of overall national employment levels, and the type and quality of the jobs created. The creation of jobs around the construction and operation of a barrage will not necessarily represent a net increase in employment, as these jobs may otherwise have been created elsewhere – for example, in the construction of a conventional electricity generating plant. More important is the balance between the creation of skilled and non-skilled labour, their permanency over time, and the potential for learning and innovation through the project. These factors need to be considered in comparison with other electricity generation technologies.

A net migration of labour into the Severnside region could have a significant impact on the demand for accommodation during the construction phase in an area that is already under pressure from rising population (the population in the west of England is expected to increase by 117,000 by 2026).[95] If this is not adequately catered for then there is a risk that these demands could result in an increase in urban sprawl and poor quality housing development, upwards pressure on the cost of accommodation, and community cohesion issues.

Any decision to proceed with a barrage would need to be accompanied by detailed strategy for the provision of both short and long-term accommodation for migrant labour, along with the additional services required. There may also be a number of possible measures that could be taken, including programmes to up-skill the local workforce and efforts to ensure the participation of existing local businesses, both of which would have wider regional benefits.

4.7.5 Development and housing

A Severn barrage would have significant impacts on local communities and housing, as well as the potential to create new opportunities for development at regional and sub-regional levels in the south west of England and in south Wales.

At a local level, a barrage would directly affect the communities located at the landfalls of the barrage. In particular, the Cardiff-Weston barrage would directly affect the communities at Lavernock Point on the Welsh side of the estuary and Brean Down/Weston on the English side of the estuary. The extent of impacts would depend on the exact landfall of a barrage and on the detailed design and planning of the barrage alignment and whether the project would include ancillary features such as new transport links, which would have to be integrated into existing networks.

The barrage alignments chosen for study in the past were mainly based on economic and energy considerations, and the available studies recognise that land use issues would require further consideration. Any project would need to minimise the direct impacts on communities both in the location and design of a barrage, and during the construction phase, and would also require extensive engagement and consultation with these communities. Drawing on the conclusions of the World Commission on Dams,[96] this process should aim to reconcile competing needs and entitlements through an approach that recognises rights and assesses the risks, particularly in relation to local communities.

The development of a Severn barrage could result in the creation of a more attractive estuarine environment, which could in turn lead to an increase in land values and the potential for prospective development. In addition, the potential for a barrage to provide additional coastal defence around the estuary may mean that areas of coastal land gain a higher level of flood protection (from future sea level rise and storm surges), which could increase development pressure on rural and greenbelt land around the Severn. Depending on how the project was financed, there may be a strong incentive for developers to seek to enhance the commercial viability of the project by linking it to commercial and residential development, both in developing their business case, and in seeking planning permission and consent.

Ensuring people have access to good quality, affordable and environmentally and socially sustainable places to live is a fundamental sustainable development policy goal. The SDC believes a whole-system approach is needed to tackle housing affordability, encompassing supply and demand sides. In this context, the SDC recognises the need to build additional homes, and to do so in areas that help to relieve some of the acute pressures in other areas such as the south east of England. As our recent review of Government's progress on Sustainable Communities highlights,[97] we believe new homes should be built in ways that tie in with local and regional plans to ensure that they are strategically located (ideally within existing communities), have high environmental standards for energy and water use, access to public services, and result in the creation of desirable and functioning communities rather than isolated housing estates. Development must also be avoided in areas at risk of coastal or fluvial flooding.

We have a number of serious concerns over the type of development that might occur alongside a barrage. There is a serious risk that a barrage is seen as a vehicle for delivering a much larger development project, due to political or economic priorities. While appropriate and sustainable development may be welcome, the risk is that poorly-designed and badly-integrated development occurs, leading to unwelcome pressures on existing communities, incursions into greenbelt land, and a reduction in the carbon savings that a barrage could achieve due to an increase in ancillary emissions. For a private sector-led project, the relatively high discount rate required by investors (see Section 4.8.2) may lead to an additional incentive on commercial and residential development, which could fundamentally change the dynamic of the project.

The context is of course important. There would need to be a strategic overview taken of development pressures in the regions bordering the Severn Estuary, including an estimate of the likely influx of new residents and businesses as a result of barrage construction, and the long-term needs of the area both in terms of accommodation and services. As Section 4.7.4 highlights, the labour requirements during construction could be equal to the population of a whole town, so there would need to be well-developed plans to deal with this impact in the most sustainable way.

From the SDC's engagement with regional stakeholders, it was clear that, although there is a high level of awareness of possible costs and benefits for the region, the existing strategies and plans for economic development, transport, and spatial planning in south Wales and the south west of England do not account for the potential impact of a barrage. It would therefore be a priority to ensure that any barrage proposal and associated development are considered within the context of these documents as part of a comprehensive review of the regional economic and strategic planning implications of development.[98, 99, 100, 101]

This points to a strong role for strategic spatial planning, and for the economic development organisations (the South West of England Regional Development Agency and the Welsh Assembly Government), working in close cooperation with local authorities, housing associations and other regional and local stakeholders.

A number of the negative impacts identified above could lead to increased carbon dioxide emissions in other parts of the economy. For example, displacing shipping capacity could result in an increase in total freight miles due to less appropriate replacement locations, and new transport links or major new housing developments could lead to increased emissions. Some of these impacts may be containable in the long-term through regulation (e.g. new standards for zero carbon homes from 2016) or an economy-wide cap on greenhouse gas emissions. But the complexity of the issues involved makes clear the need for a broad assessment of the net carbon balance of all the options under consideration, and any associated development.

The potential for wider environmental impacts would also need to be managed strategically to ensure that increased development pressure seeks to minimise the impacts on biodiversity and habitats, both coastal and rural.

4.7.6 Leisure and tourism

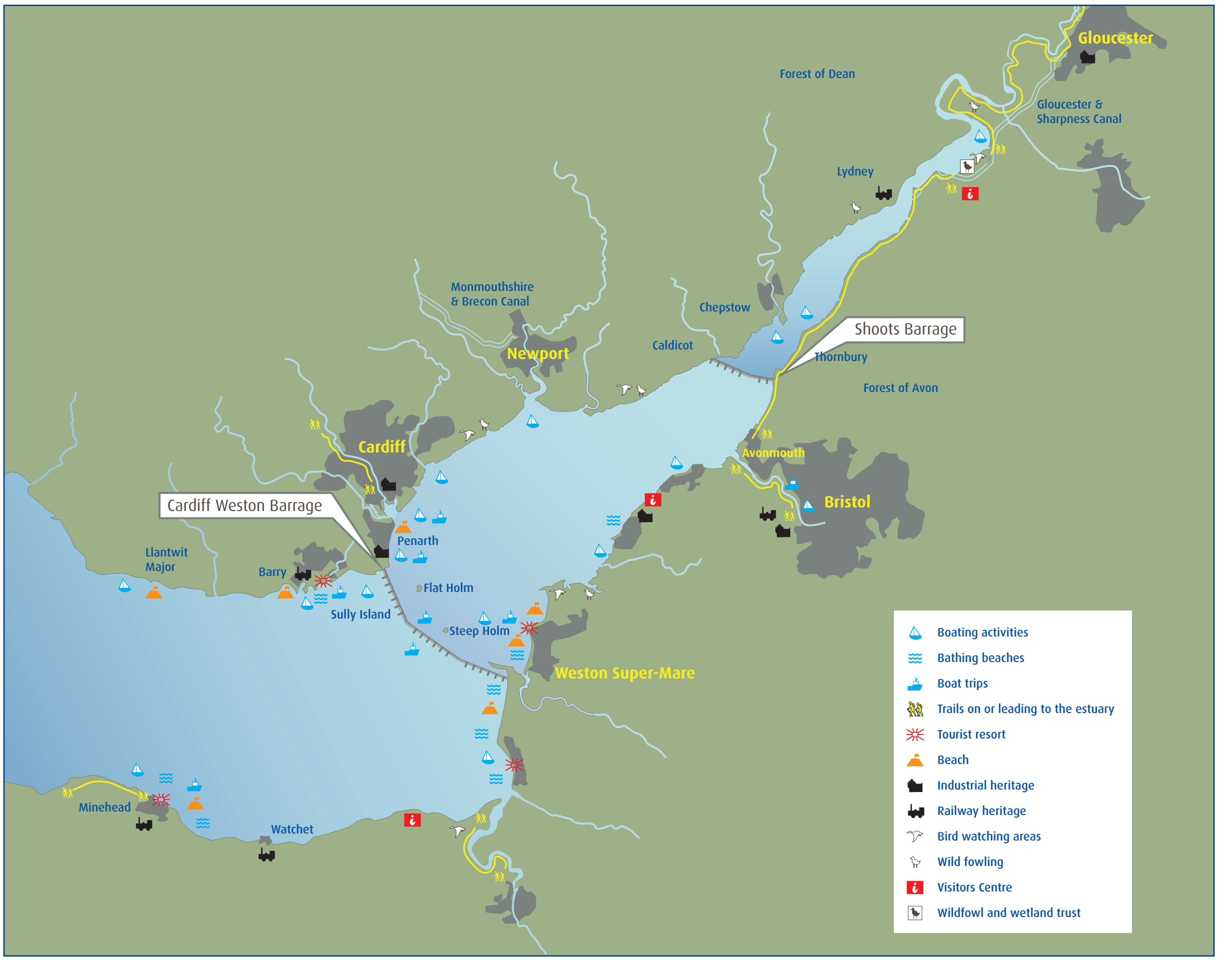
Tourism is one of the largest employment sectors in the Severnside region, with several million visitors per year and a wide variety of leisure activities taking place. These include:

- **Angling** in river tributaries upstream of a potential barrage, with some 6,000 participants estimated for salmon alone
- **Bird watching**, particularly around Bridgwater Bay and in the upper estuary at Slimbridge, the latter having about 200,000 visitors a year
- **Cardiff Bay** recreation due to the completion in 1999 of the Cardiff Bay barrage
- **Surfing** and tourism related to the unique occurrence of the **Severn Bore**, which is a naturally occurring tidal wave that travels up the River Severn and can reach heights of 2m
- **Tourist resorts**, including Barry Island, Burnham-on-Sea, Clevedon, Penarth, Weston-super-Mare and Minehead
- **Wild-fowling**, consisting of 13 wild-fowl clubs with up to 500 members on both sides of the estuary
- **Yachting** in the relatively small number of yacht havens, including those at Bristol, Chepstow, Penarth Marine (inside the Cardiff Bay barrage) and Portishead.

Figure 32 shows the tourist attractions and recreational areas in the Severnside area.

Previous work by STPG suggests that the combination of a high tidal range, strong currents, and high levels of turbidity serve to limit the level of recreational activity in the Severn Estuary. However, the effect of this may allow or encourage the existence of other forms of recreation, such as those associated with the wildlife or unique characteristics of the area.

Figure 32 **Tourist attractions and recreational areas in the Severnside area**



A previous assessment of the impact of a barrage concluded that there may be a 5-20% increase in tourism as a result of a Severn barrage, mainly due to the creation of less severe conditions in the resulting basin and the likelihood that the barrage itself would be a visitor attraction. The incorporation of two small boat locks into the original designs for the Cardiff-Weston scheme is thought to minimise the impact on recreational sailing activities.

Possible negative impacts from a barrage might include a direct conflict with popular amenity beaches (such as those at Barry and Weston-super-Mare), and the effect that a reduction in bird numbers might have on bird-watching activities. It seems likely that both barrage schemes would put an end to the spectacle of the Severn Bore, and the leisure activities associated with it.

The data available on tourism and leisure impacts is incomplete and is likely to be out of date. This would be another area that would require further evaluation, including an economic assessment of the likely sectoral impacts on the local economy.

4.7.7 Fishing activities

A summary of the fish species present in the Severn Estuary, and the implications of a barrage for their long-term survival, is presented in Section 4.6.6. Both commercial and recreational fishing activities take place in and around the Severn Estuary and in the rivers that flow into the estuary, including the Wye and Usk special areas of conservation. Salmon and eel are the most commercial important species although the importance of these fisheries has declined. The recreational exploitation of these species and privately owned salmon fishing rights continues to have significant social and economic value. Commercial fishing for white fish such as cod, whiting, bass, and sole also takes place on the estuary using a variety of methods. Very little shellfishing takes place.

The impact of a barrage on fishing activities would be as a result of a number of factors, including the impact on individual species, restrictions on the movement of vessels, the commercial viability of the fishing effort and the fishing methods employed. It is thought possible that a reduction in turbidity may help support an increase in shellfisheries, although this would depend on water quality issues as summarised in Section 4.6.4.

A full appraisal of a Severn barrage would need to include a review of current fishing practices in and around the Estuary, incorporating a wide spectrum of fishing activities, such as trawling, sea angling and shellfisheries. An evaluation of the impacts of a barrage should provide evidence on the likely impacts on fish stocks and water quality. This should also consider the economic and social value of recreational fishing activities.

4.7.8 Aggregates industry

The Severn Estuary is home to a regionally-important aggregates industry, with around 1.5m tonnes landed annually. Much of this is made up of well-sorted dredged sand taken under licence from inter-tidal sandbanks in the Severn Estuary and the wider Bristol Channel. It has been estimated that around 1,700 jobs are either directly or indirectly linked to aggregate dredging activities in south Wales.

Current or proposed plans anticipate that dredging in Welsh waters will move progressively offshore, with around 800,000 tonnes of material expected to come from the Severn Estuary and inner Bristol Channel by 2015.

A Severn barrage would have a number of potential impacts on the aggregates industry, both ongoing and during construction. Importantly, any changes in the sedimentary regime (see Section 4.5.4) could impact on the quality of sand resources, and therefore on the economic viability and environmental implications of extraction. A decrease in turbidity as a result of a barrage would most likely lead to the modification of the seabed from mainly sand-based substrate to a mixed substrate of sand and mud. On the other hand, a barrage may improve access to some sites due to modifications to upstream water levels, and a potential increase in the number of sites that are fully submerged.

During the construction phase, a barrage would also require a very large quantity of aggregates for fill and concrete. There would be a number of advantages from sourcing this locally or regionally – most importantly, the minimisation of transport-related carbon emissions – and the SDC would be concerned if this could not be achieved. This would be a positive, albeit short-term, benefit for the regional aggregates industry, with the possibility that demand could be met through a combination of existing and temporary licences. However, such a high level of demand may lead to upward pressures on the prices of aggregates, which could have negative economic effects both regionally and nationally depending on the extent to which this demand could be met from increases in supply.

As with other regional economic considerations, this issue would require further investigation if a Severn barrage were to be considered in more detail.

4.8 Cost and financing

This section looks at the estimated capital costs for the two Severn barrage schemes under consideration, before going on to analyse the unit cost of electricity output that arises from a variety of different discount rates, and their relevance. It then considers the level of Government involvement that might be required to develop a Severn barrage project, before commenting on possible financing options and the treatment of ancillary benefits.

4.8.1 Cost of construction

The last detailed estimate of the likely construction cost of the Cardiff-Weston and Shoots barrage schemes occurred in 1988 and 1990 respectively. In order to update these figures for inflation, Research Report 3 used a multiplier based on a price escalation index. It is important to note that the figures presented below are an update of previous estimates and are not based on revised data. Changes since the 1990s, such as the likelihood of being able to obtain some of the equipment overseas at reduced cost, and the reduced need for labour (along with possible increases in real labour costs), point to the need for treating such estimates as indicative rather than definitive.

That said, the SDC's research estimates construction costs of £15,066M (updated to 2006 prices) for the Cardiff-Weston barrage, and £1,498.8m for the Shoots barrage. However, a 10-15% margin of error should be applied to these figures to account for the uncertainties described above.

Both barrage schemes are highly capital intensive, with construction times of up to seven years for the Cardiff-Weston scheme. Private sector projects of this size will often be debt-financed, and due to the long delay before revenue generation, interest payments can add significantly to overall project costs. In the case of the Cardiff-Weston scheme, the cost of borrowing might run to several billion pounds depending on the interest rate applied. The calculations presented in Research Report 3 are based on the projects being financed over their lifetimes (120 years) in order to allow comparison with other technology options, but this may be unrealistic if the project were to be financed by the private sector.

4.8.2 Unit cost of output

Calculating the unit cost of output allows for a somewhat simplistic comparison of a barrage with other electricity generating technologies. The unit costs provided in Table 11 are calculated using the construction costs described above, which are converted from their current cost estimates to equivalent annual costs (EAC) by discounting revenues over the expected lifetime of 120 years.

Discounting is a way of accounting for the rate of return an investor might expect from such a project. A higher discount rate usually signifies the expectation of higher risks, whereas a low discount rate might be applied if the project were seen as low risk, possibly due to being proven technology, or because it had Government backing or access to a guaranteed source of revenue. Table 10 provides a range of commercial discount rates (8-15%), along with the discount rate recommended by HM Treasury for public sector appraisals, which is included here to give an indication of the public benefit of both Severn barrage schemes. In fact, HM Treasury recommend a declining discount rate schedule for very long-term projects, with a rate of 3.0% used for the period of 31-75 years, 2.5% for 76-125 years, and 2.0% for 126-200 years.[102]

Further, it should be noted that the costs below are based on the overall capital and operating costs of the two schemes (including interest charges), but do not include ancillary costs such as transmission network upgrades or increased system balancing costs. They do not include any allowance for the costs of providing compensatory habitat as would be required under the EU Habitats and Birds Directives (see Section 4.10.4). This is standard practice when comparing different electricity generating technologies in this way, although providing compensatory habitat would be a core part of any barrage project and the costs could be substantial. It would therefore be sensible for data on the unit cost of output to be presented as a construction-only estimate pending further investigation into the likely magnitude of these ancillary costs – in particular, the cost of providing compensatory habitat.

Table 11 **Unit cost of output (p/kWh (real)) for different barrage options at various discount rates**

Barrage option	Discount rate				
	2%	3.50%	8%	10%	15%
Cardiff-Weston					
5 year programme	2.27	3.56	8.54	11.18	19.1
7 year programme	2.31	3.68	9.24	12.37	22.31
Shoots					
Low case	2.13	2.96	6.08	7.69	12.36
Mid case	2.35	3.29	6.8	8.62	13.87
High Case	2.58	3.62	7.52	9.54	15.38

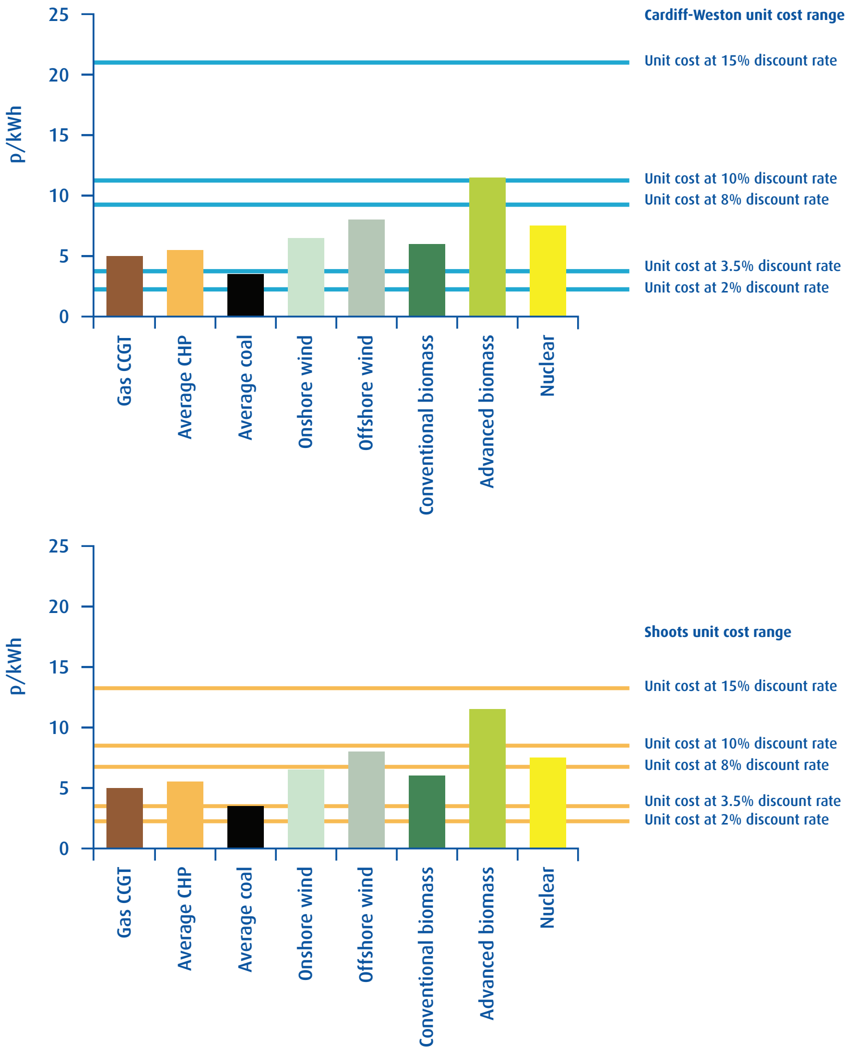
The first conclusion from this data is that the choice of discount rate has a very considerable impact on the unit cost of output. This is due to the high up-front capital cost of a barrage, and the long lifetime of the structure. The SDC's research paper on the economics of nuclear power concluded that a commercial discount rate of 9% might be appropriate for private sector construction of new nuclear plant. Recognising that there are a number of similarities between a large tidal barrage and the development of nuclear power, this implies that the 8 and 10% discount rates are the most appropriate to use if the barrage were to be developed by the private sector. As would be expected, using a social discount rate (2 - 3.5%) results in a much lower unit cost of output than the commercial discount rates. A low discount rate may be appropriate if the project were viewed as a publicly-owned project, as this would take better account of the very long-term benefits.

The second conclusion is that neither of the schemes is cost competitive when compared against current wholesale electricity prices if a commercial discount rate is applied. However, this should not be a surprise with such capital-intensive proposals, and the costs above do not take account of the low carbon premium that electricity output from a barrage would attract. A full commercial analysis would include an assumption on long-term carbon prices but, in the absence of such data, there is a good case for considering the two barrage options against other sources of low carbon electricity.

Table 11 shows how the two Severn barrage options compare against other electricity generating technologies, with the range in costs representative of the discount rates described above. This shows that at an 8% discount rate, both options lie at the higher end in comparison to other low carbon technologies; at 15%, they are well above the costs of all other technologies except wave power; but using low discount rates of 2 or 3.5% a barrage becomes highly cost-competitive.

Even allowing for the fact that the barrage figures may not be completely accurate, the conclusion from this comparison is that both Severn barrage options are unlikely to be economically viable for private sector investment in electricity generation. This has consistently been the conclusion of the UK Government. Furthermore, due to the one-off nature of barrage construction, there is only very limited

Figure 33 **Comparing the cost of a tidal barrage against other technologies**



potential for learning effects from such a project, which means that it is hard to justify Government intervention on innovation grounds.

However, opting solely for the least-cost options for generating low carbon electricity ignores a number of other considerations, including constraints on the rate that any one technology can be deployed, and the reduced risk and cost benefits from having a broad portfolio of generating technologies.[103] Research done by the Policy Studies Institute for the SDC[104] highlights the huge gap that is emerging between required and planned low carbon electricity capacity up to 2030 which, along with the new EU renewables targets, may necessitate the development of a whole series of technologies (both renewable and non-renewable) at a range of cost levels. The conclusion from this is that electricity prices will need to rise substantially in the long-run to pay for low carbon investment across a wide range of technologies, both in supply and demand. This is something that Government is currently reluctant to contemplate, despite the fact that overall costs as a percentage of GDP would be relatively small – as concluded by the Stern Review.[22]

It is also possible to argue that standard economic analysis tends to understate the social and economic gains of projects with very long time horizons. For example, none of the UK's four pumped storage power plants would be likely to go ahead on a purely commercial basis, because of the high capital cost and long timescales involved. Nonetheless, these plants, which were all commissioned in the nationalised era of UK energy policy, have proven themselves as very reliable providers of instantly dispatchable reserve power, bringing significant environmental and economic benefits.

4.8.3 Level of Government involvement

As stated in Section 1.4, current Government energy policy is based on liberalised markets, and therefore assumes that a Severn barrage would need to be financed and constructed by the private sector with minimal Government involvement. The SDC has up to now accepted and worked within this framework, but this project has required us to expand our analysis to include the full spectrum of options right up to full Government involvement and ownership. A number of reasons lie behind this decision, and are explained below.

Long-term public benefits

The 120 year expected lifetime of a barrage means that it would be providing carbon-free electricity for a very long time, and for many future generations. There is a strong argument for suggesting that a commercial economic evaluation of a barrage (based on commercial discount rates) does not take sufficient account of these benefits. Indeed, the Stern Review states that with climate change mitigation policies, it may be more appropriate to use low or even zero discount rates to better reflect the long-term nature of the problem.[22]

The private sector is only likely to accept a low rate of return for a very low risk project, signalling significant Government backing. However, going ahead with a publicly funded project would remove these constraints altogether, and would allow for the consideration of even lower discount rates (down to zero) if the public were willing to pay for the up-front capital cost of the project through general taxation. There are also a number of financing options in between these two options, all of which are considered in more detail below.

The long-term nature of the Severn barrage decision (and the time likely to be required for a decision to be made) also confers on the SDC the responsibility to consider options that are outside the framework of current energy policy, as this could change within the timescales involved.

Mismatch between risk and reward

As with any large, high profile project, the Government needs to be aware of the risk of 'moral hazard', particularly where it has an overriding or well-publicised interest in successful completion of the project. As the SDC explained in its analysis of nuclear power,[105] moral hazard is the term used to explain the phenomenon whereby individuals or organisations may intentionally engage in more risky behaviour, safe in the knowledge that the costs of failure will be borne elsewhere.

In the context of a Severn barrage, such behaviour could manifest itself through appraisal optimism, whereby promoters of a barrage might (intentionally or unintentionally) underestimate the true cost of a scheme, or systematically take on higher risks in the expectation of a Government bail-out should the scheme face difficulties or even collapse. These are numerous examples of where major projects and companies have required some form of emergency public expenditure, including the West Coast Mainline upgrade, Sizewell B nuclear power station, British Energy, and the recent collapse of Metronet.

The consequence of this is that the Government, and therefore the taxpayer, is in the position of underwriting the project, regardless of their willingness to do so. To some degree this will have the effect of reducing project costs by reducing the cost of capital, but it can also have the opposite effect by encouraging or allowing inefficiency and complacency. Of greater concern is the prospect that any serious financial problems with such a project could result in a large bill for the taxpayer to pick up, as once started, no Government is likely to allow such a project to fail.

This inherent risk for Government and the taxpayer, regardless of how a barrage might be financed, leads to a potential mismatch between risk and reward for a private sector-led project. So, despite providing an implicit guarantee of last resort to the project (and possible public money in the event of financial difficulties), in addition to the financial incentives that might be required, the Government and taxpayer would stand to gain little of the economic rewards once the project was in operation, as these rewards would flow to the private sector developer. An alternative, Government-led financing package, whilst not likely to reduce the risks, may enable a fairer allocation of the rewards.

Ensuring the public interest

A private sector-led Severn barrage project would undoubtedly put huge pressure on the developer to find alternative sources of income to the central energy project in order to improve the rate of return for investors. As described in Section 4.7.5, this could take the form of property, business or leisure development in the area to take advantage of the improved aesthetic value of the resulting basin. Proposals to upgrade or construct new transport infrastructure (e.g. ports, roads and rail) are also possible.

While these options provide a possible opportunity for regeneration and sustainable development in the region, this depends to a large extent on how they are carried out.

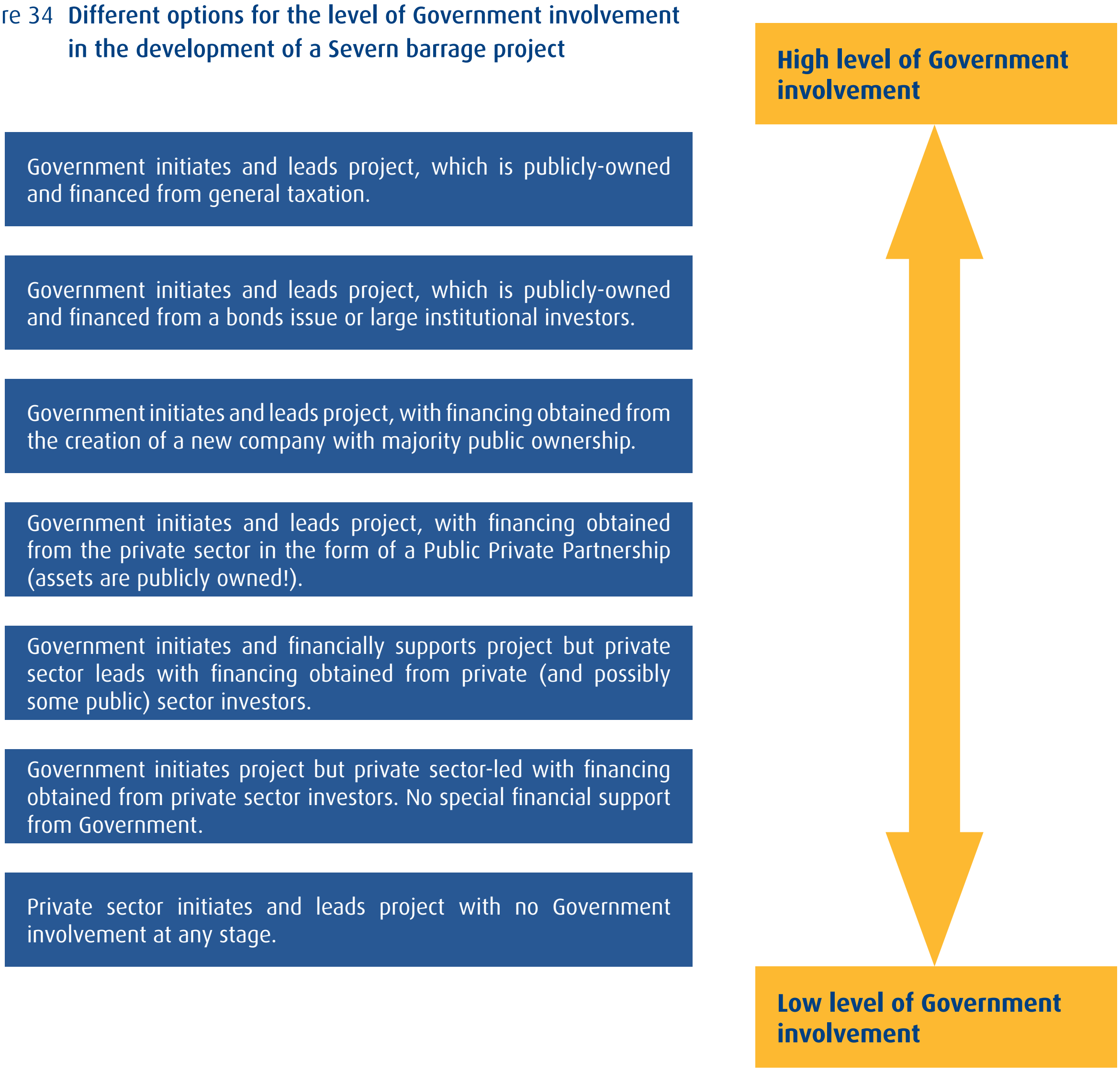
Furthermore, in constructing the barrage itself, there is a potential conflict between the private developer's desire for reduced costs and the public's desire for a well-designed and constructed project. A short-termist approach to construction risks the use of sub-standard materials and methods of construction that could negatively impact on the expected life of a barrage and on the sustainability of ancillary investments.

It may be possible to limit socially undesirable outcomes to some extent through a combination of good strategic planning, incentives and regulation, but the SDC believes it is also important to consider the impact that an alternative financing approach might have in ensuring the public interest is upheld.

Considering all the options

The SDC believes that, for the reasons given above, there is a strong case for considering all the options for financing a Severn barrage, regardless of their fit with current energy policy. A broad range of options for the initiation and ownership a Severn barrage project in relation to the level of Government involvement is presented in Figure 34. This list is not exhaustive, but it does illustrate the considerable range in Government involvement that might be possible.

Figure 34 **Different options for the level of Government involvement in the development of a Severn barrage project**



Under the current energy policy framework a Severn barrage is likely to fall into one of the bottom two categories. However, considering the high cost of output associated with a project led and financed by the private sector, it does not seem likely that it would ever go ahead without concerted Government involvement.

A decision to promote a Severn barrage may, therefore, pose a number of difficult questions for the future direction of UK energy policy. The Government may be able to make a case for supporting a barrage based on long-term carbon savings and security of supply; benefits that are not adequately valued by the electricity market. On the other hand, it would be difficult for the Government to justify treating a tidal barrage as a new renewable technology that requires innovation support (the justification behind the establishment of the RO), as the technology itself is certainly 'mature', and there is only limited potential for learning and further replication.

Regardless of the justification used, Government may be keen to ensure that support for a barrage was done in a way which is consistent with wider energy policy, and the support given to other technologies. This may require a major re-think of energy policy if Government were to take a political decision that a barrage should go ahead. Whilst supporting a one-off special project would risk the charge that the Government is 'picking winners' – something that it has explicitly ruled out[106] – there may be a good case for treating a Severn barrage project differently to others for the reasons given above.

The conclusion from this section is that, after considering and weighing up all these issues, the decision whether or not to pursue construction of a Severn barrage must eventually be a political one, as any scheme would require some level of Government involvement for which a case needs to be made. It is also clear that a positive decision would have much wider implications, requiring a fundamental reappraisal of Government involvement in the energy sector and the incentives on offer to support technologies such as carbon capture and storage (CCS) or nuclear power, right through to other renewables and microgeneration.

4.8.4 Financing options

This section will look in more details at the financing options available for construction of a barrage, and the implications of these on Government policy and the need for public support. Both private sector and public sector financing options are considered, along with several options that sit somewhere in-between.

Private sector financing

A decision to support the development of a Severn barrage by the private sector presents a number of challenges to Government, business and wider society. For example, what economic framework would be required in order for the private sector to invest in such a project and what form might this investment take?

In many ways, some of the issues surrounding the financing of a possible Severn barrage are similar to those that arise with nuclear power, except on an even larger scale. Both technologies are capital intensive, have long construction times, and are not likely to be the first choice for private sector investment in new electricity capacity unless they are able to obtain some form of low carbon premium, or direct support from Government.

As such, much of the research commissioned by the SDC on the economics of nuclear power[107] is also relevant to a Severn barrage, particularly considering the estimates for unit costs of output given above, which show that neither barrage option is likely to be commercially viable at present wholesale electricity prices.

The introduction of carbon pricing, in the form of the EU Emissions Trading Scheme (EUETS), is unlikely to offer the support needed to make a Severn barrage attractive to investors. Phase II of EUETS runs only to 2012, and agreement on the next phase is unlikely for several years. However, even with this in place, it is unlikely that this scheme will be sufficiently long-term to provide the right financial incentive for such an investment.[108]

The Renewables Obligation (RO) requires electricity suppliers to source an increasing percentage of sales from renewables and is currently set to achieve 15% renewables supply by 2015. Although a Severn barrage could be included for support under the RO, the RO end date of 2027 would probably be considered too short to justify such a long-term investment. Furthermore, the Cardiff-Weston scheme would be too large to include in the RO as it currently stands, as adding this level of output from one project would have a serous detrimental effect on the support provided to other technologies by deflating the price of Renewable Obligation Certificates (ROCs) and causing market uncertainty. It is possible that the Shoots barrage could be accommodated within the RO, although this would need further investigation, and concerns over the longevity of RO support would still apply.

With this in mind, the SDC's conclusion is that there would need to be some new support mechanism to allow a Severn barrage to proceed. This could take the form of an additional one-off policy instrument, or the modification or replacement of existing instruments. Possible options include:

- **Extension of the RO**: the existing RO could be substantially extended to provide the continuity needed for a barrage project, although this may not get over the problems identified above

- **Feed-in tariff**: a guaranteed price could be set for output from a Severn barrage, with the additional cost passed on to the energy suppliers, or alternatively to the public sector in the form of a power purchase agreement between the barrage operator and public sector organisations

- **Government-backed bond**: finance could be raised through a bond issue backed by Government, which would help to lower interest rates; however, this would transfer some of the risk to the taxpayer

- **Grant funding**: the project could receive direct grant funding from Government to a level that makes it attractive to investors; this would represent a direct cost to the taxpayer

- **Long-term low-carbon electricity contracts**: the Government could award contracts through auction that set a minimum price for new low carbon output to be delivered at a future date, with any shortfall from the actual market price being met by the taxpayer or other mechanism; such contracts could be targeted at all low carbon technologies, just some, or even a single technology

- **Modifications to EUETS**: the introduction of a floor price, or substantial extension of the compliance period, could provide additional certainty in the long-term price of carbon

- **Public Private Partnership**: the Government could enter into a long-term agreement with a private consortium, who would build the barrage and own it for a certain number of years, with the Government obliged to buy the resulting power output, probably at a pre-determined price; ownership of the barrage would eventually pass to the state at the end of the agreement

- **Severn barrage obligation**: a new obligation on energy suppliers to source output from a barrage scheme

- **Tax allowances**: the Government could provide tax incentives to a prospective developer.

It is not clear which, if any, of these potential options (or combination of options) would be sufficient to encourage a private sector bid to build a barrage. Measures that significantly reduce the risk associated with such a large capital investment are likely to be most successful, as these would reduce the cost of capital and thereby reduce the unit cost of output.

However, regardless of the option chosen, putting in place the necessary economic framework to support the construction of a Severn barrage would require a significant change or addition to current energy policy, and most likely primary legislation. This raises the issue of how any new measure would fit within the policy landscape, and whether it would require a more fundamental review of policy.

It is worth noting that the recently agreed EU renewables target (20% of all energy in the EU to be obtained from renewable sources by 2020) may require a substantial evolution of UK energy policy in order to meet the obligations that are finally agreed. This could require the introduction of new measures, or changes to existing measures, and financial support for a tidal barrage scheme may end up being seen in this context.

If a sufficiently attractive economic framework were put in place, then the SDC's work on nuclear power[107] would suggest that there are two possible routes for private financing of such a project:

- **Corporate finance**, where the project is financed on the balance sheet of the developer or developers

- **Project finance**, where the project is established as a separate legal entity to which a large number of parties may take an interest

Corporate finance is the simpler of the two, but in this case would require a substantial financial commitment from the project developer(s). Project finance is inherently complex, but it does offer some protection from bankruptcy for the developers and allows a much higher gearing ratio for debt to equity. The latter model was used in the construction of the Channel Tunnel, a project that also had some Government involvement.

Public sector financing

As already stated, public sector financing or any significant Government involvement in a barrage development would be contrary to current energy policy. Nevertheless, there is a long history of public sector financing of large infrastructure projects. Virtually all of the UK's generating capacity and transmission infrastructure prior to the privatisation of the electricity sector in the late 1980s was built in this way. Furthermore, considering the high level of Government intervention that would be required to stimulate private sector interest in a barrage, the option of public sector financing does not look quite so radical.

Although previous models of public sector financing relied heavily upon taxation and Government-backed bonds, there are a number of other approaches that may also be relevant, such as a share offer aimed at individual investors or some form of community ownership.

Public sector financing would remove, or at the very least limit, the extent to which the Government would need to make any changes to the market framework for electricity generation or renewables, as a Severn barrage could be dealt with outside existing measures as a one-off project. Upon commencement of generation, the Government could allow output from a barrage to be sold into the electricity market by a publicly-owned operating company. This may be attractive to Government, as it would avoid the need for new measures in an already crowded policy environment. But there may also be concerns over the signals this would send to other technologies, and it is possible there would be accusations of inconsistency and special pleading from other electricity generators.

If chosen, a barrage financed by the public sector would enable an economic evaluation based on a low discount rate. This is because the Government can obtain debt finance at very low interest rates, and there would be no need to justify a high rate of return from the project due to the absence of any incentive to maximise short-term profits. For example, HM Treasury recently released index-linked bonds at a nominal interest rate of 1.75%. As illustrated in Section 4.8.2, using a discount rate of 2% reduces the cost of electricity output (excluding any ancillary costs, such as habitat compensation) to less than 2.5p/kWh, making a barrage very cost-competitive with other forms of electricity generation. The actual rate of return required from the project would depend on the financing model chosen, with options that attempt to bring in external funding likely to require a higher return, and therefore the use of a higher discount rate.

Possible options for raising the required funds for a publicly-led project include:

- **Consumer levy:** the Government could introduce a new levy on consumers' bills to raise the capital required; this could be done over a 10 year period, thus limiting the price impact on consumers

- **Community ownership:** similar to share ownership (see below) or linked to a bond issue, the Government could target investment opportunities to local communities looking for a secure and stable return

- **Government-issue bond:** the Government could issue a long-term bond (or 'gilt'), which would raise the capital needed for construction at comparatively low interest rates

- **Grant funding:** a barrage could be funded solely from general taxation revenue or by increasing the national debt, although this would either require the Government to raise taxes or to cut expenditure in other areas

- **Public company with minority share issue:** the Government could establish a new public company and raise the finance partly through a bond issue or general taxation, with the remaining finance raised from the sale of a minority stake of the company to the private sector

- **Public private partnership:** the Government could allow the private sector to raise the majority of the finance for the project and lead on construction and project management in return for a guaranteed return from the electricity output, possibly in the form of fixed-term operational lease

This is not intended as a complete list of available options, and there is significant potential for new or hybrid financing models, outside of 'public private partnerships', that maintain the principle of public ownership. One possibility is that dividends (for a community ownership or shareholding finance model) or coupons (for a bond model) might be payable in delivered electricity, which could be particularly attractive for future participants (whether organisations or individuals) in carbon markets. This is an area that would benefit from further investigation and stakeholder input.

4.8.5 Consideration of ancillary benefits

As part of the SDC's engagement programme on this project we have heard a number of claims being made as to possible ancillary benefits from the construction of a Severn barrage, or through consideration of additional features, many of which are discussed in Section 4.7. The main themes are as follows:

- Flood protection from a barrage, as well as enhanced protection from 'outer barrage' options
- A new road and/or rail link over the Cardiff-Weston barrage
- A new high-speed rail link over the Shoots barrage to alleviate capacity constraints through the Severn Tunnel
- Development opportunities around the barrage landing points, or on the barrage itself
- Additional renewable energy generation as part of the barrage structure, such as wind turbines or wave devices

Where 'optional extras' to the primary barrage proposal are put forward, the SDC believes that they need to be considered on the basis of the additional costs and benefits that they represent. This means that they should be considered separately to the primary aim of electricity generation, with any additional costs to the main project justified by the benefits they would bring. Moreover, the alternatives to and justification for these elements of a proposal would need to be considered as part of the appropriate assessment where they would adversely affect designated conservation sites.

4.9 Public and stakeholder opinion

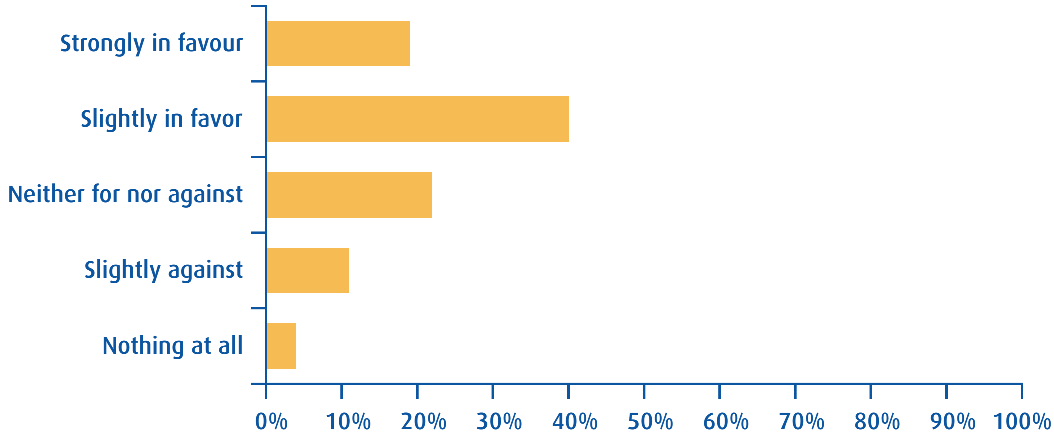
As described in Section 1.2, a major part of the SDC's review of tidal power was an extensive programme of public and stakeholder engagement. As part of this process, the engagement consultants were asked to elicit views specifically on the Severn barrage proposals, which was done through all three strands of public engagement – local, regional and national – as well as through the stakeholder engagement.

4.9.1 Public attitudes and opinions

There was some awareness of proposals for a barrage in the Severn Estuary amongst regional participants due to sustained press coverage in the Bristol and Cardiff area. Those living near the proposed sites for the Cardiff-Weston barrage had a greater level of knowledge. On a national level there was less awareness, with 63% having no knowledge of any barrage proposal and another 18% having only a little knowledge.

After being given top-level information on a barrage proposal and the potential advantages and disadvantages as part of a national opinion poll, 58% of people across the UK were in favour of a barrage and 15% against. The majority of the public consulted in the workshops that took place in Bristol and Cardiff (where more detailed information was provided) were also in favour of a barrage as they felt the benefits outweighed the disadvantages.

Figure 35 **Public attitudes to a Severn barrage**



The production of carbon-free electricity was perceived to be the most important benefit of the barrage in the regional workshops and the main reason to support it. However, a few people were against a barrage, mainly due to the environmental effects on the habitats and wildlife in the area. This concern was also seen at the national scale, with 56% of people seeing it as the most important disadvantage.

Figure 36 **Most important benefit of a Severn barrage**

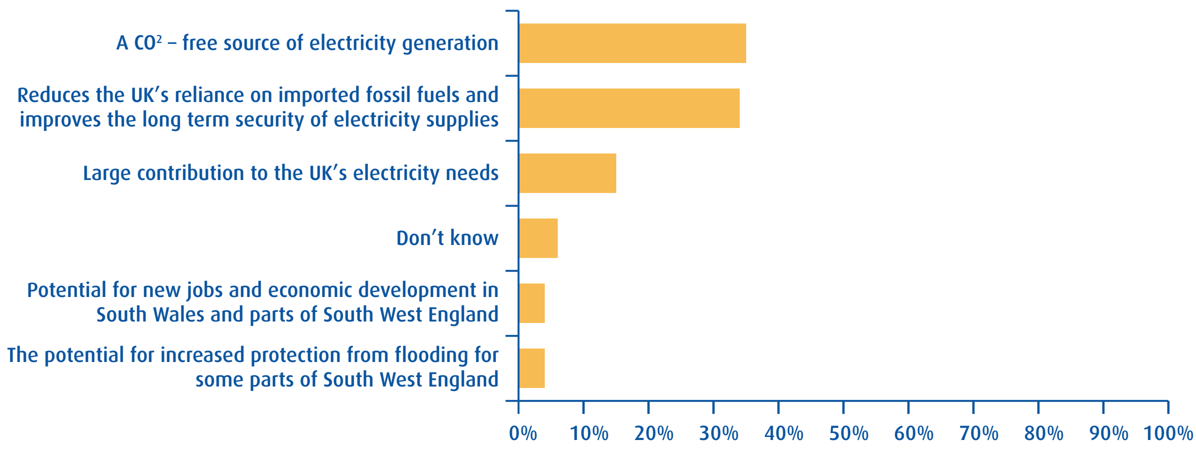
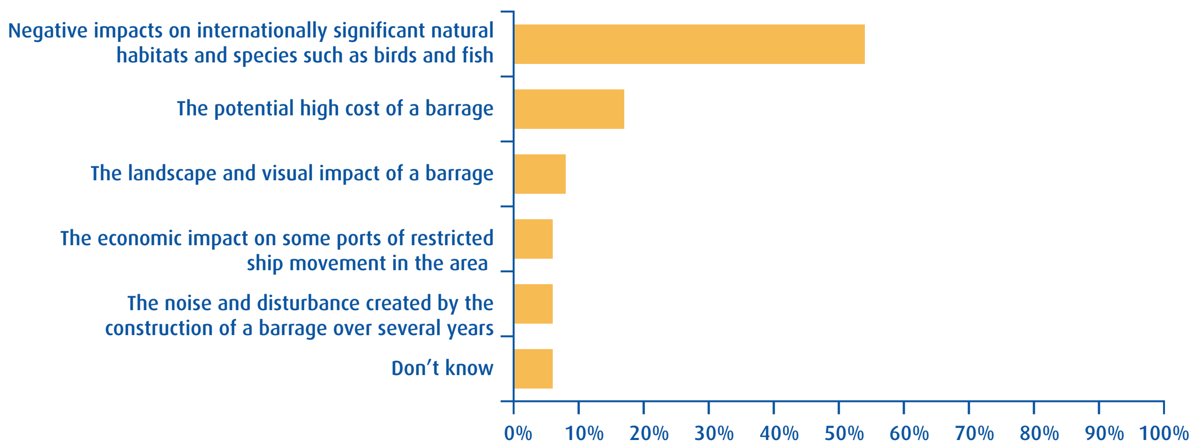


Figure 37 **Most important disadvantage of a Severn barrage**



When given information specifically about the Cardiff-Weston barrage and Shoots barrage proposal, the public in the Severn area were mainly in favour of the construction of a large barrage across the estuary. The main reasons for this were:

- The production of a significant amount of 'clean' energy over a 100+ year period. A larger barrage would use more of the potential tidal resource and could deliver 5% of the UK's energy needs
- There were concerns a smaller barrage would be replaced by a larger one at a later date, which was seen as a waste of resources
- The ancillary benefits of a road/rail crossing and the reduction of journey times between Cardiff and Bristol
- The creation of new job s, although there were concerns that local areas and infrastructures might find it hard to cope with a large influx of people
- Better flood protection
- The potential for positive impacts on tourism in the surrounding area. The Cardiff-Weston Barrage was seen as a significant visual presence, and one that could become a source of civic pride.

4.9.2 Stakeholder attitudes and opinions

The stakeholder engagement comprised two regional workshops with key stakeholders representing a range of interests and sectors, including environmental NGOs, tidal device developers, Government departments and agencies, and shipping interests. The southern workshop in Cardiff paid particular attention to the Severn Estuary barrage proposals.

Stakeholders recognised the contribution that a large barrage could make in producing significant amounts of clean renewable energy, but wanted to ensure that negative impacts would be minimised. Stakeholders generally felt the impacts could potentially be more negative than the public and had greater conditions of acceptability. Therefore many were inclined towards the smaller Shoots barrage scheme over the Cardiff-Weston scheme.

One of the main concerns was the irreversible impact on the environment, ecology and nationally and internationally designated sites and many felt there was a need for more reassurance that environmental impact would be mitigated. Whilst there was a positive attitude towards the identifiable contribution a barrage would make to renewables targets in Wales and the UK more generally, there was also concern that any development might be energy intensive in its construction.

From an economic perspective, a large number of stakeholders felt that investing in a barrage could detract from investing in other renewable energy projects and that it would be too expensive, have too high an impact and would take too long to build. These concerns were less pronounced for the Shoots barrage proposal which was seen to have no or significantly less impact on major ports.

Socially, there was recognition that there would be disruption during the construction phase and that local communities would have to live with the legacy of the barrage. Some identified possible tourism opportunities, and the potential to regenerate areas and break down the English/Welsh cultural divide. Others felt it could have a negative impact on rural settings and, as a counter to its ability to produce carbon-free electricity, would not encourage people to think about reducing energy consumption.

Due to the potentially huge impacts that a barrage would have, there was a strong call for broad public and cross-stakeholder involvement in any future discussions or decisions.

4.10 Policy process and good governance

As the SDC's analysis shows, it is very unlikely that a barrage proposal would ever be brought forward without concerted intervention by Government. This is because a fully-developed proposal would require a substantial amount of research and policy-related work, but with no guarantee of the eventual outcome. It is therefore not a process that a private sector developer would be likely to initiate.

The major role for Government in taking forward such a scheme contrasts significantly with current energy policy, which assumes a hands-off, market-based approach. However, the unique scale of a Severn barrage scheme, combined with the pressing needs of combating climate change and improving energy security, may justify an exception.

This section looks at the policy process that might be required in order to proceed to the next stage of development of a Severn barrage, bearing in mind the principle of 'good governance'. It considers the likely research and assessment stages, and the importance of early public engagement, before commenting on relevance of the EU Directives, and the process that they dictate.

4.10.1 Research and assessment stages

For a Severn barrage proposal to be taken forward, it would need to successfully pass through a number of distinct stages:

1. Pre-feasibility studies to look at a number of potentially 'deal-breaking' issues, for example compensatory habitat requirements and financing models. This stage may also need to include a final decision on the preferred alignment.
2. A Strategic Environmental Assessment (SEA) could be required to assess the proposal in the context of the wider tidal range resource, including full consideration of alternative options as part of a tidal energy plan or programme.
3. Comprehensive and detailed feasibility studies for the purpose of evaluating the viability of the project, covering detailed cost estimates, material sourcing and logistics, updated output predictions, grid upgrades, sedimentary modelling, impact on other users, impact on local and regional economy, mitigation and compensation options for lost habitat, and impact on birds and fish species.
4. Comprehensive and detailed environmental studies as part of the Environmental Impact Assessment (EIA) and Appropriate Assessment, and other studies as required, in order to submit a planning application and apply for consent under Section 38 of the Electricity Act 1989.

Depending on the scale of the proposal, special primary legislation, a 'Severn Barrage Act', is one option for drawing together one or more of these processes in a coherent way. Legislation could set up a single process for the consenting of a proposal, or it could go further and also establish financing and institutional arrangements for a project.

There may be some scope for one of more of these stages to be combined or run concurrently, but this does give some broad indication of the process that would apply. Effective engagement and consultation would be required throughout this process, as discussed further below.

4.10.2 The importance of engagement

The UK Government (and wider society) is increasingly recognising the important benefits to decision-making that can be gained through good public and stakeholder engagement. Recent experience clearly demonstrates where good engagement can support and inform policy decisions,[109] and where inadequate or no engagement results in a failure or derailment of political processes.[110] The entrenchment of positions and subsequent delay to (or abandonment of) policy that ensues can confound any attempts towards a more progressive, efficient and effective decision-making process.

As more critical and complex issues, such as a Severn barrage, come to the top of the political agenda, there is a growing need for a new model of engagement within our society to tackle these challenges. This model aims to bring together government, stakeholders and the public in a more collaborative approach to decision-making. If we are to address 'whole systems' issues, to acknowledge scientific complexity and to recognize the potential trade-offs between competing needs, we need a whole systems approach for collective decision-making.

The issue of a Severn barrage is not currently high on the public's list of concerns, but that would quickly change if a decision was taken in favour of the concept, with the potential for high-profile campaigns on both sides of the debate. The complexity and interdependency of issues and potential impacts of the Severn Barrage make effective engagement an intrinsic part of any decision-making process relating to the barrage. This thinking lies behind the SDC's own work on public and stakeholder engagement around tidal power in the UK.

Good governance and sustainable development

The SDC places great importance on promoting good governance, which is one of the three principles underpinning the UK's shared framework for sustainable development (see Section 1.2). Our research, policy and practice point consistently to the need to shift from old style government to governance. In other words, we need to move from a model where it is simply experts that decide (and then communicate their decision), to a model where responsibility and ownership is distributed beyond Government to wider society. The principles of good governance are consistent across any policy or decision-making process, and are as applicable to the Severn barrage as to any other critical sustainable development issue.

At the heart of good governance is the need to engage the public and stakeholders systematically. A two-way engagement process deepens the understanding and commitment of both decision-maker and participant. In doing so stakeholders and wider society will not only be more prepared to make changes themselves, but they will also be much more likely to permit, and not resist, the significant shifts in policy that sustainable development requires.

The benefits of engagement

From the Government's perspective, public and stakeholder engagement offers the following direct benefits:

- **a)** **It informs** the public and key stakeholders, not only through direct/indirect provision of information but also by stimulating fuller public **debate** on key issues
- **b)** It ensures **acceptable consultation processes** which generate a full and usable understanding of the full range of opinions and aspirations around key issues and decisions
- **c)** It allows the information gained to increase the **validity and robustness** of the resulting decision, and the likelihood of its successful implementation.

In addition, effective engagement programmes would deliver wider, strategic benefits that are in line with the Government's priorities on sustainable development and democratic renewal:

- **d)** Generate shared **ownership and responsibility** across society for addressing the critical challenges we face. This will raise the likelihood of successful implementation of sustainable policies, rather than leaving Government in a defensive position searching for 'quick-fix' measures.
- **e)** Understand how to **engage and mobilise the nation** on critical, long-term strategic decisions and change involving significant complexity and uncertainty. Policy-makers will increasingly be presented with complex issues of strategic importance, which need to be dealt with as whole system rather than single issues, taking into account conflicting departmental objectives. A full 'public engagement' programme would enable significant shifts in policy and action.

To grasp the full range of benefits that engagement can bring, it should not be conceived as a single activity. It is about applying a range of approaches to establishing new relationships throughout the decision-making process, from inception to implementation. Further details can be found in the SDC's position paper on engagement and sustainable development,[111] which describes a set of broad principles for effective engagement by Government and other policy-makers.

Further engagement on a Severn barrage

There is a clear need for substantial public and stakeholder engagement if a decision is taken to further investigate proposals for a Severn barrage. The SDC's own engagement programme on tidal power was necessarily high level, and was not able to go into the depth that would be required on, for example, the different barrage options and the likely environmental impacts, for a decision to be made.

Any further engagement process would need to ensure that there is a real chance to influence Government policy and the conditions attached to the development of a Severn barrage.

4.10.3 Relevance of the Directives

As described in Section 4.6.2, the Severn Estuary is protected by multiple designations, the most stringent of which are the EU Directives on Habitats and Birds, both of which have been transposed into UK legislation. The aim of the Directives is to stem biodiversity loss across Europe as a result of human development.

The preamble to the Habitats Directive reaffirms the connection with the aims and principles of sustainable development, with the implication that the legislation is not intended to simply block human development from occurring. Instead, the legislation was established to protect unique and important habitats and species by placing a series of constraints to support environmental conservation objectives when new developments are proposed on protected sites.

Supporters of the Directives argue that they allow environmental conservation interests an equal voice at the table when decisions are being taken on proposed developments at protected sites. This is seen as progressive, as environmental concerns have historically been overlooked in favour of economic or social objectives. The Directives lay out a process by which prospective developments are assessed, with full consideration of the alternatives and mitigation options before a political decision can be made. For the protected habitats and species, any decision to proceed must then be accompanied by a comprehensive package of compensatory measures designed to maintain overall coherence of the Natura 2000 network.

However, the SDC has heard from a number of stakeholders who believe that the Directives no longer reflect modern conservation priorities in light of the challenges represented by climate change. The argument is that first, the Directives make no allowance for a project that, by its nature, seeks to mitigate against climate change; and second, that they do not take into account the fact that ecosystems and habitats will be altered as a result of the changing climate, regardless of what humans do. These two arguments are used in relation to a Severn barrage to question whether a special exception should be made for a barrage as a climate change mitigation measure, and whether it would be necessary to provide compensation when the habitats being protected are already likely to undergo change.

Against this background, recent commitments to stop further biodiversity loss are relevant. At an international and European level, the increasing urgency of stopping biodiversity loss has been recognised, and political commitments have been made to take action. In 2001, EU Heads of State agreed to halt biodiversity loss in the EU by 2010 and to restore habitats and natural systems. In 2002, they joined some 130 world leaders in agreeing to significantly reduce the rate of biodiversity loss globally by 2010. In 2006, the European Commission adopted a Biodiversity Communication and Action Plan 2006 with an ambitious commitment to halt the loss of biodiversity by 2010.[112] The Communication particularly recognises that climate change is one of the key priority areas for biodiversity, and that strategic measures would be needed to help biodiversity adapt to unavoidable climate change. A strong and coherent Natura 2000 network is also a recognised part of this strategy.

Interestingly, the 2006 Communication particularly recognises that we should be alert to the risk that climate change mitigation measures such as energy developments could deplete biodiversity, and that any potential damage should be minimised and offset. This suggests that the current approach of the Directives has been affirmed, even as climate change impacts and the implications of mitigation for maintaining biodiversity are recognised.

The SDC believes that these issues are fundamental to taking a decision on a Severn barrage and we discuss them further in Chapter 5.

The political dimension

Satisfying the tests of alternatives and 'Imperative Reasons of Overriding Public Interest' (IROPI), and determining appropriate compensatory measures, would need to be undertaken in part through negotiation and discussions at a European level. At an early stage, the legal process and the evidence required to inform that process would need to be agreed. For example, a discussion of alternatives in the context of UK energy policy and better evidence of what the impacts of barrage development would be on the protected features, would be a priority.

The SDC's engagement with Government officials and others suggests increasing recognition of the challenge of climate change among Member States and potentially some pragmatism in the EC in agreeing compensatory measures, particularly with regard to large-scale renewable energy developments. However, this is untested and not necessarily universal within the EC; there is the risk that a legal challenge would lead to the issue being determined by the courts.

The clear challenge of achieving satisfactory compensatory measures has led a number of commentators to suggest possible ways forward on a Severn barrage that lie outside the current legal framework:

- Reform of the Directives to give greater importance to the development of renewable energy projects in designated areas
- Derogation from the Directives, whereby the UK could unilaterally decide to exempt a barrage scheme from the environmental legislation

These options are now discussed in more detail.

Reform of the Directives

The SDC has on several occasions heard the view that the EU Directives on Habitats and Birds do not take adequate account of the challenge of climate change. The assertion is that as climate change is seen as a greater environmental threat to humanity, any action that helps to mitigate climate change (such as renewable energy projects) should be viewed differently under the Habitats and Birds Directives, and greater flexibility should be shown. Another view is that climate change processes will already cause irreversible damage to protected sites, thereby requiring a more flexible approach to conservation.

In the context of the Severn Estuary, the statutory conservation agencies' and other groups' view is that the protected sites remain important despite the potential impact of climate change. For example, although some birds or plant species may migrate or disappear, the existence of these unique habitats may provide a home to other species, some of whom will themselves be migrating from further south.

Finally, trying to amend the EU Directives to deal with one project could be a risky strategy, as the eventual scope of possible amendments would, once the process got going, be outside any one country's control. As a result, the final outcome could be quite different, and possibly much weaker, than the instigator intended. Moreover, seeking legislative amendment would not be an easy option in terms of time and cost, and could be seen as an unusual step for a Government to take in its support of a single project.

Derogation

The SDC has also heard the view that the importance of a Severn barrage may justify a one-off derogation from the EU environmental legislation, possibly by failing to provide the requisite compensation (and amending domestic regulations that transpose the provisions of the Directive into national law). There is no mechanism within the Directive for doing this.

This approach would represent a very serious step. An important consideration when considering such an option is the UK's position within Europe on biodiversity and conservation issues. The UK has up to now prided itself on its leadership role on both climate change and biodiversity, and as noted above, has affirmed its commitment to halting biodiversity loss by signing up to and implementing measures such as the Directives.

The SDC understands from senior Government officials that the Directives are already threatened or overlooked by a number of Member States, and have been a significant hurdle for some new Member States entering the EU. There is the potential to jeopardise or open up important protections by seeking to derogate from the Directives in the context of a major renewable energy project. This could have negative carbon consequences in the long-run, by allowing projects to go ahead that would otherwise have been prevented (e.g. airports or motorways in sensitive locations).

4.10.4 Complying with the environmental legislation

It is clear from the available evidence that a Severn Barrage would have a significant adverse effect on the integrity of the protected sites, although different features would be affected to different degrees, and the overall impact would depend on the particular barrage scheme. This triggers the requirement for the UK to undertake an 'appropriate assessment' of the implications of a project for the site's conservation objectives.

It is the responsibility of the UK Government – or more specifically, the 'competent authority', for example, the responsible Minister – to undertake an appropriate assessment. In practice, the project developer would prepare the evidence base and submit all the relevant information to the consenting authority as part of the environmental impact assessment. If the assessment indicates that the proposal may have negative implications for the site's integrity, the project cannot be approved without first going through the process described below.

It is clear from the evidence, and from our engagement with stakeholders, that a Severn barrage proposal would have a range of negative impacts that would require it to comply with this process.

Step 1 **Consideration of alternatives**

The Regulations require authorities to establish that there are no alternative solutions before a project can be approved for "imperative reasons of overriding public interest" (IROPI). Article 6(4)(4) refers to the "absence of alternative solutions".

Government policy on the Habitats Directive states that authorities should consider alternative suitable and available sites for development which would be reasonable alternatives, or identify practicable approaches such as adapting working methods which would have less impact. On this basis, 'alternative solutions' seems to cover both mitigation methods (ways to reduce or avoid affecting site integrity) as well as alternatives in the sense of other options and other locations.

European Commission (EC) guidance on examination of alternatives indicates that this should include the 'zero option', and the conservation objectives and status of the Natura 2000 site should outweigh consideration of costs, delays and other aspects. The Member State rather than the project promoter is responsible for considering alternative solutions.

The requirement for a Strategic Environmental Assessment would also mandate a wide-ranging consideration of alternatives as part of consideration of a Severn barrage.[113] Research Report 3 concludes that the requirement for an SEA would apply to a Severn barrage project and would need to include a high level review of UK energy policy.

Step 2 **Imperative reasons of overriding public interest**

In the absence of alternative solutions, authorities can only approve a project based on IROPI. Reasons can include the social and economic justification for a project. The UK Government states that it "... expects there to be few cases where it will be judged that IROPI will allow a development to proceed which has an adverse effect on the integrity of the internationally important SPA or SAC designations".[114]

At a UK level, guiding principles for consideration of IROPI include the provision of a clear and demonstrable direct environmental benefit on a national or international scale. Other principles include national security and defence, and a vital contribution to strategic economic development or regeneration. The principles adopted by the UK Government favour projects of national and possibly regional importance. Recent European Commission (EC) guidance confirms that a long-term public interest is necessary to make a strong case.[115] The potential for a proposal to contribute to greenhouse gas reductions is cited as a particular example of a relevant overriding public interest (for example, the EC refers to an example of a port development in the Netherlands involving a transport nodal shift).[115]

Step 3 **Compensatory measures**

In the event that the overriding public interest of a project is judged to outweigh the nature conservation importance of the site, the Directives require compensatory measures to offset the negative impacts of a project and to ensure the overall coherence of the Natura 2000 network. Compensatory measures are independent of the actual project. This is in contrast to mitigation measures, which are undertaken as part of the project to minimise adverse impacts, such as design and construction.

The issue of compensatory measures has emerged as a key issue for the statutory conservation agencies, but also has significant practical and cost implications for any Severn barrage proposal.

Research Report 3 indicates that considerable further work would be required to predict what the impacts would be on the range of Natura 2000 and Ramsar features, and therefore what mitigation and compensatory measures might be possible. The report concludes that provision of appropriate measures to satisfy the test of overall coherence would be very challenging, "possibly to the point of not being deliverable", particularly in the case of the Cardiff-Weston proposal.

The conservation agencies share this view,[94] or go even further and suggest that it would be impossible to achieve, based on available information about the scale of a Severn barrage (with reference to a Cardiff-Weston alignment), knowledge of the Natura 2000 network of sites within the UK (number, location and type) and experience of finding compensatory measures in the context of other developments such as port development and the Cardiff Bay barrage.

Article 6 of the Habitats Directive does not define precisely what 'compensatory measures' might mean, and appropriate measures are determined on a case by case basis. Guidance from the European Commission provides some assistance, and indicates that the measures must ensure that the relevant habitats and species are conserved at a favourable status within the biogeographical region.[115] The overall aim is to prevent net loss to the network in terms of quality and quantity. The compensation should address the habitats and species negatively impacted, in comparable proportions, and should provide ecological functions comparable to the original site. Distance is not necessarily an obstacle but this depends on the function of the site, for example, the Severn Estuary's location on the west coast of Great Britain and how it fits within the Atlantic region.

There are a range of possible views as to what might be acceptable in the case of a Severn barrage. At the highest end, compensation might be approached on the basis that features must be replaced on a like-for-like basis, and that in the case of unique features or set of features not existing in any other location, compensation cannot be provided. The implication is that development which destroys unique or irreplaceable features, such as the uniquely hypertidal estuary system of the Severn Estuary, cannot proceed.

However, a less stringent interpretation could seek to identify compensation for specific attributes, such as certain fish species or intertidal habitat types. The Severn Estuary's high tidal range is not explicitly included in the features identified for under the cSAC, and the individually protected habitats and species are found in other locations and are not unique to the Severn. The Severn's status as a very large and hypertidal estuary and its position on the west coast of Great Britain would nonetheless be relevant factors.

In practical terms, options for compensation include:

- creating new habitat
- restoring a habitat that is in a poor state
- recreating habitats within the site
- recreating habitats in other designated sites
- recreating habitats at non-designated sites and then designating those sites
- designating other UK estuaries not currently designated as special areas of conservation.

It is clear that habitat creation (or recreation) at the scale of a Severn barrage would be costly and technically challenging. The sheer scale of the challenge can be seen by comparing compensation that has been provided for other projects. At Wallasea Island on England's east coast, a major wetland habitat creation project established a wetland as compensation for two port developments undertaken in the 1990s.[116] The project is an example of using managed realignment (breaching a seawall) to create compensatory coastal habitat and provide sustainable coastal flood management. The project cost £7.5 million for 115ha of new habitat.[116]

Compulsory land purchase could well be required to provide space for habitat creation, and the compensation would be a major project in its own right. The Cardiff-Weston scheme would involve the loss of some 145km^2 (14,500ha) of intertidal habitat (around 70% of the total), which is indicative of the scale of habitat creation that would be required. Classification of UK estuaries not currently classified (or required to be classified) could be a more feasible way of delivering compensation. However, other UK estuaries are smaller than the Severn Estuary, and many are already classified or being considered for classification or development – for example the Mersey.[117]

The SDC has not attempted to provide an estimate of the total cost of providing compensatory habitat as this would be a lengthy and complex process that would require a substantial body of research followed by negotiations between the relevant UK organisations and the EC. Due to the implications for a Severn barrage proposal if adequate compensation cannot be found or agreed, there is a strong case for prioritising this work; a high cost compensation package would need to be considered alongside the capital cost estimates for a barrage as part of the economic viability assessment.

5

Conclusions and Recommendations

5.1 A consensus view

This chapter presents the SDC's conclusions and recommendations on the role of tidal power in the UK, and outlines our position on a Severn barrage, taking account of the analysis and conclusions from Chapter 4.

Our consideration of a Severn barrage has involved a staged process of evidence gathering and engagement, through to final analysis and discussion. The SDC started the project with a keen interest in understanding the untapped potential of tidal power technologies in a low carbon electricity system – and with no fixed views on the issues around a Severn barrage. This has enabled us to take a completely fresh look at the opportunities and issues involved, whilst testing the principles of sustainable development on a real and controversial question – whether the Government should further consider a Severn barrage.

One of our aims with this report, and by publishing our evidence base on our website, is to be as transparent as possible in how we reached our conclusions. The main body of the report is intended as a summary and analysis of all the research we have drawn on, with a series of conclusions on a wide range of issues. This was used as the source material for the discussions that took place between the SDC's Commissioners, which focused on a smaller number of more controversial, high level issues. These discussions culminated in a series of intensive SDC sessions in Cardiff over two days in July 2007, and included a field trip to the banks of the Severn Estuary and the Cardiff Bay barrage. The minutes of the SDC's plenary sessions are published on our website.

This chapter is the product of these final discussions, and represents the consensus view of the SDC's Commissioners on a number of high level issues. It lays out a clear set of recommendations and challenges to Government to ensure the exploitation of tidal power in a sustainable way.

5.2 Tidal power in the UK

The UK has a considerable tidal power resource that could be exploited to produce renewable electricity. Although the data is somewhat uncertain, current estimates suggest that our total resource is divided roughly equally between tidal stream and tidal range potential, with a combined output equal to around 10% of UK electricity supply.

This illustrates the importance of considering all the options for exploiting this resource, as a narrow focus on just one project (a Severn barrage) could be detrimental to the development of a whole class of emerging tidal stream technologies, some of which could be sizeable generators of renewable electricity in the UK, with great export potential over the long term.

5.2.1 Tidal stream

Long-term potential

The SDC is enthusiastic about the potential of tidal stream technologies, subject to the constraints that might be imposed due to locationally-specific impacts upon the environment and natural marine processes, and the long-term costs being acceptable. The UK is in a unique position, with a superior tidal stream resource combined with the largest collection of devices being developed or tested anywhere in the world. This UK success story is the product of a number of factors, but the strong leadership shown by the UK Government and the Scottish Government in providing support for marine renewables since 1999 is also an important factor.

Tidal stream technologies could make a substantial contribution to the sustainable energy strategies of the UK's three Devolved Administrations. The UK's tidal stream resource is concentrated in Scotland, Wales and Northern Ireland and recent developments in Scotland show the potential for policy intervention at the devolved level. The SDC is very willing to offer further support to the Devolved Administrations to help maximise this potential.

Considering the progress that has been made on tidal stream, the objective now must be to 'stay the course'. In many ways the tidal stream industry is at the same stage of market development as wind power was 20 years ago, and the timescale for bringing prototype technologies to large-scale deployment needs to be as fast-tracked as possible. This will require continued support and political commitment for at least the next two decades, and a willingness to invest widely in the knowledge that not all the devices under development will succeed. The challenges for this nascent industry are considerable: securing the necessary public and private investment, achieving cost reductions, accessing the grid, satisfying environmental and regulatory requirements – along with working in the difficult marine environment.

But the rewards are potentially large: the generation of a sizeable percentage of UK electricity supply, the long-term contribution to highly skilled jobs and a knowledge economy, the export potential, and as a contribution to global efforts to reduce carbon dioxide emissions. It is this long-term perspective that must be adopted when taxpayers are asked to invest in the development of such technologies. Furthermore, considering the importance attached to innovation policy by the Stern Review, Government should ensure that it applies any lessons learned from this sector to the development of other low carbon technologies.

Policy improvements

Our engagement with tidal stream developers and those close to the industry suggests there are a number of areas where Government policy could be improved. The support and funding structures will need to be reviewed and improved in line with circumstances as they develop and change. For example, a flexible approach should be taken on the future of BERR's Marine Renewables Deployment Fund (MRDF), which has so far not had any applicants due to delays in getting demonstration projects off the ground. These delays should not be viewed by Government as failure of the technology, but as an indication of the challenges facing tidal stream developers. Lessons could be learnt from the success of the Scottish Government's £8m support package for marine energy technologies, which has had strong interest from both tidal and wave developers. Increased support for marine renewables under a banded Renewables Obligation is also very welcome, and may provide an opportunity to revise the support available under the MRDF so that it focuses on providing grant funding for project development and testing, with the aim of stimulating progress towards initial tidal arrays and pre-commercial schemes.

The European Marine Energy Centre in Orkney is an excellent example of public sector funding being used to stimulate private sector investment and innovation in a strategic and efficient way. But the opportunity to realise the full potential of EMEC must not be missed. Now that the investment is made, there may be significant potential to develop the services offered by EMEC, such as baseline environment studies and the certification of devices, and to develop the centre's marine research capacity. This would require an increase in the core funding for EMEC, but the SDC believes that such an expenditure would represent a good use of public funds.

Looking to the future, the SDC believes that there is potential to exploit the activity centred around EMEC to develop a regional 'hub' around Orkney and parts of the Caithness coastline away from the Pentland Firth for commercial testing of devices beyond the prototype stage. The seas around Orkney and Caithness represent an ideal environment for testing in conditions that are less severe than the Pentland Firth, with the possibility of creating additional grid capacity via another link to the mainland, and by utilising spare capacity at Dounreay.

In the long-term, a lack of transmission capacity would appear to be a serious constraint on development of the UK's tidal stream resource in the far north of Scotland. This is a wider problem that also has impacts on the onshore wind industry and wave power devices. The SDC's review of Ofgem,[13] which looks at the ability of renewable energy technologies to connect to the grid, concludes that **there are a number of problems with the current regime for connecting renewable generation and a real absence of long-term thinking on the solutions to overcome them. This has serious consequences for the UK's ability to meet its targets for renewable electricity, let alone the more ambitious EU targets that will eventually be implemented.** This is an issue that both Ofgem and Government will need to get to grips with as a matter of urgency.

Strategic planning and consenting

On strategic planning and consenting, the framework must be clear and robust. The lack of good baseline information on the marine environment and on the effects of large-scale deployment of the different devices is a real issue. The gaps will have to be filled over time through research of a strategic and generic nature as well as by developers – but will ultimately also be resolved through trial and perhaps sometimes error. This will require a realistic approach to risk in recognition of the big picture environmental benefits of developing this low carbon technology. In the short term, the reality is that developers may need extra support with the environmental impact and consenting process. There also needs to be more coordination between energy policy and the consenting regime to ensure that appropriate sites are selected for development, thus lessening the time and cost involved in gaining consent.

Finally, the need for a strategic environmental assessment (SEA) to be undertaken – in combination with a leasing competition for development rights to seabed owned by the Crown Estate – is already recognised as a step that will be taken when the industry reaches the stage of commercial deployment. But the timing will be crucial. An SEA can be seen as an opportunity to integrate interests in marine conservation and potential conflicts of use in the marine environment with fishing, shipping, and recreational activities, while at the same time proactively influencing and supporting appropriate site selection. This approach – whether in the form of an SEA or in a marine spatial planning framework under a new Marine Act – will have a long-term impact on how the industry develops. The Scottish Government is in the process of completing a strategic environmental assessment for marine renewables around the west and north coasts of Scotland, and the Welsh Assembly Government is also developing a marine renewable strategy.

5.2.2 Tidal lagoons

It is very difficult to come to a clear view on the long-term potential of tidal lagoons due mainly to the lack of authoritative evidence, and the fact that the concept remains unproven. The picture is exacerbated by the controversy around cost estimates, and the tendency of some tidal lagoon proponents to position the concept in opposition, and as an alternative, to a Severn barrage.

The SDC's analysis of tidal lagoon potential indicates very few direct conflicts with barrage proposals, with the exception of large-scale tidal lagoon development, or a Russell Lagoon type scheme, in the Severn Estuary. There is little evidence to suggest that such large-scale proposals would be economically preferable to a Severn barrage, and it is possible that they would cumulatively cause at least as much environmental disturbance. Conversely, there are a number of potential sites around the UK where tidal lagoons may be technically viable. These are generally areas of relatively shallow water where there is a good tidal range resource, and include possible sites around the Swansea Bay (for a possible small-scale development), Liverpool Bay, and the mouth of the Mersey Estuary.

Despite there being no examples of tidal lagoons anywhere in the world, the technologies used are not in themselves new or innovative; the innovation is in the concept, design and construction. This places tidal lagoons in a difficult position in relation to the available financial incentives for renewable energy technologies, which are currently justified on the basis of innovation and long-term cost reductions. The situation is not helped by the insistence of some tidal lagoon proponents that the technology does not require subsidies to be economically viable.

A lagoon concept does offer some obvious benefits over a barrage; depending on its position and size, fish and navigation passage might be affected to a far lesser degree. However, an offshore lagoon still involves a substantial civil structure in a coastal bay or estuary, and it follows that lagoons would not necessarily be the environmentally benign source of tidal energy that is sometimes claimed. The impact of a tidal lagoon structure on coastal processes and sediment transport needs careful evaluation to test the environmental acceptability of potential schemes in coastal areas.

The concept also has merit in offering potential opportunities for community involvement in ownership or partnership of a scheme; this is being actively investigated in north Wales. But public acceptability would need to be addressed through engagement around information and awareness gaps in environmental and social impacts, as well as the important question of visual and landscape effects at a local level.

The SDC's conclusion is that there is a strong public interest in seeing the development of one or more tidal lagoon demonstration projects to test the concept, and provide real-life cost, energy output, and environmental data. Demonstration projects could help identify cost-savings – for example, in the use of innovative materials or improved construction methods – and this may justify financial support for tidal lagoons. Any proposals would need to comply fully with the relevant environmental legislation and consenting processes, and this process in itself could be a useful learning experience.

We therefore recommend that the Government investigates options to encourage one or more tidal lagoon demonstration projects. This could take the form of inclusion in the Renewables Obligation, or an open competition to solicit private sector or community interest. The additional expenditure would not need to be large, but the potential benefits could be extensive considering the resource available, both in the UK and internationally.

5.2.3 Tidal barrages

Our analysis of tidal barrages has inevitably focused on the question of a Severn barrage. This reflects our remit on this project, the extensive information already available on these proposals, and the practical reality that the Severn contains the majority of the UK's tidal range resource. We have also reviewed a number of other tidal barrage options, including proposals for the Mersey. There does not seem to be an extensive overlap between tidal barrages and tidal stream devices, leading to the conclusion that they can, on the whole, be considered separately.

The UK's potential for developing a number of different tidal barrage options other than the Severn is extensive. The main reason why this potential has not been developed in the past is that the schemes studied have appeared not to be economically viable. Moreover, tidal barrages, like large hydropower schemes, can be hugely disruptive to the local environment and estuary systems, and can have a number of regional economic and social impacts, all of which need to be considered. **The SDC is therefore supportive of further investigation into UK tidal barrage options outside of the Severn Estuary**, although each should be considered on a case-by-case basis as the potential benefits and impacts will differ considerably. Furthermore, the conclusions we have developed on a Severn barrage (see below) may be applicable to other barrage proposals.

5.3 Conditions for a sustainable Severn barrage

The proposal for a tidal barrage across the Severn Estuary brings into sharp focus all five of the UK Government principles of sustainable development. There is no doubt that it would make a long-term and significant contribution to reducing carbon dioxide emissions from electricity generation, and would help improve the UK's energy security through its predictability of output and by avoiding the import of fossil fuels. At the same time, it would have profound and irreversible effects on an internationally important hypertidal estuary system.

The SDC began its in-depth discussions on a Severn barrage from a general position in favour of the development of renewable energy sources, recognising that renewable energy has a crucial role to play in mitigating against climate change. Our approach, therefore, was to examine the conditions under which a Severn barrage might be sustainable.[118] We then worked through the issues to see whether the identified benefits were real and material, and which of the negative impacts might be 'deal-breakers' unless dealt with adequately. Our discussion of deal-breaking issues led to agreement on a set of conditions that would need to be fulfilled for any project to be sustainable. A number of these conditions represent major challenges for current Government policy.

The subtlety of this approach is important. The SDC is neither advocating unquestioning Government support for a barrage, nor is our aim to suggest conditions that would effectively make its development impossible. Instead, we recognise the importance of giving serious consideration to a Severn barrage, within a framework that places a **high value on the long-term public interest** and on **maintaining the overall integrity of internationally recognised habitats and species**.

This section draws on the analysis and conclusions from Chapter 4 to present the SDC's consensus position on a series of high-level issues that are fundamental to ensuring a sustainable Severn barrage. We do not take a position on the relative merits of the various barrage schemes but have instead considered the issues generically, with an inevitable focus on the larger Cardiff-Weston scheme due to the availability of more detailed evidence and the greater degree of impact it would have – environmentally, economically and socially.

5.3.1 Energy policy context

In considering the benefits of a Severn barrage, we have a number of concerns about its impact on wider energy policy. In particular, there is the risk that such a large project could divert Government attention away from the huge effort that is required in reducing energy demand, encouraging other renewables, developing sustainable heat networks, and on carbon capture and storage. The SDC is also concerned that such a project could send the wrong kind of signals to consumers, with the risk that it could further entrench citizens' separation from the source of their energy and the resulting impacts, and could therefore encourage complacency in reducing energy demand.

Some of these issues emerged during our review of nuclear power, leading us to identify the negative impact that a new nuclear programme might have on reducing energy demand and on technological lock-in as two of our five key disadvantages. A Severn barrage could also have these disadvantages, and would not move us any closer to a more decentralised, flexible energy system.

The SDC has been encouraged by the positive attitude shown in the 2007 Energy White Paper towards tackling energy demand and sustainable heat issues, but we remain concerned that the Government is not yet willing to match its ambitions with the radical policies needed to deliver them. And while there have been a number of positive developments on climate change policy more generally – in particular, the Climate Change Bill, and the commitment to mandate zero carbon standards for new homes by 2016 – the Government does not yet seem to have policies in place to deliver the required carbon savings over the next 15 years.

Encouragingly, public awareness of climate change has increased over the last couple of years, providing a greater degree of political space for new measures to reduce emissions. This is particularly true when action on climate change can be designed to achieve other goals, such as combating fuel poverty, increasing economic competitiveness, and improving people's quality of life. For example, proposals to break the link between increased energy consumption and the profits of energy supply companies (the 'Supplier Obligation') have the potential to improve the information provided to households through smart meters and accurate bills, which along with greater provision of energy-saving measures (such as insulation and microgeneration options) could potentially save them money. For commercial organisations, emissions trading schemes such as the Carbon Reduction Commitment or the EU Emissions Trading Scheme can help in the identification of energy savings, whilst rewarding those who are low emitters.

In this context we believe that it is possible for the Government to take on a large project such as a Severn barrage without diverting its attention (and associated resources) from other priorities. But developing a Severn barrage option would undoubtedly be a big test of Government's willingness to tackle the challenge of climate change through a whole range of policy interventions without simply opting for the 'one big solution' approach. Instead, Government could use the symbolic nature of a Severn barrage as an example of the scale of action required.

A Severn barrage would need to be just one part of a major, long-term strategy for reducing carbon emissions, with concerted action at all levels of the energy hierarchy. It would also need to develop options for both centralised and decentralised technologies, as regardless of the progress made on the development of decentralised energy sources and reducing energy demand, the UK will require large-scale, centralised electricity generation for a very long time. A Severn barrage would be a relatively well-placed centralised supply option due to the close proximity of the Severn Estuary resource to large centres of electricity demand, which would limit the need for major grid reinforcements and any potential conflict with decentralised supply options.

5.3.2 Ensuring the public interest

If pursued, a Severn barrage would be a major infrastructure project and a long-term addition to the landscape and the regional economy. This means that, regardless of how it is financed, it would be an important public asset for many generations. Getting it built would also require substantial political capital due to the complexity of the project and the need to navigate a number of financial and legal hurdles. As a result, the SDC believes that any decision in favour of a Severn barrage must be conditional upon upholding the long-term public interest, both in terms of how the project is designed and delivered, and in its ownership.

Apportionment of risks and benefits

Our analysis in Section 4.8 concludes that a barrage scheme could not be financed by the private sector without significant Government intervention in the market (and a strong lead on project initiation and consents) to create an attractive set of conditions for investment. However, the SDC has a number of concerns over the apportionment of risks and benefits for a private sector-led project.

In addition to taking the lead on project initiation, which would involve substantial expenditure on environmental and feasibility studies, Government would most likely have to underwrite private sector investment through the provision of new incentives or guarantees. This is because the electricity output from a Severn barrage would not be economically competitive with other forms of low carbon electricity generation if a commercial rate of return is required, particularly in the absence of a realistic and stable price for carbon.

Despite taxpayers and/or consumers taking on these risks and direct costs, there would be no guarantee that the project would proceed to the construction stage, particularly considering the large number of hurdles to pass along the way. There is also a high risk of moral hazard, which means that those involved in building a barrage might take on higher risks than they might otherwise, or systematically underestimate costs, in the (probably correct) expectation that the project would not be allowed to fail. This could lead to a Government bail-out in the case of cost overruns or construction problems.

As a result, a private sector-led project would pass all the additional costs, and a large share of the risks, to the public sector without providing a commensurate share of the benefits. Conversely, the private sector owners would stand to enjoy ownership of a sizeable public asset offering a guaranteed return. In our view, this is not consistent with ensuring the long-term public interest and it would not provide good value for the taxpayer or consumers.

Avoiding short-termism

The requirement for the high rate of return necessary to attract private sector investment would be highly likely to drive a dangerously short-termist approach to the design, delivery and operation of a barrage. This does not appear to us as an appropriate way to fund a capital-intensive project with such long-term benefits.

To maintain a high rate of return, private sector developers would have a very strong incentive to maximise overall revenues, and would want to attract complementary investment around the project. There is a serious risk that this could lead to wider development pressures that would not be in the long-term public interest; for example, badly designed or constructed housing developments or multiple new roads, both of which could increase net carbon emissions and pressures on the local environment.

There is also the issue of construction methods: a private sector developer may not be sufficiently incentivised to specify the highest quality materials or construction standards as their payback horizon is unlikely to extend much beyond 40 years, rather than the expected lifetime of the structure of 120 years. This could lead to the design and construction of a sub-optimal structure that would be less likely to stand the test of time. Finally, there would be no direct incentives to design and operate the barrage to maximise coastal flood protection benefits and to manage the risk from upstream fluvial flooding events where these coincide with high tidal conditions.

Approaching the financing issue through the lens of private sector ownership would not, in our opinion, take adequate account of the value of the secure, low carbon electricity that a barrage would produce over the long-term. For example, there is an obvious mismatch between the timescales being considered for cap and trade schemes or renewables incentives, and the expected lifetime (and construction time) of a barrage. A compliance period of 20 years is currently seen as long-term for cap and trade schemes (a UK manifesto on the future of the EUETS calls for emissions trajectories up to 2030),[119] and the Renewables Obligation only operates up to 2027. This also impacts on some other low carbon technologies, but would particularly apply to a barrage with its construction period of at least 5-7 years and an operational lifetime of 120 years.

Regional impacts and priorities

In addition to short-termism, the SDC has concerns over the ability of private sector developers to adequately take account of economic and social considerations, or the need for an integrated approach to strategic planning at a regional and local level. This has implications for the impact of a Severn barrage on existing ports, the potential for new transport links using a barrage, and the impact during the construction phase on housing, local businesses, and the supply of aggregates.

The complexity of the issues underlines the need for a coordinated approach to the planning of a barrage and its impact on existing and future development. For example, a barrage could have a negative effect on the long-term economic viability of existing ports in the region, leading to a loss of business and possibly the creation of new or expanded capacity elsewhere. This could in turn have implications for net carbon emissions (as a result of less efficient freight movements) and for the pressure on habitats in other locations. It would therefore be important for a Severn barrage to be considered in the context of other policies and plans – in this case, ports policy, and the long-term outlook for shipping in the UK.

Private sector developers are less likely to consider such issues voluntarily, leading to a heavy reliance on the regulatory and consenting functions of Government and the economic development organisations to ensure that regional interests are upheld. The SDC believes that this approach is problematic for such a large and complex project.

5.3.3 Complying with the environmental legislation

The Severn barrage proposals are located in an estuary that has high levels of environmental protection under national and international legislation, and its construction would involve large-scale and irreversible change to the hypertidal estuary ecosystem. This dynamic raises a particular set of scientific, moral and legal questions that are relevant to the strategic consideration of the schemes.

Natura 2000 and biodiversity

Chapter 4 summarises the protected status of the Severn Estuary, including the aims and objectives of the European environmental legislation, and analyses the likely impacts that a Severn barrage would have on the protected features based on available information. The overall integrity of the Natura 2000 network, and the biodiversity objectives it upholds, is central to the science-led approach to conservation that all European countries have adopted.

A number of commentators have suggested that the objectives embodied in the legislation may not be fit for purpose due to the challenges posed by climate change, because in a rapidly changing climate the natural range of many species, or even their very existence, may change. The SDC has not been persuaded by these arguments. It is simply untrue to claim that the Habitats and Birds Directives are based solely on the approach of protecting existing sites with fixed boundaries.

The Directives are founded on the principle of maintaining viable populations of sometimes highly mobile species, such as migratory fish and birds, and of ensuring a series of functioning habitat types over an extensive biogeographic range spanning many Member States. Designation of sites is a vital tool, but only one tool, to deliver these ends. Habitat loss in the Severn Estuary needs to be considered within the context of the biogeographic region of which the estuary is a part, and within a wider European and international context.

First, it is important to clarify what is meant by biodiversity. As discussed in Section 4.10.3, biodiversity is a measure of both quality and quantity, and therefore of distinctiveness. Some habitats are globally important because they have a unique assemblage of just a few species in large numbers (e.g. arctic tundra), others because they have smaller numbers of a very wide range of species (e.g. tropical rainforest). Replacing a distinct assemblage of a small number of threatened species with a larger number of common species does not constitute an increase in global biodiversity. So, although a Severn barrage may result in a greater quantity of animal and plant life developing in a less extreme environment, this does not of itself compensate for the loss of the existing unique and environmentally important habitats and species. The aim of environmental conservation is, in the words of the RSPB, "to conserve the special, not make the special ordinary".[67]

Second, it is clear that climate change is already having a measurable impact on some species in the estuary, but there is no evidence to suggest that the habitats it contains will be any less important in the future. Numbers of some bird species overwintering in the estuary have decreased, in some cases quite considerably, and this is attributed to warmer winters which presently make estuaries further east more attractive. The numbers of other bird species using the Severn Estuary have increased. The estuary continues to support populations of birds at internationally important percentages, and it will continue to be important in conservation terms even if its importance for different species increases or decreases over time in response to complex climatic changes. In the wider global context, the imperative to protect biodiversity will take on an increased importance as action is needed to ensure that species have space to move in response to changing climate and coastal regimes. Despite some changes, conservation and biodiversity protections should not be abandoned or ignored because of climate change. Rather, environmental conservation policy needs to consider biodiversity objectives in a long-term context to take account of climate change.

Although the hypertidal nature of the Severn Estuary creates habitats that to some may appear muddy and unattractive, it is exactly these features that make it unique from a biodiversity perspective. The habitats it contains are likely to continue to be hugely important as a feeding site for migratory birds and for fish species, and are therefore an essential element of the Natura 2000 network. **The SDC therefore accepts that maintaining the overall viability of these habitats and species is a statutory obligation that should be vigorously upheld.**

Applying environmental limits

The SDC has given careful consideration to the relevance of the EU environmental legislation ('the Directives') to the issue of a Severn barrage. Our conclusion is that the Directives are a legal embodiment of 'living within environmental limits', which is one of the five UK principles for sustainable development. The Directives are guided by 'sound science', and establish a clear decision-making process that is intended to facilitate 'good governance' whilst recognising the importance of economic and social goals in development decisions. They establish clear environmental protections for a small percentage of total UK land and marine area, and are intended to ensure that biodiversity within Europe and internationally is maintained and, ideally, enhanced.

The practical implementation of 'living within environmental limits' must eventually lead to the establishment of absolute limits on certain aspects of human development. Not doing so would render the term meaningless. Therefore, the Directives should be seen as representing an enlightened approach to dealing with environmental constraints, and one that is at the heart of sustainable development.

The Directives also set an important precedent for other areas of environmental policy. For example, the introduction of cap and trade schemes for the regulation of greenhouse gas emissions, along with the proposal for binding annual targets for reductions in emissions under the Climate Change Bill, shows how 'living within environmental limits' can be applied to climate change. The regulation of waterborne pollutants from industrial processes and sewage treatment is another clear example of environmental constraints being given a statutory basis.

As a result, the SDC's view is that **any proposal for a Severn barrage must fully comply with the Directives and adhere rigorously to the process they set out. We would be firmly against any moves to revise or derogate from the Directives to facilitate proposals for a Severn barrage.**

This conclusion does not mean that development cannot occur. The Directives explicitly acknowledge that there are circumstances in which development might be justified in protected areas, and establish a clear process for making that judgement.

Very simply summarised, the process begins with a requirement for Government to undertake an 'appropriate assessment', supported by good evidence, of how the site would be adversely affected by the proposed development. Assuming the result of the appropriate assessment shows an adverse effect at the site, then the proposal must pass through a series of three tests, as follows:

4. **Consideration of alternatives:** The first test then requires an assessment of the alternatives, including the 'zero' (no-development) option and ways to mitigate against any adverse impacts.
5. **Overriding public interest:** If there are no viable alternatives to the development, then a political decision can be taken to proceed on the basis of 'imperative reasons

of overriding public interest'. This decision would normally be taken by a Government Minister.

6. **Compensation requirement:** If this is the case, there is then a compulsory requirement to provide compensatory habitat to ensure the overall coherence of the Natura 2000 network. The practicality and cost of this requirement represents the final test of the overall viability of the proposal.

We believe that a barrage proposal would meet the first two tests of the Directives with relative ease. Although a broad interpretation of 'viable alternatives' could be taken, a more realistic interpretation might be to consider the alternatives for harnessing the tidal range resource in the Severn Estuary on a large scale. This would need to consider the relative merits of large-scale tidal lagoon development, although there seems to be little evidence to suggest that this would be less damaging than a large barrage. Even if a very broad interpretation were taken that looked at the whole UK energy system, it is highly likely that a compelling case could be made for a Severn barrage based on its renewable credentials and reliability.

Assuming this first test could be met, then the Government would need to be convinced that there are 'imperative reasons of overriding public interest' for a barrage development to proceed. Based on its potential contribution to renewable energy targets and to reducing greenhouse gas emissions, it seems highly likely that this second test would be met as well.

This leads directly to a requirement to provide compensatory habitat, reflecting the importance of the Severn Estuary within the Natura 2000 network.

Providing compensatory habitat

The aim of the compensation requirement of the Directives is to ensure overall coherence of the Natura 2000 network. The scale of habitat creation required to provide adequate compensation for a Severn barrage project would be unprecedented within the UK. Nevertheless, the SDC considers it technically, legally and financially possible for a way to be found given sufficient political will.

A habitat compensation package on this scale would be a major project in its own right. There would also be a substantial up-front capital costs attached to such a scheme which would raise the cost of electricity output for a Severn barrage as these would need to be absorbed as part of the development. It is clear that the compensation requirement would be the biggest test that any barrage proposal would have to face and may even determine the overall viability of the project.

However, the SDC believes that it would be untenable for the Government to take a decision in favour of a Severn barrage unless it is prepared for the UK to demonstrate its commitment to upholding the integrity of the environmental legislation and the processes it has signed up to. Failure to do so would undermine the Directives, set a dangerous precedent to other EU Member States and countries elsewhere in the world, and would not deliver a Severn barrage consistent with the UK's agreed framework for sustainable development.

As a result, the SDC recommends that discussion over the capital cost of a Severn barrage assumes the inclusion of the full cost of providing compensatory habitat, pending further investigation into its scientific, practical and economic feasibility. In the meantime, the capital cost figures provided in Chapter 4 should be treated as construction-only costs to avoid a systematic misrepresentation of the total cost of a sustainable Severn barrage.

5.3.4 Our advice to Government

Our conclusions on the energy policy context for a barrage, the need to consider the long-term public interest, and the importance of upholding the environmental legislation lead the SDC into new territory. Below we outline our advice to Government on the conditions necessary for a sustainable Severn barrage development based on these conclusions.

Wider action on climate change

The policy context for any decision taken on a Severn barrage is important. The benefits of a barrage (equivalent to just over two large conventional power stations, but operating for a very long time) are extremely substantial from a climate change or energy security perspective. Nevertheless, a Severn barrage would still represent just a 5% contribution to the decarbonisation of electricity supply, falling to less than 1% as a contribution to total energy use.

The Government would need to ensure that a decision in favour of a Severn barrage was only part of a major effort to deliver at least a 60% cut in greenhouse gas emissions by 2050,[120] implying almost complete decarbonisation of the electricity system and radical action to reduce energy demand. As highlighted by the Stern Review,[22] this will require a combination of carbon pricing, a strong innovation policy, and action to remove barriers to behavioural change. From the SDC's perspective, the willingness of Government to put in place the radical policies needed on energy demand, greater decentralised supply and technology innovation should be a prerequisite for any decision in favour of a Severn barrage.

An environmental opportunity

The requirement to provide compensatory habitat is generally seen as a deal-breaking obstacle for a prospective Severn barrage by both proponents and detractors alike. The SDC believes that this accounts for much of the rather dangerous discussion around reform of, or derogation from, the Directives, or conversely, for the view that a barrage scheme would be impossible under any circumstances.

Instead, there is clearly a unique opportunity to develop a compensatory habitats package that seeks to respond to the challenges of climate change in a positive way. Rather than a process which attempts to create equivalent habitat on a narrowly-defined basis, a progressive strategy would look at the long-term coherence of the Natura 2000 network (the legal test to be satisfied), and the types and locations of habitat required to support it within the relevant biogeographic region. This would explicitly aim to adapt to climate change by using the funding available from the compensation package (which in turn is made available by an income-generating energy project) to create new coastal and wetland habitats on a national scale, aiding both biodiversity and coastal protection objectives. In reality, the UK already faces this challenge in tackling sea level rise with implications for coastal defences and loss of intertidal habitat.

The SDC believes that such a strategy would represent a significant advance in the implementation of European environmental legislation by joining biodiversity and climate change objectives together, and by linking climate change mitigation and adaptation as part of a long-term framework. It therefore represents a substantial environmental opportunity, but one that would be a huge test of the Government's commitment to sustainable development, and to the evolution of environmental conservation in the face of climate change.

The need for public ownership

We do not believe it would be possible to deliver a sustainable Severn barrage through the private sector. Considering the scale of the project, the associated risks, and the complexity of the issues involved, we believe that a barrage would need to be publicly-led as a project and publicly-owned as an asset to ensure long-term sustainability, compliance with the environmental legislation, and maximum public benefit. This does not rule out innovative financing options to help lever community or private sector investment; in fact, there may be a number of innovative financing options that Government could explore.

There are some significant benefits to a project financed and owned by the public sector. It would enable the use of a low discount rate (possibly 2%), justified by the long-term public benefits the project would bring. This is supported by the Stern Review, which recommended that a very low discount rate be used when evaluating long-term climate change mitigation measures to take account of the intergenerational benefits. Using a low discount rate would substantially reduce the cost of electricity output, making it highly cost competitive.

The benefits of a low discount rate could also be applied to other aspects of the scheme – and in particular, the cost of a compensatory habitats package. The costs of large-scale habitat creation become much more manageable when they are valued in a way that better accounts for their long-term benefits to the country. **The SDC believes that a public sector-led approach would be the best way to reconcile the need for low carbon electricity generation with the protection of internationally important habitats and species.**

We are not calling for the UK's energy system to be renationalised, nor do we believe that our recommended approach should necessarily be applied to other technologies or sectors. However, for a number of reasons, a Severn barrage project is unique, and the consequences of getting it wrong would be long-lived and possibly disastrous. There are a number of precedents for the approach we prescribe, including the London 2012 Olympics, which is being delivered by a public agency through dedicated legislation, but with financing from multiple sources.

Our recommendations may be relevant to other large infrastructure projects, and the model suggested could certainly be applied to other tidal barrage proposals, but we are not proposing a one-size-fits-all solution. Instead, we are issuing a challenge to Government that will require a complete revision of attitudes towards a Severn barrage. This will not be comfortable territory, but we believe that a publicly-owned approach is essential for a sustainable, economically viable Severn barrage that reduces the risk to taxpayers whilst upholding the long-term public interest.

Avoiding a 'decide-and-deliver' approach

Despite being very positive over the potential for a sustainable Severn barrage, the SDC has outlined a series of important conditions on how such a project should be developed. Navigating through the issues and agreeing on these conditions has been a difficult process for the SDC's Commissioners, particularly due to the inevitable risk that our recommendations may be selectively applied once a decision is made.

The SDC believes that on such an important issue, Government must avoid a decide-and-deliver approach. There are a number of crucial areas of uncertainty that will need to be resolved before a final decision can be made – in particular, the achievability and cost of providing compensatory habitat. This will require a sequential process and one that is genuinely open to the possibility that there may be obstacles to development that cannot be overcome.

5.3.5 Moving forward

A number of the SDC's recommendations – in particular the need for public ownership and for a radical approach to providing compensatory habitat – represent major challenges to Government policy. This is because a Severn barrage does not fit well within current policies on energy or environmental conservation, which were not designed with such a large, one-off project in mind. Our recommendations may also have implications for other areas of policy, particularly large infrastructure developments.

As a result, we recommend that any decision to further investigate a Severn barrage is taken with due regard for the complexity of the issues involved. The Government should not rush into a decision, nor should proponents of a barrage encourage it to do so. It is hugely important that the whole decision-making process is transparent and open, with public engagement as a major element from the start. Not only would this advance the principle of 'good governance', but it would significantly reduce the risk of a public backlash or legal action at a later date.

Below we consider some of the key considerations for Government if it is in favour of developing a sustainable Severn barrage project.

Policy appraisal

If the Government is minded towards developing a sustainable Severn barrage, then it will need to consider the implications for energy and environmental conservation policy in light of the SDC's advice, and to decide whether it is willing to take on the role of project lead that would be required. This will involve a detailed examination of the most appropriate organisational setup for the further work required, and a clear timeline for how the work should proceed.

An early decision may need to be taken on which of the barrage options should be selected for further investigation. This would need to take account of the results from any ongoing engagement work (see below) to avoid an approach that is dictated solely by engineering and economic factors.

Compensatory habitat requirements

As already stated, the SDC has not conducted an analysis of the compensatory habitat package that would be required to satisfy the conditions of the EU Habitats and Birds Directives.

Considering the overwhelming importance of this particular factor, it would be prudent for Government to focus on obtaining an early indication of the feasibility of compliance with the Directives, and the cost of doing so. This would need to include an assessment of the impacts of a barrage on protected habitats and species, leading to a quantification of the compensation required and a decision (following negotiations with the European

Commission) on whether this could be provided in a way that maintains the overall viability of the Natura 2000 network. Following the SDC's advice on pursuing this as an 'environmental opportunity', this work should also look at how the provision of compensatory habitat could be linked to the UK's long-term climate change adaptation strategy.

As the SDC has clearly stated, if compliance with the Directives is found to be scientifically or legally unfeasible, then proposals for a Severn barrage should not be pursued, as the development would then not be able to satisfy the principle of 'living within environmental limits'.

Detailed project evaluation

An important secondary process would inevitably involve a comprehensive research programme to tackle the outstanding technical, economic, environmental and social issues. It would not be appropriate for the SDC to be prescriptive about how this research should be carried out, or by whom. However, considering the SDC's recommendations on the financing of any barrage, we believe this would be best led by Government, or by a committee appointed by Government.

Engagement

Running alongside the processes discussed above should be an in-depth public and stakeholder engagement programme focused on tidal barrage options in the Severn Estuary to help identify the rights, opportunities and risks associated with such a development.

Ideally run independently from Government and building on the SDC's engagement work, this should seek to gain a greater consensus on the conditions for public acceptability, with a strong focus on the impacts on local communities. This would help to provide an insight into what factors would be most important in developing proposals in the long-term public interest. A whole range of barrage options could be presented, alongside non-barrage options where direct conflicts emerge. This work would, in our view, be essential in deciding how best to proceed further and could help to shape research priorities.

A cross-Government approach

Because of the location of a Severn barrage (linking England and Wales), and due to energy policy being a reserved matter, the UK Government (through the Department for Business, Enterprise and Regulatory Reform (BERR)) would need to take the lead in taking forward any proposals. BERR would need to work closely with the Department for Environment, Food and Rural Affairs (Defra) on issues such as climate change, marine spatial planning, and nature conservation policy, with Defra and the Environment Agency on flood and coastal protection policy and strategy, and with HM Treasury on economic and financing issues.

Nevertheless, there is a crucial leadership and strategic role at a national level in Wales and at a regional level in the south west of England. This would need to be led by the Welsh Assembly Government (WAG) and the South West of England Regional Development Agency (SWRDA) as the organisations responsible for economic development. They would need to ensure that any barrage proposals are fully integrated into revised spatial planning and regional strategies, and that the proposals maximise the long-term public benefit in a sustainable way. They would also need to involve other key stakeholders, including local authorities, ports, shipping and surface transport interests, and local community and business groups within existing Severn Estuary networks.

There would also be an important role for the statutory conservation agencies, and in particular the Countryside Council for Wales, the Environment Agency, and Natural England. Their expertise would be required to assist in the design and delivery of any environmental research programme, and they would have an important role to play in specifying and ensuring the creation of any compensatory habitat that might be required. This work would require a constructive approach to the proposals and one that seeks to uphold the requirements of the environmental designations whilst maximising the environmental opportunity that might be afforded under a compensatory habitat scheme.

The SDC's role

Our advice to Government is based on our assessment of the current evidence, and it is up to the Government to decide how to proceed.

As the Government's independent advisor and watchdog on sustainable development, the SDC is committed to working with the UK Government and the Devolved Administrations to integrate sustainable development approaches into all decision-making and policy processes. Our conclusions present a number of challenges for Government, for the private sector, and for British society as a whole and we will be looking to see how these are dealt with and acted upon. In assessing schemes of this kind – which have long lead times and very long-term benefits and impacts – a new approach is required which explicitly recognises that there are risks and uncertainties at a scale hitherto unrecognised. The assumptions underlining those risks – of going ahead with a project of this kind, or the impacts of climate change – must be laid out in a very transparent way.

The SDC would therefore be interested in working with Government and other key stakeholders to explore some of the substantive issues we raise, drawing on the expertise of our Commissioners and staff. We are particularly interested in further exploration of the 'environmental and ecological opportunities' afforded by a Severn barrage project, and in improving decision-making processes, planning, and citizen engagement connected to promoting and securing sustainable development outcomes linked to schemes of this kind.

We are also keen to explore innovative financing models that are public sector-led, incorporating long-term discounting approaches, but with a role for the private sector, to help deliver sustainable investment outcomes over the very long-term, and for fresh ways to secure sustainable and reliable future energy markets.

We look forward to working with a range of interested parties in evolving a constructive debate on the issues raised by this report.

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Glossary of terms

BERR Department for Business, Enterprise and Regulatory Reform (UK) (previously DTI)

BETTA British Electricity Trading and Transmissions Agreements

CCGT Combined cycle gas turbine

CCW Countryside Council for Wales

CEC Connection Entry Capacity

CHaMP Climate Change Marine Protection

CO_2 Carbon dioxide

Defra Department for Environment, Food and Rural Affairs (UK)

DETI Department of Enterprise, Trade and Investment (Northern Ireland)

DNOs Distribution Network Operators

DTI Department for Trade and Industry (now BERR)

EA Environment Agency

EAC Equivalent annual cost

EC European Commission or European Community[121]

EIA Environmental Impact Assessment

EMEC European Marine Energy Centre

EU European Union

EUETS European Union Emissions Trading Scheme

GW Gigawatt (= 1000MW)

GWh Gigawatt hour

IEA International Energy Agency

IROPI Imperative Reasons of Overriding Public Interest

IPCC Intergovernmental Panel on Climate Change

JNCC Joint Nature Conservation Committee (UK)

kV Kilovolt (=1000V)

kW Kilowatt (=1000W)

kWh Kilowatt hour

MRDF Marine Renewables Deployment Fund

MW Megawatt (=1000kW)

MWh Megawatt hour

NE Natural England

NGET National Grid Electricity Transmission plc

NGOs Non-governmental organisations

NWDA North West Development Agency

Ofgem Office of Gas and Electricity Markets

R&D Research and development

RO Renewables Obligation

ROC Renewables Obligation Certificate

RSPB Royal Society for the Protection of Birds

SAC Special Area of Conservation

SEA Strategic Environmental Assessment

SDC Sustainable Development Commission

SNH Scottish Natural Heritage

SPA Special Protection Area

SWRDA South West of England Regional Development Agency

tC Tonnes of carbon

TEC Transmission Entry Capacity

TNUoS Transmission Network Use of System

TW Terawatt (=1000GW)

TWh Terawatt-hour

UKERC UK Energy Research Centre

UN United Nations

WAG Welsh Assembly Government

Drafting Team Oliver Knight and Karla Hill
Art Direction Andy Long
Design Andy Long and Jerome Dutton
Photography Jerome Dutton
Maps ©MAPS IN MINUTES™/Collins Bartholomews (2007)
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