Joint Marine Programme

Turning the tide

Power from the sea and protection for nature

Iwan Ball

December 2002

Author: Iwan Ball
Project Co-ordinators: Dr. H.D. Smith
Dr. R.C. Ballinger

Marine and Coastal Environment Group (MACE)
Department of Earth Sciences
Cardiff University, Main Building
PO Box 914, Cardiff CF10 3YE
Tel: +44(0)29 2087 4830
Fax: +44(0)29 2087 4326
http://www.earth.cardiff.ac.uk

Acknowledgements

The author wishes to thank WWF Cymru and the Wildlife Trusts for their support and for their valuable comments on the draft report. The author is also indebted to staff at WWF-UK for their technical assistance in producing the report.

Maps and figures were produced with the assistance of Mr. Alun Rogers, Cartographic Unit, Department of Earth Sciences, Cardiff University.

The assistance of Nigel Langford (Renewable Energy Enquiries Bureau, ETSU) and Kevin Griffiths (Transport, Environment and Sustainable Development Statistics, Welsh Assembly Government) in providing information and statistics is also gratefully acknowledged.

For further information, please contact:

WWF Cymru
Baltic House
Mount Stuart Square
Cardiff CF10 5FH
Tel: 029 2045 1306
Fax: 029 2045 4971
E-mail: cymru@wwf.org.uk

WWF-UK
Panda House,
Weyside Park, Godalming
Surrey GU7 1XR
Tel: 01483 426444
Fax: 01483 426409
www.wwf.org.uk

The Wildlife Trust of South and West Wales
Nature Centre, Fountain Road
Tondu, Bridgend, CF32 0EH
Tel: 01656 724100
Fax: 01656 729880

The Wildlife Trusts
The Kiln, Waterside
Mather Road
Newark, NG24 1WT
Tel: 01636 677711
Fax: 01636 670001
www.wildlifetrust.org.uk

Contents

Executive Summary

INTRODUCTION

The UK government's commitment to reduce greenhouse gas emissions under the Kyoto agreement, and the National Assembly for Wales' commitment to sustainable development and review of energy policy in Wales, has stimulated consideration of all options for renewable energy. The UK has a target to supply 10 per cent of electricity from renewables by 2010. Specific targets for Wales are currently being debated.

A report by the Royal Commission on Environmental Pollution, *Energy – the Changing Climate* (June 2000), has ensured that the proposal for a 16km tidal barrage across the Severn Estuary has remained on the agenda. However, since the last studies on the Barrage were reported in *Energy Paper 57* (commonly referred to as the tripartite studies) in 1989, renewable energy technology has progressed, and other less expensive options have been developed that could have less of an environmental impact. These include stand-alone tidal stream turbines, constructed tidal lagoons, shore-based and offshore wave energy devices, and marinised offshore wind turbines.

Against this background, this study sets out the options for harnessing marine renewable energy resources, and the effects of these technologies on coastal and marine ecology, with a particular focus on Wales, where there is a potentially large renewable energy resource base. In particular, the study aims to:

- describe the technological options available for harnessing tidal, wind and wave power;
- describe their possible application in Wales and the implications of these technology options for wildlife and coastal/estuarine ecosystems; and
- discuss the need for wide consultation and appropriate assessment of any marine renewable energy proposals.

TRIGGERS FOR MARINE RENEWABLE ENERGY DEVELOPMENT

- The Kyoto Protocol, agreed in December 1997, set a goal for developed countries to reduce their annual emissions of the six main greenhouse gases to below 1990 levels by 2008-2012. In June 1998, the UK agreed to cut its emissions by 12.5 per cent. Subsequently, the UK government set a more challenging domestic goal, to reduce CO_2 emissions to 20 per cent below their 1990 level by 2010.

- Energy generation is a significant contributor to greenhouse gas emissions. Many of the means by which emissions can be reduced have been devolved to the National Assembly for Wales (NAW), reflecting the government's aim to provide a positive strategic approach to planning for renewable energy from the regional level downwards. As part of the NAW's obligation to contribute to the abatement of greenhouse gas emissions, there is a compelling case for increasing the proportion of energy generated by renewable sources.

- While the overall energy scene in Wales currently appears relatively healthy, the long-term position remains more uncertain. Gas is the primary fuel for electricity generation in Wales. Above average growth in demand for gas is predicted in Wales, against a background of a projected decline in UK North Sea gas reserves. Although reliability of supply is not considered to be a significant issue, increased dependence upon imports and associated price increases and fluctuations may subject the future supply of energy in Wales to a high degree of uncertainty. The situation is exacerbated by the expected closure of most of the UK's nuclear capacity at the end of their currently predicted lives, mostly in the period 2010-2020. The removal of this form of zero-carbon energy production, providing 22 per cent of UK electricity, will be difficult to replace. Concerns about future security of energy supply in Wales therefore present a powerful argument for investing in energy efficiency measures and renewable energy generation.

- Wales has a potentially large renewable energy resource base, due to its climate and geography, and there are commercial and rural development opportunities associated with the development of several renewable technologies. Recognising this potential, the NAW intends to develop Wales as a "global showcase" for clean energy production. However, most renewable energy technologies require significant space, mainly because the energy sources they harness are diffuse. Land-based renewable schemes are already facing constraints due to conflicts over land use and lack of suitable sites where planning permission is likely to be forthcoming. Marine renewable energy resources can make a potentially significant contribution to meeting future energy needs, as schemes could be deployed on a much larger scale at sea than on land.

TIDAL ENERGY

- Tidal power can be harnessed either through the energy stored in tidally impounded water, or by extracting energy from the tidal movement of water (tidal streams) using tidal turbines, analogous to underwater wind turbines. The former can utilise naturally occurring tidal basins, for example by building a barrage across an estuary, or by offshore tidal power generation based upon the relatively new concept of constructed offshore tidal lagoons.

- The coast of Wales probably has the most favourable conditions anywhere in the world for tidal power development, due to the high tidal range. These average seven to eight metres on the spring tides in several estuaries, and as much as 11 metres in the Severn Estuary. The theoretical potential from tidal energy in the UK as a whole has been estimated to be around 50 TWh/yr, although the present status of technology and financial constraints suggest much of this potential is unachievable. Nevertheless, tidal energy is the most predictable of the marine renewable resources, and variation over the tidal cycles can be predicted with considerable accuracy well into the future.

- Although studies have shown the UK tidal stream resource to be between 31 and 58 TWh/yr, only around 10 TWh/yr could feasibly be exploited, in relatively shallow sites near to high demand for power (providing around 2 per cent of UK electricity demand). Marine currents generated by tidal streams around the Welsh coastline offer as many opportunities as other places in the UK. They represent a viable resource, particularly when focused around headlands or in large estuaries. Sites off Pembrokeshire, the Lleyn Peninsula, Menai

Straits and the Severn Estuary offer development potential. Their geographical proximity for transmission purposes to major demand centres in England and Wales provide advantages over other sites currently being investigated for tidal stream exploitation in Scotland.

TIDAL BARRAGE

- The paradigm for tidal power generation has been the estuarine tidal barrage. The first commercial-scale modern-era tidal power plant was built at La Rance near St Malo, France (240 MW) in the 1960s. Two other schemes have been operating in the Bay of Fundy, Canada (25 MW) since 1982, and in China (100 MW) since 1987. There are several non-commercial power-generating barrages in existence worldwide, including a 200 kW tidal barrage on the River Tawe in Swansea Bay, that operates the gates of a lock.
- Tidal energy has been extensively researched in the UK under a government programme which ran from 1978 to 1994. Several major potential sites for barrage construction were identified, the most notable being the 8,640 MW Severn Tidal Barrage (STB) proposal. It has been estimated that this would generate 17,000 GWh/yr, providing up to 7 per cent of the annual electricity consumption in England and Wales. Other potential barrage sites in Wales have been identified at Conwy (33 MW), Loughor (5 MW), Milford Haven (96 MW), and Dyfi (20 MW) estuaries.

- It is evident that, from a developer's perspective, the primary problem facing tidal barrages is not technological, but financial. Large-scale tidal projects such as the STB are presently considered to be commercially unattractive. The restructuring of the electricity market has increased the financial risk attached to investments in generating plants. It is unlikely that projects such as the STB, which would require large long-term investments with lengthy pay-back times, would be undertaken by a commercial company in the liberalised market for electricity. This is a view shared by the Royal Commission on Environmental Pollution. Such projects are therefore unlikely to proceed without significant Government intervention.

- Aside from the financial risks, it is generally accepted that barrage construction would induce significant environmental changes to estuarine ecosystems. Concerns relate primarily to habitat disturbance caused by changes in water levels which would modify currents, and to sediment (and associated pollutant) transport and deposit. Environmental constraints are a key obstacle to the development of the STB, as most of the estuary is covered by three large Sites of Special Scientific Interest (SSSI). It has also been designated as a Special Protection Area (SPA) under the European Birds Directive and as a Wetland of International Importance (Ramsar Site). It is also a proposed Special Area of Conservation (pSAC) under the EC's Habitats Directive, which forms part of the Natura 2000 Network.

- The net environmental effect of barrage development is likely to be site-specific, with some species possibly benefiting at the expense of others. There is limited operational experience of large-scale projects upon which such judgements can be based. Clearly, detailed site-specific environmental assessment and long-term monitoring would be required for each barrage scheme.

TIDAL LAGOONS

- Placing the impoundment structure offshore may potentially resolve many of the environmental and economic problems presented by estuarine barrage systems, and could put tidal power back among the choices for commercial-scale renewable power generation. It is most economical to build an impoundment structure in a shallow area, so it follows that the most attractive sites for offshore power generation are those where the tidal range is high and there are broad tidal flats at minimal depth, such as in the Severn Estuary. Tidal Electric Ltd. (TE), a US-based company, is developing two tidal power plants in Wales (Swansea Bay [30 MW], and off Rhyl, North Wales [432 MW]), using its new offshore lagoon concept for tidal power generation. Other locations in Wales have large tidal ranges and many suitable sites for further installations could conceivably be developed (including a potential site in the Bristol Channel), generating thousands of megawatts.

- Offshore impoundment structures are likely to have an environmental impact by changing the behaviour of currents and waves which will, in turn, change existing sediment transport regimes. The operation of the turbines is also likely to cause some localised turbulence. However, an independent appraisal of the Swansea Bay development concluded that the environmental impacts of the scheme are likely to be acceptable and may even have significant benefits, such as protecting the Crymlyn Burrows or creation of a wildlife habitat. Clearly, careful in-depth studies of environmental impact will need to be conducted prior to, and during, development, construction, operation and decommissioning, in order that future projects can be guided by the experience of these initial projects.

- Although the development of offshore tidal power will have visual, sediment transport and marine life impacts, these are unlikely to be of the same magnitude as the impacts associated with estuarine barrage construction. Given the viability of the technology, this approach has the potential to generate significant amounts of renewable energy, with a lighter environmental “footprint” than a tidal barrage. The technology is apparently competitive within the Renewables Obligation, which creates a limited protected market for renewables. However, the three projects in Wales will be the first embodiment of the offshore impoundment structure approach to tidal power, and will therefore bear the inherent risks of unforeseen problems arising. Further studies should address the commercial, technical and environmental aspects of the technology.

- There may be merit in conventional barrage concepts, but tidal power generated by barrage schemes is unlikely to make any contribution to renewable energy targets in Wales in the short- to medium-term, and certainly not by 2010. Tidal power may have a role to play in reducing greenhouse gas emissions from power generation in the long term but, given the associated financial, technical and environmental risks, it ought to be as one of the last renewable options to be developed, not the first. Novel ideas such as offshore tidal lagoons suggest that there may be new ways to develop the tidal barrage concept. These impoundments offer large-scale energy generating capacity with advantages over conventional barrages (tidal lagoons can be designed to generated energy on the flood and ebb tides, while barrages generally only generate on the ebb), with a potentially less significant environmental impact.

TIDAL STREAM (NON-BARRIER TIDAL)

- Tidal stream is the name given to high velocity tidal currents, created by the movement of the tides and frequently enhanced by topographical features that focus the tidal currents into a predictable and concentrated form of renewable energy. A number of devices are in different stages of development, the most advanced being a 300 kW full-scale tidal stream generator developed by Marine Current Turbines Ltd (MCT), which is being tested off Lynmouth in Devon. The only project at present being undertaken in Wales involves research since 1997 by Tidal Hydraulic Generators Ltd (THG) into a seabed mounted tidal-flow water turbine farm. The project is supported by Pembrokeshire Coast National Park through the Environment Development Fund, with additional funding from ETSU (DTI). Phase 3 of the project involves the installation of a 1 MW average (5MW peak) turbine in a sheltered location in Milford Haven waterway.

- Limited funding has meant that tidal stream technology has yet to be demonstrated on a realistic scale, and most of the work has so far been theoretical or small scale. It is clear that tidal stream devices can be made to work, but their long-term reliability and cost-effectiveness needs to be demonstrated in the marine environment to take the technology forward to commercial reality.

- The successful exploitation of the offshore tidal stream resource in Wales could make a substantial contribution to reduction of greenhouse gas emission in the long term, while ensuring diversity of energy supply. However, further studies are required to identify the resource available in Wales, including deep-water sites. Several energetic locations around the Welsh coastline, such as around headlands and in straits, may have the velocity over a large enough area to permit the installation of much larger devices, when the technology matures.

- Tidal turbines are expected to have a minimal environmental impact, although this cannot be confirmed due to the lack of test-bed projects. However, the turbine rotors rotate at low speeds and small-scale schemes certainly present less of a threat to migratory fish passage than large tidal power barrages. The development of acoustic fish guidance may realise the possibilities of safely diverting fish around turbines. An environmental impact study for a tidal power generation scheme for Orkney and Shetland concluded that, providing schemes are deployed with some care, they should not have any significant adverse effect on the environment, and steps can be taken to ensure that such schemes are not a navigation hazard to shipping.

WAVE ENERGY

- A number of wave energy devices (WEDs) are at different stages in their development and evaluation, but most have yet to demonstrate their long-term reliability and effectiveness in harsh maritime environments. Shoreline wave energy conversion is technically developed but not fully commercially proven, and is some way from being commercially competitive. The next stage of shoreline/nearshore devices will need to demonstrate success in several areas, including efficiency of energy capture, turbine performance, and durability. It is widely accepted that the future for wave energy is to move offshore where there is a much larger resource. However, most offshore WEDs are still at the research and development stage, with much work needed to tackle key development issues, reduce uncertainty and verify concepts.

- In the UK, three projects have been awarded contracts under the Third Scottish Renewables Order (the first Renewables Order open to wave power): LIMPET 500 (500 kW), Pelamis (750 kW), and the Swedish Floating Wave Power Vessel (FWPV) (1.5 MW). Currently there are no plans for deployment of projects in Wales. Nevertheless, Wales has a potentially significant wave energy resource, particularly in the high-energy environments of the south-west which are open to the full force of the Atlantic Ocean. However, to exploit even a fraction of this requires the overcoming of substantial technical and economic challenges. The most technically developed WEDs, Oscillating Water Columns (OWCs), may not be very well suited to areas where there is a large tidal range, thereby ruling out many shoreline and nearshore locations, particularly in the Severn Estuary. WEDs may be used elsewhere on the Welsh coast in areas of high wave energy and low tidal range. More detailed analysis of the wave energy resource is required for Wales; in addition, environmentally suitable sites and their development potential have yet to be identified.

- Despite their less advanced development status, floating offshore systems may have much wider development potential in Wales, since they are more tolerant of wider tidal ranges, and do not involve shoreline modification or breakwater construction. Floating buoy systems also have a low freeboard, which minimises their visual impact upon the offshore seascape. Wales' wave energy development potential is likely to be limited by the following considerations:

    1. environmental constraints based on potential negative impacts and local public concerns, particularly with regard to visual impact;
    2. utility constraints based on the time variability of the wave resource and a weak onshore distribution network in areas where the resource is optimal; and
    3. financial constraints based on the limited number of economically feasible sites for shoreline-based systems.

- Compared with current utility generated electricity, WEDs are no longer considered cost competitive in Wales. Very significant improvements in efficiency, capital cost, and operation and maintenance costs are required to change this situation. However, it may be more cost-effective to focus initial development efforts on smaller WEDs that provide electricity directly to a niche market or dedicated end user, than for sale to a utility. These applications may provide the best opportunities for WED technology demonstration and development in Wales.

- Wave energy is unlikely to make a significant contribution to renewable energy targets and reduction of greenhouse gases in the short term – by 2010. However, it could be an important option for the longer term as the technology matures and costs are reduced. The NAW should continue to monitor the relative costs, status of development and potential applications of wave energy conversion. A Scottish Commission has been formed to promote the development of a wave energy industry in Scotland. A similar body could be established in Wales, which could encourage private sector developers to pursue WED demonstration and development here.

OFFSHORE WIND

- The UK's offshore wind resource has the potential to provide more than three times the country's present electricity needs. It has been estimated that the full potential resource of offshore wind energy in Welsh coastal waters is around 79,000 GWh/yr. However, this potential does not take account of a number of economic, technical, planning and environmental constraints, which are likely to limit the actual installed capacity. Even so, wind turbines are one of the best-developed renewable energy technologies, and will be a key contributor to the target for renewable electricity generation by 2010.

- Wind turbine technology used in current offshore projects is largely an adaptation of onshore systems, and consists of turbines of the order of 2 MW to 3 MW (although units of up to 5 MW are already under construction), with some additional corrosion protection. Although it is unlikely that there will be any major changes in turbine concept with the move to offshore in the short term, interesting modifications on conventional onshore designs are beginning to appear. These include, *inter alia*, the development of floating support structures for turbines, which could extend development of wind farms further offshore into water depths of up to several hundred metres, thereby reducing the visual impact from the shoreline and avoiding sensitive coastal areas.

- At present there is only one offshore wind farm operating in the UK. This comprises two 2MW Vestas turbines erected 1 km off the coast of Blyth, Northumberland. In April 2001 the Crown Estate released details of 18 further developments that have qualified to lease parts of the seabed, subject to further conditions. These are expected to be the first tranche of offshore wind development, and include three sites in Wales: Rhyl Flats, off Abergele (150 MW); North Hoyle, off Prestatyn (90 MW); and Scarweather Sands, off Porthcawl (90 MW). North Hoyle was granted final consent in early October 2002 for a project of up to 30 wind turbines, 7.5 km offshore. The development will receive a £10 million share of the funds available under the Capital Grant scheme available for offshore wind energy projects. Four other proposed sites for wind farm development are in Liverpool Bay, which could have landscape implications for Wales.

- The Renewables Obligation and the Climate Change Levy Exemption will provide the support for offshore wind to make a potentially significant contribution to the 2010 renewables target. However, it is not clear whether the cost of electricity from offshore wind will be commercially competitive outside the Obligation, as no truly commercial offshore wind farms have yet been developed. Evaluation of the early schemes will verify the validity of estimated electricity prices. Generating costs could be reduced with future technological innovation. However, it has been estimated that the price per kWh for electricity generated by offshore floating wind farms may be twice as much as conventional bottom-mounted schemes, providing little incentive for the exploitation of deep water sites.

- Both the North Hoyle and Rhyl Flats project developers have prepared Environmental Statements, while the Scarweather Sands proposed development is currently the subject of an Environmental Scoping Study. The main environmental concerns over offshore wind farm development relate to the potential impact upon bird migration patterns and disturbance at bird feeding areas and fish spawning or nursery areas. Unless developments are proposed for very sensitive sites in terms of marine nature conservation, bird populations or fisheries, the main impact could be visual intrusion on the seascape. Guidelines for seascape assessments have recently been developed by the Countryside Council for Wales (CCW). Visual intrusion may prove to be a particular constraint to wind farm development in Wales, which relies heavily upon coastal tourism and has a high level of protected coastal landscapes.

- The three proposed developments outlined above, should they proceed, could provide the basis for Wales to become a key player in the evolving offshore wind energy market. However, it is difficult to identify where further offshore developments could occur. Although much of the Welsh coast may qualify in terms of suitable water depth, development in many areas is constrained by environmental sensitivities and weak access to the national grid. Potential areas that have been identified include the coastal waters of north-east Wales, Cardigan Bay, Carmarthen Bay and Swansea Bay. However, much of mid-Wales around Cardigan Bay is inadequately served by the national grid, and areas around the Gower and Cardigan Bay are contentious due to their environmental sensitivities. Further studies are required to identify and evaluate potential sites, and to examine how economic activity in Wales could benefit from such developments. These should include consideration of brownfield sites as potential areas for the deployment of shoreline wind turbines, particularly on existing features such as breakwaters and jetties, for which no other commercial use can be envisaged.

STRATEGIC ISSUES COMMON TO ALL MARINE RENEWABLES

- It is acknowledged that the single most serious problem facing the successful exploitation of marine renewable energy in Wales – and indeed the UK as a whole – is the difficulty of network connection. The grid was not designed to receive energy from small, multiple sources in remoter parts of the country and transmit it to the main demand centres. Sites with the greatest potential for marine renewable energy generation are often situated near the end of the distribution network which (in many rural shoreline areas) can be weak and in need of strengthening to accept new generation capacity. There are no north-south national grid links within Wales, and the infrastructure in mid-Wales is particularly weak. Potential developers may be faced with large network connection charges, which represent a major cost centre that lies outside their control. The government has announced that it is studying the possibility of developing an offshore high voltage direct current (hvdc) network for the connection of renewable energy sources sited along the west coast of Britain, which would feed into the existing transmission system nearer to the centre of UK demand. This could potentially overcome the deficiencies of the existing grid infrastructure in serving remote coastal areas in Wales, although the environmental implications of such an ambitious scheme have yet to be satisfactorily evaluated.

- The Renewables Obligation ensures a price of up to a maximum of ~5p/kWh for electricity from renewable energy sources, by placing an obligation on electricity suppliers to provide 10 per cent of their electricity from renewable sources by 2010. Also, the Climate Change Levy, and the exemption from it for electricity purchased from renewable energy sources, is worth a further 0.43p/kWh. The target is for marine renewables to be commercially competitive without the need for these market support measures, for which they would need to be generating electricity at a price competitive with other sources of energy. However, it should be remembered that external costs are often not taken into account in the cost comparison of different energy sources, which puts renewables as a whole at a disadvantage. Also, as the source of energy is free, the technology is not susceptible to fuel price fluctuations. Care should be taken in comparing the projected costs of various technologies that are at different stages of research and development.

- No energy technology can be completely lacking in environmental impact, but offshore renewables look likely to offer less negative environmental impact than most. Environmental Impact Assessments (EIAs) are already a necessary requirement of the consent routes for offshore wind farms, and should also figure in the consent process for other marine renewables. EIAs should take into account potential impacts during site preparation, construction, operation and decommissioning stages. Public consultation with all user and interest groups is also a vital part of the process. Lessons can be learned from the offshore oil and gas industries in addressing environmental issues, including the application of strategic environmental assessment (SEA) and cumulative impacts of developments. Furthermore, under Regulation 48 of the Habitats Regulations, it is necessary for plans and projects which may have a significant effect on a European Marine Site (SAC or SPA with subtidal or intertidal zones) to be subject to an "appropriate assessment of the implications of the site". These plans and projects do not need to be situated within the boundaries of the SAC or SPA, but might only need to be "adjacent" to be required to undergo an assessment.

- The complicated consent process involving a plethora of statutory bodies that have an interest in the licensing arrangements for developments below low-water mark is widely acknowledged to have been a significant barrier to the implementation of renewable energy, particularly for small companies developing renewables technology. As a result of the planned deployment of offshore wind farms, the general issues of deploying specific offshore renewable energy schemes (planning, the consent process, the role of the Crown Estates) are now being streamlined, to replace the previous system of sectoral controls. This will involve the creation of a "one-stop shop" by the DTI that will encompass nearly all the procedural steps. It should be noted, however, that decisions on offshore wind and water generating stations larger than 1 MW in territorial waters of England and Wales require a consent from the Secretary of State for Trade and Industry under Section 36 of the Electricity Act and will, therefore, be taken outside Wales. As more development takes place within the relatively shallow waters close to shore, the potential for further deployment of large-scale renewable energy technologies may be constrained. Consideration should be given to clarifying the legal framework for development beyond the 12-nautical mile limit of the territorial sea.

CONCLUSION

- Arguably, if we do not develop marine renewable energy resources, we will be unable to meet our commitments to reduce greenhouse gas emissions while still supplying future energy needs. Offshore wind is now considered to be an integral component of the UK government's strategy in order to achieve the post-Kyoto target of providing a 10 per cent contribution from renewables. However, other marine renewables, namely tidal currents and waves, possess higher energy intensity than most renewables and offer a more predictable and reliable source of energy, and therefore constitute a potentially cost-effective source of future energy. The main obstacle is that these technologies are less developed. Even so, many problems facing the development of new marine renewable energy technologies are generic, and progress in one area could benefit others.

- The prospects for marine renewables are difficult to evaluate with any certainty beyond the short-term (i.e. 2010). Medium- (2025) and long-term (2050) prospects depend on several factors including government support and funding, research and development progress in overcoming existing technological difficulties, and cost reduction to enable commercial competitiveness. The market remains substantially influenced by government policy, and future decisions on other elements of energy policy, particularly the future of the UK nuclear industry, are likely to significantly influence the prospects for renewables.

- ETSU (Energy and Technology Support Unit – now incorporated into Future Energy Solutions) has prepared technology status reports on offshore wind, wave and tidal stream energy as part of the DTI's New and Renewable Energy Programme. These reports aim to identify Technology Route Maps (key technological milestones) in the development of these technologies. The principal goal of the programme is to assist the government in meeting its target of 10 per cent of electricity generated from renewables by 2010.

  With the first medium sized offshore wind-farms already under development, ETSU believes **offshore wind** will make a significant contribution to this target. Beyond 2010 (or earlier if possible) the aim must be to make offshore wind commercially competitive without the incentive/market enablement mechanisms currently in place. This is achievable: experience with onshore wind energy has demonstrated how costs can fall dramatically as installed capacity increases.

  The prospects for **wave energy** in the short term (up to 2010) appear confined to *in situ* prototype testing and commercial scale demonstrations of existing well-established device concepts. In the medium term (2025), new device concepts could be developed which, along with further innovation in the design of offshore WEDs, could contribute to the long-term viability of this technology.

  As with wave energy, the prospects for **tidal stream** technology very much depend on the specific device concept, with a number of devices each at different stages in their development. Marine Current Turbines Ltd envisage the possibility of installing around 300 MW-worth of turbines by 2010. If this is feasible, tidal stream technology could make a reasonable contribution to the government's 10 per cent renewables target. ETSU, however, believes the prospects for commercial development of tidal stream technology are likely to be post-2010, although this does not rule out earlier commercial scale demonstrations.

Constructed **tidal lagoons**, on the other hand, may offer greater potential, with Tidal Electric claiming that an initial tranche of offshore tidal power installations can deliver 8000 MW by 2010 – enough to meet the 10 per cent renewables target. Much of this potential is located in North Wales/Liverpool Bay (1500 MW) and the Severn Estuary (4500 MW) which, together with the proposed developments in Swansea Bay (30 MW) and North Wales (432 MW), could make Wales a key player in pioneering this technology.

RECOMMENDATIONS

The seas around Wales, and particularly the offshore marine environment, offer huge open spaces with potentially large renewable resources of wind, wave and tidal energy, where new energy technologies could be employed on a much wider scale than on land. Based on the findings of the report, WWF and the Wildlife Trusts recommend that:

- All proposals for marine renewable energy projects should be subject to an Environmental Impact Assessment (EIA) and full consultation before consent is given. The EIA should inform the design of the project and should identify measures to be adopted during the construction and operation of the project to avoid or reduce impacts where practicable. All efforts must be made to avoid the 'right technology in the wrong location'.

- The construction of large tidal barrages such as the Severn Tidal Barrage should not be undertaken in view of the financial and environmental risks.

- The National Assembly for Wales should recognise the potential marine renewable energy resource base available in Wales and how this can contribute to future energy security and diversity needs within the principles of sustainable development. With the right approach, Wales can be at the forefront of developments in this field and reap the potential economic and environmental rewards.

- Marine renewable technologies should be advanced by academic and SME partnerships in Wales. Targeted research funding should therefore be made available to encourage research activities in these fields and to attract an increasing number of researchers. This should accelerate technological innovation of wave and tidal energy schemes and bring the technology closer to commercial competitiveness.

- The National Assembly for Wales should vigorously pursue opportunities to increase energy efficiency and promote energy efficient technologies and set up a Sustainable Energy Agency to monitor renewable energy development and progress in energy efficiency.

- Strategic Environmental Assessment (SEA) should be implemented to ensure a more transparent planning process for marine renewables by involving the public and by integrating environmental considerations into the decision-making framework. SEA should also be integrated into a wider assessment of the social and economic effects of development proposals. This will help to achieve the goal of sustainable development.

1 Introduction

1.1 BACKGROUND

Energy policy has to serve all aspects of sustainable development: economic, social and environmental. However, it is clear that environmental concerns must be considered as an equal priority with socio-economic needs. Environmental considerations are important at a site-specific level and regional level as well as when addressing national and global concerns.

There is now an overwhelming body of scientific opinion identifying that the continued use of fossil fuels is increasing levels of CO_2 and other greenhouse gases in the atmosphere, resulting in the enhancement of the ‘greenhouse effect’ and associated global warming. Clearly, changes in energy production and use have an important part to play in reducing the threat of climate change. In response to this threat, there is a global movement on the part of governments to reduce emissions of greenhouse gases such as CO_2.

The UK government’s commitment to reduce greenhouse gas emissions under the Kyoto agreement and the National Assembly for Wales’ (NAW) commitment to sustainable development and review of energy policy in Wales has stimulated consideration of all options for renewable energy. The UK has a target to supply 10 per cent of electricity from renewables by 2010. Specific targets for Wales are currently being debated.

Renewable energy sources are defined as natural energy sources that occur continuously and sustainably in the environment and can be harnessed for the benefit of mankind. They can be used for both electricity and heat generation. These sources of energy produce significantly lower levels of environmental pollutants than conventional sources of energy. In particular, renewable energy sources generally emit no greenhouse gases or are neutral over their lifecycle in greenhouse gas terms.

Wales has a potentially large renewable energy resource base, due to its climate and geography, and there are commercial and rural development opportunities associated with the development of several renewable technologies. Recognising this potential, the NAW intends to develop Wales as a ‘global showcase’ for clean energy production. However, most renewable energy technologies require significant space, mainly because the energy sources they harness are diffuse. Land-based renewable schemes are already facing constraints due to conflicts over land use and lack of suitable sites where planning permission is likely to be forthcoming. Marine renewable energy resources can make a potentially significant contribution to meeting future energy needs, as schemes could be deployed on a much larger scale at sea than on land.

Wales has significant potential to be at the forefront of the development of a major new offshore renewable energy industry. The coastal zone and offshore areas present a rich asset of potentially suitable sites for harnessing marine renewable energy. It is anticipated that several new marine renewable energy technologies, such as tidal stream turbines, constructed tidal lagoons, shore-based and offshore wave energy devices, may become deployable on a commercial scale in the future, some sooner than others. However, offshore wind technology is already well advanced, to the extent that the industry is poised for major and rapid deployment.

It is recognised that marine renewable energy generation, in common with all types of development, is likely to have some environmental impact, although this may be significantly less than other conventional forms of energy generation. Nevertheless, marine renewables are not necessarily benign. The benefits in terms of reduced emissions have to be strategically balanced with other effects and impacts, including those on biodiversity. Some marine renewable projects have the potential for much greater implications for biodiversity than others.

Against this background, this study addresses the policy issues surrounding the development of marine renewables and outlines the environmental impacts, including those on biodiversity, of different marine renewable energy technologies, with a particular focus on Wales. In particular, the study aims to:

- describe the technological options available for harnessing tidal, wind and wave power;
- describe their possible application in Wales and the implications of these technology options for wildlife and coastal / estuarine ecosystems; and
- discuss the need for wide consultation and appropriate assessment of any marine renewable energy proposals.

1.2 STRUCTURE OF REPORT

The structure of the report and brief outline contents of the following chapters is as follows:

Chapter 2	Energy Demand and Consumption in the UK Provides an overview of the overall energy situation and patterns of electricity supply, availability and consumption in the UK, and likely future changes. Particular attention is given to the Welsh context. The implications for Wales of greenhouse gas emissions and global warming are examined and relevant climate change policy measures and initiatives are discussed.
Chapter 3	Marine Renewable Energy Resources – Current Situation and Future Potential for Wales Provides an overview of renewable energy in the UK as a whole and the present contribution by renewables in Wales. Proposed renewable energy targets for Wales are discussed and the case for developing marine renewables is presented. An overview of the potential UK resource is followed by a description of the marine renewable energy resources available to Wales.
Chapter 4	Tidal Energy Evaluates the technology and key issues associated with harnessing tidal energy. An outline of the current status of tidal energy development in the UK is provided, and the potential for future developments in this sub-sector is summarised. The chapter provides an understanding of the commercial competitiveness of tidal energy schemes and the targets it needs to achieve to become viable. The chapter concludes with an assessment of the potential environmental and socio-economic impacts of developing tidal energy.

Chapter 5	Wave Energy Evaluates the technology and key issues associated with harnessing wave energy. The chapter follows the same structure as outlined above.
Chapter 6	Offshore Wind Energy Evaluates the technology and key issues associated with harnessing offshore wind energy. The chapter follows the same structure as outlined above.
Chapter 7	Strategic Issues Affecting the Development of Marine Renewables Describes a number of strategic factors that constrain or influence the utilisation of marine renewable energy resources. The key technical, economic, planning and environmental factors that apply across the range of marine renewable energy technologies are considered, including network connections and charges, the consents process, and requirements for Strategic Environmental Assessment. Some of the key issues associated with formulating a strategy for developing marine renewable energy in Wales are considered. The chapter concludes with a summary of the current status and future potential of the three marine renewable energy sub-sectors in Wales.
Chapter 8	Conclusion Summarises the main findings of the study.

2 Energy demand and consumption in the UK

2.1 THE OVERALL ENERGY SITUATION

Overall energy consumption for energy use in the UK has increased by 13 per cent since 1970 and by 11 per cent since 1990. On a temperature corrected basis[1], this equates to an increase in energy consumption of 15 per cent between 1970 and 2001 and by 10 per cent between 1990 and 2001. Overall consumption increased by 2 per cent between 2000 and 2001 to a new record high of 237.7 million tonnes of oil equivalent (Mtoe) Over the last 20 years it has been steadily increasing at about 1 per cent a year.

Trends in the consumption of primary fuels for energy use are illustrated in *figure 2.1*, while *figure 2.2* compares primary energy consumption by fuel type for 1970, 1990 and 2001. Around 90 per cent of primary energy used in the UK is derived from fossil fuels (RCEP, 2000). Consumption of natural gas fell in 2001 for the first time since 1992 and accounted for two-fifths of all energy consumption in the UK. Since 1990, while use of natural gas has increased by 86 per cent, solid fuel consumption fell by 38 per cent and accounted for 17 per cent of all fuel consumed in 2001. The shift occurred because gas is more convenient and less polluting than coal, and because it costs less, both for space heating and for electricity generation[2]. Over the past 10 years, petroleum consumption has not changed a great deal, although consumption of energy from renewables and waste continued to increase in 2001.

Whereas the average rate of primary energy use in the UK is about 300GW, the average rate of final consumption is only about 210 GW (RCEP, 2000). The difference represents losses within the energy system. Energy industry use, losses during conversion to secondary fuels, and losses during distribution accounted for 32.5 per cent of inland energy consumption in 2001 (DTI, 2002a). The largest component is energy losses in the course of electricity generation. On average, for every 2½ units of fuel that goes into power stations, approximately 1 energy unit of electricity is produced. Since electricity is used for a wide range of uses, and trends in electricity consumption determine the levels of energy required to generate it, the remainder of this chapter focuses on final energy consumption.[3]

2.2 FINAL ENERGY CONSUMPTION

Overall consumption by final users (excluding non-energy use) has followed the same pattern as overall primary energy consumption since 1970, accounting for around 70 per cent of the total consumption throughout the period. Final energy consumption in the UK, as shown in *figure 2.3*, was 160.8 Mtoe in 2001 (DTI, 2002a). This is an increase of 1.5 per cent since 2000, and final energy consumption is at a higher level than in any other year over the last 30 years (DTI,

---

[1] As energy consumption is partly dependent on weather (in a cold year more energy is consumed to maintain a consistent internal temperature than in a warmer year), energy consumption is adjusted for temperature to identify the underlying trend.

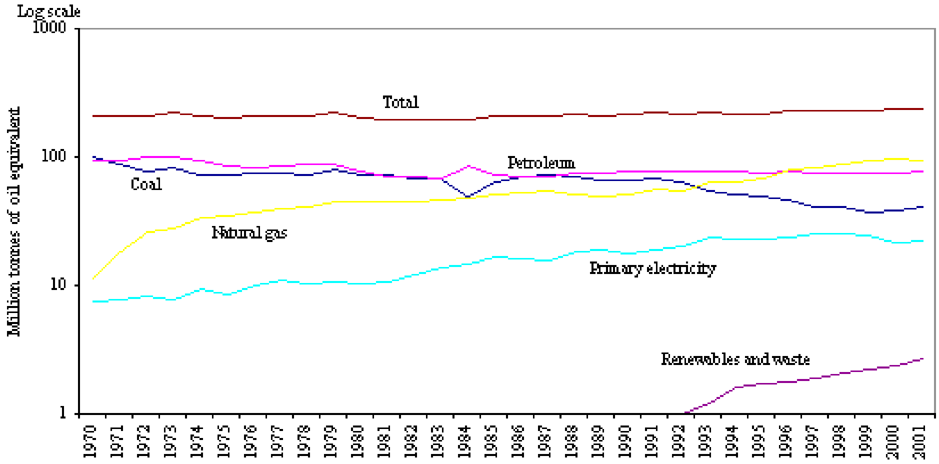
[2] Combined Cycle Gas Turbine (CCGT) power stations were introduced in 1992.

[3] Final energy consumption covers the final fuels that are consumed by users so the final amounts of electricity and manufactured solid fuels are measured, rather than the amount of fuel used to generate or manufacture them.

2002b). Overall final energy consumption has increased by 10 per cent since 1970 and by 9 per cent since 1990 (DTI, 2002b). Projections published by the Department of Trade and Industry's (DTI) Performance and Innovation Unit (PIU) show energy use continuing to grow steadily (PIU, 2002).

The fuel mix has also changed significantly over the years (*figure 2.4*). In 1970 natural gas accounted for 3 per cent of overall final energy consumption, and in 2001 for 36 per cent[4]. Consumption of solid fuels has fallen by 90 per cent between 1970 and 2001. During the same period electricity consumption has increased by 74 per cent, exhibiting a steady growth of 2 per cent a year over the last 20 years.

Figure 2.1 Primary energy consumption, 1970-2001



[4] Production of natural gas was at a record level of 108.3 Mtoe in 2000 (DTI, 2002a).

Figure 2.2 Primary energy consumption by fuel type for 1970, 1990 and 2001

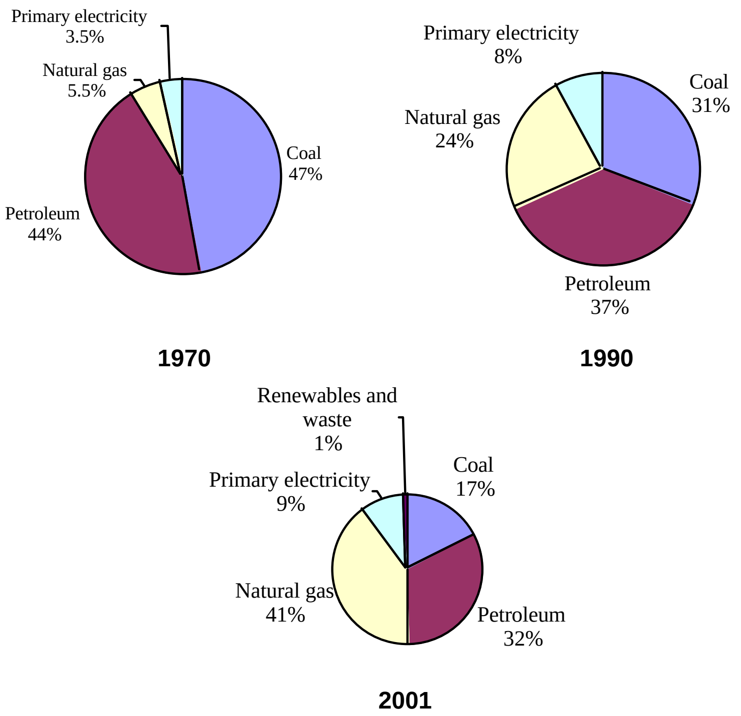
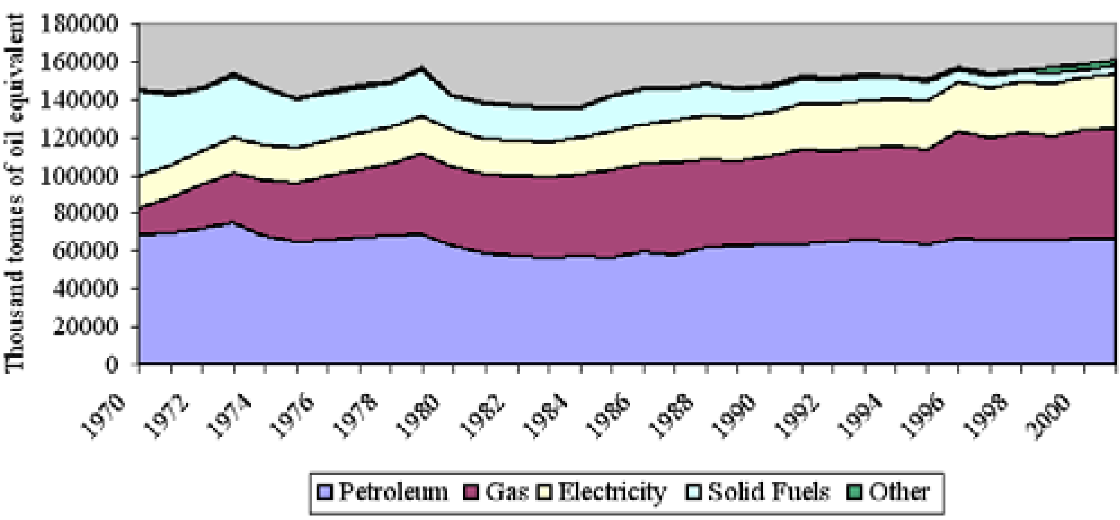


Figure 2.3 Trend in final energy consumption, 1970-2001



2.3 Electricity supply, availability and consumption

About a third of primary energy use in the UK is to generate electricity (RCEP, 2000). The generating capacity currently available on the UK electricity grid is in the region of 79 GW, although this figure varies slightly with the source of information (compiled at different times) and the assumptions made by the compiler (Newton & Hopewell, 2002).

The trend in electricity consumption by different sectors since 1970 is shown in *figure 2.5*. Demand for electricity is predominantly from final consumers. Electricity's share of consumption by final users has increased from 11 per cent in 1970 to 18 per cent in 2001, reflecting its convenience as a form of energy. Over half the energy industry's use of electricity is by the electricity industry itself, with petroleum refineries being the next most significant consumer (DTI, 2002c). Consumption of electricity by industry accounted for 37 per cent of total consumption in 1970. However, despite a 55 per cent increase in electricity consumption by industry in the past 30 years, this proportion fell to 33 per cent of total consumption in 2001. Similarly, the domestic sector's share of total consumption has fallen from 39 per cent in 1970 to 33 per cent in 2001, despite a 43 per cent increase in electricity consumed by households since 1970. The biggest growth has been in the services sector, where electricity consumption has grown by 11 per cent over the last 5 years and now stands at 2½ times its level in 1970.

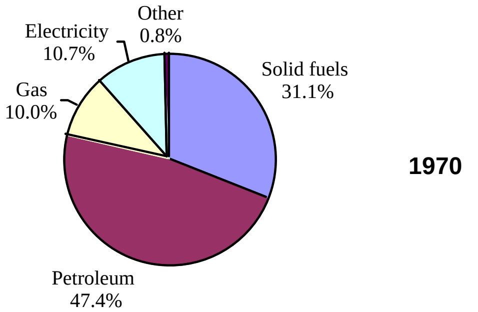
The mix of fuels used to generate electricity continues to evolve in capacity terms, as shown in *figure 2.6*. Output from gas-fired power stations fell by around 4 per cent in 2001 to 139.4 TWh, the first recorded fall since CCGT stations began to operate in 1992, but gas retained the largest share of the market (37.1 per cent). This fall was despite two new CCGT stations coming on-stream during the year and four others making their first full year contributions (DTI, 2002c).

Generation from nuclear sources peaked at 26 per cent on 1997, but in 2001 it had reduced to 22.1 per cent. Despite a reduction in the use of coal from 67.3 per cent in 1990 to 27.8 per cent in 1999, generation from coal-fired stations in 2001 rose for the second consecutive year. This may be attributed to high gas prices which, combined with a plentiful supply of cheap coal (mainly imported), made coal-fired generation more attractive than gas. Generation from coal in 2001 was 125.4 TWh (33.4 per cent of the electricity market), which was higher than for any year since 1996 (DTI, 2002c). Oil's share has fallen from 6.8 per cent in 1990 to 1.3 per cent in 2001.

2.3.1 The Future

According to recent government scenario-based projections of supply and demand in the long (2050) and medium (2020) term, electricity is likely to remain a key form of energy in the future. It has a rising share of energy demand under all scenarios. This raises concern over diversity and flexibility in the electricity system (*figure 2.7*). Security is improved by having a diversity of different sorts of fuel in use within the energy system, while flexibility is important as it helps the energy system to react to unexpected events.

Figure 2.4 Final energy consumption by type of fuel, 1970 and 2001



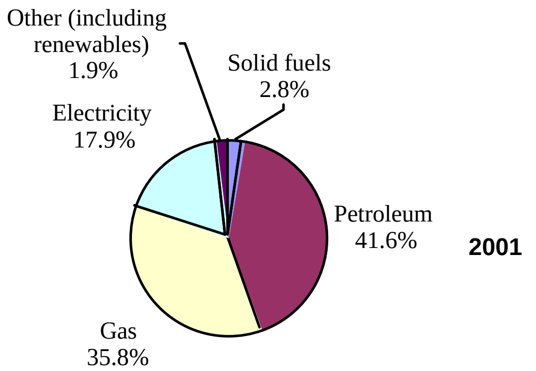


Figure 2.5 Trend in electricity consumption, 1970-2001

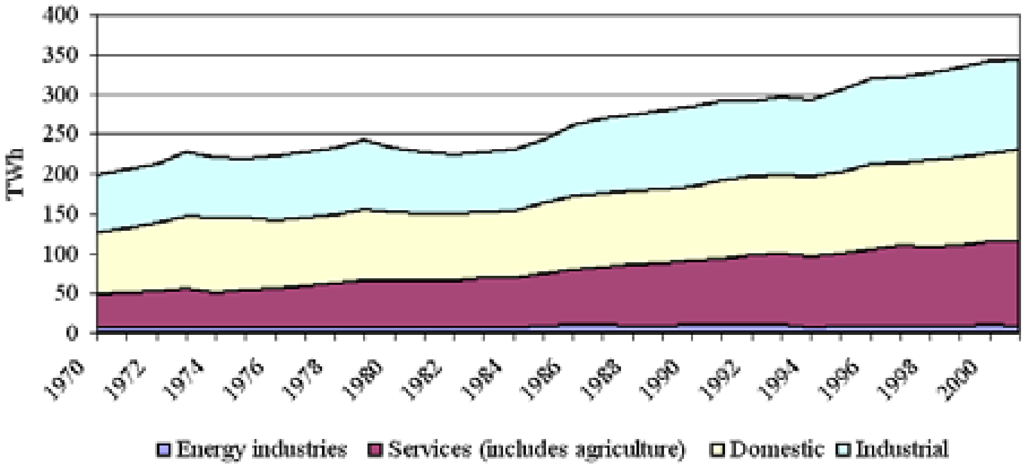
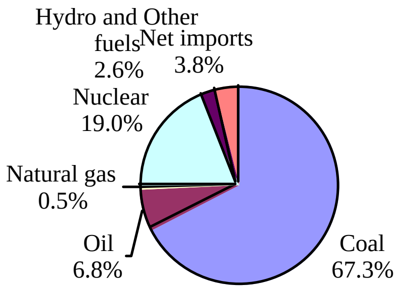


Figure 2.6 Electricity generation by fuel type, 1990 and 2001



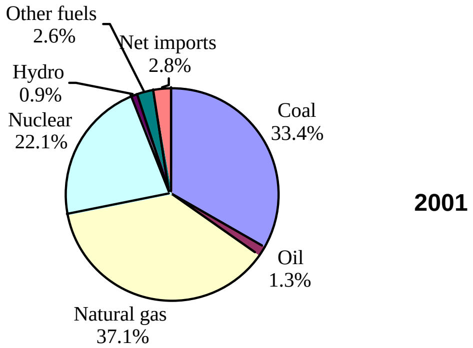
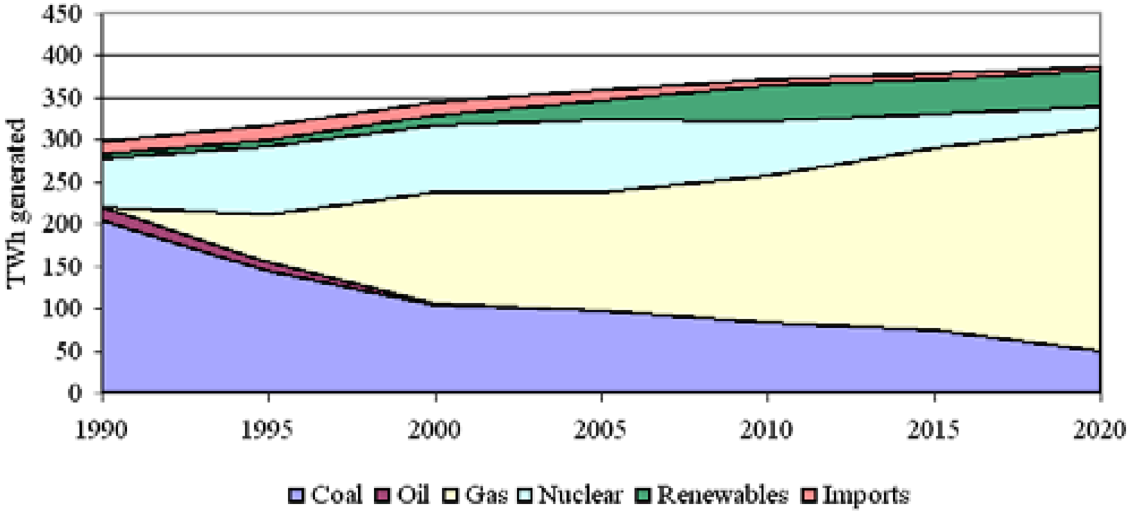


Figure 2.7 Electricity generation by fuel type, 1990-2020



When gas grew from a 0.5 per cent share of electricity generation in 1990 to around 37 per cent in 2001 (*figure 2.6*), it increased diversity. Further growth in the share of gas will represent a reduction in diversity (PIU, 2002). Forecasts based on 'business as usual' suggest that gas may account for 60 per cent to 70 per cent of electricity production in 2020. Although CCGT plants represent an improvement in the efficiency with which electricity is generated, they still burn a fossil fuel and are, as such, non-sustainable.

Nuclear's current installed base of 22 per cent comprises the older Magnox technology (currently being decommissioned), and the advanced gas-cooled reactor (AGR) stations, plus the pressurised water reactor (PWR) at Sizewell B (Newton & Hopewell, 2002). By 2020, nuclear output is expected to fall to about one-third of its current level (PIU, 2002). The use of coal is also likely to drop over the next 20 years in almost all scenarios, along with UK production of coal. Similarly, DTI projections (based on known discoveries) suggest that oil production levels may fall to less than 20 per cent of current levels by 2020. Furthermore, the UK may need to import up to a third of its gas requirement by 2010, with this figure increasing to 80 per cent in the following 10 years (PIU, 2002).

During this period, about half of the current generating power capacity (36 GW) is expected to close. According to DTI projections, changes in demand mean that up to 50 GW of new capacity could be needed (PIU, 2002), although this could be halved with strong energy efficiency programmes. Without government intervention, new capacity is likely to be met primarily by gas, largely in CCGT plants. However, in the long term, a large share for gas in the energy sector may not be consistent with substantial cuts in carbon emissions. An emphasis, therefore, on diversity and environmental sustainability might lead to an emphasis upon renewable energy sources. However, this would have important implications for the electricity network, which is described in *box 1*.

2.4 THE WELSH CONTEXT

Total electricity generation in Wales is estimated to be about 30 TWh/yr (ISGD, 2001). This amount is either used in Wales, or fed into the integrated National Grid for England and Wales. This comes from an installed capacity in Wales of 5.5 GW, of which approximately 50 per cent is gas-fired, 25 per cent coal-fired, 22 per cent nuclear and 3 per cent from renewables.

There are several substantial electricity plants in Wales – these are listed in *table 2.1*. In the north, electricity comes from two major natural gas-fired combined cycle power stations at Connah's Quay and Deeside, the nuclear station at Wylfa (operated by BNFL Magnox Generation), and the pumped storage stations at Dinorwic and Ffestiniog. Predominantly in Mid-Wales, but also scattered around all of Wales, are a range of hydro and other 'renewable' stations. In the south, there are coal-fired power stations at Aberthaw and Fifoots Point (ex Uskmouth). The Aberthaw plant is not currently fitted with flue-gas desulphurisation (unlike the smaller Fifoots station in Newport), so its future operation will be limited by environmental constraints (Syred, 2002). Other main suppliers in the south are a gas station at Barry, and a soon-to-be-commissioned General Electric Gas Turbine, which is to be part of a natural gas-fired combined cycle power generation plant at Baglan Energy Park in Port Talbot. There are also a few medium-size on-site gas-fired combined heat and power (CHP) stations in Wales, which generate primarily for industrial purposes and often export to the National Grid (ISGD, 2001). There are two major gas-fired stations currently at the proposal stage for Ebbw Vale and Anglesey.

Overall, Wales is a net exporter of electricity to England. As shown in the *table 2.2*, Wales has proportionally more power generation capacity, and slightly more renewables capacity, than the UK overall.

Box 2.1: Current structure of the electricity industry in England and Wales

The structure of the UK electricity supply market has changed considerably since privatisation in 1990-92. The **generation** market in England and Wales has changed from a highly concentrated market with around seven major players to a market with many diverse generating companies, some owning only one plant. There are now around 40 companies regarded as major power producers. The reduction in horizontal market concentration has resulted in greater competition in the market and has lead to a significant reduction in the market shares held by the largest generators.

The high voltage (400 kV and 275 kV) **transmission** system covering England and Wales, through which electricity is moved, is owned and operated by the National Grid Company plc (NGC). The NGC has a role in balancing generation and demand at all times, to ensure the security of the network. This is accomplished through electricity trading. On 27 March 2001, the New Electricity Trading Arrangement (NETA) replaced the 'Pool' as the means by which bulk electricity is traded between generators and suppliers.

Distribution remains a monopoly business and under the Utilities Act 2000 it has become a separately licensable activity. There are 9 distribution companies operating 12 authorised distribution areas (at 132 kV down to 220 V). Distribution Network Operators (DNOs) are under a statutory duty to connect any customer requiring electricity within a defined area, and to maintain that connection. Furthermore, the Utilities Act 200 places statutory duties on DNOs similar to those on the NGC, requiring them to facilitate competition in generation and supply, and to be non-discriminatory in all practices.

The **supply** of electricity was fully liberalised in 1998-99, and all consumers are now free to choose their supplier. Any company holding an electricity supply licence can sell electricity. There have been moves to vertically integrate the electricity business with former generating companies acquiring electricity supply companies, and supply companies purchasing generating stations or acquiring interests in companies building new power stations. A number of the major generators are active in the supply market, some through acquiring the former Public Electricity Suppliers (PESs).

Each of these changes, to some extent, has fuelled interest in low-capital, small-scale, fast revenue generating projects, including renewable energy sources. Much of this technology would be small-scale and situated close to where its output is used. The configuration, operation and regulation of current national electricity networks (Scotland included) may therefore need modification. The result may be an increase in 'embedded' electricity generation, where small-scale generating units (which include renewables) are connected directly to the lower voltage distribution networks. This is counter to the current system where large generating units are connected directly to the higher voltage transmission network.

Table 2.1 Major electricity power stations in Wales (source: adapted from ISGD, 2001)

Fuel Source	Power Station	Installed Capacity (MW)	Typical Annual Output (TWh/yr)
Coal	Aberthaw	1,500	5.91
	Fifoots Point	360	2.52
Oil	None	0	0
Gas (CCGT)	Connah's Quay	1,420	9.95
Gas (CHP)	Deeside	500	3.50
	AES Barry	235	1.65
	Shotton Paper	240	1.68
	GE Baglan	500	under construction
Renewables	Rheidol (hydro)	56	0.11
	Dolgarrog (hydro)	35	0.07
	Maentwrog (hydro)	30	0.07
	Cefn Croes (wind)	58.5	under construction
	Carno (wind)	34	0.09
	Llandinam (wind)	31	*not known*
	Llyn Alaw (wind)	20	0.05
	Llidartywaun (wind)	19	0.05
	Penrhyddlan (wind)	13	0.03
	Mynydd Clogau (wind)	11	under construction
	Bryn Titli (wind)	10	0.03
	Mynydd Gorddu (wind)	10	0.03
Pumped Storage	Dinorwic and Ffestiniog	-	2.2
Nuclear	Wylfa	1,000	7.73

Table 2.2 UK and Wales power generation (source: NAW, 2002a)

	Wales	UK total	Wales as proportion of UK (%)
Population (millions)	3.0	60.0	5.0
Power Generation			
Total capacity (GW)	5.5	72	7.6
Electricity produced (TWh)	33.5	381	8.8
Nuclear capacity (GW)	1.0	13.0	7.7
Renewables capacity (GW)	0.33	5.3	6.2
Renewables production (TWh)	0.88	10.6	8.3

Electricity generation exceeds demand in North Wales. In the south, however, demand exceeds supply since the closure of the large Pembroke oil-fired station. Demand is highest along the heavily populated M4 corridor. Elsewhere, in rural areas, demand is sparse and scattered. Electricity distribution in Wales is via the England and Wales National Grid, as described in *box 1*, through links in the north and south. There are no north-south national grid links within Wales. Regional and local distribution systems are operated by Manweb (Scottish Power) in the northern half of Wales, and Western Power Distribution (ex Hyder/SWALEC assets) in the south (both non-Welsh based companies).

The restructuring of the electricity industry in 1990 and the privatisation of the electricity companies means that it is no longer possible to present regional data on the supply of electricity, as it would disclose information about individual businesses that are in competition with each other. However, now that competition has been fully introduced, the DTI has started to examine ways in which electricity data can be collected at a regional and sub-regional level (DTI, 2002a).

The strength of the electricity infrastructure in Wales will necessarily be considered in the context of renewables later in this report. However, it is generally accepted that the infrastructure in Mid-Wales is relatively weak. This implies that a move to more embedded electricity generation (through scattered renewable stations) may require significant investment in new infrastructure control systems throughout Wales (ISGD, 2001).

2.4.1 Future energy supply in Wales

While the overall energy scene in Wales currently appears relatively healthy, the long-term future position remains more uncertain (ISGD, 2001). Gas is the primary fuel for electricity generation in Wales. Above average growth in demand for gas is predicted in Wales due to more spare potential for switching to gas especially through local CHP schemes, and the plan to stimulate growth through European Structural Funds (Sustainable Energy Ltd., 2001). This increase in demand and output is forecast to far outweigh the effects of increased energy efficiency of new CCGT power plants.

Against a background of a projected decline in UK North Sea gas reserves by 2004 (*section 2.3.1*), this dependence raises strategic issues concerning future imports of gas. This is being investigated by a long-term study by the Performance and Innovation Unit (PIU) of the Cabinet Office. While reliability of supply is not considered to be a significant concern in light of large Norwegian reserves, price increases and fluctuations associated with imports may subject the future supply of energy in Wales to a high degree of uncertainty (ISGD, 2001). Gas reserves have been found in the Irish Sea, close to the coast of the Republic of Ireland, as well as off the North Wales coast, where exploitation is proceeding in the form of a new power plant. If the expected rise in gas prices does occur, further exploration and exploitation of these resources may become viable.

Although coal extraction has been a key feature in the economic history of Wales, its use in generating energy (particularly in new capacity) is likely to diminish in line with increasingly stringent environmental standards unless technology can address the challenge of reducing emissions. Similarly, oil is currently too expensive and environmentally unfriendly to use directly to fuel power stations, hence the closure of Pembroke Dock. The situation is exacerbated by the expected closure of most of the UK's nuclear capacity at the end of their currently predicted lives, mostly in the period 2010-2020 (*section 2.3.1*). Trawsfynydd nuclear power plant was decommissioned in 1993, and Wylfa is due to close in 2004. Furthermore, it seems that there are no plans for new plant at the moment. The removal of this form of energy production, providing 22 per cent zero-carbon electricity, will be difficult to replace. The future of the UK nuclear industry is currently the subject of investigation by the Cabinet Office-PIU energy review.[5]

A recent report by Sustainable Energy Ltd. (SEL) to the NAW[6] stated that these issues of resource limitations and potential price increases associated with imports 'could have a significant impact on the Welsh economy and on the living standards of Wales' population, particularly in disadvantaged areas', from 10 to 20 years time onwards. The report concluded that increases in energy costs could change the economics of renewable energy technologies, and future energy supply concerns present 'a powerful argument for investing urgently…in renewable energy generation of heat and power'.

---

[5] Available at: *www.cabinet-office.gov.uk/innovation/2002/energy/report/TheEnergyReview.PDF*

[6] Available at: *www.wales.gov.uk/subitradeindustry/content/consultations/renewableresources-e.htm*

2.5 GREENHOUSE GAS EMISSIONS AND GLOBAL WARMING – IMPLICATIONS FOR WALES

Naturally occurring greenhouse gases maintain the Earth's surface at a temperature 33ºC warmer than it would be in their absence (DTI, 2002c). However, the global use of fossil fuels over the last two centuries has increased the concentration of greenhouse gases in the atmosphere with a net result of a global increase in temperature. This century, the average temperature of the Earth's surface is projected to increase by 0.2ºC to 0.5ºC per decade as a result of global warming (NAW, 2002a).

Greenhouse gas emissions for the UK as a whole fell by 13 per cent between 1990 and 2000, mainly due to a fall in carbon dioxide (CO_2) emissions of 7.5 per cent. Carbon dioxide emissions contribute more than 80 per cent of the potential global warming effect of anthropogenic emissions of greenhouse gases (DTI, 2002c). Current UK emissions of CO_2 are around 155 MtC (Million tonnes of Carbon). The increased use of coal in power stations in 2000 and 2001, in place of gas (which releases fewer CO_2 emissions per unit of energy burned) resulted in higher levels of CO_2 emissions for these years. Under a 'business as usual' scenario, CO_2 emissions are expected to be around 110 MtC in 2050.[7]

The most recent data on greenhouse gas emissions for Wales are shown in *table 2.3*, together with their percentage contribution to UK emissions. The total CO_2 emissions in Wales in 1999 were estimated at 11.2 MtC. From the table below it can be seen that CO_2 emissions in Wales have only slightly increased in the period 1990 to 1999. However, the percentage contribution made by Wales to overall UK emissions of CO_2 has increased from 6.7 per cent in 1990 to 7.5 per cent in 1999. This suggests that Wales has not been as successful as other regions of the UK in reducing CO_2 emissions during this period.

Total emissions of greenhouse gases in Wales, on the other hand, have fallen since 1990, mainly due to reductions in emissions from the energy sector (DEFRA, 2001). This may be attributed to decreased use of Aberthaw coal-fired power station; the increased use of Deeside gas-fired power station; closure of Pembroke power station; and reduced oil refinery emissions.

[7] This figure includes the effect of the current Climate Change Programme, closure of most of the current nuclear capacity, and historic fuel switching in the electricity supply industry.

Table 2.3 Greenhouse gas emissions for Wales, 1990, 1995, 1998 and 1999

Greenhouse Gas	1990	1995	1998	1999
CO_2 (MtC) Proportion of UK (%)	11.1 6.7	10.7 7.0	11.2 7.3	11.2 7.5
Methane (MtC equiv) Proportion of UK (%)	1.6 7.5	1.3 7.5	1.3 7.9	1.2 8.3
Nitrous Oxide (MtC equiv) Proportion of UK (%)	0.95 5.2	1.0 6.2	1.1 6.7	1.0 8.7
Hydrofluorocarbons (HFC) (MtC equiv) Proportion of UK (%)	0.00002 0.0006	0.016 0.4	0.048 0.9	0.050 3.0
Perfluorocarbons (PFC) (MtC equiv) Proportion of UK (%)	0.11 17.9	0.03 9.5	0.03 17.0	0.03 15.7
Sulphur hexafluoride (SF6) (MtC equiv) Proportion of UK (%)	0.02 10.1	0.02 6.4	0.03 6.3	0.03 6.2

(source: Statistics produced by NETCEN on behalf of DEFRA: www.aeat.co.uk/netcen/airqual/statbase/emissions/devad.html)

Disaggregation of the above data reveals that the significant majority of emissions are associated with energy supply activity (34 per cent of total in 1990 / 21 per cent of total in 1998) or with energy use (in business, the domestic sector and in agriculture). The demand for heat in Wales is higher than the UK average due to its larger industrial base (42 per cent of gas supplied in Wales is to industry compared to 27 per cent in the UK) (NAW, 2002a). Also, over 40 per cent of domestic residences in Wales have less energy-efficient solid walls, compared with a UK average of 27 per cent. However, according to the NAW, heat demand is not increasing as fast as electricity demand, and there tends to be more scope for reducing heat demand than electricity demand through energy efficient measures (NAW, 2002a). In view of the greater carbon intensity of electricity compared with other fuels, this suggests that the main focus is on reducing carbon emissions in the energy supply sector (i.e. electricity generation).

The impact of climate change on Wales is the subject of a recent report by the NAW, *Climate Change Wales – Learning to Live Differently*[8]. The key impacts are those associated with the rise in sea level, increased winter rainfall, and increased occurrence of storms and flooding. The cumulative effect of these could have significant implications for many areas. It has been suggested that as a consequence, low-lying areas of Wales where much of the population is concentrated (e.g. Cardiff, Newport and Swansea) will probably need increased sea protection defences (Syred, 2002). Much of the existing industrial development in Wales could also be affected as it is located along the southern and northern coasts. There could be a wide range of associated economic consequences, including increased insurance costs, expenditures on flood and storm defences, increased water management costs, as well as longer-term changes in

[8] Available at: *www.wales.gov.uk/subienvironment/topics-e.htm#2*

agricultural output. The impacts upon the tourism industry will depend on the effects of climate change on other popular holiday destinations.

Large areas of Wales are protected because of their sensitive ecosystems and landscapes. There are more than 1,000 Sites of Special Scientific Interest (SSSIs) covering about 10.7 per cent of Wales, along with three National Parks and five Areas of Outstanding Natural Beauty (AONBs) covering 25 per cent of Wales. Furthermore, about 550km of the Welsh coastline is designated Heritage Coast. Understanding of the sensitivity of habitats and species to climatic change is poor, making it difficult to predict the impacts. In evidence presented to the EDC, the Countryside Council for Wales (CCW) stated that while there will be gains and losses of habitats and species, the overall effects of climate change on wildlife are likely to be negative (CCW, 2002). Quoting a recent study of losses/gains of coastal habitats in sites protected under the Habitats Directive (assuming current sea-level rise predictions and 'best-guess' coastal defence scenarios), CCW showed that in Wales there could be a net loss of intertidal habitats and sand dunes. A small gain in saltmarsh could be provided through managed retreat. In terms of marine species, since the UK is at the biogeographic boundary between warm and cold water systems, changes in sea temperatures may have 'particularly dramatic effects on species distribution, including commercial fish' (CCW, 2002).

The scale of future climate change is uncertain, making adaptation planning difficult. Many experts believe that these changes are irreversible without drastic action, which underlines the importance of taking immediate action to reduce emissions of greenhouse gases.

2.6 CLIMATE CHANGE POLICY AND MEASURES

The discussion of how Wales aims to satisfy its future energy demands while contributing to reducing greenhouse gas emissions and global warming must occur in the context of national and international climate change policy. This section summarises the policy measures, initiatives and instruments that are being put in place to minimise climate change impacts of energy use, and encourage the uptake of renewables.

2.6.1 The International response to climate change

The United Nations Framework Convention on Climate Change (UNFCCC) was established in 1990, with the aim of providing an international platform for the deliberation of climate change issues based upon sound scientific evidence from the Intergovernmental Panel on Climate Change (IPCC). Although not legally binding, the UK in 1992 accepted a proposition under the UNFCCC (Rio Commitment) that developed countries should prevent emissions of greenhouse gases in 2000 from exceeding their 1990 levels. In the event, the UK had no difficulty in honouring this commitment, largely due to the 'dash for gas' (which is a less carbon intensive fuel than coal or oil) in the early/mid-1990s.

It also provided the instigation for the Kyoto Protocol, agreed in December 1997, which set a goal for developed countries to reduce their annual emissions of a basket of the six main greenhouse gases. Under the Protocol, the UK is committed to reduce the emissions of these greenhouse gases between 2008 and 2012 to 12.5 per cent below the 1990 level. This is its agreed share of the 8 per cent reduction for the EU as a whole. Subsequently, the UK government has set a more challenging domestic goal of a 20 per cent reduction in CO_2 emissions below 1990 levels by 2010.

The European Commission has launched the European Climate Change Programme (ECCP), aimed at identifying additional policies and measures that will be necessary if the EU is to meet its climate change targets. These include a Directive aimed at encouraging renewable sources of energy, proposals for a CHP strategy, an energy efficiency action plan, and initial proposals for the development of a Europe-wide greenhouse gas emissions trading scheme. Virtually all members of the EU now have key programmes aimed at reducing greenhouse gas and other polluting emissions. The UK strategy is outlined in the following section.

2.6.2 UK Climate Change Programme and the RCEP

The UK government and devolved administrations have published two Climate Change Programmes, in January 1994 and in November 2000. These have reported on changes in greenhouse gas emissions since 1990; given projections for future emissions (in the case of CO_2 based on the DTI's projections of energy use and current energy policies); and put forward proposals for new measures to bring emissions below the projected levels. These projections, set out in the DTI's *Energy Paper 68* (DTI, 2000), forecast a 2.6 per cent decrease on 1990 levels of CO_2 emissions by 2020 (based on its middle ground scenario) (DTI, 2000). However, the Royal Commission on Environmental Pollution (RCEP) report, *Energy – The Changing Climate* (RCEP, 2000) is less optimistic and predicts that the UK is likely to see an increase in CO_2 emissions after 2012, reaching a 2 per cent increase on 1990 levels by 2020.

The measures set out in the UK Climate Change Programme (CCP) are designed to deliver greater reductions in emissions than required under the Kyoto Protocol. According to the government, this is to give a high degree of confidence that the targets will be met. Also, as previously noted, the government has set a domestic goal (deriving from a manifesto commitment in the 1997 General Election) to further reduce the UK's annual CO_2 emissions in 2010 to 20 per cent below their 1990 level. According to the RCEP (2000) these measures have contributed to keeping emissions below the level they would otherwise have reached, but their aggregate effect was less than that from the substitution of gas and nuclear energy for coal in electricity generation. Most of these measures are still in existence, and some have been extended. The key legislative and policy instruments are outlined in *box 2*.

The size, duration and starting points for future greenhouse gas emission targets remain uncertain. The RCEP has recommended a 60 per cent reduction in CO_2 emissions for the UK by 2050. The DTI has indicated in a response to this report that meeting such a target is feasible, but would pose a significant challenge. Evidence presented to the UK government's Review of Energy Policy (*section 2.6.4*) suggests that achieving the RCEP's target demands a twin-track approach consisting of:

- far greater emphasis upon demand-side management and on energy efficiency; and
- the development and utilisation of renewable energy technologies.

2.6.3 Action by the National Assembly for Wales

While the UK government retains overall responsibility for the Kyoto target and for ensuring a programme is put in place to deliver it, many of the means by which emissions can be reduced have been devolved to the devolved administrations. This reflects the government's aim to provide a positive strategic approach to planning for renewable energy from the regional level downwards. The NAW is currently undertaking an assessment of renewable energy for Wales and setting regional targets for renewables as part of its Review of Energy Policy in Wales (*section 2.6.5*).

The NAW has a duty under Section 121 of the Government of Wales Act to promote sustainable development. It is the only government in Europe to have such a constitutional duty. The strategic plan for the NAW (*www.betterwales.com*), includes the following targets for sustainable development:

- the generation of 5 per cent of electricity from renewable sources by 2003;
- to pursue a course of developing Wales as a 'global showcase' for clean energy production; and
- to encourage the development of strong environmental goods, services and renewables industrial sectors.

Within the context of sustainable development, the opportunity exists for the NAW to develop policies which will deliver effective protection of the Welsh environment and contribute to tackling global environmental threats such as climate change.

Box 2.2: Key UK energy policy instruments to tackle climate change and promote renewables

The Utilities Act 2000
The Utilities Act 2000 is significant because it lays the foundation for further policy and aims to promote greater competition in energy markets and more effective regulation in the interests of consumers. It lays the groundwork for forming energy efficiency targets and gives impetus to the development of renewable sources of energy by way of the Renewables Obligation.

The Renewables Obligation
The Renewables Obligation (RO), introduced through the Utilities Act, forms part of the UK's Climate Change Programme. It was launched on 1 April 2002. The RO required licensed electricity suppliers to supply a specified and growing proportion of their sales from renewables. Suppliers are required to demonstrate their compliance to Ofgem. The RO will remain in place until 2027 and is the mechanism by which the government seeks to achieve its 2010 target of 10 per cent of electricity from renewables. This way it promotes the advancement of renewable energy while leaving the choice of technologies to the market.

The Climate Change Levy
The Climate Change Levy (CCL) came into effect in April 2001 through legislation in the Finance Act 2000, and forms a key part of the UK Climate Change Programme. The CCL is a tax on the use of energy in industry, commerce and the public sector. With the exemption of large-scale hydro-power, electricity and heat produced from renewables are exempt. The aim is to provide an incentive for business to opt for 'green' electricity. Revenue from the levy is recycled to business via a cut in employees' National Insurance Contributions and extra support for energy efficiency measures.

The Carbon Trust
The Carbon Trust became operational in April 2001. Its aim is to promote research and development of a low-carbon economy to help achieve long-term reductions in greenhouse gas emissions. The integrated programme has made available up to £200 million over two years to help business invest in low-carbon technologies.

Capital Grants Scheme
Capital grants to support renewables are available through a number of mechanisms. The government has set aside around £300 million of direct financial support for green energy, and expects to create a £2 billion a year market for renewable energy by 2010 (DTI Press Release 02/10/02). Out of a recent £100 million allocation for renewable energy, £25 million has been set aside for offshore wind, and £5 million for demonstration and testing of wave and tidal technologies. A promise of a further £20 million has been made, to be split equally between two offshore wind-farms off the North Wales and Norfolk coasts, which are the first projects to have gained all the necessary consents. The offshore wind capital grants programme has increased from £68 million to £74 million over three rounds.

2.6.4 UK energy policy and support for renewables

The UK government is in the process of developing an energy policy. A report to government, *The Energy Review*, was published on 14 February 2002 by the Performance and Innovation Unit (PIU) of the Cabinet Office (PIU, 2002).[9] The Review proposes energy policy objectives for the period up to 2050, develops a vision for achieving these objectives, and identifies the practical steps that need to be taken in the short and medium term as well as the longer term. A consultation paper on the key issues arising from the report was published by the government in May 2002,[10] and a White Paper, which will set out future energy policy, is intended around the turn of the year (Mitchell, 2002).

The PIU report recommends that promoting energy efficiency and expanding the role of renewables are the most cost-effective means of meeting immediate priorities for energy policy and the Kyoto targets. In this respect, the Energy Review gives a very significant boost to renewable energy in five key ways:

1. it argues that climate change objectives should be achieved through the energy system, thereby benefiting low-carbon options such as renewables;
2. it argues that low-carbon options need to be created or maintained, providing a boost not only for currently available technologies, but for a diverse range of renewables including offshore wind, wave and tidal power, some of which are in their infancy;
3. its modelling demonstrates that a combination of energy efficiency, renewables and CHP would be the low-cost option for a low-carbon future in 2020, thereby combining environmental and economic objectives;
4. it sets out reasons why renewable options should be supported and explains why support is required now, as opposed to purchasing technologies from abroad in the future; and
5. it argues that while energy security is important at all times, the current situation does not require government intervention. Security would be improved by developing renewables.

In addition to the existing target of 10 per cent of electricity being generated from renewable resources by 2010, the Review recommends a new target of 20 per cent renewable sourced electricity by 2020. Clearly, the rate of deployment of renewables will have to increase rapidly from now on if this target is to be achieved, and the Review recommends that the institutional barriers currently impeding renewable generation in the UK should be tackled urgently. For example, NETA (*box 2*) aims to reduce both wholesale and customer prices while improving energy efficiency. To do this it will reward those who can accurately forecast what they will produce. This is a concern for small generators and intermittent renewable energy producers because the resource (e.g. wind or wave) often cannot be guaranteed or controlled, thus putting the market for the electricity produced at risk (Syred, 2002). Modifications to the current trading arrangements have been proposed but have yet to be implemented (Jackson, 2002).

---

[9] Available at: *www.piu.gov.uk/2002/energy/report/index.htm*

[10] Available at: *www.dti.gov.uk/energy/developep/energyconsreport.pdf*

2.6.5 Review of energy policy in Wales

Energy policy in Wales is the overall responsibility of the UK government. However, there are areas within energy policy in Wales where responsibility is devolved to the NAW. These are detailed in *table 2.4* below. It is for the NAW to determine policy in relation to devolved matters.

Table 2.4 Energy policy areas where responsibility is devolved to the NAW (source: PIU, 2002).

Area	Devolved in Wales
Environment policy	✔
Promotion of renewable energy	✘
Promotion of energy efficiency	✘*
Support for innovation	✔
Housing	✔
Building regulations	✘
Planning (apart from the energy consents listed below)	✔
Power station consents (over 50 MW onshore / 1 MW offshore)	✘
Overhead electricity line and gas pipeline consents	✘

* The NAW controls the budget and/or funds for certain energy efficiency schemes in Wales, e.g. the Home Energy Efficiency Scheme, the Energy Efficiency Best Practice Programme, and part of the activities of the Carbon Trust Wales.

Although responsibility for promoting renewables is at present not devolved to the NAW, the Assembly has a cross-cutting duty, as previously mentioned, under the Government of Wales Act to promote sustainable development across all of its activities. This duty allows the pursuit of renewable energy policies and permits consent to be granted for power-generating plants with a capacity less than 50 MW onshore/1 MW offshore, under the NAW's planning function.

The Economic Development Committee (EDC) of the NAW is currently undertaking a Strategic Review of Energy Policy in Wales. The EDC chose energy policy as the subject for its most recent review because it believes a secure and competitively priced supply of energy is critical to economic development in Wales, and for industry to compete in the world-wide economy. The first report of the EDC, on renewable energy, was published for consultation on 25 April 2002.[11] The EDC selected renewable energy as the first topic in the Review because of the perceived urgency associated with planning issues and with facilitating an early start to an enhanced renewables programme.

One of the principal aims of the NAW's energy policy is to make Wales a 'global showcase for clean energy production'. The consultation report recognises that Wales has a potentially large renewable resource base and there are commercial and rural development opportunities associated with the development of several renewable technologies. Furthermore, the EDC suggests that a mix of on-shore and offshore wind, biomass, tidal and wave sources will yield

[11] Available at: *www.wales.gov.uk/keypubassemecodev/content/energy/renewables_con_%20report-e.pdf*

the most appropriate medium-term contribution to power production. In order to achieve this the report makes six broad recommendations on the policy issues the EDC considers most critical.

The consultation report argues that over the next 20 to 50 years, it will be necessary to move towards a zero-carbon electricity system, and advises the NAW to develop renewable resources indigenous to Wales to achieve emissions reductions. However, this should occur without prejudicing tourism or areas of environmental significance. The report further calls for the NAW to adopt Welsh targets for both electricity production and heat production from renewable sources by 2010 and 2020, bearing in mind the overall target for the UK of 10 per cent of electricity generated from renewable sources by 2010. The aim is to set these targets in the light of the responses to the consultation on the report, a summary of which will be available in late 2002. Possible targets for Wales are discussed further in the context of existing renewables capacity in *section 3.3*.

3 Marine renewable energy resources – current situation and future potential for Wales

3.1 OVERVIEW OF RENEWABLE ENERGY IN THE UK

Renewable energy utilisation in the UK in 2001 is shown in *figure 3.1*. Biofuels and wastes accounted for 85.6 per cent of renewable energy sources with most of the remainder coming from large-scale hydro-electricity production (10.7 per cent). Onshore and offshore wind together accounted for 2.7 per cent. The contribution made by marine renewables (predominantly offshore wind) was around 0.01 per cent. Total use of renewables, expressed in thousand tonnes of oil equivalent, is compared in *table 3.1* below for the last three years, using 1990 data as a reference point.

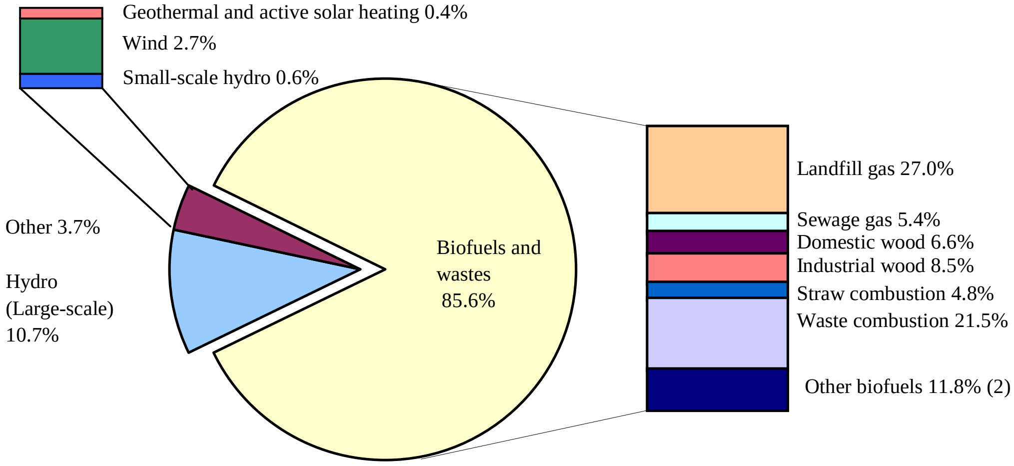
Of the 3.1 million tonnes of oil equivalent of primary energy use accounted for by renewables in 2001, 2.4 million tonnes was used to generate electricity, and 0.7 million tonnes to generate heat. Total electricity generation from renewables in 2001 amounted to 10,099 GWh, 38 per cent of which came from large-scale hydro generation. This means that renewable sources accounted for 2.6 per cent of electricity generated in the UK last year. Between 1990 and 1996 the volume of renewables used to generate electricity grew at an average rate of 8.5 per cent a year. After 1996 the rate of increase quickened and over the most recent five years it has averaged 15.5 per cent a year (DTI, 2002a).

Table 3.1 Total use of renewables (source: adapted from DTI, 2002c)

Thousand tonnes of oil equivalent	1990	1999	2000	2001
Active solar heating and photovoltaics	6.4	9.5	11.2	13.4
Onshore wind	0.8	73.1	81.3	82.5
Offshore wind and wave	-	-	0.1	0.4
Hydro	447.7	458.8	437.2	348.8
Landfill gas	79.8	572.0	731.2	835.8
Sewage sludge digestion	138.2	188.8	168.7	168.4
Wood	174.1	571.9	502.8	468.8
Straw (for heat)	71.9	72.2	72.2	72.2
Municipal solid waste (biodegradable)	119.1	377.0	393.3	454.7
Other biofuels	64.7	433.8	558.7	653.7
Total	**1,102.7**	**2,757.1**	**2,956.8**	**3,098.6**

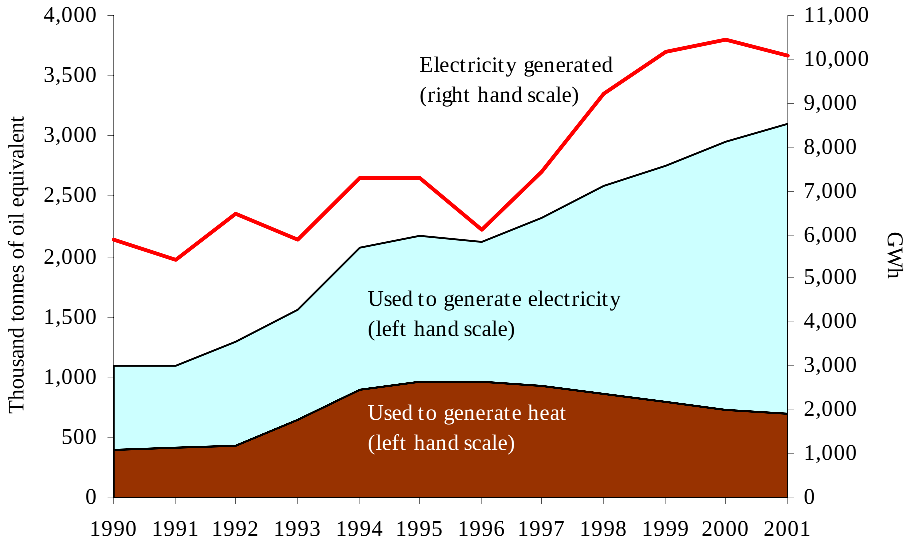
The growth in electricity generated from renewables, on the other hand, has been more erratic as shown in *figure 3.2*. This is because the amount of electricity generated is influenced by the efficiency of the renewable energy plant – on an energy supplied basis hydro inputs are assumed to be equal to the electricity produced, whereas sources such as waste and landfill gas lose energy during their transformation into electricity. As shown in *figure 3.2*, electricity generated from all renewable sources in the UK in 2001 was 3.5 per cent less than in 2000 (largely due to a 21 per cent reduction in large-scale hydro generation). Nevertheless, the average rate of growth in electricity generated from renewables has been around 10.5 per cent a year.

Figure 3.1 Renewable energy utilisation in the UK in 2001 (source: DTI, 2002c)



Total renewables used= 3.10 million tonnes of oil equivalent

Figure 3.2 Growth in electricity from renewables (source: DTI, 2002a).



3.1.1 Overview of present contribution by renewables in Wales

In response to many requests for regional information, statistics on the amount of electricity generated from renewable sources in the UK and the capacity to generate electricity from renewables have been disaggregated below the national level since 2000. The information relevant to Wales is compiled in *table 3.2* below.

It has been necessary for the DTI to combine renewable sources into four categories so that information about individual sites provided to Future Energy Solutions (formerly ETSU) and the DTI in confidence is not disclosed. A breakdown of the 'wind and wave' category would, however, reveal that wave and offshore wind energy do not currently contribute to renewable energy in Wales, although the latter is likely to come on-line in the near future. Tidal energy, in its various forms, is also notably absent. In addition to marine renewable resources, solar photovoltaics have not been included in the table because they are estimated on a UK-wide basis that cannot readily be broken down into regional components (DTI, 2001a).[12]

Table 3.2 Renewable energy in Wales, 2000 and 2001 (source: DTI, Energy Trends)

Sources	**Number of sites generating electricity from renewable sources**		**Capacity of sites generating electricity from renewable sources (MW)**		**Generation of electricity from renewable sources (GWh)**	
	2000	2001	2000	2001	2000	2001
Hydro	22	23	140.1	147.5	386.0	259.1
Wind and wave	17	18	62.2	63.8	346.4	336.8
Landfill gas	7	8	12.8	14.8	75.8	94.5
Other biofuels and wastes	4	3	6.5	6.1	20.0	18.9
Total	50	52	221.6	232.1	828.2	709.4

There are 52 sites in Wales generating electricity from renewable sources, compared with 394 in England, 157 in Scotland and 38 in Northern Ireland. These 52 sites accounted for 9.2 per cent (232.1 MW) of the UK's electricity generating capacity from renewable sources in 2001. Actual generation of electricity (output) from renewable sources in Wales in 2001 was 709.4 GWh, which is 7.0 per cent of the UK total.

Despite having only 18 sites generating electricity from wind, compared with 51 in England and around 34 in Scotland, Wales has 35 per cent of the capacity to generate from wind and in 2001 produced 35 per cent of the output from wind. Scotland was the next largest (24 per cent capacity and 26 per cent of generation) followed by the North-west of England (12 per cent of capacity and 11 per cent of output).

[12] In total, solar PV amounts to only 2.8 MWe capacity and 2 GWh of generation.

It is estimated that in 2000, 3.2 per cent of electricity was generated from renewable sources in Wales (NAW, 2002b). This compares favourably with the UK as a whole, for which it is estimated that renewable energy sources provided 2.8 per cent of electricity in the same year.

3.2 RENEWABLE ENERGY TARGETS AND GREENHOUSE GAS ABATEMENT FOR WALES

The PIU study (2002) recognises that facilitating the delivery of a low-carbon energy system should now be at the heart of energy policy. The RCEP (2000) has proposed that the UK government should adopt a strategy that puts the UK on a path to reducing CO_2 emissions by 60 per cent from current levels by 2050.[13] Scenario-based projections of energy supply and demand in 2020 and 2050 suggest this is possible, but large changes would be needed in the energy system and in society.

The NAW needs to position itself so that it can move towards the levels of greenhouse gas emissions that are likely to be needed as part of the global response to climate change. Given the possibility that future, legally binding, international greenhouse gas emissions targets will become more stringent beyond the 2012 Kyoto deadline, a precautionary approach suggests that policy action by the NAW is required now to establish a range of future low-carbon energy options. To fail to do so could jeopardise the ability to deliver upon existing and future environmental obligations, put the security of the energy supply system at risk, and fail to capitalise on economic advantages for Wales associated with developing a range of low-carbon technologies.

The PIU study concluded that significant carbon emissions reductions can only be achieved in scenarios where environmental objectives are prioritised. This, coupled with the potentially more stringent future greenhouse gas emission targets, promotes the environmental objective as a strong priority within future energy policy. If Wales is to reduce CO_2 emissions by 20 per cent of 1990 levels by 2010 in line with UK government policy, it will need to reduce annual emissions to 8.9 MtC, representing a decrease of 2.3 MtC relative to 1999 levels. If the more challenging RCEP target of a 60 per cent reduction by 2050 is to be achieved, Wales would need to reduce annual emissions to 4.5 MtC (based on 1999 levels), representing a decrease of 6.7 MtC relative to 1999 levels.

As previously noted, the significant majority of CO_2 emissions in Wales are associated with energy supply activity or with energy use. For the UK as a whole, the energy system is the source of 80 per cent of UK greenhouse gases and 95 per cent of CO_2 (PIU, 2002). The main contribution to achieving the above emission targets (as also noted by the SEL (2001) study) must, therefore, come from changes in the way in which energy is supplied and used in Wales.

3.2.1 Setting a renewable energy target for Wales

While energy conservation and energy efficiency measures (both outside the scope of this study) have key roles to play, the other challenge is to reduce the amount of carbon emitted for

[13] This would be in line with a global agreement which sets an upper limit for the CO_2 concentration in the atmosphere of some 550 ppmv.

each unit of energy consumed. This will require a change in the energy supply mix to incorporate increased generation from renewable energy sources.

In the context of the need for Wales to achieve significant reductions in CO_2 emissions, *table 3.3* shows the potential savings in CO_2 emissions that could be achieved by different levels of renewable energy generation.

Table 3.3 CO_2 savings from different levels of renewable energy generation (source: SEL, 2001)

Renewable energy generation (TWh/yr)	Annual CO_2 savings (MtC)
2	0.31
4	0.57
6	0.82
8	1.07
12	1.55
16	2.07

As noted in *section 3.1.1*, renewable energy generation in Wales is currently around 0.71 TWh (709.4 GWh) per year. There are presently no Wales-wide targets for reductions in greenhouse gas emissions or development of renewable energy capacity. Although the NAW already has a target to generate 10 per cent of electricity from *clean sources* by 2010[14], clean sources can include non-renewable sources of energy such as clean coal. It would appear that the establishment of some form of target for the development of renewable energy in the short (2010), medium (2025) and long term (2050) is a matter of priority for the NAW in order to focus policy measures and provide the impetus for long-term energy planning. This study has not considered what constitutes appropriate Welsh targets for electricity production from renewable sources – this is a matter for the NAW to decide upon following consultations with stakeholders, and will depend upon the desired balance of economic, social and environmental objectives.

In Part 1 of the Review of Energy Policy in Wales, the NAW outline three possible bases upon which targets for 2010 could be set (*table 3.4*).

[14] *Plan for Wales 2001*, October 2001.

Table 3.4 Possible scenarios upon which to base renewable targets for Wales (source: NAW, 2002a p.13)

Pro-rata to the UK target	Since the UK production is 380 TWh, the 2010 target for the UK is 38 TWh from renewables. The Welsh share pro-rata to population would then be 1.9 TWh.
Target equal to 10% of Welsh electricity production	This would lead to a renewables target of 3.35 TWh on the basis of current consumption, or 4 TWh on the basis of forecast consumption of 40 TWh in 2010.
Target equal to 10% of Welsh consumption	Based on figures for electricity use in Wales of 16-19 TWh, this would give a renewables target of 1.9 TWh.

Targets are specified in terms of annual production (TWh) because a target specified as a percentage of total generating capacity is not considered appropriate by the NAW due to the effect on the figures of the possible closure or construction of a large generating plant in Wales. *Table 3.5* sets out how targets of 2,3 and 4 TWh compare on these 3 different bases.

Table 3.5 Comparison of potential renewables targets for Wales (source: NAW, 2002a p.15)

	Possible 2010 Welsh Target		
	2 TWh	**3 TWh**	**4 TWh**
% UK target	5.3	7.9	10.5
% Welsh production	5.6	8.2	10.7
% Welsh consumption	10.5	18.8	21.1

To set this is context, it has been estimated (EDC, 2002) that the 4 TWh figure would require a range of developments similar to the following:

- three large (150 MW) offshore wind-farms;
- one new onshore large wind-farm (extra 50 MW);
- dramatic increase in small and medium-sized on-shore wind-farms (something over 200 MW is reportedly needed);
- two large and six smaller biomass CHP schemes (total 80 MW);
- two large CHP plants fuelled by municipal waste (15 MW);
- about 15 CHP plants fuelled by landfill gas (20 MW);
- about 30 new small-scale hydro plants (15 MW);
- one small tidal barrage (30 MW); and
- one tidal stream operating (5 MW).

It should be noted that the above options are merely indicative. The particular mix of schemes would depend upon commercial investment decisions and where planning permission is obtained.

Various estimates have been made of potential future outputs from renewable sources under different scenarios reflecting different levels of development, including a recent study by AEA Technology (AEAT, 2001).[15] The simplest scenario (*Business as usual*) outlined in the study leads to output of 1.70 TWh by 2010; the most extreme (*Green future*), to 4.53 TWh. These figures are broadly in line with the NAW's current thinking on a realistic range of renewables targets for Wales of between 2 TWh and 4 TWh of electricity production by 2010. Other stakeholders, however, have proposed more challenging targets – both WWF and FoE Cymru advocate a figure of 6 TWh of renewable capacity by 2010, which equates to around 30 per cent of Welsh electricity demand.

3.3 THE CASE FOR DEVELOPING MARINE RENEWABLES

The UK government is committed to reducing the UK's CO_2 emissions by 2010 (from 1990 levels) and to the generation of 10 per cent of all UK electricity from renewable sources by 2010. However, the government, and the NAW for that matter, should be careful that it does not become preoccupied with achieving the 2010 target, to the exclusion of longer-term targets and needs. If the RCEP's proposed target of a 60 per cent reduction in CO_2 levels by 2050 is adopted, new renewable energy generation in Wales may need to contribute reductions of approximately 6.7 MtC by 2050. For renewable energy to contribute even 20 per cent of this, renewable energy generation of about 12 TWh/yr will be required (a 17-fold increase in present deployment). This supports the estimation put forward by the SEL (2001) study, although the calculations are based on different years' data for CO_2 emissions and renewable energy generation in Wales.

It should be remembered that in terms of development of new technologies (as opposed to the market deployment of existing technologies), the 2010 time-scale is a short one. The SEL study agrees that, with support for research and development, present nascent technologies such as tidal and wave power may reasonably be expected to be major contributors to long-term renewables targets, such as those proposed by the RCEP.

The requirement on electricity suppliers to provide 10 per cent of their electricity from renewable energy sources by 2010, subject to acceptable costs, has already done much to stimulate the development of renewable technologies. However, it is already accepted in many quarters that the 10 per cent target for renewables by 2010 is unlikely to be feasible if we rely solely on onshore renewables, due to the conflict over land use. Most renewable energy technologies require significant space, mainly because the energy resources they utilise are diffuse. Onshore wind-farms, which currently account for about 47 per cent of the generation of renewable-sourced electricity in Wales, are already facing constraints due to conflicts over land

---

[15] A Review of Strategic Study of RE Resources in Wales by AEA Technology (September 2001). This comments on the report by Sustainable Energy Ltd.

Available at: *www.wales.gov.uk/subitradeindustry/content/strategicstudy-e.doc* use. With the best sites already taken, the number of suitable sites for additional turbines, where planning permission is likely to be forthcoming, is limited.

However, the seas around Wales, and particularly the offshore marine environment, offer huge open spaces with potentially large renewable resources of wind, wave and tidal energy, where new energy technologies could be employed on a much wider scale than on land. If targets are to be met, all available renewable energy technologies will need to be exploited (along with the introduction of energy-saving measures), including offshore wind, wave and tidal resources. This is a view shared by the House of Commons Science and Technology Committee on Wave and Tidal Energy (STC, 2001). Furthermore, the committee argues that it is particularly important that genuinely renewable energy sources such as wind, wave and tidal energy are exploited, rather than reliance placed upon renewable, but carbon-producing sources such as energy from waste. Some experts believe that if we do not develop and use marine renewable energy sources, we may be unable to meet future energy needs, let alone targets, from renewable sources. This is because there is insufficient space in areas of high population to deploy renewable energy technologies on a large enough scale (Fraenkel, 2001).

The argument outlined above is the key reason for investing in new marine renewable energy resources. However, there are other factors that favour their development. These are briefly outlined below.

- **Energy intensity** Offshore wind is already considered to be an integral component of the government's strategy to achieve the renewables target, arguably because it will be the only way wind energy can be exploited on a sufficiently large scale in the future. However, other marine renewables such as tidal currents and waves offer higher energy intensity than most renewables, and are therefore more cost-effective (Fraenkel, 2001). For example, it has been estimated that the energy captured per annum for each m^2 of a tidal turbine rotor at the locations with sufficiently fast currents for economic exploitation, is of the order of 4 to 10 times more than that from a wind turbine at a good wind location (Fraenkel, 2001).

- **Aesthetic impact** Furthermore, deployment of devices offshore may negate many of the objections commonly expressed in relation to the aesthetic impact of onshore renewable energy technologies, particularly wind-farms. Even the visual intrusion caused by offshore wind-farms can be minimised if the turbines are deployed a sufficient distance from land. On the other hand, the low-visual impact of certain tidal and wave energy converters allows these devices to be located closer to shore – tidal current turbines can be either totally submerged out of sight or, like wave energy devices, be partly submerged with a limited visual profile. They are, therefore, likely to be more acceptable in a nearshore or shoreline environment, and this can result in significant cost savings through the shorter electrical connection to shore.

- **Predictability of supply** Marine renewable resources such as tidal energy and wave power are generally more predictable than onshore renewables such as wind and solar power. Tidal energy is the most predictable of the marine renewable resources, and its variation over the tidal cycles can be predicted with considerable accuracy well into the future (Fraenkel, 2001). Wave power, although weather-dependent and therefore subject to more significant fluctuations, is also easier to integrate into the Grid than some other renewables – it is often possible to predict peaks and troughs of supply and demand at least six hours in advance, owing to the large amounts of maritime data that have been accumulated. The annual variations in wave energy (higher in winter/lower in summer) also broadly match the seasonal variations in energy demand. Even offshore wind is more reliable than the onshore resource, due to higher average wind speeds offshore, and less variability due to decreased turbulence. The improved predictability and reliability of marine renewable resources, particularly tidal energy, makes the electrical output inherently more valuable to an electricity utility as future electricity sales can be contracted at known times when a premium might be gained due to high demand (Fraenkel, 2001).

- **Technology transfer** Many technical problems facing the development of marine renewable energy technologies, particularly those associated with operating in the harsh marine environment, have already been overcome by the offshore oil and gas industries. This suggests that skills and experience gained in this sector can be successfully utilised to facilitate the development of marine renewable energy technology. The offshore industry is seeking to diversify into new areas of business, in light of the decline in North Sea oil and gas reserves predicted over the coming decades (*section 2.3*). The *Energies from the Sea Task Force Report* concluded that marine renewables (wave and tidal energy) could be one of the key areas into which the industry could expand. The DTI's *PILOT* programme (*Oil and Gas Industry Task Force*) also identified that offshore wind and tidal current systems offer major opportunities for the transfer of technology and skills from the offshore oil and gas (DTI, 2001b). Growth in marine renewables could, therefore, help to offset unemployment in these declining industries.

- **Economic development** Wales has a potentially large marine renewable resource base (*section 3.4*), due to its climate and geography, and there are commercial and rural development opportunities associated with the development of several renewable technologies. Furthermore, as recognised by the NAW in its Renewable Energy Policy Review, Wales' traditions in heavy manufacturing and civil engineering can provide the right background for investment in these sectors. Development of marine renewable energy in Wales can make an important contribution to the Welsh economy and bring employment to regions and sectors otherwise deprived of industrial development. As noted by SEL (2001) this has already been demonstrated successfully by governments of other European countries (e.g. Denmark, Germany and the Netherlands), where a strong commitment to renewable energy has provided the foundation for domestic growth in this sector. Denmark's flourishing wind energy industry employs more people than are now employed in the UK's coal mining industry (Wells & Langston, 2001).

- **Export potential** In addition to the UK's domestic demand for renewable energy, there is a potentially large export market for marine renewable energy technology. The European Commission projects that the European market for renewables in 2010 will be valued at 37 billion ECU, with a further 17 billion ECU from exports into expanding world markets (DTI, 1999). Other estimates suggest this could be much higher. For example, Thorpe (1999) estimates the global export market for wave energy devices alone to be around £500 billion. The *Science and Technology Committee on Wave and Tidal Energy* observes that the benefits will be particularly large for the companies who develop the technology first. In the committee's opinion, the enormous potential export market for wave and tidal energy devices easily justifies the public investment now needed to ensure success.

Although current measures such as the Renewables Obligation appear to be successful in creating a market for renewable energy, it is widely accepted that further innovation and development is required, particularly in the case of tidal and wave energy, if marine renewables are to make a substantial contribution to this market. Further support will create this technology push, which could bring down unit costs in the longer term of the various technologies as experience is gained and volumes increase. The costs of supporting a research programme are small compared to the possible future consequences of having insufficient energy supplies (Salter, 2001).

3.4 OVERVIEW OF THE RESOURCE POTENTIAL

This section presents an outline of the most recent assessments of potential (and available) tidal, wave and wind resources. An overview of the potential UK resource is followed by a description of the marine renewable energy resources available to Wales. There has not been extensive research into the overall resource for marine renewable energy generation around the coast of Wales, so the information presented is merely indicative and should not be interpreted as a recommendation for the development of any site. However, the account could provide an initial basis for the identification of more promising areas where further resource evaluation and monitoring could take place.

It should be noted that sites with the greatest resource potential may not necessarily be suitable for energy generation. There could be numerous constraints on development, such as environmental sensitivities and other planning constraints, inadequate connection to the National Grid and centres of demand, and constraints associated with the physical geography and topography of the area. These factors should be taken into account in future studies that assess the marine renewable energy resource potential for Wales.

The information on marine environmental conditions relating to renewable energy resources for Wales (*sections 3.4.3 to 3.4.7*) is taken from the *West Coasts of England and Wales Pilot* (Hydrographic Office, 1993), unless referenced differently.

3.4.1 The resource potential for marine renewable energy in the UK

Tidal Resource

A study commissioned in 1991 by the EC to estimate the tidal energy potential in Europe from barrages across estuaries concluded that a technically feasible resource of 105.4 TWh/yr (from 64 GW installed capacity) was available.[16] The study found that the resource is unevenly distributed throughout Europe, and that the UK held 47.7 per cent of the resource – primarily attributable to the very high tidal ranges in relatively few estuarine locations, such as the Severn Estuary.

---

[16] Assuming a 5 per cent discount rate over the technical life of the project.

Tidal energy has been extensively researched in the UK under a government programme which ran from 1978 to 1994. In an end-of-programme report, ETSU (now part of AEA Technology) concluded that 'the UK has probably the most favourable conditions in Europe for generating electricity from the tides', with the total theoretical potential put at about 50 TWh/yr if all practical barrage sites were developed. However, assuming that only the most promising and economic schemes were developed, only 18 TWh/yr would be produced, 12.5 TWh/yr of which would come from the proposed Severn Barrage scheme alone (*section 4.2.1*) (ETSU, 1996).

Although the potential for tidal barrage power remains large, the prospect for the practical development of tidal energy has moved away from large barrage projects to smaller-scale systems that harness tidal streams. Although tidal currents with sufficient velocity to offer the possibility of cost-effective energy production only occur at comparatively few locations, such as around headlands and in straits, the UK resource is believed to be large enough to deliver tens of TWh per annum (Fraenkel, 2001).

There have been three studies examining the potential tidal stream power resource in UK waters. The first was commissioned by ETSU on behalf of the (then) Department of Energy, and was published in 1993. A more recent assessment, completed in 1996, was funded by the EC JOULE-II energy research programme. Both resource assessments indicate that there is a substantial theoretical resource of up to 60 TWh/yr, although over 70 per cent of it is found at the extreme ends of the country, near Orkney and near the Channel Islands (Binnie Black & Veatch (BBV), 2001). A more recent re-evaluation completed in 1998 and published in ETSU R-122 (ETSU, 1999), suggests an arguably more realistic approximation of 36 TWh/yr. This evaluation is based upon a series of six selected sites (the Bristol Channel being one), with maximum velocities of 2.5 to 6 m's. Other potential sites were excluded for lack of information.

Wave Resource

Considerable work has been undertaken on the evaluation of the UK wave energy resource. This includes a study of wave climate using the Meteorological Office's wave prediction model (Winter, 1979) at 15 locations around the British Isles for the period from February 1983 to July 1986 (Whittaker *et al.*, 1992). The study identified numerous hotspots along the coastline. For 78 of these sites with favourable features for a wave energy scheme, a more detailed analysis was carried out. The resulting deep-water resource was estimated at 600-700 TWh/yr, approximately double the (then) UK's electricity demand. Predicted wave power levels for most parts of the UK's western coast not shielded by Ireland were between 66 and 76 kW/m. However, this is a theoretical maximum which does not account for the practicalities and cost of energy conversion and transmission to shore (Craig, 1999).

The UK nearshore resource (i.e. at 20m water depth) showed more variation, ranging from 25-35 kW/m off south-west England to 30-40 kW/m for Shetland. When calculated in a similar manner to the deep-water resource, the UK nearshore wave resource was estimated to be 100-140 TWh/yr (Thorpe, 1999).

The shoreline resource varies considerably around the UK and is very site specific, with some areas being considered unsuitable for wave energy devices. Thorpe (1999) warns that any estimate, therefore, is subject to considerable uncertainty. Taking these factors into account, the estimated UK shoreline resource is around 2 TWh/yr.

The most recent evaluation by ETSU of the *practicable* (as at 1999) resource, which takes account of technical, economic and other non-technical constraints, puts the UK resource at:

- 50 TWh/yr – offshore wave;
- 2.1 TWh/yr – nearshore wave (closer than 20 miles to coast);
- 0.4 TWh/yr – shoreline wave.

These are the figures quoted in the Science and Technology Committee Seventh Report on Wave and Tidal Energy (2001).[17]

Offshore Wind Resource

One of the foremost attributes of offshore wind energy is the large resource. The technical potential for electricity generation from offshore wind in Europe is well in excess of predicted electricity demands. By the end of 2000, approximately 80 MW of offshore wind energy was installed and operating in Denmark, the Netherlands, Sweden and the UK (OWE, 2001). According to ETSU (*Technology Status Report – Offshore Wind Energy*, January 2001) the UK's practical offshore wind resource is only limited by cost. As distances from the coast and water depths increase, the costs become prohibitive. Close to shore and in shallow depths the resource is constrained by effects on shipping, fisheries, defence, wildlife and conservation interests, and visual acceptability.

Offshore wind speeds are higher than coastal wind speeds at sea level. Ten kilometres offshore, speeds may be 25 per cent higher than at the coast. There are large areas of the Irish Sea and North Sea where wind speeds are in excess of 9 m/s (at 50m height), which is greater than onshore winds over much of Europe (BWEA, 2000). While Ireland and Scotland have the highest wind speeds in the UK, much of England and Wales also have access to winds in excess of 8 m/s (again at 50m).

As the offshore wind resource is so large, uncertainties in the exact levels of wind speed are of little relevance, except in the context of assessing electricity prices from offshore wind-farms, for which accurate estimates are vital (BWEA, 2000). Most early installations are likely to be relatively close to shore, where uncertainties are greatest. For example, although wind turbulence is lower offshore, the influence of land features can extend a considerable distance (as much as 50 km or more) out to sea (Barthelmie, 1999). A further difficulty is a shortage of site measurement data against which to test modelling predictions.

Although relatively few studies have attempted to quantify the potential offshore wind resource, it is widely acknowledged that the UK has the greatest scope for developing offshore wind energy in Europe. A report commissioned by the CEGB estimated that the annual potential from offshore wind was in the order of 230 TWh/yr, and that the resource could be utilised to meet an annual energy demand equivalent to total UK electricity consumption at the time the study was carried out[18] (BWEA, internet resource). A later study of offshore wind energy in the EC, performed in 1994 under the JOULE-1 programme, suggested that the magnitude of the wind

---

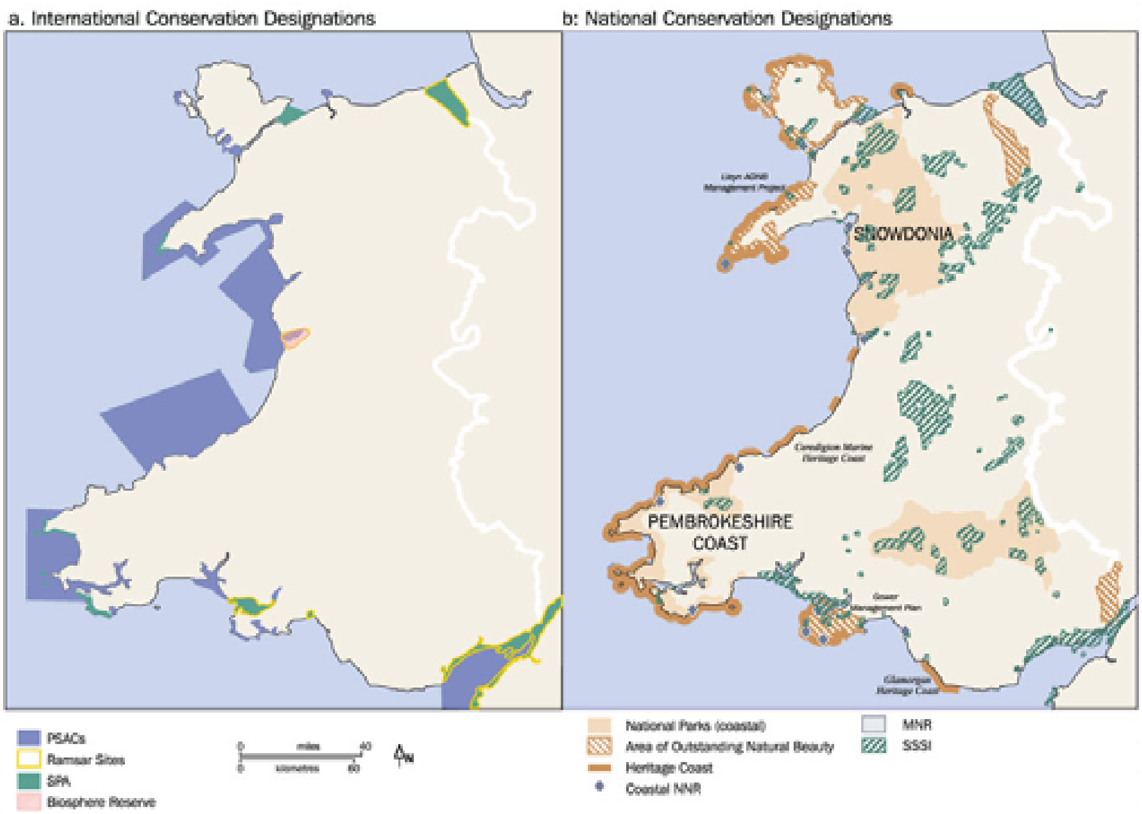
[17] For a detailed explanation of the derivation of these figures, refer to ETSU R-122 (ETSU, 1999).

[18] The data used in the study was obtained from six upper air stations-balloons over the period 1961-1970 combined with readings taken from British Ocean Weather Ships.

resource around the UK could be significantly greater than 230 TWh/yr (PB Power, 2001). The study considered the assumption made in the CEGB study that wind turbines would be excluded within five kilometres of the shore to be unfounded, and that deployment of turbines closer to shore would considerably increase the exploitable resource.

The wind resource assessment exercise undertaken by PB Power suggests that there are very favourable conditions off the coast close to the major load centres in southern and south-east England. It is interesting to note that the areas with greatest potential for offshore energy conversion, in terms of highest mean wind speeds, are in broadly similar areas to the best locations for the development of onshore wind-farms. It should also be noted that the resource assessment does not necessarily indicate that the wind characteristics would result in feasible generation opportunities, as there may be factors that constrain development. These are discussed in *chapter 6*. Nevertheless, even without detailed wind characteristics, it is evident that the UK is ideally located in terms of the length of coastline with relatively shallow water and high average wind speeds.

Figure 3.3 Statutory conservation designations for the Welsh coast.



3.4.2 General features of the Welsh coastal zone

The Welsh coastline is 1,562 km in length, which equates to about 8 per cent of the total coastline of Britain (Doody, 2001). Approximately 50 per cent of the coastline is made up of coastal cliffs with an elevated landscape. On the South Wales coast, limestones – including the coral-rich Carboniferous Limestone of Gower – predominate. In the south-east, the Pembrokeshire coast includes rocks of Precambrian age (among the oldest in the UK), and resistant volcanic rocks which help to define the cliffs and offshore islands. The cliffs of Pembrokeshire continue into Cardigan Bay, giving way to extensive low-lying sand dunes and alluvium, developed in front of steep cliffs to the north. In the north-west, the coast loses its sedimentary habitats and again becomes dominated by elevated coastal cliffs and hinterland.

There are two major estuary systems lying on the border with England: the Severn Estuary in the south, and the Dee Estuary in the north. With the exception of these two estuaries, Wales has no navigable rivers to compare with the rest of the UK and those of mainland Europe. The principal rivers are the Severn, Wye, Usk, Taff, Neath, Tawe, Towy, Cleddau, Dyfi, Mawddach, Conwy, and Dee. The historical losses of habitat notably in estuaries continue, but on a smaller scale than in the past (Doody, 2001). Generally, it is the small-scale cumulative losses which overall can cause most damage, although larger development proposals, such as for a tidal barrage for the Severn, could lead to large losses of intertidal estuarine habitats.

Protection of sites through statutory legislation has resulted in some (but by no means all) proposed developments being refused planning permission within designated sites. Statutory conservation designations for the Welsh coastline are shown in *figure 3.3*. Three National Parks and five areas of outstanding natural beauty (AONBs) cover almost a quarter of the country. In addition, there are 1,000 Sites of Special Scientific Interest (SSSIs), more than 100 nature reserves and six Environmentally Sensitive Areas. Pembrokeshire Coast National Park is the UK's only coastal park, and covers much of the coastline of the south-west Wales peninsula and several offshore islands, including Skomer, Skokholm, Ramsey and Caldey, which are of international importance for their seabird and seal populations.

3.4.3 Topography and offshore bathymetry

Marine waters are shallow around most of the Welsh coast and all lie within the European Continental Shelf. Offshore of the Pembrokeshire peninsula in the south-west, the Celtic Sea is composed of a series of banks, which lie in a NE/SW direction (*figure 3.4*). Some of these banks are of considerable length, but of no great depth – the most clearly defined is Labadie Bank in the approach to the Bristol Channel. The seabed appears to consist of sands, a great deal of broken shell and occasional patches of pebbles, gravel, small stones and mud. The approaches to the Bristol Channel are mainly a featureless area composed chiefly of sands, although to the North, depths increase to nearly 120m in the gulley known as the Celtic Deep. The Bristol Channel itself has a mainly sandy bottom with some mud patches at its western end, although further east there are areas of gravel and rock outcrops. The northern edge of the channel is characterised by a series of sandbanks, the shape and depths of which are constantly changing.

The coastline for five miles east of Nash Point on the northern side of the channel consists of cliffs 30m high, decreasing in height further east. In general, the northern coastline is low lying, backed by sand-dunes or rounded slopes, and in places protected by embankments especially east of Cardiff where land is being reclaimed. Two small islands, Flat Holm and Steep Holm, lie approximately 16 miles east of Nash Point, in the approaches to the estuary of the River Severn. The Severn Estuary, one of the largest estuaries in Britain, is considered to begin at a line joining Lavernock Point (51° 24´ N, 3° 10´ W) and Sand Point (51° 23´ N, 2° 59´ W) and to extend to a line joining Sudbrook Point (51° 35´ N, 2° 43´ W) to Cross Hands, two miles ESE, where the river begins.

St George's Channel and the Irish Sea contain a series of depressions, some of which have depths greater than 100m. The bottom is mainly composed of sand and gravel, although there are areas of mud north of Anglesey. Depths in the eastern part of the Irish Sea are generally in the range of 20-50m. The exceptions to this are the areas where banks are encountered, where depths may be less than 15m.

Cardigan Bay is entered between St David's Head (51° 54´ N, 5° 19 W´) and Bardsey Island, 55 miles NNE. The east and north-east parts of the bay contain several shoals, which extend up to 11 miles offshore. This series of ridges run NE/SW from the coast. The bay generally consists of numerous indentations with high cliffs and bold headlands. However, the central and northern coastline consists of areas of low ground comprising saltmarsh and sand dunes backed by higher ground. Sandwaves, some of which reach a height of seven metres above the seabed, exist in Cardigan Bay, off the North Wales coast and Liverpool Bay.

The north-west coast of Wales is characterised by the bold and rocky Lleyn Peninsula. The peninsula, together with the south-west coast of Anglesey form Caernarfon Bay, which is indented by many small bays with ledges and rocks extending 1.5 miles offshore. Anglesey is separated from the mainland by the Menai Straits, a narrow navigable waterway. The Skerries, a cluster of rugged islets and detached rocks, lie off the NW extremity of Anglesey.

3.4.4 Sea level and tides

The Welsh coastline is subject to one of the highest tidal variations anywhere in the world. In particular, the tidal range in the Severn Estuary is second only to the Bay of Fundy in Canada. The spring tide here is exceptional and can vary between a range of 4.6m at Bridgwater (51° 08´ N, 3° 00´ W), to one of 12.3m at Avonmouth (51° 30´ N, 2° 42´ W). The greatest range at Avonmouth can be as much as 14.8m.

Predicted tidal levels are subject to variations resulting from the effects of wind and/or differences in barometric pressure. Significant events, where variations exceed 0.6m, are termed storm surges. Positive storm surges, which travel as waves, can attain considerable height particularly if the peak coincides with high-water springs. Conversely, negative storm surges can considerably reduce sea level.

Similarly, strong winds from the south-west can cause positive tidal surges that drive water into the Irish Sea and raise sea level. The effect is more significant in shallow extremities such as Liverpool Bay and the Severn Estuary. Meteorological conditions can also cause negative tidal surges that cause tidal levels to be lower than predicted. This effect is likely to be accentuated by strong winds from the NNE.

3.4.5 Tidal streams and currents

The flow of water is largely determined by tidal forces, which vary considerably around the Welsh coastline (*figure 3.5*). The effects of other forces, such as those due to wind and density, are usually imperceptible.

The in-going streams run towards the Irish Sea through St George's Channel and North Channel nearly simultaneously, as do the out-going streams running from the Irish Sea. Both the in-going streams divide into two branches – west and east. The west branches meet south of the channel between the Isle of Man and Ireland, whilst the east branch of St George's Channel stream runs between Anglesey and the Isle of Man to Liverpool Bay. The out-going streams run in the reverse directions.

There are great differences between the streams in the fairways and near the coast, where there is large variation depending on the coastal landforms. Tidal rates are greatest where tidal streams are concentrated around headlands or in straits. In the centre of the Celtic Sea, the streams are generally weak, seldom exceeding ½ knots (kn). Closer inshore the rates become greater, generally following the direction of the coastline. For example, at the entrance of the Bristol Channel between Lundy and the South Wales coast the spring rate is about 1.5 kn. However, further east into the Bristol Channel rates generally increase until the entrance to the River Severn is reached, where a rate of 8 kn can be attained.

Off the west Wales coast, spring rates are about five knots and are only exceeded by the rates in Jack Sound and Ramsey Sound off Pembrokeshire, and Bardsey Sound off the Lleyn Peninsula. Further north, rates of between five and six knots can be expected off South Stack and between the Skerries and Carmel Head (Anglesey). Similar rates can also be attained along the north coast of Anglesey. In the Menai Strait, rates can reach eight knots through the restricted waterway at the northern end. Within the River Dee estuary the spring rate is about four knots.

The tidal stream may be affected by both wind-drift currents and storm surges (*section 3.4.4*). The former may be generated after periods of strong winds from a constant direction, the rate of which varies according to the wind speed and its duration. Wind-drift currents may approach or even exceed the rate of offshore tidal streams, and may enhance the rate of the tidal stream in certain areas.

3.4.6 Waves and swell

The wave climate off the Welsh coast is shown in *figure 3.6*. Sea waves are generated locally by wind (*section 3.4.7*) and can be very variable in direction. Some of the largest waves are experienced with winds from between south and north-west, although strong easterly winds can also give rise to rough seas, particularly on the north coast of Anglesey. Naturally, winter is the stormiest season, with about 57 per cent of observations over the open sea recording waves of more than two metres. However, this is reduced to around 20 per cent by July. A strong southerly wind can cause particularly rough conditions in St George’s Channel, due to the funnelling effect.

In the southern half of Wales, and particularly in the Bristol Channel, the predominant swell waves are from between south-west and north-west, with waves of three metres and over being recorded on about 40 per cent of occasions in winter and around 10 per cent in summer. South-westerly swells are apparent on the north shore of the Bristol Channel as far east as Swansea Bay.

The predominant swell in the Irish Sea is from between south and south-west, with an increased frequency of northern swells in spring and summer. Swell heights are much reduced compared to St George’s Channel and the Bristol Channel, with three metres or more being recorded on about 15 per cent of occasions in January, and on around 2 per cent in July.

3.4.7 Coastal and offshore winds

Offshore winds around the Welsh coast are shown in *figure 3.5*. The predominant offshore winds are from between the south and north-west. There is an increase in the frequency of north to north-easterly winds in spring and a decrease in easterly winds in summer. The strongest winds are reported during autumn and winter, with winds stronger than force 6 being reported on around 40 per cent of occasions in the north, and 35 per cent in the south during December. By July the frequency decreases to about 6 per cent in the north and 9 per cent in the south.

There are often marked variations in both wind speed and direction, due to sudden changes in pressure patterns. Also, within about 20 miles of the coast local modifications may be caused by the topography and by the land and sea breeze effects. An increase in wind strength, due to the funnelling effect, is most marked at the following places:

Locality	**Wind Direction**
Bristol Channel – E	W
Bristol Channel – W	SW
Milford Haven	S to W & N
Holyhead	NW
River Dee Estuary	NW or SE
River Mersey Estuary	NW or SE

Some of these locations have already been identified as potential offshore wind-farm sites by PB Power (see *section 3.4.1*). In a further analysis of the potential resource around the UK, Sustainable Energy Ltd. (2001) report upon a study performed in 1992 (*table 3.6*), which made the following estimates in respect of the potential for development within the Irish Sea and other parts of Welsh coastal waters:

Table 3.6 Offshore wind resource around Wales and the UK (source: SEL, 2001)

Regions	**Area (km^2)**		**Wind Speed Range (m/s)**	**Total Generation (GWh)**	
	Probable Site	Possible Site		Probable Site	Possible Site
Irish Sea and Welsh Coast	2,361	4,684	8.1-9.2	25,546	53,640
UK Total	21,712	11,849	7.7-10.0	231,622	134,323

SEL notes that numerous constraints were applied within the survey to identify areas for development as ‘excluded, possible and probable’.[19] The potential and possible sites included in the table provides a full potential resource of approximately 79,000 GWh/yr for the Irish Sea and Welsh coastal waters. However, this does not take into account numerous economic, technical, planning and environmental constraints that are likely to reduce the actual potential installed capacity. For example, fishing interests were not included in the assessment of sites, since they were considered to be essentially political. The key areas in terms of fishing interest are shown in *figure 3.7*. Oil and gas platforms, pipelines and cables were also ignored (*figure 3.8*).

[19] These constraints are listed in the report by Sustainable Energy Ltd. (SEL, 2001 p.73).

Figure 3.4 Seabed characteristics

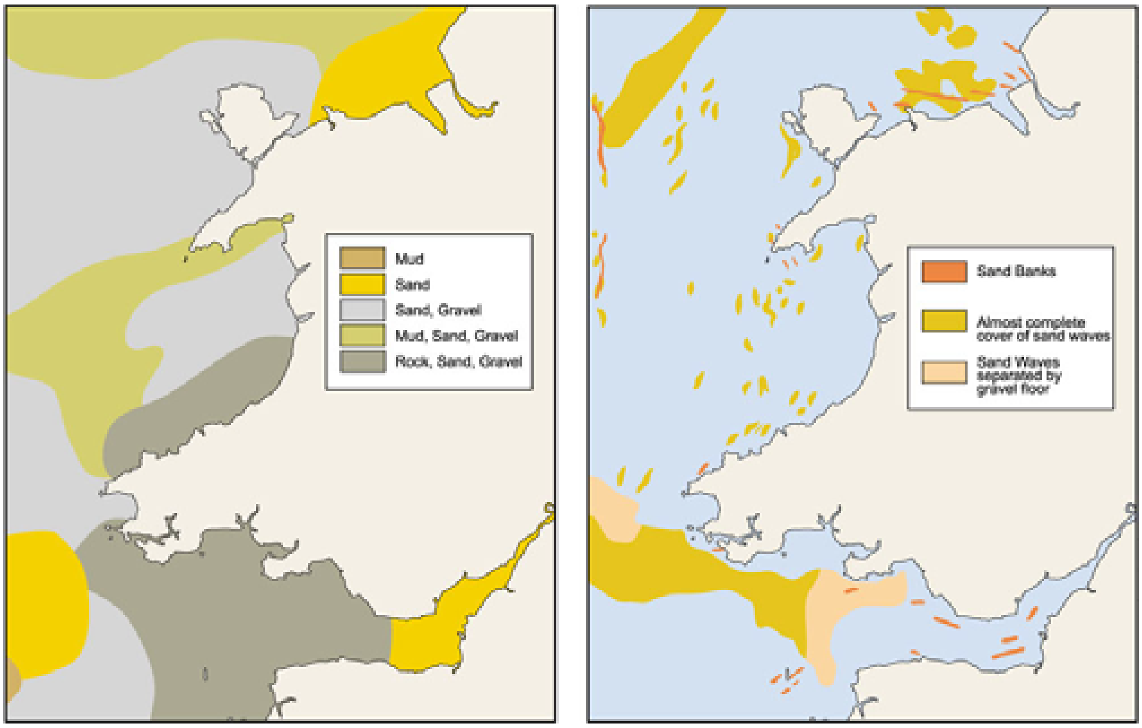


Figure 3.5 Winds and tides off the Welsh coast

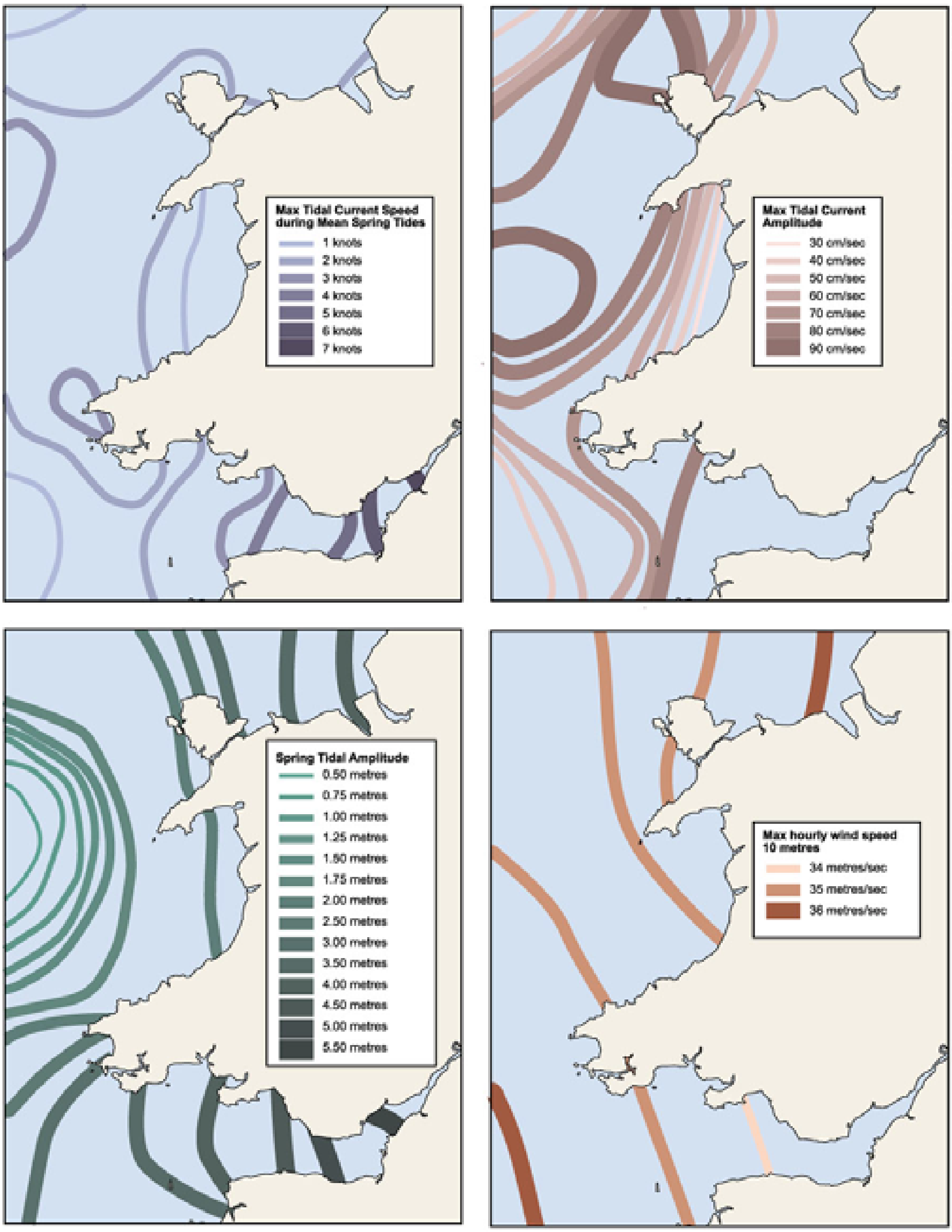


Figure 3.6 Wave climate off the Welsh coast

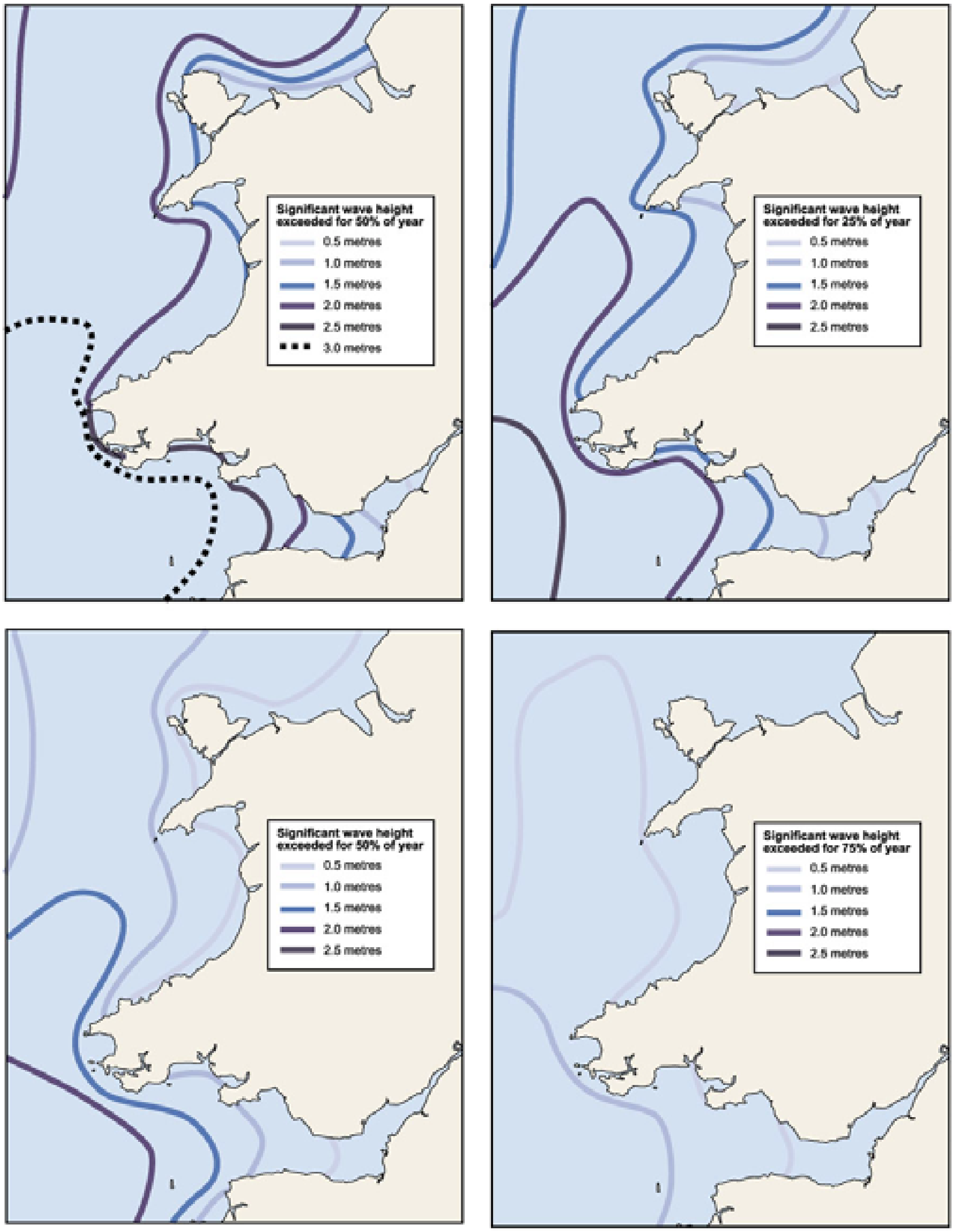


Figure 3.7 Areas of importance in terms of fishing interests

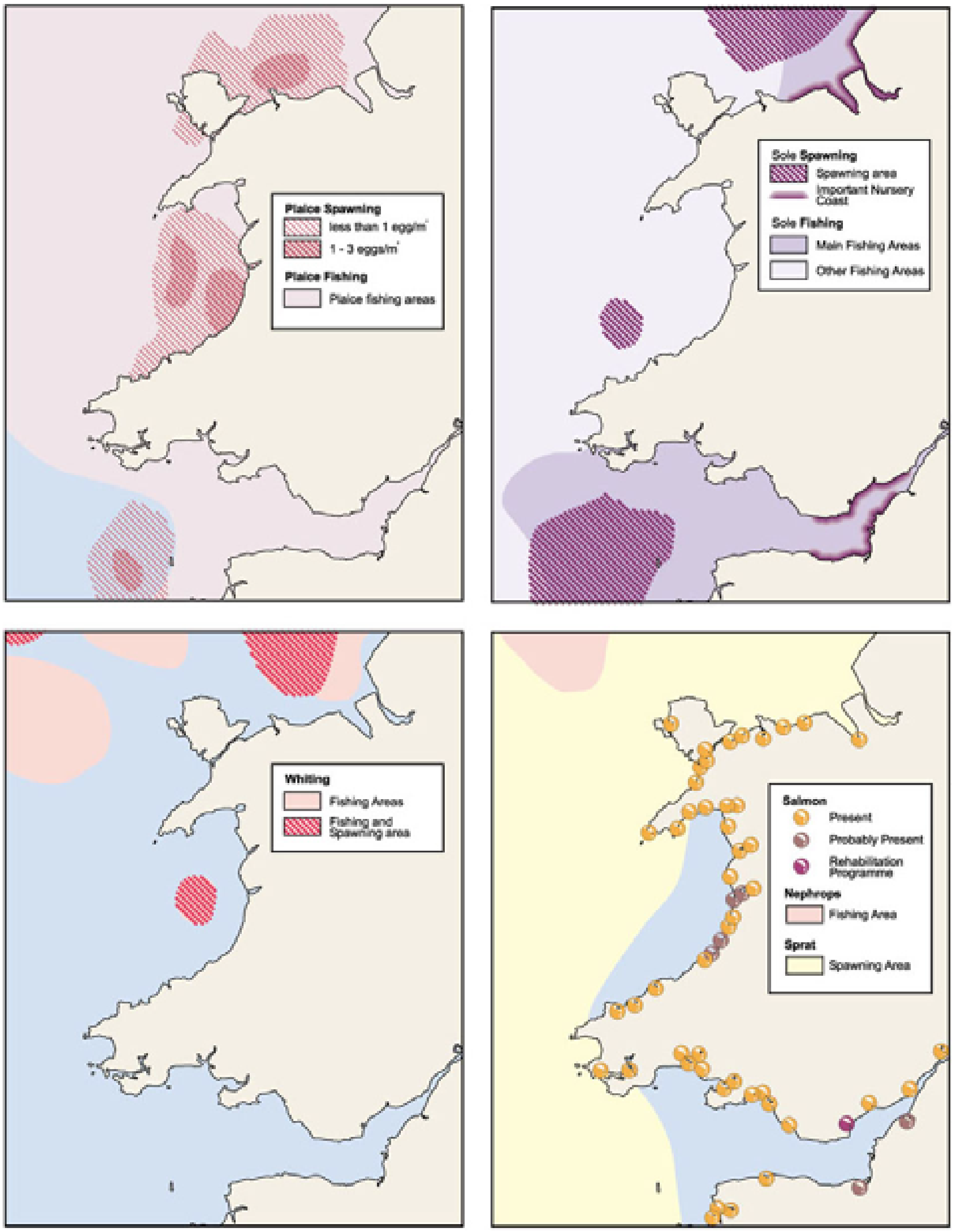
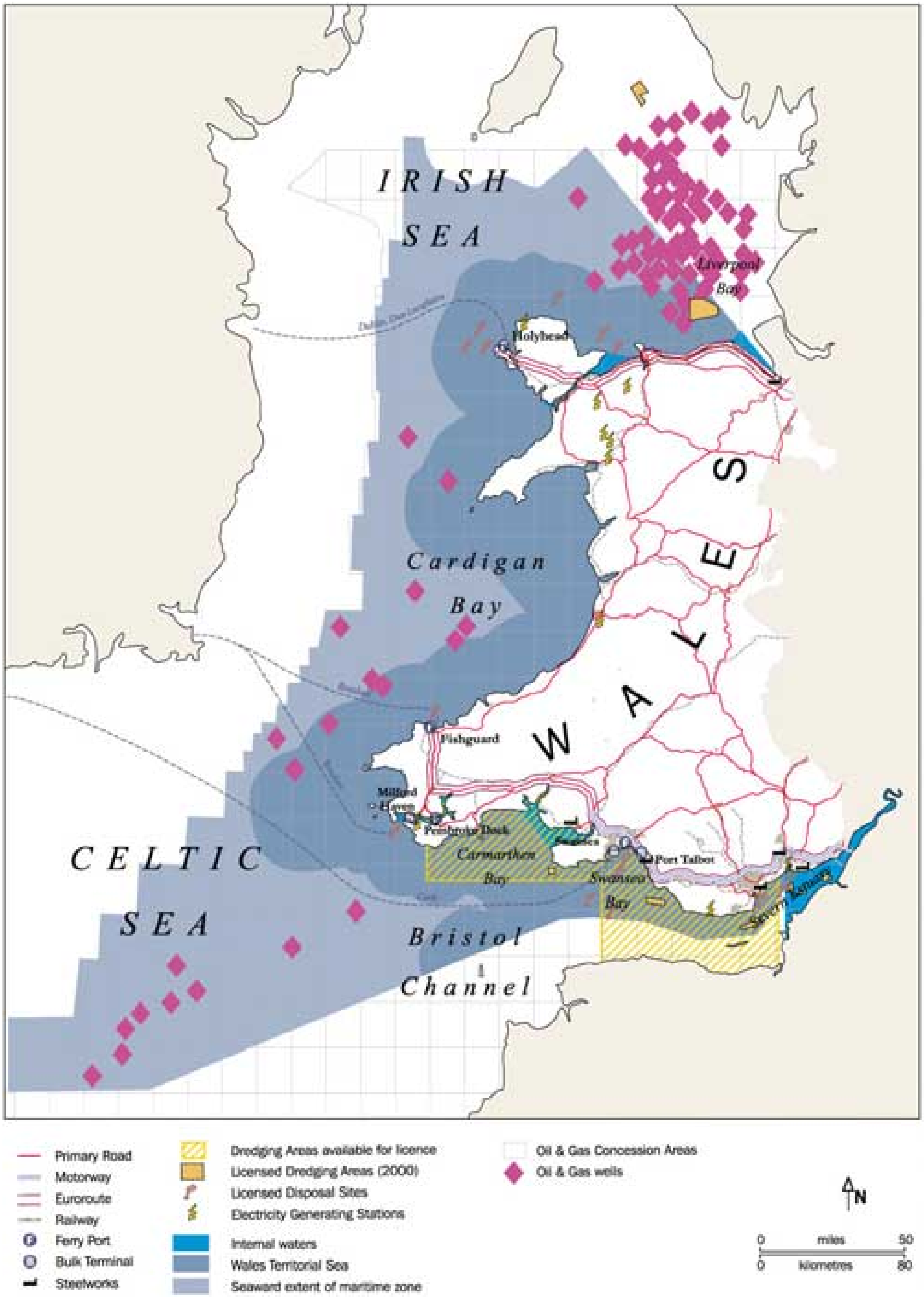


Figure 3.8 Development in coastal and offshore areas



4 Tidal energy

4.1 INTRODUCTION

Tidal energy exploits the natural rise and fall of coastal tidal waters caused principally by the interaction of the gravitational fields of the sun and the moon. The concept of harnessing tidal energy is centuries old, and there is evidence to suggest that tide mills were in use on the coasts of Spain, France and the UK since the Middle Ages. Tide mills were gradually replaced by cheaper and more efficient methods of power generation, although tidal energy until relatively recently still retained its promise of providing large power outputs on a predictable basis.

When the UK renewable energy research and assessment programme started in the mid-1970s, the tidal barrage option was perceived as being quite significant. Although the potential for tidal barrage power remains large, the prospects for its practical development on a significant scale seem limited at present. Due to privatisation and market liberalisation, there has been a shift away from large civil projects like tidal barrages to smaller scale systems.

The decision to terminate the UK tidal barrage programme was announced in the DTI's Energy Paper 62 in 1994. The reasons given were that tidal barrages had irregular (albeit predictable) output, low load factors, long construction times, large capital costs, and consequently high generation costs, at least within a private sector context. This was despite the fact that the UK probably has the most favourable conditions in Europe for generating electricity from the tides, with the potential being put at about 50 TWh, if all practical barrage sites were developed. The DTI is therefore keeping a watching brief on developments in order to pick up the work on the programme should circumstances change significantly in favour of tidal barrages. Indeed, tidal barrages may again be on the renewable energy agenda as a result of the RCEP report on *Energy – The Changing Climate* (RCEP, 2000), which revisited the proposal for a tidal barrage across the Severn Estuary.

Tidal stream technology is a variation on the conventional concept of harnessing tidal energy, and involves capturing and converting the energy found in tidally generated coastal currents. Theoretical work on tidal current turbines has been in progress since the 1970s, but it has only been in the last 5-10 years that the technology has progressed sufficiently that the first prototype devices can now be deployed. This chapter identifies the range of devices available for harnessing tidal energy, and evaluates the technical, commercial and environmental viability of each approach.

4.2 TECHNOLOGY DESCRIPTION

Tides – the daily rise and fall of ocean levels relative to coastlines – are a result of the gravitational force of the moon and sun as well as the revolution of the Earth. The moon exerts a larger gravitational force on the Earth because, although it is much smaller in mass, it is a great deal closer than the sun. This force of attraction raises the oceans, which comprise 71 per cent of the Earth's surface, into two 'bulges' on opposite sides of the planet. These remain fixed while the Earth rotates, giving a twice-daily cycle of high and low tides. The gravitational attraction of the sun also affects the tides in a similar manner, but to a lesser degree depending on the relative positions of the Earth and the moon. When the Earth, moon and sun are linearly aligned (a full or new moon), the gravitational attractions are combined, resulting in very large ‘spring tides’. At half moon, the sun and moon are at right angles, resulting in lower tides called ‘neap tides’. Coastal areas experience two high and two low tides over a period of slightly greater than 24 hours.

Tidal energy can be harnessed either through the energy stored in tidally impounded water, or by extracting energy from the tidal movement of water (tidal streams) using tidal turbines (analogous to underwater wind turbines). The former can utilise naturally occurring tidal basins, e.g. by building a barrage across an estuary, or by offshore tidal power generation based on the relatively new concept of tidal lagoons. These approaches to generating energy from the tide are described in greater detail in *sections 4.2.1- 4.2.4*.

4.2.1 Tidal barrages

The paradigm for tidal power generation has been the estuarine tidal barrage. The technology used to convert tidal energy into electricity by tidal barrages is very similar to the technology used in traditional hydroelectric power plants. The simplest generating system for single basin tidal power schemes, known as an *ebb generating* system, involves the creation of a dam or ‘barrage’ across a tidal bay or estuary. Tubular ducts in the barrage contain huge turbines, which drive electricity generators enclosed in waterproof bulbs. Sluice gates are opened to allow each incoming ‘flood’ tide to fill the estuary basin. At high tide the sluice gates are closed, creating a hydrostatics head behind the barrage. When the ebb tide creates an adequate difference in the elevation of the water on the different sides of the barrage, the sluice gates are opened. Water from the basin escapes through the ducts, spinning the turbines to generate electricity.

Tidal power schemes designed to generate electricity by *flood generation* operate in the reverse mode. Water is allowed out of the basin through the sluices until low tide. The sluices are then closed against the incoming (flood) tide so that the water level outside the barrage rises above that impounded within the basin. When the appropriate hydrostatic head for driving the turbines has been achieved, the sluice gates are opened and water is allowed to pass through the turbines until the water level in the basin has reached about mid-tide. At this time the head of water across the barrage is no longer adequate to drive the turbines.

In theory, tidal barrages can be designed to generate electricity on both the flood and ebb tide. Two-way generation, as it is termed, combines both modes of operation by generating over parts of both the rising and falling tide. Towards the end of a period of ebb generation the sluices are opened in order to reduce the basin level quickly to prepare for the period of flood generation. This reduces the period over which ebb generation might otherwise have occurred. A similar process occurs at the end of the flood generation, when it is necessary to open the sluices to fill the basin as quickly as possible prior to ebb generation.

The energy available for extraction by a tidal power plant varies by a factor of around four over the spring-neap cycle. Furthermore, electricity generation from tidal power plants is characterised by periods of maximum generation every twelve hours, with no electricity generation at the six-hour mark in between. Moreover, since the time of high water advances about an hour each day, the supply of electricity from a tidal power scheme may, therefore, not match the daily pattern of electricity demand. One solution is to pump water in the opposite direction to the flow during generation. If pumping takes place when the basin and sea levels are nearly the same, and if the water is used later in the tidal cycle when the head is greater, then an energy gain is possible in theory. This would allow electricity to be generated when demand is greatest, thus enabling the plant to function with some of the characteristics of a 'pumped storage' hydroelectric facility. Of the three methods of operation, ebb generation without pumping is preferred because it provides the minimum unit cost for energy generation.

The amount of energy available from the tides is approximately proportional to the square of the tidal range. The most favourable locations, therefore, for tidal barrages are found where local geographical features amplify the tidal range. In order to produce practical amounts of power, a difference between high and low tides of at least five metres is required. The amplitudes of tidal cycles are increased substantially, particularly in estuaries, by local effects such as shelving, funnelling, reflection and resonance. For example, the combined effect of these factors in the Severn Estuary causes the four-metre tidal range at the mouth of the Bristol Channel to be amplified to more than 11 metres in the vicinity of the Severn Bridge, on spring tides. This is one of the highest tidal ranges anywhere in the world, second only to that of the Bay of Fundy in Nova Scotia, Canada.

At present, although the technology for power generation by tidal barrages is well established, it is expensive, and relatively few are in operation worldwide. The first commercial-scale modern-era tidal power plant was built at La Rance near St Malo, France, in the 1960s. La Rance barrage is 740m long, and incorporates a road crossing and a ship lock. It contains 24 two-way pump turbines (10 MW), operating in a tidal range of up to 12 metres, with a typical head of approximately five metres. The operational pattern initially adopted at La Rance was to optimise the uniformity of the power output by using a combination of two-way generation (which meant running the turbines at less than the maximum possible head of water), and incorporating an element of pumped storage. For spring tides, two-way generation was favoured; for neap tides and some intermediate tides, direct pumping from sea to basin was sometimes carried out to supplement generation on the ebb.

Although some mechanical problems were encountered early in its operational life, which subsequently led to the barrage generating only on the ebb tide, overall the project is considered a success and has demonstrated the reliability of tidal barrage power generation schemes. Typical plant availability has often been more than 90 per cent and net output has been about 480 GWh/yr with significant gains from pumping in some years (NATTA, undated). La Rance was supposed to be one of many tidal power plants in Rance, until its nuclear programme was significantly expanded in the late 1960s.

Elsewhere, two other commercial schemes have been operating in the Bay of Fundy (25 MW) since 1982, and in China (100 MW) since 1987. There are also several non-commercial power-generating barrages in existence worldwide. Several major potential sites for barrage construction have been identified in the UK, the most notable being the 8640 MW Severn Tidal Barrage (STB) proposal. It has been estimated that the STB would generate 17,000 GWh/yr, providing up to 7 per cent of the annual electricity consumption in England and Wales. Other potential barrage sites in Wales have been identified at Conwy (33 MW), Loughor (5 MW), Milford Haven (96 MW), and Dyfi (20 MW) estuaries.

4.2.2 Tidal Lagoons

Tidal Electric Inc has developed and patented a tidal generator that combines existing hydroelectric power generation technology with conventional maritime water impoundment techniques to generate energy using the oceans' tides as its sole power source. The technology involves an offshore impoundment structure, segmented into three or more compartments and fitted with conventional low-head hydroelectric generating equipment. The bulb-type turbine/ generator sets are similar to those in use at La Rance tidal power station, where they have demonstrated their reliability since 1965. Furthermore, Tidal Electric claims that the technology is capable of mechanical efficiencies in the range of 95+ per cent, and is commonly available from a range of manufacturers (Tidal Electric Ltd., 2001)

Box 4.1 The Severn Tidal Barrage

The Severn Estuary has one of the highest tidal ranges in the world, second only to the Bay of Fundy in Canada. At the mouth of the estuary the difference between low and high tides is some 4m, but in the vicinity of the Severn Bridge the tidal range increases to more than 11m due to the funnelling effects of the estuary. Proposals to take advantage of this huge tidal range to generate electricity date back to the early 20th century, when the idea to construct a barrage was prompted by concerns about coal shortages and coal-fired generation during the First World War. The original proposal for a 1.36 TWh scheme involved a 5000m-long dam near the site of the Second Severn Crossing.

Many schemes have been suggested since then, but it was not until 1978 that the Severn Barrage Committee (SBC) was set up to advise government on whether to proceed with a scheme for harnessing the tidal energy of the Severn Estuary. In 1981 the SBC reported in favour of an ebb generation scheme on an alignment from Lavernock Point near Cardiff to Brean Down near Weston-super-Mare. Following the initial study, a two-year, £4.2 million project was launched between 1987 and 1989, funded equally by the (then) Department of Energy, the Central Electricity Generating Board, and the Severn Tidal Power Group (STPG) – a consortium of leading British construction and power engineering companies. These studies were reported in Energy Paper 57, *The Severn Barrage*, commonly referred to as the 'tripartite studies'.

The report outlined the proposal for a 16km (10-mile) barrage, with a total capacity of 8640 MW. The scheme described would have the potential to supply up to 17,000 GWh/yr – around 7 per cent of the annual electricity consumption in England and Wales. Based on an estimated capital cost of £8.28 billion (1988 money terms and construction costs), a life of 120 years, and assuming that the full cost of the barrage is recovered from electricity sales, the cost of electricity at 8 per cent discount rate was calculated as 5.53 p/kWh. The cost of grid strengthening, assuming 10 per cent of lines underground, was estimated as £1.23 billion. It was also estimated that the Barrage would displace some 18 million tonnes of CO_2 that would otherwise be released from conventional coal-fired power stations.

The STB, should the scheme proceed, would be the largest civil engineering project in Europe. A total of 216 bulb turbine generators, each of 40 MW capacity, would be contained in two powerhouses. These would be accommodated in 54 concrete caissons located in deep water in the main channel to the south of Steep Holm island. The Barrage would be fitted with 166 sluice gates to allow the incoming tide to refill the impoundment ready for the next power generation period, and two major locks 50m wide x 360m long (with approach breakwaters) to enable the passage of large commercial vessels. Smaller locks would also be located on each side of the estuary for use by recreational boats and smaller craft.

Despite the obvious engineering challenges, the tripartite studies indicated that the STB is a feasible project well within the scope of existing technology. Good knowledge of marine engineering and electro-mechanical equipment involved in barrage construction has been gained at La Rance in France, which also demonstrates the reliability of the technology, which has been in operation for more than 30 years. Construction would utilise tried and tested methods similar to those used for the closure of the Zealand estuaries in Holland. All the loading, lifting and transport techniques proposed for the construction of the STB have been proven in North Sea operations and further developed during the construction of the Second Severn Crossing. Construction is expected to take about seven years from the start of major works.

It has been over 12 years, however, since the tripartite studies were published and the context of the Barrage has changed dramatically during the intervening years, not least with respect to the privatisation of the electricity industry. Supporters of the Barrage cite the concern over the future security of electricity supplies and the predicted consequences of climate change as the main reasons for renewed interest in the Barrage, and claim the support of the RCEP report, which includes the STB in three of four modelling scenarios for achieving a 60 per cent cut from current annual CO_2 emissions by 2050. The STPG conceded that the debate surrounding the proposals had moved on and in July 2001 successfully lobbied the DTI for a 'Definition Study for a New Appraisal of the Severn Barrage Project'. The objectives of the study, which has yet to be made public, were to:

- identify the changed circumstances since the last studies were completed in 1989;
- identify the issues arising from these changes which may affect the viability of the project;
- form a view as to whether a new appraisal of the project is justified; and
- identify issues where more detailed study is recommended

The impoundment structure is located offshore (making it completely self-contained and independent of the shoreline). However, the tidal generator needs to be located in shallow water because its power source is the difference in water levels caused by the tides. Optimal sites may therefore be located only a few metres beyond the low tide level in near-shore areas. Turbines are situated in a powerhouse that is contained within the impoundment structure, and electricity is transmitted to shore via underground/underwater cables. The impoundment structure is a two-directional dam and uses conventional barrage design techniques. Construction can take advantage of the most economical materials available, using locally obtained loose rock, sand and gravel, although other materials can be used if circumstances require. Tidal Electric cites economics as being the primary driver in choosing the materials and construction methods. The reason given being in the event of a failure of the structure, the likely consequences would be limited to the economic impact of interruption of service, and would not include safety issues or collateral property damage (Tidal Electric Ltd, 2001)

The simplest generation profile is the single-pool impoundment. In contrast to a conventional barrage, which typically generates only on the ebb tide, the single-pool offshore generator generates on both the ebb and flood tides and therefore exhibits a single pool/double effect generation profile. Generation is maximised when turbine flow is concentrated at maximum head where the highest turbine efficiencies are achieved. With the single-pool concept, therefore, generation is delayed until a suitably high operating head of water develops outside the impoundment, to allow the flow of water to provide greater energy. This generating profile provides a load factor of about 48 per cent with power available roughly half of the time (Tidal Electric website).

The availability of the single-pool generating profile can be improved by adding two smaller pools intended for capturing the smaller heads available during the transition periods (as the tide is either ebbing or flooding). This is described as a three-pool generating profile. This also provides greater flexibility, as the sequence can be optimised to meet the needs of the operator. For example, if there is a demand for maximum output, all three enclosures generate only during the extreme high tide periods and the extreme low tide periods. On the other hand, if the operator needs a continuous output, then the chambers generate sequentially, reducing the overall output, but providing continuous power throughout the tidal cycle. This flexibility is important because, unlike conventional tidal barrages, power can be supplied in a manner that conforms to demand, either as base-load or as peak-load power. Ullman (2002) notes that, since wholesale pricing during a single 24-hour period can vary by a factor of between 6 and 20, even a small amount of power at the right time can make significant contributions to the revenue stream of the power plant. Indeed, Ullman (2002) estimates that predictable power is two or three times more valuable in the marketplace than unpredictable power.

The three-pool generation profile produces a load factor of about 62 per cent, with power available some 81 per cent of the time. The area of impoundment is roughly double the area required for a single pool generation facility. Doubling the area of the impoundment structure incurs an increase of about 40 per cent in the materials required for construction, although the overall capital costs of the project are estimated to increase only by 15 per cent (while the load factor increases by about 30 per cent). These figures will clearly vary from site to site due to variations in the cost and availability of materials. However, Tidal Electric believes that there economies of scale to be achieved, with larger projects being more economical than smaller ones. At 100 MW, the estimated capital costs are in the region \$1200-\$1500 per kilowatt capacity. Operating costs are described as being minimal (Tidal Electric website).

The amount of power generated is strongly related to the size of the tidal range. The output varies with the square of the tidal range. Second, the power output is directly related to the area of the impoundment structure, which in turn dictates the amount of water passing through the turbine during each generating phase. For these reasons, Tidal Electric has sought to identify locations with the highest tidal ranges in the world as potential sites for deploying offshore tidal generators; the most well-developed plans are for three tidal power plants in Wales (*section 4.3*). Other preliminary projects have been identified in Africa, Mexico and Chile, and feasibility studies are in progress for projects in India and Alaska.

4.2.3 Power from tidally-generated coastal currents

As tides ebb and flow, currents are often generated in coastal waters (quite often in areas far removed from bays and estuaries). While most marine currents are too slow to be worth exploiting, suitable fast currents can be found in locations around the coast where movements of water are constrained by the topography of headlands and islands (similar to the funnelling effects of winds through valleys and around hills). This results in acceleration of the water to speeds where considerable kinetic energy is available for extraction. In other parts of the world, there are also major marine flows caused by non-tidal factors, such as global oceanic circulation and variations in seawater density between areas caused by differences of temperature and salinity. These are not considered in the context of this study.

The kinetic energy of tidally generated coastal currents can be harnessed using the same principles as used in wind turbines. However, as seawater is some 800 times denser than air, tidal currents can yield useful levels of energy at much lower velocities. For example, a flow of water 1m/s (approximately two knots) carries the same kinetic energy density as wind blowing at 9m/s (or 18 knots) (Fraenkel, 1999). This kinetic energy can be converted to electricity, with relatively high efficiency, using an underwater turbine (or groups of turbines) deployed laterally across the flow at locations with strong currents. For this purpose the likely requirement for economic and practical operation is a location where the mean peak spring tide velocity is in the range 2-3m/s (four to six knots) (Fraenkel, 1999; Osborne, 2000; ITPower website). Although such locations, with suitable bathymetry and other environmental conditions for development, may be relatively limited, the conditions suitable for tidal current exploitation often extend over a large sea area. This provides the potential for numerous devices to be deployed thereby increasing the installed capacity to take advantage of the favourable conditions in the area. Moreover, as tidally generated marine currents are a predictable resource the ebb and flow of tides result in currents which reach peak velocity four times each day), the availability of power output can be planned for with some precision in advance (Osborne, 2000; Fraenkel, 2001). Although studies have shown the UK tidal stream resource to be between 31 and 58 TWh/yr, only around 10 TWh/yr could feasibly be exploited, in relatively shallow sites near to high demand for power (providing around 2 per cent of UK electricity demand).

Two technologies – tidal fences and stand-alone tidal stream energy converters – based on similar principles, are now being developed to harness the energy of these currents. These currents have the major advantage of being an energy resource as predictable as the tides that cause them, unlike wind or wave energy.

Tidal Fences

Tidal fences can be thought of as giant turnstiles that extend across a channel, that capture the kinetic energy of tidally-generated currents as water is forced through underwater turbines. However, unlike estuarine barrages, which create an artificial impoundment, tidal fences can be deployed in unconfined basins, e.g. in channels between small islands or in straits between the mainland and offshore islands. Such schemes are attracting an increasing amount of attention as a viable option for generating large amounts of electricity from tidal currents, without some of the more environmentally destructive aspects of barrage construction. However, it should be recognised that the environmental effects of such a scheme are influenced by the deployment location and that a tidal fence constructed across the mouth of an estuary would also present many of the environmental problems common to tidal barrages. The main advantage of a tidal fence is that all the electrical equipment (generators and transformers) can be kept high above the water. Also, by decreasing the cross-section of the channel, current velocity through the turbines is significantly increased.

The tidal fence concept is being pioneered by Blue Energy Canada Inc, based on multiple Ocean Class Davis Hydro Turbines linked in series across an ocean passage, estuary or inlet. Referred to as the 'Blue Energy Power System', these are large-scale, site-specific, custom engineered energy installations, which will vary in size and output capacity by location. In a typical design, multiple vertical axis Davis Hydro Turbines are mounted in a modular duct structure to form a tidal fence or tidal bridge across a river, tidal estuary or ocean channel. Suitable locations require a tidal regime greater than 1.75m, or where velocities exceed about 1.75m/s (3.5 knots). Each turbine measures 10.5m in diameter, with peak power outputs in the range of 12MW. Smaller energy loads can be met by deploying the Blue Energy 'Mid-Range' 250 kW power system in off-grid communities, remote industrial sites and regions with established net metering policies (Blue Energy Canada Inc, 2001).

The superstructure of the tidal fence can be utilised as a base for a bridge, or as a platform for other commercial developments including offshore wind turbines. It can also carry utility piping and wiring such as water mains, gas lines, phone lines, fibre optics and power lines. The developers of the Blue Energy Power system maintain that deployment requires no new construction methodology and that anchoring a turbine fence is comparable to erecting a marine bridge or pier structure. The first turbine units placed in the water can be generating power immediately after installation and hook-up, with additional units added later with no power shutdown. Furthermore, as the fixed rotor blades are mounted in durable concrete caissons, it is structurally and mechanically straightforward, and the transmission and electrical; systems are similar to existing hydroelectric installations. All the gearing, auxiliary equipment and electrical systems are mounted above high water level and are therefore readily accessible for maintenance and repair. The load capacity of the Blue Energy Power System can be optimised, either by pumped storage (so that energy can be stored when not needed and then utilised during periods of peak demand, or when there is less production) or by utilising existing capacity for peak demand loads. Alternatively, there may be opportunities associated with the development of hydrogen fuel cells, to ensure optimal use of all power generated by the system (Blue Energy Canada website).

Several countries have expressed an interest in the Blue Energy Power System. Most notably, in June 2001 Blue Energy California (BE-CAL) was formed to pursue the development of 'The

Brothers' Tidal Fence concept to generate high-density, renewable energy in San Francisco Bay. The proposed 304m long by 24m deep turbine array will generate some 70-100 MW, or more than 1,170 MWh a day. The fence will extend across a channel, connecting the shoreline to East Brothers Island, north of the Richmond-San Rafael Bridge. The project calls for the 16ha site to also include a Renewable Energies Interpretative Centre and other public amenities such as planned open space, trails, picnic tables and recreational facilities.

Blue Energy Canada Inc has also developed a proposal for a 4km-long tidal fence across the Dalupiri Passage between the islands of Samar and Dalupiri in the San Bernardino Strait in the Philippines. Pending government approval, the Dalupiri Ocean Power Plant will utilise 274 Ocean-Class Davis Turbines, each generating between 7-14 MW, giving a total estimated capacity of 2200 MW of power at peak tidal flow (1100 MW base average). If successful, this will be one of the largest renewable energy developments in the world. Tidal currents in the area are up to 8 knots, and water depths are about 41m. There is the added advantage that the seabed is relatively flat across the channel. Construction of the tidal fence is expected to take six years to complete, although the modular nature of the system allows generation to commence in the fourth year, with the installation of the first turbine. The scheme is described as the first phase of a proposed 'Build Own; Operate Transfer' (BOOT) project worth an estimated US$38 billion that will be transferred to the Philippines after 25 years.

Blue Energy has also looked at the UK as a possible site for their technology, and has indicated that the Severn Estuary might be suited. It seems confident that its technology could be economically viable, even with tidal flows of less that 2m/s (Open University Energy & Environment Research Unit, 2001).

It is understood, however, that critical development timescales at Blue Energy have been delayed by the lack of a working model (Blue Energy Canada Inc, 2001), and that the company is pursuing the development of a working commercial-scale demonstration project. The aim is to install two 'Mid-Range' 250 kW turbine units off Vancouver Island on the coast of British Columbia. The estimated cost is in the region of US$12m. Blue Energy states that further research work will demonstrate the integration of the renewable technology with a hydrogen fuel cell, to utilise surplus energy generated during peak tidal flow.

Tidal Stream Energy Converters

Tidal Stream Energy Converters (TSECs) is an umbrella term used in this study to cover a number of device concepts designed to extract and convert the mechanical energy in the current into a useful form. This is typically achieved through the rotation of an axial flow turbine, much the same as an underwater wind turbine. The mechanical energy produced is then converted via a gearbox to electrical power using a generator, normally an asynchronous induction generator or synchronous generator, which could facilitate grid connection, particularly of larger numbers of devices (ETSU, 2001a). Alternatively, direct drive generators are being researched, where the turbine power would be converted directly without the need for a gearbox. It is envisaged that tidal turbines could be deployed in arrays to capture the resource, with the individual generators electrically connected by an offshore ring circuit, with a single cable to then transmit the power to shore (ETSU, 2001a).

The optimal sites for tidal turbines are in locations where coastal currents run at 2-3m/s (four to six knots) to generate between 4-13 kW/m^2. Slower currents tend to be uneconomic, while stronger currents (>3m/s) can exert undue stress on the equipment. Such currents provide a high energy intensity compared to most other renewables. For example, the energy captured per annum for each square metre of tidal turbine rotor at the locations with sufficiently fast currents for economic exploitation is in the order of four to ten times greater than that from a wind turbine in a good location (Fraenkel, 2001). Tidal turbines can, therefore, be relatively small in relation to their power rating compared with other renewable energy technologies. For example, a 1 MW tidal turbine rotor would be less than 20m in diameter, whereas a typical 1 MW wind turbine requires a rotor of about 60m in diameter (Fraenkel, 2001). Furthermore, tidal turbines can achieve a higher capacity factor or load factor than is common with wind turbines, potentially in the range 35-40 per cent with a conventional two-tide regime. Consequently, Peter Fraenkel, director of UK-based Marine Current Turbines Ltd, believes that the energy captured per megawatt of installed capacity is likely to be up to 50 per cent higher from a tidal turbine farm than from a wind-farm.

The first ‘Proof of Concept’ axial flow tidal turbine was successfully tested in Loch Linnhe, Scotland, in 1994. The device, which resembled an inverted wind turbine with a 3.5m diameter rotor, was developed by a consortium consisting of IT Power, Scottish Nuclear and NEL (formerly the National Engineering Laboratory). It was suspended below a floating catamaran pontoon and successfully delivered some 15 kW in 2.25m/s current velocity. However, it highlighted a number of problems associated with mooring floating tidal current turbines, which have resulted in subsequent axial flow turbine designs incorporating fixed foundations.

At present, the most advanced design of this type is being developed by Marine Current Turbines Ltd as part of the **SEAFLOW** project (*section 4.3*). These devices consist of twin axial flow rotors of 15m to 20m in diameter, each driving a generator via a gearbox, similar to a hydroelectric turbine. The twin power units are mounted on wing-like extensions either side of a tubular steel monopile foundation some three metres in diameter. The monopile is set into a hole drilled into the seabed from a jack-up platform similar to offshore wind turbines. Underwater conditions five metres below the surface are relatively calm and predictable, and waves decay rapidly with depth, especially where there are strong currents. Therefore, given a suitable location for deployment, the degree of over-design necessary for the technology to withstand extreme conditions is relatively small compared to wind or wave energy devices.

The submerged turbines, which would generally be rated from 600 kW to 1000 kW, would be grouped in arrays or ‘farms’ under the sea, in locations with suitably fast currents, much like wind turbines are deployed on land. The main difference is that tidal turbines need less sea-space than offshore wind because the flow is bi-directional (rather than multi-directional as with winds) so that tidal turbines can be positioned closely together transversely across the flow. Consequently, Fraenkel (2001) claims that the power density of a tidal turbine farm is of the order of 50-100 MW/km^2 compared with 10-20 MW/km^2 for a wind-farm. It is envisaged that turbines will be installed in batches of about 10 machines. The implication is that a smaller area of sea is required for a given installed capacity of tidal turbines, and cable costs for interconnecting the turbines are reduced accordingly. Another advantage of this technology is that turbines can be installed in small batches on a modular basis, so that revenues can be realised relatively soon after the capital investment costs are incurred. This also enables future project expansion at a reduced marginal cost. This is in contrast to tidal barrages and other large-scale engineering projects where the lead time between investment and revenue can be many years.

Other device configurations are also being contemplated that would convert the tidal stream to hydraulic power and then to electrical power through a hydraulic motor and electrical generator. For example, The Engineering Business Ltd (EB), a UK company based in Northumbria, has developed the patented **Stingray** tidal stream generator (Trapp & Watchorn, 2001) (*box 4.2*), which produces electricity using the oscillatory movement of hydroplanes driven by flowing water. A 150 kW demonstration device is being tested in Yell Sound, Shetland.

The Stingray device was first proposed as a concept in 1999, and is a development from the surface positioned **Active Water Column Generator (AWCG)** system, and is one of a family of oscillating tidal stream power generation devices patented by EB in 1997. The AWCG project was partly funded by a DTI Smart Award, which enabled the company to develop a mathematical model and design, build and test a scale model of the AWCG machine. The AWCG concept utilises large hydroplanes, which are acted upon by the moving water and have their attack angle controlled to move a semi-buoyant, closed top, open-bottom collector up and down in the water (Watchorn & Trapp, 2000). As the collector is moved up and down, air is alternately drawn into and expelled from the chamber through a turbine mounted on the collector top. Depending on the speed of the water flow, the size of the hydroplanes, collector and the exit hole, the speed of the air stream can be increased relative to the water by factors typically between 20 and 30 times. The design is comparable in principle with the Oscillating Water Column (OWC) wave device (*section 5.2.1*). Trials of a scale model of the AWCG device, undertaken in a series of locations in the north-east of England, demonstrated that the AWCG principle could collect and concentrate the energy from the water into the air stream. However, EB is looking at alternative ways of demonstrating the use of oscillatory hydroplanes through the use of bottom-mounted devices such as the Stingray.

Box 4.2 Stingray Tidal Stream Generator

The Stingray Tidal Stream Generator has been in development for more than four years at The Engineering Business Ltd (EB). Development was assisted in the summer of 2001 by a DTI award of £160,000, under the New and Renewable Energy Programme, for a three-month fast-track feasibility study into designing and building a 150 kW Stingray demonstrator, with the remaining project costs being met by EB. After a thorough technical review by the DTI, the Energy Minister, Brian Wilson, announced in January 2002 that the DTI would provide up to 75 per cent (£1.1m) of the funding required to build and operate a Stingray demonstrator for a one-year period (Anon, 2002). Subsequently, a 150 kW Stingray device has been deployed in Yell Sound, Shetland during summer 2002.

The Stingray generator produces electricity using the oscillatory movement of hydroplanes driven by flowing water (EB, 2002). The hydroplanes rise and fall as the angle of each hydroplane is altered at the end of each stroke. A hydraulic cylinder is connected to the hydroplane arm and the up and down movement generates high pressure oil which is used to drive a hydraulic motor, which in turn drives an electric generator. The generator output feeds an industrial drive system giving dc output. In a Stingray farm the output from a number of devices feeds a dc bus, which typically connects through a submarine cable to land, where an inverter produces ac power for the user (Trapp, 2002).

An initial desk study was undertaken to define site characteristics and identify potential sites to test the Stingray demonstrator. Aspects that were taken into consideration included location, topography, tidal regime, water depths, seabed type, other seabed users and the consents process. Yell Sound was identified as a potentially suitable location, and a preliminary environmental appraisal identified no overriding environmental constraints. Local consultation also identified that the Stingray project had strong local support.

The demonstrator Stingray in Yell Sound has been designed to produce time-averaged power of 150 kW from a four-knot current in about 30m of water. The demonstration machine is about 20m high, with base dimensions measuring 21m x 19m. The swept height of the 15.5m-wide hydroplanes during normal operations is 11.5m. The whole structure weighs some 185 tonnes with ballast. The main objectives of the demonstration project are to (Anon, 2002):

- demonstrate the concept of oscillating hydroplanes to harness tidal stream power;
- validate dynamic and hydrodynamic model data;
- provide financial data to validate Stingray financial predictions;
- demonstrate EB's ability to design, build and operate a TSEC;
- demonstrate a Stingray launch and recover system; and
- stimulate commercial interest in tidal stream energy and the Stingray system.

EB has also commissioned a seabed survey and environmental assessment of the impact of Stingray. EB believes that the Stingray will initially capture about 15 per cent of the passing energy in the swept area of the hydroplanes, although as the technology develops it is hoped that this will increase to 20-30 per cent or more. The 150 kW demonstration device is, therefore, predicted to produce between 300-500 MWh over a full year, including transmission losses and allowing for equipment down-time (Anon, 2002). This is sufficient to provide power to some 80 to 130 homes.

4.3 TECHNICAL STATUS IN THE UK

Tidal Barrage

The theoretical tidal energy potential available in Europe from the construction of barrages across estuaries was addressed in a study commissioned by the EC in 1991 (ATLAS(a) website). The study concluded that a technically feasible resource of 105.4 TWh/yr (from 64 GW installed capacity) was available, assuming a 5 per cent discount rate over the technical life of the project. However, only 51.8 TWh/yr would be available below 0.071 ecu/kWh at 1991 prices at this discount rate. The resource was shown to be unevenly distributed throughout Europe, with the bulk of the resource shared between the UK (47.7 per cent) and France (42.1 per cent).

Tidal energy has also been extensively researched in the UK under a government programme which ran from 1978 to 1994 (with a total expenditure of £20.5m). Several major potential sites for barrage construction were identified, the most notable being the 8640 MW Severn Tidal Barrage (STB) proposal. However, large-scale projects such as the STB are considered commercially unattractive, and to date no development has been undertaken. The restructuring of the electricity market has increased the financial risk attached to investments in generating plants. Tidal energy projects require very high capital expenditure at the outset, with relatively long construction periods leading to lengthy pay-back periods. As a consequence, the unit cost of generation is highly sensitive to the discount rate used. Access to suitable funding is therefore a serious problem. It is very difficult for any government to justify a £10 billion investment when the output will not be seen for at least seven years (Richardson, 2001). For the same reasons, it is unlikely that projects such as the STB would be undertaken by a commercial company in the present liberalised market for electricity. This is a view shared by the Royal Commission on Environmental Pollution (RCEP, 2000), which states in its report, *Energy – the Changing Climate*:

> 'To the extent that the availability or cost of capital finance is a constraint on investment decisions, any energy source with high capital costs will be unattractive. This is aggravated for very large projects such as the Severn Barrage… The decisive consideration which the government regards as ruling out both a Severn Barrage [and any new nuclear power station at present] is that neither project would be undertaken by a commercial company in the liberalised market for electricity that now exists'.

Such projects are therefore unlikely to proceed without significant government intervention. Nevertheless, the RCEP advocates that in view of the large amounts of energy that would be available, the construction of tidal barrages should be kept under consideration for the long term (assumed to imply 2050). Specifically, the RCEP notes that the use of this technology to generate electricity would become more attractive if it becomes necessary to construct barrages in order to prevent flooding of urban areas as a result of rising sea levels. The RCEP calls upon the DTI to commission a desk study to determine whether there are credible combinations of estuarine barrages that would overcome the problem of intermittency of supply.

Aside from the technical and financial risks, it is generally accepted that barrage construction would induce significant environmental changes to estuarine ecosystems. Concerns relate primarily to habitat disturbance caused by changes in water levels which would modify currents and sediment (and associated pollutant) transport and deposit. Environmental constraints are a key obstacle to the development of the STB, as most of the estuary is covered by three large SSSIs. It has also been designated as a Special Protection Area (SPA) under the European Birds Directive and as a wetland of international importance under the Ramsar Convention. It is also a proposed Special Area of Conservation (pSAC) under the EC's Habitats Directive, which forms part of the Natura 2000 Network. The features for which it has been selected reflect the large tidal range. The net environmental effect of barrage development is likely to be site-specific, with some species benefiting at the expense of others. There is limited operational experience of large-scale projects upon which such judgements can be based. Clearly, detailed site-specific environmental assessment and long-term monitoring would be required for each barrage scheme.

Tidal lagoons

Novel ideas such as offshore tidal lagoons suggest there may be new ways to develop the tidal barrage concept. These impoundments offer large-scale energy generating capacity with advantages over conventional barrages (tidal lagoons can be designed to generated energy on the flood and ebb tides, while barrages generally only generate on the ebb), with a potentially less significant environmental impact.

At present, the UK is the sole location where detailed proposals have been produced for tidal lagoons. Three offshore tidal power projects are being proposed for Wales by US-based company Tidal Electric. Wales was selected to trial the technology because of the huge tidal range, its proximity to a large market, and because the UK government has created the Renewables Obligation to enhance the economics of renewable technologies. Given a successful start in Wales, Tidal Electric expects to broaden the deployment of its technology to many high tidal range areas of the world (Tidal Electric Ltd., 2001).

The largest of the three proposals for Wales is the North Wales Tidal Power Project, which would involve the creation of a £500 million tidal impoundment occupying more than 52 square kilometres of seabed off Rhyl, North Wales. Tidal Electric has been working with a consortium of political and environmental groups in North Wales in order to identify and conceptualise a tidal power project that would be configured in such a manner as to help reduce coastal erosion and the periodic flooding that has affected the area. Tidal Electric claims that such a configuration would provide an estimated 432 MW of power, while contributing to coastal defences in the area. If the project goes ahead it will be the largest renewable energy scheme in the UK. The circular impoundment will be about 14 kilometres long and more than three kilometres wide, with the closest point a mile from the coast. A smaller scheme (30 MW) is planned for Swansea Bay, South Wales, in cooperation with the Environment Trust. Furthermore, a 30 MW scheme has been proposed for development near Fifoots Point in the Bristol Channel of the Severn Estuary. In April 2000 an agreement was signed between Tidal Electric and AES Electrical Ltd, which owns the 360 MW coal-fired power station at Fifoots Point, and it is proposed that the two power plants would share management staff, facilities and a 400 MW grid connection.

According to Tidal Electric, the construction of a tidal power plant is divided into civil works and equipment manufacture. In the case of a scheme the size of the proposed Fifoots Point development, the equipment manufacture is estimated to take about 16 to 18 months, and the civil works around two years. Equipment costs (turbine, generator, control system, powerhouse) and ‘soft costs’ (design, construction financing, legal consents, etc.) are not considered to be site-specific, unlike the materials cost, which represents the largest construction risk (i.e. failure to deliver). Tidal Electric notes, however, that for a development in the Bristol Channel, there could be considerable flexibility in the civil works scheduling as the amounts of material required per day are well within the capacity of several potential suppliers.

The technology has received the broad support of environmental campaigners, and Friends of the Earth in particular (FoE, 2002), although it should be recognised that many of the environmental effects of the construction and operation of such a scheme cannot be stated with any certainty at present. For example, detailed modelling of sediment transport and the hydrodynamic environment may provide an indication of the extent of environmental interaction such a scheme is likely to exert. However, since this is essentially a new technology, the full range and magnitude of environmental impacts may not be known until the first scheme has been built. The technology has also received a positive review by AEA Technology plc on behalf of the DTI, which believes the environmental impacts (of the Swansea scheme) are likely to be acceptable, and foresees no insuperable problems in implementing the concept (Ullman, 2002).

Tidal Stream (Non-barrier tidal)

The prospects of using tidal currents as an energy resource was effectively dismissed by the *UK Tidal Stream Review,* published by ETSU in 1993 on behalf of the (then) Department of Energy (DEn). The report concluded that, although the UK tidal current energy resource is large, capable theoretically of meeting some 19 per cent of total UK electricity demand at the time, the unit cost of extracting such energy would not be economic under the cautious costing assumptions applied at the time. The most favourable results estimated that there could be a resource of about 20 TWh/yr in UK waters, capable of being exploited at a cost of up to 10 p/kWh, at a discount rate of 8 per cent. As a result DEn decided not to support any proposals for funding tidal scheme energy schemes under the UK Renewable Energy Programme.

As a result, only limited resources have been available to permit experimentation and development of TSECs. Consequently, much of the work has so far either been theoretical or small-scale experimentation. Nevertheless, a number of TSECs have been, and continue to be, proposed. There is no consensus, however, on the best design, or any certainty that it has yet been identified (ETSU, 2001a).

Given this continued interest, and development of technologies not available at the time of the 1993 review, ETSU (on behalf of the DTI) appointed Binnie, Black & Veatch (BBV, 2001) in December 2000 to re-examine the commercial prospects for obtaining energy from tidal streams. The study was based on what was considered to be the most promising conceptual design – the axial flow tidal turbine (*section 4.2.3*) developed by Marine Current Turbines Ltd (MCT) as part of the SEAFLOW project (project ref. JOR3-CT98-0202). This is the world’s first pilot project for the exploitation of marine currents at a commercial scale and is supported by a grant of €1 million from the EC under the JOULE programme. Following a favourable review of the technology by BBV, this was followed by a grant towards the first phase of work from the DTI worth £960,000. The German partners (IEE at Kassel University) also received a grant worth approximately €150,000 from the German government. The main research and development programme for the SEAFLOW project is as follows (MCT website):

- Phase 1 (1999-2003) Installation of the first large monopile-mounted experimental 300 kW, 11m diameter rotor system off Lynmouth, Devon, UK, at a cost of £2.3 million.
- Phase 1a (2002-2004) Conversion of the Phase 1 system off Lynmouth to twin 150 kW rotors, each of about 8m in diameter, to demonstrate the commercial technology. The estimated cost is £1.2 million.
- Phase 2 (2003-2005) Design, manufacture, installation and testing of what is expected to be the first 'full size' twin rotor system to be rated between 750-1200 kW. Unlike the first phases, the device will be connected to the grid for the first time, and will operate with bi-directional flows. This device is intended to be the prototype and test-bed for the commercial technology. MCT is also planning to carry out several test-bed projects in other regions, e.g. South-east Asia and North America during 2004-5. The estimated cost is £3 million.
- Phase 3 (2004-2005) The installation of two or three extra units to the Phase 2 system to create the first small 'farm' of tidal turbines. It is anticipated that this would provide an installed capacity of about 2.5-5 MW, depending on how many units are deployed and their power rating. The estimated costs for Phase 3 are in the region of £4m-£7m depending upon project size, although it is hoped that the project will be partly self-financing through revenue generated from the sale of electricity.

The BBV (2001) study estimated that the unit cost of energy from a 30 MW scheme (taking into account reduced production costs achieved through economies of scale) could be between 3.36 p/kWh (5 per cent discount rate) and 6 p/kWh (15 per cent discount rate). This is very much lower than the unit costs for TSECs quoted in the 1993 report. Consequently, ETSU believes that at these prices, tidal stream could become, or would be close to being, a viable option within the Renewable Energy Obligation (ETSU, 2001a). These predictions now need to be verified in the above demonstrations.

Similarly, field-tests on the demonstrator Stingray generator in Yell Sound (*box 4.2*) will provide the first indication as to whether this device has a commercial future. As noted by the developers, the ability to innovate and develop to improve efficiency and reduce costs has been well demonstrated by the wind power industry, and it is reasonable to assume that similar improvements will be possible with TSECs (Trapp & Watchorn, 2001).

Other device concepts, some of which remain at the conceptual or research and development stage, may prove equally or more economically attractive, or may offer different generating opportunities e.g. in deeper water. For example, Tidal Hydraulic Turbines Ltd is currently testing a prototype hydraulic accumulator system in the Milford Haven waterway, Pembrokeshire (*box 4.3*). Research work began on the project in 1998 and, through the support of the National Assembly for Wales' Environment Development Fund, the first phase of field trials has been conducted. Funding has been acquired in the form of a grant from ETSU for the second phase.

While both the above devices appear promising, the most advanced of the TSECs is undoubtedly the SEAFLOW project, with the Stingray and Pembrokeshire Tidal Power Scheme yet to reach the stage where cost and energy output estimates can be asserted with confidence.

Box 4.3 Pembrokeshire Tidal Energy Project

The Pembrokeshire Tidal Energy Project was conceived in 1997 as a means of generating electricity from renewable maritime sources with the minimum of environmental disturbance. Research work by Tidal Hydraulic Generators Ltd began in 1998, and funding of £45,000 from the National Assembly for Wales' Environment Development Fund (EDF) enabled the first phase of field trials to be conducted in Milford Haven waterway, Pembrokeshire, in 2001. The project is being supported by the Pembrokeshire Coast National Park Authority, as local manager of the EDF, and a consortium of local businesses.

The novel design features of the tidal energy generator make the project unique. The generator, which is described as a hydraulic accumulator system, is laid out in the schematic of a lattice structure, with multiple independent free-flow turbines. The system gathers energy from a large area of fast moving current and condenses it via a central collector into a single electricity generating point. The whole unit, which is $80m^2$ and stands at 15m high, is ballasted to hold it in place. The turbine heads can then turn through 360 degrees to seek the tidal direction. In locations with the appropriate tidal current required for cost-effective use, it is likely that the seabed will be rock, or scoured down to heavy aggregates, rather than light sand.

The turbines are designed for deployment at a depth greater than 50m, which would be below any potential wave damage caused by storm effects. Many existing systems can be used to position and recover such a structure. This is an important consideration as sea conditions are often so extreme that in-situ maintenance is not an option and the design must allow for simple removal of the unit for servicing with the minimum environmental disturbance. However, the unit is designed to run a minimum of 10 years without service, and incorporates a cleaning/polishing system to remove fouling, and net, rope and debris cutters to eliminate the need for regular maintenance. The units are designed to produce electricity for more than 20 hours a day, requiring around two knots of tidal flow.

As the proposed system was to be used in a National Park, environmental considerations were paramount. For example, the structure is held in place under its own weight to avoid seabed damage, and the developers claim that vegetable oil can be used as an environmentally friendly lubricant. Visual impacts are also reduced, as the complete structure is submerged beneath the sea.

Research into the device is continuing with an ETSU grant for Phase 2 of the project, which is assessing the performance and reliability of the device under different conditions. It is intended that Phase 3 of the project will involve the installation of a 1 MW average (5 MW peak) device in a seabed location. Commercial generation of electricity could commence from the completion of Phase 2, but is fully planned for Phase 3.

4.4 TECHNICAL VIABILITY

Tidal Barrage

The prospects of commercially exploiting tidal energy remain uncertain. Tidal energy, and barrage construction in particular, is a mature technology, but as with all large civil engineering projects, there would be a series of technical risks to evaluate and address. Risks are associated with the size of the civil engineering works required and delays to the construction schedule, with the eventual effect being upon the interest charges during construction (ATLAS(a) website). For reasons explained in the preceding section, therefore, it is evident that, from a developer's perspective, the primary problem facing tidal barrages is not technological, but financial. Furthermore, as there are no apparent economies of scale to be achieved (ATLAS(a) website), major reductions in capital costs appear unlikely. Further research in this area should therefore focus upon the two main market barriers to barrage construction: reduction in costs and mitigation against environmental impacts.

There may be merit in conventional barrage concepts, but tidal power generated by barrage schemes is unlikely to make any contribution to renewable energy targets in Wales in the short- to medium-term, and certainly not by 2010. Tidal power may have a role to play in reducing greenhouse gas emissions from power generation in the long term but, given the associated financial, technical and environmental risks, it ought to be as one of the last renewable options to be developed, not the first. As recognised by the RCEP, it may be the case that tidal streams turn out to be a more immediately attractive technology for using tidal energy to generate electricity.

Tidal Lagoons

Placing the impoundment structure offshore may potentially resolve many of the environmental and economic problems presented by estuarine barrage systems, and could put tidal power back among the choices for commercial-scale renewable power generation. Tidal Electric claims that an initial tranche of offshore tidal power installations, such as those proposed off the Welsh coast, can deliver some 8000 MW by 2010, enough to meet the 10 per cent renewables target. Much of this potential is located in North Wales/Liverpool Bay (1500 MW) and the Severn Estuary (4500 MW) which, together with the proposed developments in Swansea Bay (30 MW) and North Wales (432 MW), could make Wales a key player in pioneering this technology.

These projects will be the first ever embodiments of the offshore impoundment structure approach to tidal power. As such, the technology is subject to the inherent risks of unforeseen technical problems arising, and despite thorough engineering planning and output may be lower than that predicted by mathematical modelling. Until a device is built and deployed, there can be no certainty that the scheme will prove to be viable. However, there may also be technical innovation that makes the concept more attractive than anticipated.

Although the efficiency and reliability of low-head electric turbines have been demonstrated in numerous projects, including La Rance tidal barrage, they have not been used in the specific application proposed by Tidal Electric. Early projects must demonstrate the functioning of the design and economic performance if the company is to attract outside investment. Careful monitoring of the initial projects will indicate the accuracy of projections and actual performance will determine whether future projects would be competitive. Further studies should address the commercial, technical and environmental aspects of this technology.

In future there may be opportunities to further enhance the power output of offshore tidal lagoons through hybridisation with wind power or wave power technology. According to Ullman (2002), capital costs of offshore wind-farms could be reduced by as much as 70 per cent by placing wind turbines on the impoundment structure.[20] Similarly, Ullman (2002) quotes an estimate by Wavegen (developers of the LIMPET wave energy device) that mounting a LIMPET on the seaward wall of an offshore tidal lagoon would reduce the device's capital cost by 75 per cent.

[20] Foundation costs account for a significant amount of the capital costs of offshore wind turbines – see *section 6.5*.

Tidal stream (Non-barrier tidal)

As the majority of tidal stream generators are not close to market, the assessment of the commercial prospects for the technology is open to debate. Marine Current Turbines Ltd's business plan envisages the development of commercial tidal turbine projects by 2005-06, and the possibility of installing around 300 MW worth of turbines by 2010. If this is feasible, tidal stream technology could make a reasonable contribution to the government's 10 per cent renewables target.

According to the BBV report (2001), the size of the resource available using current technology (SEAFLOW) and small to medium-sized schemes is likely to be about 10 TWh/yr, based on the 1993 Tidal Stream Review resource estimates. However, a significant proportion of the resource appears to be at sites that are in water depths greater than 50m, or are remote from areas where demand is high. Development at these sites will require major investment and advances in the technology to be commercially viable.

There are already a number of device concepts at different stages in their development and evaluation. While most of these designs utilise well-established engineering concepts, their long-term reliability and cost-effectiveness needs to be demonstrated in the marine environment to take the technology forward to commercial reality.

The Science and Technology Committee on Wave and Tidal Energy (2001) observed that there appear to be no major technical barriers to the effective development of these technologies, which could not be solved by transferring expertise and knowledge from the offshore industries. The UK has the most developed device concepts, and has strong offshore marine engineering capabilities, which, combined, could make the UK a key player in the emerging tidal energy market. However, further research and innovation is required in several areas to reduce risk and uncertainty and to improve the economic prospects for tidal stream.

These areas have been highlighted in the BBV (2001) study, specifically with regard to the axial flow tidal turbine (*section 4.2.3*) developed by Marine Current Turbines Ltd. On a more generic level, progress is required to develop large-scale prototypes of already well-established device concepts (such as the Stingray generator), which can be subjected to long-term performance evaluation in realistic operating environments. For example, the next stage in the Stingray is to design, build, install and operate a 5 MW 'pre-commercial' Stingray power station with a projected 15-year life. EB believe that if encouraging results can be obtained from the 150 kW demonstrator, then this power station could be installed by 2004. ETSU (2001a) note that research is also required to continue to seek improvements to individual components on existing design concepts to improve their further development towards commercial competitiveness.

There are also a number of less well-developed device concepts where further research work is required to provide estimates of potential energy capture, device capital and operational costs, and to evaluate the potential cost per unit of energy produced. Small-scale testing of these new devices should provide an indication of whether there is sufficient justification for the development and deployment of larger prototypes for subsequent commercial generation.

There is a need to demonstrate tidal stream energy on a large-scale to establish its credibility and reduce the perceived risk as rapidly as possible. However, the Science and Technology

Committee on Wave and Tidal Energy (2001) noted that the current level of public spending on tidal energy research is insufficient to give the technology the impetus it needs to develop fully. Understandably, most investors are unwilling to put money into such large-scale projects until their commercial credibility has been established. There is a strong case therefore, for increased government funding, similar to that shown to wave and, in particular, wind power. Testing of devices on a realistic scale is the only way in which companies can gain the extensive private sector investment needed to take tidal energy devices to commercial reality.

4.5 COMMERCIAL COMPETITIVENESS

Tidal barrage projects require very high capital expenditure at the outset, with relatively long construction periods and low load factors, resulting in lengthy pay-back periods. As a consequence, the unit cost of generation is highly sensitive to the discount rate used. For example, applying a 15 per cent discount rate rather than an 8 per cent discount rate doubles the estimated cost of electricity generated by the Severn Barrage (RCEP, 2000). The restructuring of the electricity markets has increased the financial risk attached to investments in generating plants, and made projects with high initial costs even less attractive.

Attempts were made to investigate smaller, less expensive tidal barrage options, notably on the Mersey. The Mersey Barrage Company (another consortium of major UK companies) tried to obtain NFFO support for their scheme, but was ultimately unsuccessful, and the Mersey project and several other smaller barrage proposals were abandoned. In 1994 the UK's tidal barrage programme was more or less wound up, after the government had spent around £12 million on it.

The costs of electricity generation from tidal currents are speculative because most TSECs are still at the research or development stage. As such any predictions about economic viability must be viewed with caution. The *UK Tidal Stream Review* published by ETSU in 1993 estimated that the UK resource was capable of being exploited at a cost of up to 10 p/kWh, at a discount rate of 8 per cent. However, the report may have been over-cautious in the costing assumptions applied, and improvements in the efficiency and performance of many devices and the development of new design concepts since the review, have resulted in renewed optimism over the cost of tidal stream energy.

For example, an independent review by BBV (2001) of the technology developed by Marine Current Turbines Ltd (MCT), estimated that the unit cost of energy from a 30 MW scheme could be between 3.36 p/kWh (5 per cent discount rate) and 6 p/kWh (15 per cent discount rate). MCT believes that in the longer term, generating costs of less than 3 p/kWh can be achieved. Similarly, an EU-supported project on *The Exploitation of Tidal/Marine Currents* (project ref. JOU2-CT94-0355) completed in 1996 by IT Power and Tecnomare (UK) estimated electricity costs for 'First Generation Systems' at around 3.5 p/kWh, for a 3m/s rated current under favourable circumstances (i.e. with high load factors). A *Feasibility Study of Tidal Current Power Generation for Coastal Waters: Orkney and Shetland*, conducted by the International Centre for Island Technology (ICIT) and IT Power, gave a predicted electricity cost of about 6 p/kWh for a cluster of eight turbines of 20m diameter mounted on steel monopiles.

At these predicted prices, tidal stream would appear close to becoming a viable option within the Renewables Obligation, which ensures a price of up to a maximum of ~5 p/kWh for electricity from renewable energy sources. Furthermore, the Climate Change Levy, and the exemption from it for electricity purchased from renewable energy sources, is worth a further 0.43 p/kWh. However, even at a cost of 4-6 p/kWh, tidal energy is significantly more costly than electricity from an average fossil fuel plant (about 2-3 p/kWh). In the long term, therefore, the target is for tidal stream to be commercially competitive without the need for market support measures. This would require tidal stream schemes to be generating electricity at a price competitive with other sources of energy (ETSU, 2001a). It is worth noting that external costs are often not taken into account in the cost comparison of different energy sources, which puts renewables as a whole, and tidal energy in particular, at a disadvantage.

The estimated costs of tidal energy have fallen over the last 10-15 years and may already be competitive in certain niche markets. Arguably, there is no reason why prices should not continue to decrease. Supporters of tidal stream energy point out that wind energy, which is now considered to be nearing commercial competitiveness, was even more expensive than tidal stream energy when it was first actively supported by government. Tidal energy has achieved similar reductions in cost without the significant subsidies received by the wind power industry (STC, 2001). Furthermore, Fraenkel (1999) observes that the potential for economy from large-scale marine current turbine installations may be significantly better than for land-based wind turbines due to the much larger scale of installations that will be possible.

It must be noted, however, that tidal stream technology is still at a relatively immature stage of development and the true cost of electricity produced will only be certified after large-scale schemes have been in operation for a while.

4.6 ENVIRONMENTAL ASPECTS OF TIDAL ENERGY

All forms of electricity generation have an impact upon the environment, but it is generally accepted that renewable energy technologies are less environmentally degrading than most other forms of power generation, especially in relation to atmospheric emissions. There are, however, some environmental difficulties arising from renewable energy sources. Even so, in taking a strategic view, these need to be assessed both against their positive contribution to achievement of climate change targets and a wider range of sustainability objectives.

Of all the renewable energy technologies, tidal energy, and tidal barrage construction in particular, has attracted the most concern over its potential impact upon the environment. Any tidal power barrage is likely to impact upon such diverse areas as navigation, recreation and amenity, employment, and (of particular importance) the ecology of the local environment, especially upon estuarine habitats of importance to birds and migratory fish. The balance and extent of these impacts are likely to vary for different types of scheme, depending upon the specific design details. Furthermore, there is likely to be a complex inter-relationship between the various impacts and their causes, which can only be established through site-specific long-term monitoring and assessment studies.

Much of this information has yet to be collected, primarily due to the relatively few large-scale tidal energy barrages in existence worldwide. Evidently, no detailed preliminary environmental studies were undertaken prior to the construction of La Rance tidal barrage in the 1960s, although the UK's first tidal power research programme devoted considerable effort to both specific and generic understanding of potential environmental changes that could occur as a result of estuarine barrage construction. Although the programme found that no major environmental changes have so far been identified which could preclude further development of the technology, the conclusions reached on potential environmental impacts are inevitably less certain than those reached on technical feasibility. Lack of experience of the potential impacts of large-scale operational schemes, therefore, would suggest that the precautionary principle should be applied in the evaluation of any new proposals.

Similarly, the limited experience with TSECs enables only an incomplete picture to be formed of their possible environmental effects. As no large-scale tidal stream power schemes have been developed, and the only deployment of tidal stream turbines has been of small-scale prototype devices for short periods, there is a large degree of uncertainty about potential environmental impacts. Preliminary environmental appraisals have been carried out on some device designs (e.g. the Stingray tidal stream generator), as well as Environmental Impact Assessments for a small number of specific schemes (e.g. the Orkney and Shetland Islands tidal power scheme (ICIT/IT Power) and the SEAFLOW project). These suggest that there are no major environmental issues associated with the specific devices assessed, provided that they are deployed with some care. However, it is likely that many of the potential impacts would be site-specific and would have to be assessed separately for each scheme. Also, assessments have been performed on specific devices, and may not take account of the cumulative impact of numerous devices deployed in a tidal farm.

It is worth noting that currently, all proposed marine Special Areas of Conservation and Special Protection Areas (which form part of the Natura 2000 Network) are on or adjacent to the coast. However, it is possible that further suitable sites will be identified offshore, within 12 nautical miles of land, for example for harbour porpoise or important seabird colonies. English Nature proposes that until such sites are identified, all potentially suitable habitats must be treated with care, ensuring that these areas are not damaged or altered in any way that could prejudice their selection.

ETSU (2001a) has identified numerous areas where further research work is needed with respect to the environmental effects of harnessing tidal stream energy. These include the possible interaction between submerged rotating devices and marine creatures, and the influence of tidal extraction schemes on coastal processes, tidal flows, seabed scouring and sediment transport, and fishing. It may become evident that, as an increasing number of EIAs are undertaken for specific schemes, a range of generic issues can be identified that are common to all tidal stream power schemes. Some of the potential problem areas identified by ETSU are addressed briefly below, along with areas of uncertainty arising from the deficiency in the existing knowledge base.

4.6.1 Ecological Effects

The potential impacts of tidal barrages are most evident upon estuarine environments. Britain's estuaries provide a sufficient population of invertebrates to support an average annual peak (due to migration) of about 1.5 million wading birds. They are an integral part of many of these wading species' lives without which many populations would be severely reduced, including some populations of international significance (Institute of Biology, 2001). Barrages reduce tidal range with a consequent loss of exposed mudflats that are important feeding grounds for birds. Estimates for mudflats loss for the proposed barrages for the Severn and Mersey are 65 per cent and 45 per cent respectively. *Table 4.1* below shows estuaries where barrages have been proposed up to 1990, and the corresponding numbers of wildfowl and waders that could be affected by barrage construction.

Table 4.1 Barrage proposals for estuaries with 40,000+ waders or 25,000+ wildfowl

Estuary	Average Total (rounded) Waders	Wildfowl
Wash	200,000	63,000
Morecambe Bay	157,000	24,000
Humber	85,000	20,000
Dee (Welsh)	82,000	24,000
Solway	77,000	35,000
Severn	51,000	26,000
Langstone Harbour	40,000	13,000
Mersey	31,000	32,000

(*source:* Institute of Biology, evidence submitted to Science and Technology Committee on Wave and Tidal Energy, 2001).

The reduced flow as a result of an estuarine barrage may also affect the nature of mudflats and the plant and animal communities they support. Potentially more significant is the impact of barrage construction upon salt marshes in estuaries, which are of major ecological importance. The UK has about 440 km^2 of salt marsh, much of which is to be found in estuarine environments. While many salt marsh plants are widespread, some are localised. Several invertebrates, particularly types of moth and spider are intimately associated with salt marshes and have a very restricted distribution. Generally barrages would mean that some estuarine salt marshes would be inundated less frequently. As a result the upper marsh zone may become permanently exposed, resulting in the ecosystem becoming more terrestrial, with the consequent loss of salt marsh habitat and the communities they support.

Estuarine barrages could also have an effect on water quality. For instance, estuaries tend to receive large pollutant loads from industry, nutrient rich runoff from agriculture and sewage inputs. Dilution is a key process in the dispersal of these pollutants. Barrages could impede pollutant removal, resulting in longer retention times within the impounded area and the creation of new sinks for pollutants. The longer duration of the high water and the removal of the lower half of the tidal cycle also have considerable implications for land drainage. Additionally, there are other environmental impacts associated with the installation of the barrage infrastructure and the effects that the inevitable disturbance will have on the seabed and benthos, as well as on landfall sites either side of the estuary.

Evidence concerning the potentially serious impacts of tidal power generation on migratory fish was presented to the Science and Technology Committee on Wave and Tidal Energy by Dr Andrew Turnpenny of Fawley Aquatic Research Laboratories (Turnpenny, 2001). According to Dr Turnpenny, the issue of migratory fish passage across tidal power barrages was one of the major barriers to tidal power development during the 1980s and, owing to the continued decline of migratory fish species in the UK, the fish protection issue has become even more sensitive.

Much of the scientific research into fisheries issues arising from tidal power has been undertaken in relation to the proposed Severn Barrage. The single largest fishery problem arising from tidal power generation is the inevitable passage of migratory fish through the hydroelectric turbines, with consequent injury risk (Turnpenny *et al*., 2000). In the case of the Severn, these fish species include a number of threatened or declining species, including Atlantic salmon, sea trout, Allis shad, Twaite shad and the European eel. In the estuarine phase, fish may swill back and forth with the tide, potentially being forced through the turbines several times during a single migration. For the nine-metre diameter turbine design proposed for the Severn, injury rates were predicted to be 40 per cent for adult salmon (100cm), and 53 per cent for juvenile shad (7cm).

The conventional method of preventing fish entry into turbines on riverine schemes is to place fine-meshed screens (~12mm mesh) across the water intakes (Turnpenny *et al*., 1998). However, this is not feasible in the marine environment owing to the much higher debris loads. Self-cleaning screens could potentially be used, but these are expensive and could inflict fatal injuries on delicate species (Turnpenny, 2001).

Surprisingly, the operator of La Rance barrage (Electricité de France) claimed that there was no apparent adverse effect of the barrage on fisheries. Possibly, its closure during the construction phase may have removed any migratory fisheries that previously existed. Studies of the Barrage scheme in the Bay of Fundy generally show a very high impact level on migratory fisheries (Turnpenny, 2001).

It is generally accepted that barrages do incur an environmental impact and, if deployed insensitively, could seriously impact upon some internationally important bird populations, threatened or declining fish species, as well as the invertebrate and flora of estuaries. Additional ecological impacts are associated with the changes in the hydrography and sedimentary processes of estuaries. However it is worth considering that the existing sea level rise anticipated due to climate change is likely to change the nature of some estuaries. The Institute of Biology therefore suggests that the imaginative use of barrages might pay for some ameliorative conservation measures, although it stresses that ‘a not inconsiderable research effort would be required to ascertain whether there was sufficient merit to this’ (Institute of Biology, 2001).

The Environment Trust, partner with Tidal Electric in the proposed offshore tidal generator for Swansea Bay, considers that offshore tidal generator impoundments will contribute to the local environment over time. However, the Trust acknowledges that the proposed impoundment will have visual, sediment transport and marine life impacts, but believes the positive benefits of offshore tidal power will outweigh these negative impacts.

Entrapment of fish in the turbines of an offshore tidal lagoon is not considered a major problem by either Tidal Electric or the Environment Trust, which believe that adequate screening and sounding will minimise the risk posed to marine life. Furthermore, they point out that any impact will only be during the movement of water from the sea into the impoundment structure (flood generation), as when the reverse occurs (ebb generation) it is envisaged that the currents will be of significant magnitude to deter the entrapment of marine life (Environment Trust, 2001).

The operation of turbines in a tidal generator impoundment structure would create some localised turbulence, resulting in an underwater pressure wave. Tidal Electric claims that mature fish and mammals would be able to sense this and avoid the area. Smaller creatures could conceivably be pushed away by the pressure wave created by the blades although this has yet to be demonstrated in tests. The survival rate for fish swept through the turbines is put at 94 per cent (Tidal Electric, 2001).

It is worth noting that the tidal generator impoundment concept presents an entirely different situation to a conventional barrage across an estuary, which anadromous fish must navigate twice if they are to migrate upstream to spawn before returning to sea. While mortality rates may be similar for fish passage across turbines regardless of whether they are encased in a conventional barrage or in a tidal generator, fewer fish will pass through the tidal generator’s turbines. Consequently, Tidal Electric claims that fish mortality will be several orders of magnitude lower than for a conventional barrage.

There are no tidal impoundment systems of the type proposed by Tidal Electric, making it difficult to assess the likely ecological impacts. While it is possible to make estimates of potential damage based on theoretical considerations, drawing upon experience of similar types of structures, it would be preferable to base them on practical examples because unpredictable consequences are always a possibility.

Concerns have also been expressed over the danger that the revolving rotor blades of a tidal stream turbine present to marine animals. The injury risk to seal populations was a specific concern in relation to the tidal power generation scheme in the Orkney and Shetland Islands. However, the EIA carried out in connection with the project (ICIT, 1995), found that the environmental impact of operational tidal turbines was likely to be minimal (Fraenkel, 2001).

Peter Fraenkel, managing director of Marine Current Turbines Ltd, believes the risk of injury to wildlife as a result of collisions with the rotor blades of the axial-flow tidal turbine is very low. Evidence presented to the Science and Technology Committee on Wave and Tidal Energy Fraenkel (2001) argues that a tidal turbine rotor is limited to a rotor blade tip velocity of no more than around 15m/s (approximately 30 knots) to avoid loss of efficiency due to cavitation. In contrast, a ship’s propeller typically rotates at 10 times the speed of turbine rotors. Moreover, the turbine stays in one place but many motorised craft move often move at speeds faster than marine fauna (Fraenkel, 2001). Most marine creatures found in areas of high currents are strong swimmers. There is therefore reason to hope that fish can use the pressure field around tidal devices to avoid them. There are no reports of fish being killed by going through the turbines of La Rance tidal barrage, and the risk should be less for individual non-barrier turbine devices that can be circumnavigated by fish.

According to Dr Turnpenny, research into fish injury mechanisms in turbines has advanced over the last 10-15 years and there are now much better prospects of quantifying possible damage to fisheries and, more important, designing and operating turbines to be more ‘fish-friendly’. The development of fish acoustic guidance is now regarded as the ‘best available technology’ for safely diverting fish around a turbine. Several of these systems have been independently evaluated and have been shown to achieve ~80 per cent fish diversion efficiency, with 95 per cent or higher for sound-sensitive species such as herring (Turnpenny, 2001)

The prevention or reduction of marine fouling of devices is a problematic issue that will need to be addressed. Fouling of submerged structures by encrusting organisms is a problem common to all operations that take place in the marine environment. Fouling will induce a significant drop in efficiency and the common response is to paint the structure with an anti-fouling preparation, many of which are highly toxic. This may be the environmental factor of greatest concern, but concentrations of biocides from the paint will be much lower at good tidal stream sites than in low energy sites (Salter, 2001).

Common concerns about the toxicity of marine paints and the need to ensure corrosion protection and the control marine growth can be readily countered using techniques such as cathodic protection developed from experience with offshore oil and gas development, or by using less environmentally damaging anti-fouling paints. Specific measures, such as self-cleaning mechanisms, for countering fouling of tidal energy devices and reducing maintenance requirements are currently under investigation, but these have yet to be proven.

4.6.2 Hydrodynamic environment and sedimentary processes

Tidal energy schemes, in particular those requiring substantial civil engineering works, are likely to affect the hydrodynamic environment and it is possible that sediment movement out to sea would be impeded. Changes in the pattern of sediment transport, deposition and erosion in an estuary as a result of barrage construction could result in a wide range of possible impacts upon scheme performance, navigation, land drainage and flood protection, water quality, marine biology and the inter-tidal system. Specifically, raised water levels could result in siltation of river channels discharging upstream of a barrage, to the detriment of land drainage and flood evacuation. Changes in the sedimentation pattern could also influence the nature of the seabed e.g. covering of an area of hard rock by sediments, which would in turn lead to changes in colonisation by plants and animals. Sediments also act as a sink for certain pollutants, which could be re-distributed if scour mobilised them.

Tidal Electric acknowledges that its design for a tidal generator based on an offshore impoundment will impact the surrounding area by changing the behaviour of currents and waves, which will in turn change existing sediment transport regimes (Tidal Electric Ltd, 2001). ABP Research Ltd has been commissioned to undertake sediment transport modelling for the Swansea Bay project that will dictate design parameters so that the structure will not deposit more sediment in shipping channels or increase the removal of beach sands. ABP has specific interest in the development of the tidal generator because of the potential implications the structure could have on shipping movements in and out of its ports in Swansea and Port Talbot. It is in ABP’s interests, therefore, that the design of the offshore impoundment does not affect the sediment regime of Swansea Bay, and the study should provide useful information for other potentially similar schemes in North Wales and the Bristol Channel.

It has been proposed that the shape of the seabed should be modified in regions where tidal stream velocities are already high, to increase the velocity further still (Pearson, 2001). Power available from a turbine varies as the cube of the velocity. If the velocity can be doubled, the available power increases by a factor of eight. It is therefore important to make use of velocities which are as high as possible, which would enable the number of turbines required to be significantly reduced, as this would have a marked effect on capital cost. This can be achieved through the creation of artificial reefs that either decrease the cross-sectional area of the flow or deflect flows into preferred areas. ‘Barrier’ reefs to decrease flow would be submerged significantly more than the turbine diameter. On the other hand, ‘deflector’ reefs to deflect tidal stream flow would necessarily be closer to the surface but could, conceivably, be kept below the keel depth of small boats. However, the prediction of the effects of reefs on tidal stream flow is extremely difficult, and would require extensive modelling involving computational fluid dynamics to determine the potential effects on the hydrodynamic environment and associated sedimentary processes (Pearson, 2001).

4.6.3 Visual impact

An important general point arising as a result of barrage construction is the potential change in the character of the foreshore along the enclosed coastline. Construction of a barrage across an estuary could result in upper parts of the existing foreshore being inundated less frequently. Moving the waterline seawards in this way would lead to a change in the character of the foreshore, with a succession to a more terrestrial habitat. There would be some scope for managing the character and use of this new marginal land, e.g. for agricultural purposes. However, the question of whether this change is likely to be ecologically and aesthetically acceptable is an important issue in the overall acceptability of a barrage scheme.

The Environment Trust believes that the major impact of offshore tidal generators based on the impoundment concept will be their visual intrusion on the seascape, which it believes can be alleviated through landscaping. Once the structure has been colonised, the visual impact of the impoundment structure will be minimised.

The visual impact of TSECs is thought to be minimal. Devices are generally submerged out of sight, and the only indication of the presence of a turbine would be the surface piercing structure with mooring rails and ladders. They are therefore likely to be more acceptable closer to shore than wind farms and this can result in significant cost savings through the shorter electrical connection to shore (Fraenkel, 2001). In a review of tidal stream power commissioned by ETSU, Binnie, Black & Veatch (BBV, 2001) concluded that the main visual impact associated with underwater turbines is likely to be the land-based electrical sub-station and power transmission cables.

4.6.4 Emissions and materials consumption

Tidal energy schemes produce no polluting emissions while generating electricity. However, emissions are produced and resources are consumed during other stages in their life cycle, most notably during construction and installation. There are also certain aspects of operation which give rise to emissions, such as the provision of spares and maintenance, and the provision of power to the scheme when the turbines are not running, which will incur emissions from the average generating mix (ATLAS(a) website). These are likely to be of greatest significance for large-scale civil engineering projects, such as tidal barrages and offshore tidal generator impoundments. The emissions associated with the construction and operation of the STB are shown in *table 4.2*.

The impoundment structure for the offshore tidal generator proposed by Tidal Electric will be constructed of locally obtained loose rock, sand and gravel and is described as having a ‘natural appearance’, similar to existing shoreline coastal defence projects (Tidal Electric, 2001). There has been discussion of using ash from the Fifoots coal power station, slate waste, steel slag and other ‘waste’ type materials in the construction of the Bristol Channel tidal power plant, which would presumably be less expensive. The RSPB has been commissioned by Tidal Electric to assess the potential impacts of the use of these materials. According to Tidal Electric, ‘…the economics of using these materials would have to be compelling for them to be included in the design’ (Tidal Electric, 2001).

Table 4.2 Emissions associated with the construction and operation of the Severn Tidal Barrage

Parameter	Value
CO_2 Emission Factor (kg/TJ)	1622
SO_2 Emission Factor (kg/TJ)	19
NO_x Emission Factor (kg/TJ)	5
Particulates Emission Factor (kg/TJ)	0
VOCs Emission Factor (kg/TJ)	<1
CO_2 Emissions during construction (kg/TJ)	5163
SO_2 Emissions during construction (kg/TJ)	52
NO_x Emissions during construction (kg/TJ)	23

(source: ATLAS(a) website). *Note:* These values are based on a preliminary assessment and are merely indicative.

4.6.5 Decommissioning

The technical life of barrage schemes would be upwards of 120 years for the civil structure. Major electrical generation plant turbines would have a technical life of about 50 years. This is also likely to be similar for Tidal Electric’s offshore impoundment. Bulb-type turbine/generator sets have been in use at La Rance since the 1960s and are only now beginning to show signs of age. The economic life for barrage projects has yet to be defined. Decommissioning costs have not been estimated for any barrage project as it has been assumed that they would become permanent structures.

Decommissioning of TSECs has so far received little consideration since no devices have been deployed commercially. Prototype designs have provided for ease of maintenance and modification by enabling devices to be recovered simply, and it is assumed that devices will be completely removed at the end of their useful lives. Nevertheless, a full strategy for safely removing the device and for disposing of any non-recoverable items must be prepared in consort with the detailed design of the machine.

4.7 SOCIO-ECONOMIC IMPACTS AND SEA-USE CONFLICTS

The socio-economic impacts of certain types of tidal energy schemes are likely to be more significant in comparison to most other marine renewable energy projects. Some of these effects may be beneficial, and some potentially adverse. A tidal barrage is considered to have the greatest potential for socio-economic impact, and the issues have been well documented in the case of the proposed Severn Tidal Barrage. It is widely accepted that such a scheme would have many national and regional benefits. For example, it is estimated that the construction would provide some 200,000 man-years of work, and 35,000 people would be employed during the peak period. Many of the jobs that would be created would be in shore-based construction facilities. Furthermore, once the barrage is operational, it is anticipated that up to 30,000 new permanent jobs could be created in south-west England and South Wales (STPG, undated).

Apart from employment opportunities, construction of the barrage is predicted to have positive effects on inward-investment. For example, regional economic growth rates are predicted to increase by between 2 per cent and 2.75 per cent, and there could be an associated increase in land values. Promoters of the STB claim that leisure and tourism could also benefit through the creation of a large area of protected water with a more stable tidal range and reduced current velocities. This would allow a more extensive range of leisure activities, e.g. sailing, canoeing, wind-surfing, and water-skiing, to occur on the estuary. Greater recreational opportunities could result in an increased demand for marinas, water-sports facilities and accommodation (subject to planning constraints). It is anticipated that the STB will itself become a tourist attraction, drawing up to a million visitors a year (STPG, undated). Increased leisure use of the estuary would need careful zoning to avoid conflict between the various recreational activities, commercial shipping, and environmental conservation interests.

The most recent proposal for the STB incorporates a trunk road running across the Barrage, which would connect Cardiff and Swansea with Bridgwater and Exeter. Such a road would significantly reduce travelling times between these areas, enabling other parts of the country, particularly the manufacturing regions, to benefit from new business prospects created by the Barrage. However, as the power generated by the Barrage would be available through the Grid, there is no obvious reason why industries should be located near to the Barrage.

A major effect of the STB would be to enclose some of the ports in the Severn Estuary behind a barrier, which could potentially restrict vessel navigation and availability of port access. Vessels would be required to pass through two locks in the Barrage, which could delay transit time, particularly if operational difficulties occur. Navigation may also be affected by changing the water levels and, possibly, by modifications in the pattern of sedimentation. The latter could result in the silting up or gross movement of navigation channels both in the main estuary, and in port approaches. These problems could also potentially affect ports immediately outside a barrage. Various specific engineering recommendations related to locking and navigation requirements can now be made, as can general qualitative statements on the relative impacts of various barrage schemes on the availability of port access, which is a key factor in the assessment of a port’s economic viability. However, in a climate of intense competition, port authorities are understandably apprehensive about any potential cause for loss of trade.

Tidal Electric’s proposed offshore tidal lagoons will necessarily have to be sited in shallow water, as the power source is the difference between high and low tide, and should therefore have little impact upon commercial shipping. Any construction below low tide is merely for the purpose of supporting that part of the structure that is above low tide. The navigational hazard presented by such structures would therefore be minimal, as they would be situated well away from shipping lanes in deeper water. It is assumed that such structures would be accurately recorded on charts and would be clearly marked with adequate lights, buoys and radar reflectors. Tidal lagoons may present more of an obstacle to recreational craft, which tend to use near-shore waters, although optimum sites for power generation may not always be suitable environments for recreational boating. Nevertheless, recreational boat users could potentially benefit from the area of protected water created on the shoreline side of the impoundment structure, which could prove suitable for mooring small craft. Tidal Electric claims that the proposed installation of a tidal generator impoundment off the North Wales coast is being hailed by the local recreational boating sector as a boon to their business, as it will create a large area of calm water in which pleasure boats can moor and marinas can operate (Tidal Electric, 2001).

Tidal stream turbines could pose an obstacle to shipping, although the majority of high energy locations with fast currents are usually close to a rocky shore, and are not in areas that are used as shipping lanes. All the resource studies undertaken so far have assumed that only areas outside regular shipping lanes will be used for tidal stream energy systems. Recreational craft may not necessarily be affected because devices would be submerged by several metres, although there is concern over the potential effects of the wake vortex on small sailing vessels.

Certain designs of TSECs may pose more of a navigational obstacle than other devices. For example, vertical axis rotors are surface-piercing (albeit with a reduced visual profile), whereas other devices may be completely submerged. Installations can be accurately recorded on charts, and carry lights and radar reflectors. Arguably they may serve to assist navigation in the same way that navigation buoys do, by being more identifiable to mariners than unmarked and often hazardous natural features nearby. On the whole it is likely that tidal stream devices will be less hazardous to ships than natural hazards and other vessels (Salter, 2001).

It is likely that large deployments of tidal stream devices will need to be part of a shipping and fisheries exclusion zone (Fraenkel, 2001). However, high current areas are not generally used for fishing or potting, for obvious reasons. Nevertheless, BBV (2001) notes in its review of tidal stream power that fishing communities are understandably nervous of anything that could infringe upon their livelihoods, and work is needed to prove that tidal stream power can coexist with shipping. In the view of the potentially large tidal current resource around the coast the most appropriate strategy may be to cherry-pick the best sites, those at which no conflicts of interest occur, moving on to the more difficult ones as expertise builds.

To date, no studies have addressed the employment opportunities or economic benefits to local communities of harnessing tidal stream energy. However, it can be assumed that some activities, such as turbine manufacture with its skilled labour force, could provide the basis of continuing employment for manufacturing similar or related products. The benefits will be particularly large for those companies who develop the technology first, with opportunities to sell Intellectual Property Rights (IPR) around the world, and perhaps exclusive arrangements with generating companies (STC, 2001).

5 Wave energy

5.1 INTRODUCTION

Waves, particularly those of large amplitude, contain large amounts of energy. Wave energy is, in effect, a concentrated form of solar energy. Winds generated by the differential heating of the Earth pass over open bodies of water transferring some of their energy to form waves. This power is concentrated from the initial solar power levels of about 100 W/m^2 to waves with average power levels of 70 kW per metre of crest length, winter averages of 170 kW/m and storm levels of over 1 MW/m crest length (ETSU, 2001b).

Despite its early pre-eminence in wave energy research during the 1970s and ’80s under various government and industry sponsored programmes, the UK (with the notable exception of Wavegen and some universities) has failed to exploit this potential. Although wave power was initially perceived as one of the main contenders in the renewable energy field in the UK, the failure of these programmes to deliver economic supplies of electricity left the technology with a credibility problem. Consequently, the ‘deep-sea’ wave programme was wound-up on economic grounds following a review by ACORD, the government’s R&D advisory group in 1982. Since then other countries, including Australia, Denmark, India, Japan, the Netherlands, Norway, Portugal and Sweden – some with much less energetic wave regimes – have either already deployed wave energy schemes, or are planning to deploy them in the near future (Thorpe, 1999). These programmes have developed new devices that represent a significant improvement over older concepts, and this has resulted in a resurgence of interest in wave energy.

In March 1999 the UK government launched its new Wave Energy Programme, which is supporting research and development of prototype wave energy converters. Worldwide, a variety of wave energy devices (WEDs) have been proposed, utilising different energy extraction methods. Many have not progressed beyond the design stages, although several have been deployed at sea as prototype or demonstration schemes. All these devices are relatively small in size and output (the largest is 2 MW), in order to reduce prototype costs (enabling easier funding) and the technological challenges. The range of devices is described in *section 5.2*.

5.2 TECHNOLOGY DESCRIPTION

Wave energy devices (WEDs) extract and convert the energy generated by waves into a useful form, usually mechanical motion or fluid pressure. There are several methods of doing this, involving oscillating water/air columns, hinged rafts, and gyroscopic/hydraulic devices which convert the mechanical energy into electrical power using a generator. Alternatively, direct drive generators are being contemplated where the motion of the wave is converted directly to electrical power (ETSU, 2001b).

Wave energy converters can either be deployed on the shoreline, in shallow coastal waters, or in deeper waters offshore. The most popular and well-developed technologies are the Oscillating Water Columns (OWC) and the Tapchan, which are designed to be fixed to the shoreline. These are termed ‘first generation devices’. Lessons learned from the construction and operation of these early WEDs led to the development of second generation devices, which incorporated modifications on earlier designs. The second generation of WEDs also include near-shore and point absorbers, such as float systems, which are arguably more suited to more modest wave climates such as the Mediterranean (Duckers, 1998). Third generation devices are designed to capture the greater energy of deep-water waves and may be deployed offshore in the longer-term future.

5.2.1 Shore-based devices

Fixed generating devices, which are mounted either to the seabed or shoreline, are easier to fabricate and maintain than offshore systems. In addition, they do not require deep-water moorings or long lengths of underwater electrical cable. However, shore-based systems capture much less energy as they experience a much less powerful wave regime (Thorpe, 1999). Bottom friction reduces power levels in depths less than 80m, so that inshore sites get less than a quarter of the deep-water resource (ETSU, 2001b). This can be offset by choosing favourable locations where the effects of wave refraction focus wave energy. However, the overall shoreline resource available is much smaller and locally attractive sites are at a premium. Furthermore, energy from easterly winds is not available. The deployment of such schemes could also be limited by requirements for shoreline geology, tidal range, existing shoreline use, and nature conservation designations.

Oscillating water column

The majority of shore-based systems are Oscillating Water Columns (OWCs), which consist of a partially submerged hollow structure that is open to the sea below the waterline. Electricity is generated by a two-step process. As a wave enters the column, air is forced up the closed column past a turbine and increases the pressure within the column. As the wave retreats, the trapped air is drawn back past the turbine due to the reduced air pressure on the seaward side of the turbine. A Wells turbine is usually used, which as the property of rotating in the same direction regardless of the direction that the air passes the blades (Thorpe, 2001). The rotation of the turbine is used to generate electricity.

The first UK onshore OWC, built on Islay in the Inner Hebrides by Queen’s University Belfast was dismantled in 1999. Although it had a very low power rating (75 kW), it served a useful purpose as an experimental test-bed and survived for eight winters on the edge of the Atlantic. A second larger OWC, called the OSPREY (Ocean Swell Powered Renewable EnergY), which incorporated a wind turbine (rated at 1 MW) was planned for installation by Applied Research Technology (ART – now Wavegen) 300m off Dounreay. However, the device was destroyed by heavy waves during installation in 15m of water. The 2 MW prototype, which cost around £3.5m, was holed below the waterline before the steel ballast tanks could be filled with sane to stress the tanks and anchor the complete unit securely on the seabed. Unfilled, the tanks were very vulnerable and the unseasonal storms during deployment in August 1995 made it impossible to repair the cracks that opened up.

The experience gained in the construction and attempted deployment of OSPREY has proved invaluable and has accelerated the deign of subsequent devices, including the LIMPET – a second-generation shorelines wave energy converter (*box 5.5*), and WOSP 3500 (*box 5.1*). A new OSPREY design has also been developed (OSPREY 2000), which will be a composite steel/ concrete construction with installation procedures designed to minimise the time required to install the device in open waters. The device reportedly has a 60-year structural design life with a 20 year M&E plant upgrades, and is designed to operate in 15m of water within 1 km of the shore, generating up to 2 MW of power for coastal customers.

Box 5.1 Wind and Ocean Swell Power (WOSP) 3500

WOSP is an integrated near-shore wave and wind powered station designed by Wavegen. It is the most recent development of the OSPREY concept. Similar to the OSPREY 2000, the wave energy device, which is rated at 2 MW, is based on the principle of an OWC. However, WOSP maximises the renewable energy resource of the near-shore environment through the addition of a 1.5 MW marinised wind turbine on top of the device, which brings the installed capacity up to 3.5 MW for each system. Wavegen argues that the extra structural loading from a wind turbine of up to 1.5 MW is low compared with the wave loading for which the OSPREY structure is designed, and it is well within the capacity of the OSPREY base to support a wind turbine. The power generation of the wind and wave units is integrated through the on-board power electronics and fed via a common cable to shore.

The benefits of WOSP, as perceived by Wavegen, include:
- greatly increases accessible renewable energy resource;
- substantial installation and infrastructure cost reductions;
- integrated project development reduces fixed costs;
- offshore siting minimises visual intrusion of wind turbines;
- combined wind and wave energy fluxes complement power output; and
- wind turbines pre-installed before launch avoids costly offshore installation cranes.

As with OSPREY, WOSP modules are designed to be installed individually or in multiple units when larger quantities of electricity are required.

Tapered Channel Devices (TAPCHAN)

The TAPCHAN is the first successful export of Norwegian technology for capturing wave energy. It consists of a tapered channel that feeds into a reservoir at a higher elevation. The narrowing of the channel causes the waves to increase their amplitude (wave height) as they move towards the reservoir, until the wave crests eventually spill over the walls of the channel into the reservoir several metres above sea level. The stored water is then returned to the sea via a conventional low-head turbine – an adaptation of traditional hydroelectric power production. Since the TAPCHAN has few moving parts (all contained within the generation system), it has low maintenance costs and a greater reliability than other shore-based devices. Also, the system is able to provide power on demand, as the reservoir is able to store the energy until it is required.

The first system was built on an island near Bergen in 1985, and Ross (1998) reported on Norwegian plans to build a £6 million 1.1 MW wave power station based on the TAPCHAN concept in Java, which was due for completion in the winter of 1998. Chile, India and Sri Lanka have also expressed interest in the system. Unfortunately, TAPCHAN systems are not suitable for all coastal regions as they require deep water close to shore, consistent waves with good average wave energy, and a tidal range of less than 1m. The potential market for such a device is therefore limited within Wales.

Pendulor Device

The Pendulor device consists of a rectangular box, which is open to the sea at one end. A pendulum flap is hinged over this opening, so that the action of the waves causes it to swing back and forth. This motion is then used to power a hydraulic pump and generator. Worldwide, only small devices have been deployed, most notably in Japan.

5.2.2 Offshore systems

The power available in waves is much greater offshore. These devices, deployed in waters at depths from 30m to 100m, are designed to exploit the greater wave power density offshore before energy dissipation mechanisms have had a significant effect. There is a much larger number of possible sites and hence a larger accessible resource offshore. However, devices are subject to more powerful waves than shoreline devices and therefore face greater technical challenges.

In order to extract energy from the waves, the devices need to be at, or near, the surface, and therefore require flexible moorings and electrical transmission cables. Transmission costs and losses will therefore be higher, but with power rising with the square of the amplitude and stresses (and so structural costs) rising a little less than the first power, the cost effectiveness should improve (ETSU, 2001b). In deeper water there is also more of a chance to yield to extreme loads. However, the obstacles to the early deployment of prototypes offshore are greater than for those onshore or near-shore. Several different types of offshore device have been developed, but none has yet been deployed commercially. The four main categories of offshore devices are described below.

Box 5.2 The IPS OWEC Buoy System

Two Swedish companies, Interproject Service AB (IPS) and Technocean (TO) have developed an ‘Offshore Wave Energy Converter’ or ‘OWEC’ of the buoy type, based on 20 years of research, laboratory tests and full-scale trials in the open sea. The developers claim the system, which is ready for commercial production, is very flexible and has an efficiency of 30-35 per cent from waves to electricity under good conditions.

The basic unit consists of a circular or oval buoy with diameter and weight adapted to the predominant wave climate at the deployment location. The buoy is held in position by an elastic mooring enabling it to move freely up and down against a dampening water mass contained in the long vertical tube (the acceleration tube) below the buoy. The relative movement between the buoy itself and the water mass is transferred by a working piston in the acceleration tube into an energy conversion system located within the buoy hull.

Production buoys with diameters from 3-4m up to 10-12m can be arranged in groups upwards from five units. The dimensions of the buoy are dependent on the oceanographic location, water depth, wave climate, seasonal variations and desired power output. Every unit can be a complete power station. Alternatively, groups of IPS OWEC buoys may be connected to a central generation unit. A minimum water depth of 20m is required for optimal performance, although the design can be modified to operate in shallower water at a reduced efficiency.

The developers claim that in waters west of Scotland and Ireland, where wave energy is of the order of 50-70 kW/m wave front, a 10m IPS OWEC Buoy will generate more than 1.4 GWh of electric energy per year. The total investment cost per installed kW is claimed to be low in comparison with other renewable energy systems, with production costs in the region of 0.25 SEK/kWh (£0.02 / kWh) or less (Interproject Service website).

Float-based devices

Float systems generate electricity through the harmonic motion of the floating part of the device as opposed to fixed systems, which use a fixed turbine powered by wave motion. If the motion of the float is reacted against an anchor or other structure that resists motion, then energy can be extracted (Thorpe, 1999). Floats can act as point absorbers, which draw in energy from a width of water greater than their own physical diameter. The point absorber concept, which uses a large array of small devices to capture energy, is attracting increasing research interest. Such arrangements can be highly efficient, and the relatively small structures are well suited to modularised line production (Duckers, 1998).

One example of a device using a float is the *Swedish Hosepump*, which has been under development by Technocean since 1980 (Sjostrom, 1993; Bergdahl, 1992). The device consists of a specially reinforced elastomeric hose (the internal volume of which decreases as it stretches), connected to a float that rides the waves. The interior of the Hosepump is filled with seawater. The rise and fall of the float stretches and relaxes the hose thereby pressurising the water, which is fed through a non-return valve to a central turbine and generator unit. In this manner, several Hosepump modules can be connected together. A system of five modules connected in parallel to a single turbine and generator was installed in Lake Lygnern. During 1983-4 a plant consisting of three modules with a turbine and generator was installed in the open sea at Vigna. Despite losses of equipment in severe storms, the tests proved the feasibility of the approach. Currently there are plans for commercial deployment of Hosepump/IPS buoy systems (*box 5.2*) in several countries.

Pneumatic devices

Offshore pneumatic devices utilise air as the medium for generating electricity, in a concept similar to a shore-based OWC. A floating OWC was developed in the UK Wave Energy Programme but was discontinued in favour of the bottom-fixed near-shore device (Thorpe, 1999). Research in Japan, however, has continued to focus on developing a large, floating OWC known as the *Mighty Whale*. A prototype of the device is currently being tested by the wave energy group at the Japanese Marine Science and Technology Centre (JAMSTEC), in 40m of water in Gokasho Bay off Mie Prefecture. The overall rated power capacity of the prototype is set at 110 kW and it is hoped that the device could provide an energy supply to fish farms in the calm waters behind the device, and aeration/purification of seawater. If the device achieves its predicted performance and reliability, it is intended that this will be the start of a large, national deployment programme for Japan (ATLAS(b) website).

Box 5.3 Archimedes wave swing

Research into the Archimedes Wave Swing (AMS) has been undertaken by Teamwork Technology of the Netherlands since 1994. In April 1999 the conceptual design of the AWS was finalised. The device, constructed using knowledge and experience gained from the dredging industry, consists of a number of inter-connected, air-filled chambers of 10-20m diameter, situated below the sea surface. These are topped with moveable floats, similar to hoods, on the air chambers, which oscillate vertically with wave action. As a wave crest moves over a hood, the pressure on it rises, the trapped air is pushed into another chamber, and the hood starts to sink. The process is reversed in a wave trough. Each wave repeats this process.

The mechanical power required to damp the free oscillation is converted into electrical power by means of a specially designed 'Power Take-Off (PTO) System', which consists of a linear electrical generator and an electronic converter. The complete structure is submerged and installed on the seabed, with the top of the structure approximately 10m below sea-level. The support structure is mounted on a pontoon, which allows the device to be brought to the surface when problems occur. Currently a 2 MW demonstration unit (1:2 scale of the future commercial system) is being tested in Portugal. This is the most powerful WED currently in operation.

The next device is already under development and will be a 5-6 MW unit with a single mooring point. The design is being subjected to stability studies with the aim of installing the first of many units in a 'wave park' in autumn 2003.

For further information see *www.waveswing.com*

Another pneumatic device is the *SEA Clam*, which is the result of research by Coventry University. The device utilises a flexible membrane or bag to enclose a volume of air. As the bag is compressed by wave action it drives air through a turbo-generator. The latest concept involves a twelve-sided hollow ring, 60m in diameter with flexible outer wall sections made of reinforced rubber (Jamieson, 2002). As waves compress these sections, air is forced via a central chamber through a Well's turbine. The circular design of the device allows it to receive waves from any direction. The prototype unit is rated at 2.5 MW, although a system of five units could provide an output of 12.5 MW (Thorpe, 1999; Jamieson, 2002). No information on costs is at present available.

Moving body devices

These are the most sophisticated type of offshore device and comprise a solid body which moves in response to wave action or motion of water particles (Thorpe, 1999). Many different moving body concepts have been developed world-wide. The two best known designs are the *Archimedes Wave Swing* (*box 5.3*) and the *Edinburgh Duck* (also known as *Salter's Duck*) (*box 5.4*). Two other promising designs currently being developed, based on the principle of point absorbers, are outlined below:

- *McCabe Wave Pump (MWP)*. The device was conceived by Peter McCabe in 1980, and is described in detail by Thorpe (1999). It consists of three narrow rectangular steel pontoons that are hinged across their beam and point into the oncoming waves. The front and back pontoons move in relation to the central pontoon (which is held relatively still by a damper plate) by pitching about the hinges. Energy is extracted from the movement by linear hydraulic ramps. This energy can be used to provide electricity (~ 400 kW) or to produce potable water by supplying pressurised seawater to a reverse osmosis plant. In August 1996, a 40m-long prototype was deployed off the coast of Kilbaha, County Clare, Ireland, and a commercial demonstration scheme is currently being built (Thorpe, 2001).

- *PS Frog*. This device was conceived at Lancaster University and consists of a paddle some 21m wide facing oncoming waves, attached to a cylindrical lower part. The lower part contains all the mechanical and electrical plant including a reaction mass, which moves with respect to the hull. Hydraulic rams allow the 400t reaction mass to move along guide rails as the device moves in a combination of pitch and surge, and enables energy to be extracted via high pressure oil. This oil feeds an accumulator (to smooth out power fluctuations) and thence a hydraulic motor and electrical generator. The device, which weighs 110t and has a displacement of 1300t, is connected to the seabed by compliant moorings. It can be moored in a wide range of water depths, but 40m is thought to be optimum. The average annual capture efficiency has been estimated at 66 per cent for random seas with an average power output of 529 kW per device (Thorpe, 1999). An independent analysis (Thorpe, 1999) concluded that while the device is an elegant theoretical concept, it has yet to undergo detailed design and analysis. As such, its productivity and costs are subject to considerable uncertainty. Nevertheless, there appear no insuperable difficulties in developing a viable device.

Hydroelectric devices

Several designs of this type of WED, which operate on the same principle as the TAPCHAN, have been produced. The forerunner is the Floating Wave Power Vessel (FWPV) developed by Seapower International AB of Sweden. In April 1999 Seapower was awarded a Scottish Renewable Order (SRO) guaranteeing it a 15-year contract with Scottish Power plc and Scottish and Southern Energy plc, to supply electrical energy to Shetland. The station, which was due to start operating in late 2002, weighs 1,200 tonnes and is capable of producing a maximum output of 1.5 MW. A site 500m off Mu Ness, near the Dale of Walls on the west coast of Shetland, has been selected for the project (Shetland Times, 05/09/00).

The FWPV concept is based on a floating platform that continuously shifts to accommodate the incoming waves. The waves break against a ramp (an artificial steep beach) and spill into a basin. The basin is regulated at a certain height above sea-level and the water is released via a number of low-pressure turbines that drive electrical generators. Computer controlled ballast tanks support the FWPV and take the platform to a suitable depth to optimise the efficiency at different wave heights and lengths. Automatic remote sensors detect extreme storm events and the device is programmed to sit lower in the water and allow extreme waves to pass over the entire structure. The anchoring system is designed to withstand a 100-year wave event. As the FWPV is a floating device, it can be built at a shipyard and towed into position.

Box 5.4 Edinburgh Duck

The Duck was one of the first WEDs to emerge from the 1970s wave programme. The approach adopted by the Edinburgh University team led by Dr Stephen Salter was to develop a WED which would exploit the maximum amount of the wave energy resource available in deep water (Thorpe, 1999). This required the Duck to operate under more energetic wave regimes, which would place great technical demands on the device. The design of the Duck therefore incorporated novel features and unconventional engineering practice, which gave rise to questions over the technical viability of early designs. However, many of the perceived deficiencies have been addressed in a radical re-design of the Duck (Salter 1993; Thorpe, 1999).

The most recent design – the 1998 Duck – basically consists of a series of oscillating 'ducks' linked in a linear fashion along a spine that lies parallel to the approaching wave-fronts. The Duck body is a buoyant cellular structure, slip-formed from pre-stressed and reinforced concrete. One side of the body forms the 'beak' of the Duck, while the other has a concave semi-cylindrical shape which follows the outer contour of the spine. Each Duck body is 45m long with a maximum 14.4m diameter and is designed to be moored in 100m of water. Voids in the Duck provide buoyancy, and the nodding motion of the Duck in response to waves, pumps fluid through turbines to power the generators.

The capital costing for a 2 GW scheme (334 Ducks) was estimated to be around £2.4 billion, which represents a cost reduction of 60 per cent from an earlier design. It has been suggested that such a project could achieve a positive rate of return if it could sell its electricity for 3 p/kWh or more (Thorpe, 1999). The generating costs of the 1998 Duck are estimated to be 5.3 p/kWh and 8 p/kWh at 8 per cent and 15 per cent discount rate respectively.

There are a number of aspects of the 1998 Duck, not least the cost, which require significant research and development to prove the feasibility of the concept (Thorpe, 1999). Arguably, the most significant of these is its sheer size. Capital costs associated with the civil structure and mechanical and electrical plant are accordingly substantial and installation of the infrastructure would present a significant civil engineering challenge (Thorpe, 1999).

5.3 TECHNICAL STATUS IN THE UK

The technical status of WEDs reviewed in this chapter varies widely. Many WEDs have been, and continue to be, proposed. There is no consensus, however, on the best design or any certainty that it has yet been identified (ETSU, 2001b). Some have already been built as full-scale prototypes or demonstration schemes, whereas many WEDs remain at the conceptual or research and development stage.

Most of the research into wave energy capture is being undertaken by small engineering companies. There are few major players world-wide with wave energy forming their main product line. The key player in the UK is Wavegen, which has been responsible for the first commercial wave power station in the UK (LIMPET – see below). The extensive research activities already described, and the inclusion of wave energy in SRO-3 (the first renewables order open to wave power) could result in the deployment of commercial sized WEDs in the next few years.

The current status of wave power in the UK is summarised below:

- Three projects were awarded contracts under SRO-3: (i) LIMPET device (500 kW) shoreline OWC deployed by Wavegen on the Scottish island of Islay in November 2000 (*box 5.5*). The device achieved maximum power output shortly after commissioning was completed. (ii) Pelamis (750 kW) floating offshore device developed by Ocean Power Delivery (OPD) of Edinburgh (*box 5.6*). (iii) Floating Wave Power Vessel (FWPV) developed by Seapower International AB of Sweden, capable of a maximum output of 1.5 MW (*section 5.2.2*).

- Wavegen is currently developing a new generation of LIMPET shoreline devices, which it is believed, together with the new generation of OSPREY/WOSP devices, will form a cluster of wave power stations in the Western Isles.

- Wavegen has also received around US$10m funding for the development of a new offshore device called HYDRA. It is understood that work has been in progress on the floating device for over two years. It has a nominal rating of 2 MW. At this stage technical information regarding the device is not in the public domain. Wavegen hopes to construct the device towards the end of 2002, and test it in the Orkney Islands.

- In addition, Wavegen is developing the POWERBUOY, an offshore floating wave station in conjunction with the oil industry. This will provide sufficient power for pumps and other equipment for satellite wellheads and power-deficient platforms to extend the productive field life. Wavegen believes it will be a key enabling technology in the development of marginal offshore oilfields, where development of a major production platform is not economically justified (Wavegen website).

Recently Wavegen was advised that it is the sole successful bidder for the AER III (Alternative Energy Requirement III) wave energy tender in the Republic of Ireland, following extensive technical and commercial evaluation by ETSU on behalf of the Irish government. The Republic of Ireland has a near-shore wave resource of 48 TWh, but imports more than 90 per cent of its energy requirements.

Box 5.5 LIMPET 500 OWC Wave Device

Following the success of the 75 kW prototype OWC on the Scottish Island of Islay (*section 2.1*), work began in summer 1999 on LIMPET, a second generation shore-based OWC generator. Developed by Wavegen in a joint venture with Queens University Belfast, Instituto Superior Técnico (Portugal), the European Union and Charles Brand Engineering, the project is the first WED in the UK to generate power for the Grid commercially. Rated at 500 kW, it is able to provide enough electricity for about 400 local homes. It received a 15-year contract under the third round of the Scottish Renewables Obligation (SRO-3) in 1999, under which is receives 5.95 p/kWh it supplies to the electricity network. Operational since November 2000, LIMPET is sited at Claddach Farm near Portnahaven on Islay. Facing south-west, this location directly faces the predominant direction of incoming waves, and over a year receives an average wave power of nearly 20 kW per metre of wave front.

LIMPET operates on the OWC principle. The concrete structure is built to form an inclined tube (angled at 45º) with its opening about 2.5m below the mean water level. The collector comprises three 6m x 6m tubes approximately 25m long. Changes in the external water level as a result of wave action cause a variation in the water level within the collector chamber. This variation alternately compresses and decompresses the air within the chamber, causing air to flow backwards and forwards through a pair of Wells turbines. Wind turbines can also be added to LIMPET modules, similar to the WOSP 3500 design (*box 5.1*), to further enhance the power output.

The device is designed to operate right on the shoreline and is built into the surrounding rock. Capital costs of deploying further devices are therefore site specific. According to Wavegen, the 500 kW Islay LIMPET plant cost around US$1.44m to build. Although a commercial plant, it is used for ongoing research and development and as a result it is equipped with additional costly features that would not be required on a production plant (DBEDT Hawaii, 2001). The capture chamber is the major capital item, which uses around 1,200m^3 of reinforced concrete, whereas further devices will use less than 600m^3. Costs could conceivably be reduced by incorporating OWC technology within rubble mounds or caisson breakwaters to provide self-financing coastal protection schemes, providing power or potable water to local communities (Wavegen, 2000). Key innovative features of the shoreline technology, according to Wavegen (2000) are:

- low cost power;
- simple air turbine, providing high reliability;
- maximum local input;
- all electrical equipment on land;
- easy plant access by road;
- easy construction and installation with no marine operations; and
- sixty-year life with minimal maintenance.

According to Wavegen, several factors underpinned the selection of Islay as the site for the current LIMPET project, aside from the favourable wave climate. It is easily accessible and has significant electricity demand that is currently met by importing power from the mainland. Furthermore, the island has a population which is extremely enthusiastic about renewables in general and wave power in particular.

5.4 TECHNICAL VIABILITY

The assessment of the commercial prospects for wave energy is open to debate. OWCs such as OSPREY and LIMPET remain the most well-developed wave energy conversion devices, but they may not be the best designs. The OWC has to stand upright and receive the full impact of the waves on its outer wall, then admit the water through an opening (which is itself a second weak point) near the base and receive another pounding on the back wall as the water surges through the opening. Furthermore, such devices may not be very well suited to areas where there is a large tidal range, as the design of the internal cavity spaces cannot easily be optimised given the variable tidal height. Fixed shoreline OWCs may therefore not be suitable for deployment in the Severn Estuary, although they may be used elsewhere on the Welsh coast in areas of high wave energy and lower tidal range.

Floating devices may have advantages in near-shore locations, but if the technology is to be applied at sea, it may as well be located further offshore to harness the greater energy of offshore waves. The main disadvantage is that power will have to be transmitted back to shore. Unfortunately offshore devices are still mainly in the research and development stage, with much work needed to tackle key development issues, reduce uncertainty and verify the concepts. In the meantime, shoreline and near-shore devices can be perceived as being ‘stepping stones’ to the development of future offshore devices, while being useful in their own right.

Box 5.6 PELAMIS Wave Energy Converter

PELAMIS is a novel offshore wave energy converter being developed by Ocean Power Delivery Ltd (OPD), based in Edinburgh. The device has been the focus of a four-year development programme which recently (March 2002) secured £6m funding from an international consortium of venture capital companies (OPD, 2002). The PELAMIS is a semi-submerged articulated structure composed of cylindrical sections linked by hinged joints. The wave-induced motion of these joints is resisted by hydraulic rams which pump high pressure oil through hydraulic motors that, in turn, produce electricity. Power from all the joints is fed down a single umbilical cable to a junction on the seabed. Several devices can be linked to shore through a single cable. The device is moored with flexible cables which allow the device to face oncoming waves. A 750 kW machine with a similar output to a modern wind turbine will be 150m long and 3.5m in diameter.

The PELAMIS design was conceived from the outset to use proven off-the-shelf technology from the offshore industries. OPD believe that once a market for specialist hydraulic components and power conversion systems has been established through the installation of a significant number of devices, the appropriate industries will develop and manufacture many of the new components required to improve system efficiency and reduce capital costs. Survivability was identified as the key objective of the design, before consideration was given to effective ways of improving power capture. This has resulted in a robust design, which can be installed in a range of water depths and seabed conditions. Furthermore, the complete device can be constructed, assembled and tested off-site with a minimum of installation work required on-site.

OPD aims to have a working prototype producing electricity to the Grid within the next two years (OPD, 2002). The device has already been tested at intermediate scale in the Firth of Forth as part of a DTI-supported programme to address all key aspects of technical risk. Currently a full-scale system is being tested before being installed in the first full-scale demonstration next year (2003).

In 1999 OPD won a contract to install a pair of PELAMIS machines off Islay under SRO-3 (750 kW project). More recently the company has secured an agreement with BC Hydro, the Canadian West Coast utility, to carry out a full feasibility study for a 2 MW scheme for installation off Vancouver Island during 2003. It is anticipated that these projects could form the basis for larger, multi-machine ‘wave farms’. OPD claims such an array of 40 PELAMIS machines (30 MW installation) would occupy a square kilometre of ocean and provide enough electricity for 20,000 homes (OPD, 2002).

5.5 COMMERCIAL COMPETITIVENESS

The lack of commercial WEDs and the commercial confidentiality surrounding new designs mean that the cost and performance of these devices are difficult to assess. There is a very wide range of projected costs from a variety of WED developers and researchers, most of which are based on theoretical calculations or small-scale tests. Only a few are based on working, larger scale prototypes or small commercial facilities. Until large-scale tests have taken place, the lack of in-service data and the consequential theoretical predictions remain an important source of uncertainty (Thorpe, 1999).

What is certain is that wave energy technology is undergoing development, and predicted costs are likely to be reduced. Thorpe (1999) has assessed the predicted generating costs for a range of WEDs at 8 per cent and 15 per cent discount rates. The resulting distributions were then broken down into their lower, middle and upper quartiles, where:

- the lower quartile represents the most favourable combination of all aspects of the scheme;
- the higher quartile is a representation of the risk involved in developing a scheme; and
- the median represents the most likely generating costs, following successful R&D.

Table 5.1 Predicted generating costs at inter-quartile probabilities for a range of WEDs

Device	Cost @ 8% Discount rate (p/kWh)			Cost @ 15% Discount rate (p/kWh)		
	25%	50%	75%	25%	50%	75%
Limpet	5.6	6.2	6.9	8.9	9.7	10.7
OSPREY	4.1	4.4	4.7	6.3	6.8	7.3
Duck	4.7	5.4	6.2	7.4	8.4	9.8
PS Frog	3.1	3.5	4.3	4.6	5.6	6.9
MWP	5.1	5.9	6.8	8.3	9.6	11.1
Sloped IPS Buoy	3.2	3.9	4.7	5.4	6.5	8.0

(*source:* Thorpe, 1999).

The typical inter-quartile range is generally less than 20 per cent of the median value. These values suggest that predicted energy costs for WEDs are not yet truly competitive with electricity supplied from the grid at today's costs (ETSU, 2001b). Further innovation is required to overcome the technical challenges required to achieve true commercial competitiveness. Technology transfers from the offshore oil and gas industries and advances in remote monitoring technology may yield these opportunities. The industry also has the potential to develop economies of scale through mass production by modularisation of the sub-systems (DBEDT Hawaii, 2001).

In the long term the target is for wave power to be commercially competitive without the need for market support measures such as the Renewables Obligation and Climate Change Levy (*box 2.2*). According to the ETSU, the initial target for wave power is for it to achieve the cost of energy expected from the early offshore wind and biomass projects, although ultimately it would need to generate electricity at a price competitive with other sources of energy. In today's electricity markets this is in the region of 2.5 p/kWh, although this is expected to change over time (ETSU, 2001b).

5.6 ENVIRONMENTAL ASPECTS OF WAVE ENERGY CONVERSION

The deployment of wave power schemes could have a varied impact on the environment (Thorpe, 1999), some of which may be beneficial and some potentially adverse. General studies have been carried out on the potential impact of offshore energy devices, as well as Environmental Impact Assessments (EIAs) for specific schemes. However, knowledge of the extent of many potential problems is limited due to the relatively few full-scale projects that have been deployed long-term in the coastal and marine environment (a notable exception being the Islay I OWC).

It is likely that many of the potential impacts would be site-specific and would have to be assessed separately for each scheme. Whether or not any negative effects are tolerable is a case for careful consideration and consultation for individual projects. In a report to the DTI, ETSU advises that as experience of offshore renewables increases and an increasing number of EIAs are undertaken for specific schemes, a range of generic issues may be identified that are common to all wave power devices (ETSU, 2001b). Some of these potential problems are discussed below, along with areas of uncertainty arising from the existing level of knowledge.

5.6.1 Visual impact

The visual impact clearly depends on the type of device as well as its distance from the shore. Offshore devices such as floating buoy systems or floating platforms situated several kilometres from land are likely to have minimal, if any, visual impact due to their low freeboard. Submerged devices will not be visible, apart from the associated onshore cables and transmission network. As much of the coastal area is heavily dependent upon tourism, obstruction-free visual planes may be an important consideration in developing offshore marine renewables in Wales.

Near-shore and shoreline devices are likely to have some visual impact, and such schemes may be particularly sensitive in areas of designated coastline and those use for recreational purposes (Thorpe, 1999). However, the development of high-energy rocky coastlines, the most suitable for shoreline devices, are not likely to present any significant conflicts with other uses of the coastal zone, e.g. tourism. Nevertheless, these coastlines are valued for their rugged beauty and wilderness quality, and the construction of a shoreline device could be considered to denigrate the overall aesthetic value of such an area. Onshore overhead electricity transmission cables may also contribute a detrimental visual impact.

An environmental assessment of a prototype OSPREY device off Dounreay in Scotland was undertaken by Environment & Resource Technology Ltd. (E&RT, 1994), which concluded that 'the device would not be particularly intrusive to the existing view in daylight or at night time'. However, Thorpe (1999) reports that to comply with Northern Lighthouse Board requirements, any such devices would have to be painted yellow and fitted with a revolving yellow light with a range of 2-3 miles. These modifications, along with the addition of a wind turbine as in the WOSP 3500 design (*box 5.1*), are likely to significantly increase the visual impact of the device.

According to Wavegen, the LIMPET device on Islay is positioned such that it is not visible from the road or any of the local houses (DBEDT Hawaii, 2001). However, this device could also become more visible with the addition of an optional wind turbine. Nevertheless, low-profile WEDs are generally far less visually obtrusive than wind turbines which are typically 40-60m in height (*section 6.2*). Furthermore, even large (10m high) WEDs can be incorporated into breakwaters or harbour structures, thus providing electricity for a locality with a high latent demand.

5.6.2 Noise

Some devices are likely to be noisy, especially in rough conditions (Thorpe, 1999). This may be a particular nuisance in the case of near-shore and shoreline devices. However, according to proponents of wave energy conversion, the sound of a device working is expected to be no noisier than the surrounding wind and waves, provided adequate sound baffling is used. On a relatively calm day the LIMPET device is audible from approximately 200m (Ross, 1995) although this may not be representative of other devices as the turbine is enclosed and includes axial sound attenuation. Clearly, noise levels are less of a concern in uninhabited areas.

Sound travels further underwater and this may have implications for the navigation and communication systems of certain marine animals, particularly pinnipeds and cetaceans (Thorpe, 1999; Mirko, 2001; DBEDT Hawaii, 2001). Thorpe (2001) believes it unlikely that cetaceans would be adversely affected, as much of the noise likely to be generated is below the frequency threshold for dolphins, although whales use a broader waveband for communication and sonar. Further research is therefore required to determine any potential adverse effects on marine mammals due to noise from WEDs.

Assuming WEDs do not interfere with the navigational systems of marine animals, the physical barriers posed by such devices are not thought to be a problem, but clearly become more of an issue if several devices are grouped together or are arranged linearly in long lengths. Thorpe (1999) advises that in positioning such schemes, care should be taken to avoid interruptions to migratory pathways and/or breeding grounds.

5.6.3 Disturbance of Benthos and Seabed

One of the greatest impacts of harnessing wave energy on the natural environment results from the construction and maintenance of devices and any associated developments, such as the onshore transmission network and sub-stations. Although many of these impacts are not exclusive to wave energy devices, they should be taken into account in environmental assessment procedures.

Many of the most recent devices are of modular construction and can be assembled in shipyards, which minimises environmental impacts at the site of deployment. Nevertheless, some shore-based systems may require modifications to the existing shoreline. For example, in the case of the prototype Islay OWC, it was relatively easy to build a temporary dam or bund on the shoreline to protect the unit. However, the LIMPET was a much larger device with a 20m-wide lip, and it was necessary to build the unit back from the excavated coastline and remove a protective bund to make the system operational (Fujita Research website).

Installation of the support structures and cable-laying for WEDs may cause disturbance to marine life and compaction of the seabed. However, any such disturbance is thought to be temporary, and the ecology of these areas is likely to recover (DBEDT Hawaii, 2001). On the other hand, the effects on wave climate, and in particular the wave regime, may be more significant. Changes in the wave regime could influence the nature of the shore and shallow sub-tidal areas and the communities of plants and animals they support. According to Thorpe (1999) fixed structures such as the OSPREY are more likely to alter the wave climate than floating devices. However, the ecological impact of changes in the wave climate caused by near-shore and shoreside devices are not fully understood and need to be researched further.

5.6.4 Hydrodynamic environment and sedimentary processes

As previously noted, WEDs may have a variety of effects on wave climate, patterns of vertical mixing, tidal propagation and residual drift currents (Thorpe, 1999). Some devices e.g. TAPCHAN focus wave energy using sizeable barriers that channel large waves to increase wave height for collection in an elevated reservoir. On-shore arrays of such devices could physically alter the coastline through increased coastal erosion where waves are concentrated, and greater sedimentation in adjacent areas (DBEDT Hawaii, 2001).

Offshore WEDs may reduce wave action on the shoreline, particularly if there are large arrays of such devices. Modelling carried out for the assessment of WEDs off the coast of the Outer Hebrides indicated that devices tuned to medium period waves and sited less than 30km offshore would reduce wave height at the shore and favour sediment accretion (Probert & Mitchell, 1979, 1983, cited in Thorpe, 1999). The extent of accretion clearly depends on the amount of sediment available for mobilisation. An environmental assessment of the prototype OSPREY device off Dounreay concluded that there was insufficient information on the behaviour of sediment at these water depths to allow for a quantitative assessment of the likely disturbance (E&RT, 1994). Nevertheless, it was considered unlikely that there would be any significant build-up of sediment in the area of reduced wave activity behind the advice.

As previous work in this area is limited, an assessment of a proposed scheme should take into account any potential effects of the device upon sedimentary processes within the area and the likely effects on flora and fauna.

5.6.5 Anti-fouling

Anti-fouling measures will inevitably be needed to prevent submerged structured being colonised by nuisance aquatic organisms. Colonisation by a wide range of organisms could lead to changes in the corrosion and fatigue behaviour of the infrastructure, reduced efficiency, and could hinder inspection and maintenance of devices.

Specific fouling prevention measures for WEDs have not yet been developed, although existing practices in the shipping and mariculture industries involve the use of anti-fouling paints to prevent the growth of fouling organisms. Anti-fouling paints contain a biocide within the matrix of the paint, which is designed to be released slowly over time into the water surrounding the treated structure. These substances are, by definition, toxic to a range of target and non-target organisms and have the potential to persist and bioaccumulate in the marine environment resulting in chronic toxicity effects.

Fouling of seawater conduits at coastal power stations have been controlled by the injection or electrolytic generation of chlorine. Due to the effects of dilution it is not clear if the use of this measure in a more open sea location might be environmentally harmful. Further research should investigate the numerous options for the prevention of marine fouling, including the use of new, less-environmentally damaging anti-fouling paints.

5.6.6 Emissions

WEDs produce no polluting emissions while generating electricity. However, emissions are produced during other stages in their life cycle (most notably during construction and installation) and these should be taken into account when comparing them with traditional forms of electricity generation. The typical stages in the life cycle of a WED have been identified by Thorpe (1999), as:

- resource extraction;
- resource transportation;
- materials processing;
- component manufacture;
- component transportation;
- plant construction;
- plant operation;
- decommissioning; and
- product disposal.

The most important life cycle stages for atmospheric emissions are those associated with the highest energy use, such as the manufacture of the materials (Eyre, 1995), while energy use in all transport stages is likely to be negligible. Energy use in the construction, decommissioning and disposal processes is also likely to be at least an order of magnitude lower than for materials manufacturing (Thorpe, 1999).

An evaluation of the life cycle emissions for the Wavegen OSPREY device has been undertaken (Bates, 1995 cited in Thorpe, 1999; Thorpe *et al.*, 1998). The results demonstrate that wave energy (and other renewables) can offer significant reductions in emissions of gaseous pollutants when compared to fossil fuel-based generation. The only exception is for CCGT, where emissions of SO_2 are effectively zero (Thorpe, 1999).

5.6.7 Decommissioning

Some manufacturers claim the lifespan of their WEDs to be of the order of 60 years. However, there is a need to consider from the outset what will happen to these devices at the end of their working lives. Decommissioning of WEDs has so far received little consideration. Every trace of the prototype Islay OWC was removed after eight years, but this was a single device. Removal of a large number of full-scale wave energy schemes would be comparable in cost to decommissioning offshore oil and gas installations.

In reality the disposal of thousands of tonnes of concrete and steel pose significant problems. Leaving seabed-mounted devices to natural erosion or reducing them to rubble on the seabed may be the cheapest option, but would cause a permanent alteration to the inshore environment. On the positive side they would create artificial reefs that attract fish and increase the habitat diversity of the area. However, diversity is not always an attribute when assessing the marine conservation value of an area and the effects of artificial reef creation can be unpredictable on indigenous marine species. Further work is needed in this area. Decommissioning of WEDs on land may be more expensive, but would allow the scavenging and recycling of useful parts.

5.7 SOCIO-ECONOMIC IMPACTS AND SEA-USE CONFLICTS

The socio-economic impacts of wave energy conversion are not significant compared with conventional power stations, or indeed other renewable energy schemes. The main issues are outlined in the following sub-sections.

5.7.1 Navigational hazard

Once in position, WEDs could pose potential navigational hazards to shipping due to their low freeboard, which could make them difficult to detect visually or by radar (Thorpe, 1999; DBEDT Hawaii, 2001). For single devices this could be overcome by detailed recording of positions on navigational charts and by making devices more visible through the addition of reflective paint, lights and transponders.

Clearly marked navigational channels would have to exist between large deployments of WEDs. Thorpe (1999) reports that several of the areas proposed for WEDs around European coastlines are in major shipping channels. Risk assessment studies should address the possibility of collision in these areas, as the consequence of an incident involving an oil tanker could have a devastating impact on adjacent shorelines.

5.7.2 Interaction with commercial and recreational fishing

Deployment of WEDs could lead to resource use conflicts, particularly if the designated area is already supporting other economic activities. There would be considerable opposition, for example, to a wave energy scheme positioned within established fishing grounds or in nursery areas. This highlights the need for wide consultation before proceeding with any schemes. For safety reasons it may be desirable to establish an exclusion zone around WEDs to protect mooring and anchoring lines. This would result in a larger area dedicated to wave energy conversion than occupied by the devices. This could impinge on other activities, particularly if there is an extensive array of WEDs.

Decommissioning devices on the seabed may also affect the ability to fish an area using trawl nets, although the creation of an artificial reef is likely to favour recreational angling opportunities.

5.7.3 Interaction with recreational activities

Conflict could arise in siting WEDs if the scheme is thought to interfere with other potential uses of the coastal zone such as recreational boating, surfing and windsurfing, and beach use. The latter may not be an important consideration as WEDs are typically located in high energy environments, predominantly on exposed rocky coastlines. Certain recreational activities such as windsurfing and dinghy sailing could potentially benefit from the more sheltered areas created behind and array of offshore WEDs.

5.7.4 Local communities

Manufacture of WEDs could bring employment opportunities to some communities, particularly in areas where there is a shipbuilding tradition and the knowledge base and experience gained from the offshore industries. For instance, there is speculation that Wavegen will choose to manufacture a series of new WEDs for deployment off the Western Isles at Arnish on Lewis, leading to an early re-opening of the yard (DTI, 2002d). Such facilities provide an ideal opportunity for renewables related manufacturing, while contributing to the re-generation of an industry in decline.

The government has stated its belief that it is essential that communities should see direct, tangible benefits from renewable energy developments in return for accepting and promoting them (DTI, 2002). Crofting communities are entitled by law to half the development value of projects which take place on their land. Speaking in May 2002, Energy Minister Brian Wilson stated: ‘If crofting law did not exist in the Highlands and Islands then it would have to be invented for this purpose… That is a principle which could usefully be applied throughout the UK if we are serious about winning acceptance for renewable projects’ (DTI, 2002d). There has been strong public support for renewables projects in crofting areas, which is related to the perceived benefits in terms of both jobs and royalties. This conveys a message to potential developers that if they want support for their projects they should offer something in return. Furthermore, the minister assured landowners, and in particular community-owned estates in the Highlands and Islands, of the DTI’s support along with the Scottish Executive in identifying and developing potential renewable energy assets at their disposal (DTI, 2002d).

6 Wind energy

6.1 INTRODUCTION

The UK's offshore wind resource has the potential to provide more than three times the country's present electricity needs (BWEA website). This makes offshore wind power one of its most promising renewable energy technologies. Conservative estimates suggest that wind alone could meet the government's 10 per cent renewables target by 2010, which would require 12,000 MW of turbines (WWF-UK, 2001).

There are presently more than 50 onshore wind-farms in the UK consisting of arrays of several or several tens of turbines. However, future development of this form of renewable energy on land may be limited by the availability of physically suitable sites where planning permission is likely to be forthcoming. Consequently, developers are starting to look offshore to harness the wind's energy. Wind speeds are often significantly higher offshore than onshore (typically up to 0.5 m/s higher 10 km offshore) and are generally less turbulent, which contribute to the attraction of offshore sites.

Faced with similar limitations in their own countries, the Danish, Dutch and Swedish governments have, over recent years, undertaken research into the potential for siting wind-farms offshore. Denmark in particular pioneered the move to offshore wind-farms, with two offshore pilot plants of 5 MW each constructed by the electric utilities in Vindeby and Tunø Knob in 1995, culminating in the recent 40 MW installation close to Copenhagen. In comparison, the UK government has been slow to promote offshore wind energy but now looks set to follow and build upon successful experimental work elsewhere in Europe. A number of companies have expressed an interest and demonstrated their technical expertise for developing offshore wind power projects, and proposals are being looked upon favourably by the UK government.

The following section describes the technology and key issues associated with harnessing offshore wind. It is followed by an outline of the current status of offshore wind development in the UK and a summary of potential future developments. *Section 6.5* provides an understanding of the commercial competitiveness of offshore wind and the targets it needs to achieve to become viable. The chapter concludes with an assessment of the potential environmental and socio-economic impacts of developing offshore wind energy.

6.2 TECHNOLOGY DESCRIPTION

Wind energy has been harnessed for more than 2,000 years and is a technically proven energy technology. The use of wind as a renewable energy source involves the harnessing of power contained in moving air. Wind turbines use aerodynamic forces ('lift' and 'drag') to produce mechanical power that can then be converted to electricity.

Wind turbine technology used in present offshore projects is largely an adaptation of onshore systems, and consists of standard machines in the 450 kW to 600 kW range, usually with some additional corrosion protection. Each turbine consists of two or three rotor blades that drive a generator, mounted on a supporting tower that is set into a foundation. Sub-sea cabling feed the generated electricity from the turbine into the transmission network.

6.2.1 Size of turbines

Cutting the extra costs associated with the move offshore has been the major challenge in the development of offshore wind turbines. Sub-sea cabling and special foundations are the key parameters that determine cost (Greenpeace, 2000; Krohn, 2001). In the case of the Danish offshore wind-farm at Tunø Knob (1995), where turbines are located in 5-10m of water, foundation costs per turbine accounted for 23 per cent of project costs while grid connections were around 14 per cent of project costs (Krohn, 2001).

The cost of laying sub-sea cable is governed by the length of cable rather than its capacity. For example, the cost of installing a sub-sea 150 MW cable is not very different from the cost of a 10 MW cable. Therefore, a wind-farm of a given capacity composed of a small number of larger units will have a lower cost compared to a wind-farm of the same capacity composed of a larger number of smaller units. Wave energy is the most important factor in determining the required strength and weight of foundations for offshore wind turbines. Consequently, offshore turbines are generally larger than their onshore counterparts (2 MW and above), since the size and cost of foundations do not increase in proportion to the size of the wind turbine (Krohn, 2001). Larger machines also save money on maintenance, due to the smaller number of units that have to be visited by boat.

Typical offshore turbines are of the order of 2 MW to 3 MW, although units of up to 5 MW are already under construction (ETSU, 2001c). Turbines rated 2 to 2.5 MW typically have rotor diameters of around 70-80m. Hub heights above sea level vary between 60 and 80m, and are generally somewhat lower than hub heights of onshore machines of the same rating, due to lesser variations in wind speed above sea level. The minimum hub height offshore is dependent upon ensuring a minimum 1.5m gap between wave crest and any structure not deigned to withstand wave impact (Greenpeace, 2000). Most designs also incorporate a maintenance stage at the lower part of the tower, which must be kept clear of the rotor-swept area. The distance between the seabed and rotor axis necessarily increases in deeper water. For example, in water depths of about 30-40m, support structure heights will be about 100m.

6.2.2 Marinised wind turbines

Although it is unlikely that there will be any major changes in turbine concept with the move from onshore to offshore in the short term (ETSU, 2001c), interesting modifications on conventional onshore designs are beginning to appear.

Electrical Interconnection

Since the beginning of offshore deployment, high voltage transformers have necessarily been installed in turbine towers. These provide the advantages of better corrosion protection and generate heat, which prevents cold starts of the turbines (Krohn, 2001). However, there are several problems associated with the use of high voltage a.c. (HVAC) sub-sea cables, including power absorption by the cables, high losses, and high capital costs (ETSU, 2001c). These have led to interest in the use of high voltage d.c. (HVDC) cables, which may become economically viable at distances greater than 15 km between wind-farm and grid connection.

Rotor speed

Rotor speeds of modern onshore turbines are optimised for minimum noise emissions. This may be less of a consideration offshore, allowing a 10 per cent increase in rotor speeds. This would increase the effectiveness of the turbines by around 5-6 per cent. According to Krohn (2001), the increase in noise is not a concern, as the theoretical sound level reaching shore several kilometres away would be of the order of –3dB (A). Most current turbine designs have three rotor blades, but with reduced requirements for noise, there is a move towards two blades, which also allows reduced manufacturing costs.

Protection from the elements

Offshore marine turbines have to be effectively protected from corrosion caused by water and salt. Icing of the rotor is not considered to be a major problem in UK waters. Corrosion protection of outer surfaces is usually achieved through heavy painting with preparations commonly used in the offshore industries, or other surface protection techniques such as electro-zinc coating or treatment with petroleum-based agents (Greenpeace, 2000). Turbines are generally painted in the standard NATO light-grey camouflage colour to reduce the visual impact from shore. Allegedly, turbines become invisible from the shore in hazy conditions (Krohn, 2001). Electronic and electrical components are located inside the nacelle and are shielded from marine environmental influences, but special provisions are usually taken to ensure protection against vapour and salt in the ambient air.

6.2.3 Support structure

Foundations account for around 16 per cent of the total cost for an offshore wind-farm. There is, therefore, a strong incentive to develop cost-effective support structures (foundation and wind turbine towers). There are two broad options:

- bottom-mounted support structures (gravity-based/monopile/tripod); and
- floating support structures.

The choice of support structure depends upon the seabed conditions and water depths (DTI, 2002). In relatively modest water depths of 40-50m as experienced around much of the UK coastline, bottom-mounted structures are usually favoured. In existing offshore wind-farm developments only bottom-mounted support structures of the gravity-based type (e.g. Vindeby and Tunø Knob, Denmark) and the monopile type (e.g. Bockstigen, Sweden and Blyth Offshore, UK) have been used (Greenpeace, 2000). The various options are outlined briefly below:

Gravity-Based Support Structure

Traditionally, offshore wind turbines have been built on reinforced concrete foundations. Concrete caissons are built onshore in a dry dock and floated out to sea where they are filled with sand and gravel and sunk to the seabed. For a 1.5 MW turbine, the weight of the ballasted concrete caisson is around 1500 tonnes, depending upon site conditions. The world's largest wind farm, the 40 MW facility installed at Middelgrunden outside the Port of Copenhagen (*box 6.1*), utilises concrete caisson gravity-based foundations. A recent modification on the traditional design involves the use of a cylindrical steel tube instead of a concrete caisson, set on a flat steel base on the seabed. These are considerably lighter than their concrete counterparts, allowing barrages to transport and install many foundations rapidly. The foundations are filled with olivine, a very heavy mineral, which gives the support structure sufficient weight to withstand waves.

Box 6.1 Middelgrunden Shoal Offshore Wind-Farm

The inauguration of Middelgrunden Offshore wind-farm took place in Copenhagen in May 2001. Middelgrunden occupies a shallow area east of the northern tip of Amager. Here 20 wind turbines are installed in a slight arc with a total length of approximately 3.4km. The wind-farm has been established as a collaboration between the Middelgrunden Wind Turbine Co-operative and Copenhagen Energy, each installing 10 turbines. The distance between individual turbines is 183m and the wind-farm as a whole occupies an area of about 1ha.

The installed capacity of the wind-farm is 40 MW. The twenty 2 MW turbines have a total estimated electricity production of about 90,000 MWh/yr, which would provide approximately 3% of the electricity consumption within the municipality of Copenhagen. In November 2001 the turbines reached a peak record production of 5,137 MWh.

Since 1980 Middelgrunden Shoal has been used as a dumping area for construction waste, which has reduced the water depth to around 2-6m. Gravity foundations in reinforced concrete were cast and prepared locally in the Port of Copenhagen. Construction work began by removing the top layer of the seabed. The foundations were placed on solid ground then the mono-towers mounted on the foundations before finally erecting the nacelle and three rotor blades. The turbines, produced by Bonus Energy A/S of Denmark, have a hub height of 64m and a rotor diameter of 76m. The maximum distance from sea level to tip of the rotor blade is 102m.

The wind turbines are connected by a 30 kV electricity grid, and each turbine can produce independently of the other turbines. Cables between the turbines are dug 0.5m into the seabed. The energy is routed to the central turbine (No. 10), then transported through a 30 kV sub-sea cable to the Amager Power Plant.

Monopile Foundations

Monopile foundations are effectively extensions of the turbine support towers, which are either rammed or drilled into the seabed. The arrangement enables lateral and axial forces to be transferred to the seabed. Pile penetration into the seabed is of the order of 18-25m. Maximum water depth for monopile structures is though to be about 25m (Ferguson 1998a, cited in Greenpeace, 2000). This type of support structure has been used in the Bockstigen wind-farm, south of the Swedish island of Gotland, where five 0.5 MW turbines have been installed **on monopiles in 8-10m water depth.**

Tripod Foundations

Originating from the offshore oil and gas industry, this arrangement consists of a three-legged steel platform (tripod) which distributed the loads from the turbine tower to three piles at the corners of the frame, which are driven into the seabed. Penetration depths are of the same order as monopile foundations, although pile diameters are smaller. These foundations have the advantage that they require less protection against erosion than other type of foundations, which generally have to be protected by boulders in sandy areas (Krohn, 2001). So far this arrangement has not been used in wind energy applications. However, as it is suited to deeper waters, it has potential for sites further offshore.

Floating Support Structures

The problem of being constrained to shallow and moderate water depths by bottom-mounted structures can potentially be overcome by using floating support structures. This could extend development of wind-farms further offshore into water depths of up to several hundred metres. This could reduce the visual impact of wind-farms from the shoreline while also avoiding sensitive coastal areas. Two feasible types of floating support structures have been designed in the UK:

- *Buoy Type Support Structures (e.g. FLOAT system)*. The design comprises a turbine tower bolted onto the deck of a cylindrical buoy hull, which is moored to the seabed. The buoy is ballasted in the lower part to provide stability. The complete FLOAT structure (including a 1.4 MW wind turbine) would be floated out to the site of deployment where, in the first phase, mooring lines and anchors would already be installed.

- *Semi-submersible Support Structures (e.g. MUFLOW – Multiple Unit Floating Offshore Wind-farm)*. In this design the main support structure is located below the water surface. The hulls are manufactured from concrete and braced to an overall support structure capable of carrying a cluster of 3-6 multi-megawatt wind turbines. The complete arrangement is moored to piled anchor points on the seabed. The designers claim the MUFLOW system can be deployed in water depths between 75m and 500m.

It should be noted that both systems are at the conceptual design stages with limited test-bed modelling to substantiate their viability. Furthermore, it has been estimated that the increased costs involved would yield electricity prices twice as much per kWh compared to bottom-mounted schemes. There is currently, therefore, no incentive to develop these systems to exploit deep-water sites.

6.3 Technical status in the UK

A total of 10 offshore wind-farm projects are at present operational worldwide (*table 6.1*), although only one of these developments is located in UK waters. Although the concept of locating wind turbines offshore to take advantage of the wind resource around the UK coast was conceived more than 20 years ago, it took until 1996 for the first applications to be made under the fourth round of the government's NFFO renewables support scheme. These were for two developments off the east coast of Britain, at Gunfleet Sands in Essex and at Blyth in Northumberland. Blyth Offshore became the UK's first offshore wind-farm, when it was commissioned in December 2000. The development comprises two 2 MW Vestas turbines erected one kilometre off the coast at Blyth in an average depth of 8m (*box 6.2*).

Table 6.1 Present deployment of offshore wind-farms worldwide

Location	Country	Online	MW	Number	Rating
Vindeby	Denmark	1991	4.95	11	Bonus 450 kW
Lely (Ijsselmeer)	Holland	1994	2.0	4	NedWind 500 kW
Tunø Knob	Denmark	1995	5.0	10	Vestas 500 kW
Dronten (Ijsselmeer)	Holland	1996	11.4	19	Nordtank 600 kW
Gotland (Bockstigen)	Sweden	1997	2.75	5	Wind World 550 kW
Blyth Offshore	**UK**	**2000**	**3.8**	**2**	**Vestas 2 MW**
Middelgrunden, Copenhagen	Denmark	2001	40	20	Bonus 2 MW
Uttgrunden, Kalmar Sound	Sweden	2001	10.5	7	Enron 1.5 MW
Yttre Stengrund	Sweden	2001	10	5	NEG Micon NM72
Horns Rev	Denmark	2002	80	40	Vestas 2 MW

(*source:* www.offshorewindfarms.co.uk)

Box 6.2 Blyth Offshore and Blyth Harbour Wind-Farms – Two UK firsts

Blyth Offshore wind-farm, commissioned in December 2000, is the first offshore wind-farm to be built in UK waters. Two Vestas V66 turbines, each of 2 MW capacity, are among the largest erected offshore anywhere in the world, and are capable of producing sufficient power annually to supply 3,000 average households. The wind-arm is located 1 km offshore of Blyth Harbour in Northumberland, in an average water depth of 8m. The project was developed by Blyth Offshore Wind Ltd., a consortium comprising Powergen Renewables, Shell, Nuon and AMEC Wind. Construction started on the £4m project in July 2000. Financial support was received from the EC Thermie Programme.

AMEC Marine, Seacore and Global Marine Systems were the main contractors on the project. The three-blade turbines, which are situated 200m apart, have a hub height of 58m and a rotor diameter of 66m. The rotor blades rotate at a speed of 21.3 rpm. Each turbine weighs 180 tonnes. The scheme generates electricity at a cost of around 5 p/KWh. CO_2 displacement is estimated to be about 10,000 tonnes per annum.

The project was originally awarded a NFFO-4 (4th Round Non-Fossil Fuel Obligation) contract on the basis of two smaller machines. As a result of upgrading to 2 MW machines, a second power purchase contract was obtained in the competitive market for the remainder of the increased generation. The wind-farm is being monitored and evaluated as part of the DTI's Wind Energy Programme, which aims to enable offshore wind power development and to support the industry.

Blyth was the site for the UK's first semi-offshore wind-farm in 1992 – the Blyth Harbour Wind-farm. Nine 300 kW wind turbines have been erected along the East Pier breakwater at Blyth Harbour, providing an overall capacity of 2.7 MW. The breakwater is aligned to the prevailing winds and its sole use prior to the installation of the turbines, was to protect the harbour. The wind-farm concept was proposed by Border Wind in 1990 and was awarded a contract under NFFO-2. Funding was provided through the EC's THERMIE initiative. The turbines have a hub height of 30m and a rotor diameter of 25m, and are located within 300m of habitation. The total average annual energy production for the farm is 7.1 GWh, which is sufficient to supply 1689 average households in a year. Displacement of CO_2 and SO_2 emissions are estimated to be 6102 tonnes and 71 tonnes respectively. The capital cost of the project was £3.3m (1992 prices). The wind-farm was commissioned in January 1993.

For further information see:
http://www.bwea.com/map/blyth.html and
http://www.bwea.com/map/bowl.html

The Crown Estate, as landowner of the seabed out to the 12 nautical mile territorial limit, has a key role in the development of the offshore wind industry in the UK by leasing areas of the seabed for the placing of turbines (Jacobson, 1998). The Crown Estate's announcement of the first major round of UK offshore wind-farm development in December 2000 caused much interest from potential developers. As a result, eighteen companies pre-qualified for site-development under the Crown Estate procedures in April 2001 (*table 6.2*). However, the Crown Estate will grant a lease only when the developer has obtained all the necessary statutory consents from the responsible Government Departments. In other words, the Crown Estate has no regulatory responsibility and successful developers will have to apply through the DTI, DTLR and MAFF, as appropriate, to gain the consents necessary before work on the new sites can commence. To assist in this process, the DTI has established an Offshore Renewable Consents Unit (ORCU) to act as a 'one-stop-shop', which has streamlined the process of gaining consents.[21]

[21] ORCU will be publishing a guidance note on the consents process for developers.

The Crown Estate procedures for Round One limited the area of seabed to 10 km^2, a maximum of 30 turbines and a minimum installed capacity of 20 MW. Round One sites were chosen by potential developers on the basis of a range of relevant factors including water depth, wind resource and grid connection. Areas of high nature conservation value were avoided, as well as areas of seabed where existing activities and uses were perceived to be incompatible with offshore wind-farm development. At the present stage of technical development water depth, grid connection and cable length are the major economic and technical considerations. As a result, all the proposed wind-farm sites are in water depths of less than 20m, and no greater than 12km offshore (Crown Estate website).

Table 6.2 Pre-qualification for site development after Round One leasing procedure by the Crown Estates

Site Name	Company	Development	Location	Proximity to Shore
Solway Firth	Solway Offshore Ltd; Offshore Energy Resources Ltd (OERL)	2 x 30 turbines	Off Maryport and Rockcliffe	9.5km (Eng) 8.5km (Scot)
Barrow	Warwick Energy Ltd	1 x 30 turbines	Off Walney Island	10km
Shell Flat	Shell WindEnergy Aegir Ltd; Elsam A/S; CeltPower Ltd	3 x 30 turbines	Off Cleveleys	7km
Southport	EnergieKontor UK Offshore Ltd	1 x 30 turbines	Off Birkdale	10km
Burbo	SeaScape Energy Ltd	1 x 30 turbines	Off Crosby	5.2km
North Hoyle	NWP Offshore Ltd	1 x 30 turbines	Off Prestatyn	6km
Rhyl Flats	Celtic Offshore Wind Ltd (COWL)	1 x 30 turbines	Off Abergele, N Wales	8km
Scarweather Sands	United Utilities Green Energy	1 x 30 turbines	Off Porthcawl	9.5km
Kentish Flats	NEG Micon	1 x 30 turbines	Off Whitstable / Herne Bay	8km
Gunfleet Sands	Enron Wind Gunfleet Ltd	1 x 30 turbines	Off Clacton-on-Sea	7km
Scroby Sands	Powergen Renewables Offshore Wind Ltd	1 x 30 turbines	Off Caister	2.3km
Cromer	Norfolk Offshore Wind	1 x 30 turbines	Off Mundesley (Foulness)	6.5km
Lynn	AMEC Offshore Wind Power Ltd	1 x 30 turbines	Off Skegness	5.2km
Inner Dowsing	Offshore Wind Power (Site No.1) Ltd	1 x 30 turbines	Off Ingoldmells	5.2km
Teeside	Northern Offshore Wind Ltd	1 x 30 turbines	Off NE Teesmouth and Redcar	1.5km

(*source:* www.offshorewindfarms.co.uk/devs.html; WWF-UK, 2001)

The above proposals, pending the appropriate consents, are expected to be the first tranche of offshore wind development. There are three sites in Wales: Rhyl Flats, off Abergele (150 MW); North Hoyle, off Prestatyn (90 MW); and Scarweather Sands, off Porthcawl (90 MW). North Hoyle was granted final consent in early October 2002 for a project of up to 30 wind turbines, 7.5km offshore. The development will receive a £10 million share of the funds available under the Capital Grant scheme available for offshore wind energy projects (*section 6.3.1*).

The proposed Rhyl Flats development comprises 30 turbines, each with an output of between 2.5 MW and 5 MW, which will be situated approximately 10km from the North Wales coast, north-west of Rhyl. The wind-farm would supply up to 150 MW of renewable electricity into the existing North Wales electricity network, which would be sufficient to supply the domestic electricity demand of about 105,000 households on an annual basis. The wind turbines will consist of a tower up to 100m tall, on which will be mounted a rotor with a maximum diameter of 105m. The maximum height to vertical blade tip will therefore be 152.5m (COWL, 2002). Sub-sea cables will come ashore at a ‘landfall’ point near Towyn and will run underground for about 1km to a sub-station or metering building. They will then be routed on overhead wooden poles for a further 6km to the existing electricity lines near Moelfre. Subject to gaining the necessary planning consents, construction is planned to start in 2004 and the wind-farm would then operate for 20 years before being decommissioned and removed.

The proposed development at Scarweather Sands comprises 30 turbines, each with an output of 3 MW, which will be situated between eight and 11km offshore to the south of Port Talbot. The total installed capacity of the wind-farm will be 90 MW. According to the developers (United Utilities Green Energy Ltd.) the wind-farm will provide power for up to 45,000 homes and will save an estimated 3.1m tonnes of CO_2 emissions over its 20-year operational life. It will cost up to £60m to develop. Each turbine will have a hub height of approximately 75m and a rotor diameter of approximately 80m. Onshore ancillary development of a control building, and connection to the local electricity grid will also be included in the planning application. Subject to gaining the necessary planning consents, construction is planned to start in 2004/05.

Four other proposed sites for wind-farm development are in Liverpool Bay, which could have landscape implications for Wales. Together, these four projects would have a contract value of at least £500m, and would provide for the electricity needs of more than 400,000 homes (Palmer, undated). One of these sites, Burbo Bank at the entrance to the River Mersey, is the location for a proposed 90 MW wind-farm, consisting of 30 turbines, each capable of producing a maximum expected power output of 3 MW. With project planning, environmental studies and the consenting process expected to take at least two years, construction is scheduled to start early in 2004 and be completed before the end of that year. With a projected energy yield of 315 GWh/yr, Burbo Offshore is expected to generate enough electricity to power the equivalent of over 72,500 homes in Merseyside.

The remainder of this section focuses briefly outlines the North Hoyle Offshore Wind-farm, which will become Wales’ first offshore wind-farm when construction is completed in late 2003.

6.3.1 North Hoyle Offshore Wind-Farm

Final consent was granted in October 2002 for National Wind Power (NWP) Offshore Ltd[22] to develop the first offshore wind-farm in Wales, off the North Wales coast. The North Hoyle Offshore Wind-farm (North Hoyle) will be located approximately 7.5km off the coast between Prestatyn and Rhyl in Denbighshire, and will be one of the largest offshore wind-farms to be built in UK waters. The consent is for a project of up to 30 wind turbines with a maximum total installed capacity of 90 MW. The wind-farm will produce sufficient electricity for a minimum of 50,000 homes every year (equivalent to approximately one third of all the homes in Denbighshire, Flintshire and Conwy, and will offset the annual release of some 180,000 tonnes of CO_2.

NWP Offshore Ltd selected North Hoyle as the location for the offshore wind-farm because the site has the following distinguishing attributes (NWP Offshore Ltd., 2002):

- as an offshore location the proposed site is currently undeveloped;
- an excellent wind resource (which has been monitored by a 50m tall mast since summer 1999);
- relatively low exposure to large waves from the predominant wind direction (SW/W);
- relatively shallow water depth (7-11m) for the corresponding distance from shore, with a 9m tidal range;
- good seabed properties for foundations and sub-sea cables;
- strong electrical infrastructure near to the coast;
- port facilities suitable for construction and operations (Liverpool, Mostyn and Rhyl); and
- no known environmental sensitivities.

The wind turbines have preliminary dimensions not exceeding a maximum tip height of 130m above mean sea-level, with a nominal 80m hub height and 100m rotor diameter. The wind turbines will be inter-connected by buried cables, which will also comprise internal fibre-optic communication links for wind-farm control purposes. The proposed onshore connection point to the electricity distribution system is the existing 132 kV sub-station at Rhyl, operated by Scottish Power (Manweb) plc.

Construction is anticipated to last for eight or nine months, with four or five months of work offshore during the summer months. NWP Offshore Ltd hopes to complete the wind-farm by Autumn 2003 (NWP Offshore Ltd, 2002).

Regulatory and policy context

In addition to consent under Section 36 of the Electricity Act 1989 for the wind turbines, anemometry mast and associated cables, NWP Offshore Ltd also required a licence from the National Assembly for Wales (administered on its behalf by DEFRA) under Section 5 of the Food and Environment Protection Act 1985 for the placement of wind turbine support structures in the seabed (and for scour protection if required). A consent was also required from the DTLR

[22] National Wind Power was formed in August 1991 and is a subsidiary of Innogy plc. Of NWP's 13 wind-farms in the UK, six are located in Wales, representing a total investment of around £80m. Innogy's retail business, npower, supplies gas and electricity to around seven million customers. The application for the wind-farm was submitted by NWP's wholly owned subsidiary, NWP Offshore Ltd.

under Section 34 of the Coast Protection Act 1949 for the erection and maintenance in navigable waters of the wind turbines, their support structures and the cables, as far as mean high-water. Permission was also required from Denbighshire Authority under Section 57 of the Town and Country Planning Act 1990 for the onshore electrical infrastructure.

An Environmental Statement was produced as part of the consents procedure, which evaluated the potential effects of the wind-farm on all environmentally valuable or sensitive features of the marine environment (NWP Offshore Ltd, 2002). Wide consultations were also undertaken with regulators (DTI, NAW, DEFRA, DTLR, and Environment Agency); statutory consultees (i.e. CCW, government agencies and local authorities); non-statutory consultees, and the public (through project briefings and public exhibitions). NWP Offshore Ltd claims that 'no significant environmental effects have been identified' in relation to the development (NWP Offshore Ltd, 2002). However, there are features of ecological value in the vicinity of North Hoyle, including a number of statutory and non-statutory designated sites, which could be sensitive to the development. The potential impact upon these is considered in the wider discussion of the environmental effects of offshore wind-farms in *section 6.6*.

NWP Offshore Ltd is reportedly exploring ways in which the local community can be engaged and involved in the North Hoyle development. One idea being considered is the establishment of an educational Renewable Energy Centre for local people and tourists, possibly linked with boat trips to view the wind turbines (NWP Offshore Ltd, 2002). Another distinctive aspect of North Hoyle is that more than 15,000 electricity customers have already signed up to be supplied by the wind-farm before it has been built. This has been achieved through JUICE, the UK's first non-premium 'green' electricity product available to domestic customers (*box 6.3*).

Box 6.3 JUICE

JUICE was launched in Rhyl, North Wales on 1 August 2001 by npower, the national energy supplier, and Greenpeace. JUICE is described as a 'pioneering "clean" electricity product', which allows consumers to purchase electricity from renewable sources. Customers are guaranteed that for every unit of electricity they use, a unit of 'JUICE electricity' is fed into the National Grid, ensuring an equivalent amount of electricity is supplied from renewable sources.

JUICE does not carry a premium price and will enable 50,000 domestic electricity customers to receive their electricity from clearly identified renewable sources at the same cost as any other npower customer. By Winter 2003, JUICE will be sourced from the North Hoyle offshore wind-farm being developed by NWP Offshore Ltd, npower's sister company. Until then, JUICE supplies are being provided from existing onshore wind sources and the hydroelectric plant at Dolgarrog in Snowdonia.

JUICE is available to all domestic UK electricity customers. The scheme has already attracted some 15,000 customers, which represents one quarter of the UK's domestic green energy market. According to NWP, the initiative has galvanised public support for renewables and, in particular, wind energy. Mathew Spencer, Climate and Energy Campaign Director with Greenpeace commented that
'…many hundreds of JUICE customers have lobbied hard in support of this scheme. I'm sure it will have contributed to the DTI's confidence in giving approval to the scheme in record time…We're going to raise our sights and see if we can persuade the government to set up much more ambitious targets for offshore wind.'
ENDS Report 31 July 2002
For further information about JUICE visit: www.npower.com/juice or www.greenpeace.org.uk

6.4 TECHNICAL VIABILITY

The technical potential for electricity production from offshore wind in the UK is well in excess of predicted electricity demands. However, the practical offshore wind resource is limited by cost (*section 6.5*). As distances from the shore and water depths increase, the costs become prohibitive. Closer to shore and in shallow water depths, the resource is constrained by environmental and socio-economic concerns (*sections 6.6* and *6.7*) (ETSU, 2001c).

In the UK, the offshore wind energy market remains substantially influenced by government policy and incentive/market enablement mechanisms. Under these mechanisms the first medium-sized offshore wind-farms will be developed up to 2010 (*section 6.3*). The Capital Grants programme in combination with the Renewables Obligation and the Climate Change Levy could provide the support and market stimulation needed for offshore wind to make a significant contribution to the 10 per cent renewables target by 2010. However, offshore wind is unlikely to be commercially competitive outside the Renewables Obligation without further innovation (ETSU, 2001c).

Most European wind-farm manufacturers have increased turbine sizes in an effort to reduce wind-farm costs, since larger machines enable significant savings to be achieved in the costs of turbines, foundations and electrical interconnections. Although the technology has developed rapidly over the last decade, there is a general consensus that significant further improvements can be made in terms of both performance and costs (OWE, 2001). Arguably, in the short term the priority is to resolve problems associated with reliability and installation expediency of offshore turbines. The logistical difficulties presented by locating turbines offshore imply a much improved reliability requirement be placed on offshore turbines compared to their onshore counterparts. Research is continuing into the effects of subjecting specific wind turbine variants to offshore maritime conditions, and into innovative and evolutionary design of structures and components to improve turbine reliability and efficiency.

The difficulty associated with the installation of turbines is an inherent technical and economic problem to the viability of an offshore wind-farm, mainly due to the weather constraints and type of equipment required (OWE, 2001). Traditionally, floating cranes and jack-up barges have been used during installation, borrowing from technology developed for oil and gas exploitation. Costs may be significantly reduced if a technological solution can be devised to eliminate the need for such expensive vessels to be deployed during installation and major maintenance activities.

All current and planned wind-farms are in shallow water and based around structures resting on or piled into the seabed. Long-term goals for offshore technology should address siting turbines in remoter/deeper water further offshore. This may demand research into the engineering and economic feasibility of floating wind turbine systems for deep-water sites. At present, costs of moorings and floating platforms (together with the need for lengths of flexible transmission lines) are significantly greater than the cost of fixed seabed foundations in shallow water. The use of floating offshore wind energy will therefore depend critically on two factors – whether costs can be brought down, and whether land-use pressure in shallow water sites will encourage the move further offshore. The hydrocarbon deposits located offshore are currently the principal energy source for the UK. However, some of the gas reserves in these offshore fields are difficult to exploit and extract economically. The combined use of small, currently uneconomic gas reserves for power generation, together with wind turbines on a floating structure has been proposed as a novel way of ensuring security of energy supply in the future (Henderson & Patel, 1998).

With the advancement in tidal stream turbine (*chapter 4*) and wave technology (*chapter 5*) there may also be scope for integrated wind/wave hybrid devices. These could be mounted on support structures (foundations) with extended design lives that allow them to be refurbished and re-used as bases for second-generation devices when the mechanical components are decommissioned.

6.5 COMMERCIAL COMPETITIVENESS

Until the mid-1990s, large-scale development of offshore wind-farms was not really considered economically viable. A number of factors combine to increase the cost of offshore wind-farms compared with development on land (BWEA, 2000):

- The cost of cable connection from the wind-farm to the shore. This increases with the distance from the shore and accounts for between 17 and 34 per cent of the total cost.
- The need for more expensive foundations. Costs increase with water depth and can account for up to 80 per cent of the total cost.
- Increased operation and maintenance costs, with a risk of lower availability due to reduced access to the wind turbines during bad weather.
- The need to ‘marinise’ wind turbines, which may add up to 20 per cent to turbine costs.

Other costs incurred, which may be greater than those for onshore turbines, include insurance and legal costs, bank fees, interest during construction, and development and project management costs. Costs for wind-farms are very site-specific and depend on the site location and conditions. Furthermore, there is difficulty in comparing the costs of energy produced (OWE, 2001), due to:

- differences in project financing (life-time, interest rates, etc.);
- costs of operation and maintenance; and
- commercial nature of projects means that this information is not in the public domain.

Costs are therefore not compared on an equal basis since it is not possible to locate investment and operation and maintenance costs for each project. Bearing this in mind, future Danish offshore wind-farm projects show projected installed capital costs in the region of £1,100 per kW. This would yield an energy cost to Danish utilities of 3.5-4 p/kWh. The DTI has reached a similar estimate of capital cost in the region of £1,000 per kW installed, based on turbines installed quite close to shore (between 5km and 10km) and in shallow water (5-10m deep) (DTI, 2001c). These costs are roughly 30 per cent more than for onshore turbines. With the current financing structure in the UK, this would lead to offshore wind energy generation costs in the region of 5-6 p/kWh (OWE, 2001).[23]

According to ETSU (2001), the target for offshore wind energy beyond 2010 is to achieve the same cost of electricity as onshore wind energy (for similar wind speeds at hub height). The average prices of energy from land-based wind-farms have dropped from 4.32 p/kWh to 2.02 p/kWh for large schemes, and from 5.29 p/kWh to 3.01 p/kWh for smaller schemes (DTI Wind Energy Fact Sheet 3, 2001). This price reduction has been achieved largely through reductions in the capital cost of the wind turbines. The International Energy Agency (IEA) forecasts that onshore wind energy costs may fall further to 1.5 p/kWh by 2020 (ETSU, 2001c). This target has been translated by the DTI into the following development targets for offshore wind (*table 6.3*):

Table 6.3 Targets for commercial competitiveness

Performance measure	Target	Comments
Offshore wind-farm capital and installation cost	£750 / kW installed by 2010	This is the upper limit of current onshore costs
Offshore operation and maintenance costs	1 p/kWh by 2010	Typically onshore has costs a little under 1 p/kWh for modern turbines
Offshore wind-farm availability	95% by 2010	98% plus is achieved for onshore, but with very high accessibility for maintenance and repair

(*source:* ETSU, 2001c).

[23] A direct comparison should not be made with the Danish projections because Danish utilities' calculations are based on rates of return of ~5 per cent. The UK financial industry uses a much higher rate of return for commercial projects in the region of 15 per cent.

Future offshore wind-farms will benefit from cost reduction in the following areas:

- reductions in the relative costs of development resulting from the scale of projects;
- reduced wind turbine costs as designs are optimised for offshore conditions;
- reduced foundation costs resulting from new techniques (mainly the use of monopiles); and
- reductions in relative costs of sub-sea cables resulting from the scale of the projects and the use of new techniques such as direct current (dc) transmission.

6.6 ENVIRONMENTAL EFFECTS OF OFFSHORE WIND-FARMS

The development of offshore wind-farms is essentially a new industry in the UK, although certain aspects of construction, operation and decommissioning in the marine environment share many characteristics with the existing offshore industries (Metoc plc, 2000). As such, there is uncertainty over the type and magnitude of environmental effects associated with the development of offshore wind-farms. It is recognised that while wind energy has many positive environmental attributes and represents one of the few essentially sustainable energy sources, there are certain issues associated with the industry that may cause environmental concern. These issues need to be examined and assessed on an individual basis under the consenting procedure, for each proposed development.

A few studies have been carried out specifically on the potential environmental impacts of harnessing offshore wind energy, while other studies on the resource potential of offshore wind power and industry reports have made reference to likely environmental effects (usually positive). In addition, there are a number of Environmental Impact Assessments for specific projects, mainly from Denmark, Sweden and an increasing number from the UK. However, UK experience of EIA of offshore wind energy projects is still relatively limited. Recognising this, the DTI commissioned a study, conducted by Metoc plc, to help develop an agreed approach to the formal environmental assessment of large-scale offshore wind-farms around the UK coast and to highlight key research requirements to address areas where knowledge is lacking. The study identified the following phases in the life cycle of wind-farm development that could have an impact upon the environment (Metoc plc, 2000):

- **Manufacture and transport**
    - manufacture of components;
    - transport of components to port;
    - storage of components on the docks;
    - marine transporting of components to site of installation;
    - moving drilling barge/jack-up pontoon to installation site.

- **Installation of cables and turbines**
    - marine construction vessel activities on site;
    - foundation installation and associated site preparation;
    - disposal of any spoil excavated during installation;
    - installation of tower, nacelle, generator, hub, and blades;
    - cable installation (using techniques such as trenching or jetting methods, or by laying cables on the seabed) between turbines and to shore;
    - construction of ancillary buildings and infrastructure such as terrestrial cables to link the development to the National Grid, and associated traffic.

- **Normal wind-farm operation**
  - physical presence of the towers;
  - rotation of the wind turbine blades;
  - presence and operation of routine maintenance vessels;
  - physical presence and operation of ancillary structures including the cables and poles;
  - emergency repair of the turbines.

- **Wind-farm decommissioning**
  - removal of foundation, tower, nacelle and blades;
  - re-use/disposal of foundation, tower, nacelle and blades;
  - removal of cables and associated ancillary structures.

Having identified the key activities associated with developing offshore wind energy that could have an environmental effect, the following sections provide an objective summary of the current understanding of the likely environmental impacts on the marine environment. However, the significance of any potential effect can only be determined in a site-specific context, which would require an evaluation of the baseline conditions and potential changes to them. Further valuable information on the likely environmental impacts of offshore wind energy will therefore become available through the increasing number of EIAs undertaken for specific projects. It is important that this information is widely disseminated and shared in order to strengthen the knowledge base, inform the consents procedure for future developments, and target areas of research to modify and improve turbine design, installation and operation to minimise the environmental effects.

6.6.1 Biological impacts

Birds

The UK has some of the largest seabird concentration in Europe and many sites have been designated as Special Protection Areas (SPAs) under the EC Birds Directive 79/409/EEC. The protection requirement regarding SPAs are given in Article 4(4) of the Directive, where it is stated that ‘member states shall take appropriate steps to avoid pollution or deterioration of habitats or any disturbance affecting the birds, insofar as these would be significant having regard to the objectives of this Article’. Furthermore, member states shall, according to the Directive, ‘assess any plan or project that, either by itself or in combination with other plans or projects, is likely to have a significant effect on an SPA, and ensure that any such plan or project is not approved if it would adversely affect the integrity of the site, unless there are “imperative reasons of overriding public interest”.’

The Royal Society for the Protection of Birds (RSPB) has recommended that offshore wind-farm developments should avoid sites of national and international importance for birds or migratory paths (Metoc plc, 2000). Should this advice be followed, evidence from the literature suggests any detrimental effects upon bird populations are likely to be minimal. However, this raises the important issue of how close a wind-farm can be located to a designated bird protection area without causing any detrimental effects to the site or the bird population it supports. In Denmark, the Rødsand offshore wind-farm will be situated a mere three kilometres away from an SPA, which raises questions relating to the interaction of bird populations with wind-farms and how it can be ensured that such developments do not affect the integrity of bird populations.

Disturbance to birds can occur during the construction phase when cranes and vessels or construction platforms (jack-ups) are deployed, piles are rammed, wind turbines are installed, and cables are laid. The type of foundation may be significant, as it is expected that the ramming of a monopile could cause noise levels up to 150 dB and could potentially disturb both breeding and staging birds. If a caisson-type of foundation is chosen, the noise level during the construction phase will be lower (Ferguson, 1998b), although there may be increased disturbance of the seabed and benthos (*section 6.6.3*). Construction and installation will typically take place during the summer months, and may last for several months. Temporary displacement of birds during this period, however, is not considered to be a significant issue (Greenpeace, 2000; EC, 1999).

Greatest concern over the impact of offshore wind-farms on birds has been expressed in relation to the barriers posed by wind turbines, and the risk of birds colliding with the turbines as they move the short distances between feeding and roosting grounds, or between feeding grounds and breeding sites (Dirksen *et al.*, 1996, cited in Greenpeace, 2000). There is some evidence to suggest that collisions may occur most frequently at night and in weather conditions with reduced visibility. This has lead to calls for turbines to be brightly painted or illuminated to improve their visibility (also to other sea users), although this conflicts with the aesthetic requirement of turbines visible from the shore.

There appears to be a lack of consensus on the interaction of birds with offshore wind-farms, with some studies suggesting that birds tend to avoid the vicinity of turbines (Greenpeace, 2000), and other studies concluding that offshore wind-farms are likely to have little or no impact upon bird populations. These studies suggest that bird behaviour and mortality rates tend to be both species- and site-specific, making it difficult to reach any general conclusions on the extent of potential impacts. In particular, the behavioural patterns of a species may dictate the degree to which it is affected by a wind-farm development. For example, many species including eiders and common scoters are nocturnally active (although flight intensity is far less in dark periods than in moonlit periods), which could make these species more susceptible to colliding with turbines. Certain other bird species including raptors, divers or loons, ducks and waders are also reported to be more sensitive to disturbance caused by wind-farm construction and operation (Metoc plc, 2000). Studies on the offshore wind-farm at Tunø Knob have shown that common eiders and common scoters actively avoid the vicinity of the wind-farm by a distance of up to 1,500m (Tulp *et al*., 1999). The area with reduced flight activity not only covers the wind-farm itself (800 x 400m) but also a larger area surrounding it (in total 3400 x 3800m).

Similarly, radar studies from Tjaereborg in the western part of Denmark, where a 2MW wind turbine with 60m rotor diameter is installed, show that birds tend to change their flight route some 100-200m away from the turbine and pass above or around it (EC, 1999). This behaviour has been observed as consistently at night as during the day. This suggests that stationary birds may become familiar with their surroundings and obstacles and the risk of collision may be greater for migrating birds with flight paths across wind-farms.

Estimated annual bird deaths in the Netherlands attributable to collisions with wind turbines (based on a projected 1GW installed capacity) is put at 20 birds per year (EC, 1999). This suggests that more than 300 times as many birds die from collisions with moving vehicles than with wind turbines. Care should be taken, however, in interpreting such estimates as there are too few established offshore monitoring sites with long-term monitoring data upon which to draw firm conclusions. Monitoring of onshore wind-farm sites have demonstrated only minimal effect upon birds (Metoc plc, 2000) and no important effects upon bird populations. Behavioural studies at many of these sites demonstrate that the most common response to wind turbines is for birds to recognise them as obstacles and fly around them (Kerlinger, 2001). However, there is insufficient evidence to substantiate whether this is also the case offshore, as birds may be more susceptible to man-made obstacles at sea. For example, migrating birds offshore tend to fly at lower altitude than over land, thereby increasing collision risk. Furthermore, air pressure, temperature, and wind directions influence flying height and direction, and adverse weather conditions may force seabirds inshore. Migrating birds often have their flight path near the coastline, therefore the effects of a near-shore wind-farm could be greater than on land.

In general the number of birds declines with distance from shore, as there are greater feeding opportunities in shallow water. Siting wind-farms further offshore could, therefore, reduce the risk of collisions, although this would require further technical innovation (*section 6.2.3*). However, it should be recognised that turbine structures, in particular foundations, provide a habitat for fish, colonising organisms and other sources of food, which could also attract birds. While this could provide some benefit by creating new feeding grounds for birds, the incidence of bird strikes is likely to increase.

There is evidence to suggest that the negative effects of large-scale offshore wind-farms on migrating birds could be reduced if the spatial dimensions of the wind-farm are considered. For example, it is believed that larger turbines, being more visible, will reduce the risk of collision (Tucker, 1996). Also, as birds tend to avoid flying between turbines, a sparse layout arrangement is preferable to a long linear layout in corridors lying perpendicular to migration paths (Tulp *et al.*, 1999). This could lead to turbines forming barriers to bird migration, which may lead to long detours or cause birds to abandon staging or feeding sites.

It should be noted that much of this information is conjecture and needs to be substantiated by long-term offshore monitoring studies. The few studies that have looked at coastal (Border Wind, 1996; Still, 1996) and offshore (NERI, 1998) wind-farms suggest that while operational turbines can affect individual birds, leading to effects such as avoidance and bird strikes, the number of losses and degree of disturbance have not been shown to detrimentally affect bird populations. For example, a study of the nine turbines located on the sea-wall at Blyth Harbour indicated that the turbines did not disturb feeding birds. A small number of fatalities were identified (20+ in two years: eider ducks, gulls and cormorants), but the numbers do not suggest population impacts to any species (Lowther, 2000). Nevertheless, consideration should not only be given to number of fatalities but also to which species are adversely affected – for very rare species even small numbers of losses can have a detrimental impact.

Numbers of birds affected depends on the specific site and on the specific distribution of birds, as populations are not evenly distributed, but concentrated in some areas, depending on season and food supply (Greenpeace, 2000). This illustrates the need for each wind-farm proposal to be assessed individually in relation to existing environmental features and bird feeding, staging and roosting grounds, and migration pathways. Where two or more wind-farms are proposed for the same area, the cumulative impact should be assessed (*section 7.4*). As knowledge of offshore bird migration routes is sparse, more studies on bird movements are required and, specifically, on the way in which birds interact with wind-farms during different stages in their seasonal movement cycles and under different light conditions. In addition it is important that these site- and species-specific studies are widely disseminated in order to build up a composite picture of the potential environmental effects of siting wind turbines offshore. In the absence of such information a precautionary approach is recommended, and turbines should be sited away from critical habitats and topographical and other features which could cause birds to concentrate in these areas. Monitoring studies, both before (to establish baseline population numbers), during and after development should be implemented to assess the effects on bird populations.

Marine Mammals

Marine mammals, and cetaceans in particular, may be affected by disturbance and noise during installation and operation of offshore wind-farms. During installation, piling using hydraulic hammers creates high frequency noise on the moment of impact that can be transmitted great distances underwater (Greenpeace, 2000). Cranes, vessels and construction platforms may cause additional disturbance. While disturbance during the construction and installation phase is likely only to be temporary, the operation and maintenance of wind turbines may have a more long-term effect.

Underwater noise from offshore turbines must, of course, exceed the level of underwater background noise (ambient noise) in order to have any impacts on marine fauna. Generally, it is believed that for frequencies above 1kHz, the underwater noise from offshore turbines will not exceed the ambient noise, whereas it is expected that for frequencies below 1kHz, noise from turbines will have a higher level than the background noise. Generally speaking, porpoises and seals are sensitive to high frequency noises, seals in the range from 100Hz to 40kHz, porpoises at 100kHz and higher (OWE, 2001).

Sound power levels for 1 MW offshore turbines are about 103 dB, and for multi-megawatt turbines, some 106 dB are expected (Greenpeace, 2000). However, there is uncertainty over the extent of noise transmission from the air to water, and the sensitivity of any receiving marine mammals to the noise levels. Operational wind turbines may merely contribute to the background low-frequency noise levels in the area. However, in line with the precautionary principle, it is prudent to recognise that there is potential for water-borne noise and vibration transmitted from the moving blades, through the tower and into the water column, to disturb marine mammals (Metoc plc, 2000). Cetaceans in particular appear vulnerable to interference caused by underwater noise, as they rely upon sound to communicate, detect food and sense their local environment. Based on measurements from the Vindeby (caisson foundation) and Bockstigen (monopile) developments, it has been estimated that the underwater noise from the operational Rødsand offshore wind-farm will at most be audible to marine mammals at a distance of up to 20m from the foundations (SEAS, 2000).

There are insufficient scientific studies upon which to assess the potential effects of offshore wind-farm development on marine mammals, with some species likely to be more sensitive than others. Investigations near to shore have shown no negative effects from wind turbines on common and grey seals (Kube, 2000 cited in Greenpeace, 2000). However, information is deficient on how dolphins and whales are influenced by offshore wind turbines. Actual measurements of underwater noise generated by offshore wind-farms (frequency and sound power level) will enable a far better understanding of the likely effects of these developments upon marine mammals. A Danish project is currently underway involving the tracking of radio-tagged seals as part of a larger seal surveillance programme, in relation to the construction of the Rødsand wind-farm, which is in an area heavily populated by seals. This and other similar studies will be instrumental in measuring the response of marine mammals to noise generated by offshore wind-farms and to implement mitigation measures if any adverse reactions are detected.

Fish

Relatively few studies deal with the subject of the impact of offshore wind-arms on fish species. Potential operational effects may be of greater significance and construction effects, which are of limited duration (Metoc, 2000). Disturbance during construction may include noise from setting up the working platform and from piling, and vibration from working platforms or marine engines (Mitson, 1995). The effects are reported to be particularly evident when hammering down monopiles. Experience from Sweden indicates that this construction method results in a shock reaction from fish, resulting in a temporary loss of consciousness that causes fish to drift in the water as if they were dead. Although the phenomenon is observed to be temporary, it is not known whether there are any long-term effects. Fish will also be more susceptible to predation during this period.

There may also be negative effects on less mobile stages in the life cycle of fish (eggs or larvae) during construction and installation, as a result of coverage with soil or compaction, and disturbance caused by water turbidity. In some species, larvae survival can depend upon an extremely short (two or three day) window and if displaced from a suitable habitat, high levels of mortality could result. The impact upon demersal species may be greater than for pelagic species.

Whereas mature individuals in the fish population can avoid temporary disturbance during construction and installation by moving from the affected area, the operational life of a wind-farm is 20 years or more, which means that any negative operational effects are likely to be long-term. This could result in fish abandoning the area entirely (Metoc plc, 2000). Fish may be disturbed by the operational noise and vibration of turbines and possibly by the moving blades, primarily through light effects and shadows caused by the blades rotating. During operation, noise from offshore turbines can be transmitted into the water in two ways: either via the air as airborne sound, or the noise is transmitted into the water via the tower and foundations as structural noise (OWE, 2001).

It is not clear what frequency of noise emissions can be perceived by fish, although if the noise generated is of low frequency, as appears likely from available information, the noise may be audible to many fish species (Metoc, 2000). This could affect their navigation and behaviour, although the extent is likely to be species-specific and dependent upon the frequency, sound power level and duration of noise emissions. A Swedish study of the first offshore wind power project outside Nogersund, Blekinge (Sweden) demonstrated that there was no negative impact on fish from the 220 kW turbine (Larsson, 2000). Indeed, the fish population increased within

400m of the turbine, although fewer fish were caught when the turbine was in operation. Similarly, test fishing in the vicinity of the Vindeby wind-farm suggests that operational turbines do not detrimentally affect fish, although Metoc plc (2000) notes that the data used in the study were sparse and inconclusive. Furthermore, it should be noted that the majority of turbines in UK waters will have monopile foundations as opposed to the concrete gravity foundations used at Vindeby. Consequently, the difference in foundation design may, to a degree determine the frequency and level of underwater noise and vibration transmitted to the surrounding environment. It should be acknowledged, however, that modern turbine designs attempt to minimise vibration as much as possible in order to reduce wear and tear and extend the operational life of the machinery, which can only have positive environmental implications.

The reported increase in the fish population at Nogersund may indicate that the foundations of offshore wind-farms (particularly concrete gravity foundations) tend to create an artificial reef habitat that provides shelter and feeding opportunities for fish. Also, the exclusion of fishing activities in the vicinity of turbines is likely to have a positive impact upon fish numbers. However, the creation of an artificial reef could lead to a changed biotope (*section 6.6.4*) and, therefore, to a corresponding change in the marine flora and fauna (OWE, 2001). This is less likely to be a concern if the seabed is composed of hard substrate.

Certain electro-sensitive species, particularly elasmobranchs, could be affected by the magnetic fields generated by electric cables. The greatest concern relates to the potential impact upon the orientation and migration of the species most affected, and possible implications for fish breeding. However, this area, together with the effects of noise and vibration upon fish species, are deficient in information and require further study. In particular, the effects of noise, vibration and magnetic fields on fish should be measured and compared to known sensitivity thresholds, to assess the magnitude of any potential effects. Changes in the number and composition of fish populations should also be monitored prior to, during and after wind-farm installation. A planned study at Vindeby to investigate the effects of noise and electro-magnetic fields on demersal fish communities may yield further valuable information on this subject (OWE, 2001).

6.6.2 Visual impact

Offshore wind-farm development is a new industry and as such raises new concerns relating to visual intrusion, as turbines represent anthropogenic development in an otherwise structureless landscape. Visual effects may result from a combination of the physical presence and colour of the turbines, and the blade movement. Offshore wind turbines are generally larger than their onshore counterparts and the distances between turbines offshore are correspondingly greater than on land. Furthermore, while offshore turbines at present have three rotor blades, there is a move to two-blade machines, which rotate more quickly. It is reported that two-blade rotors tend to appear to tilt with respect to the horizon (EC, 1999) and are, therefore, more distracting to the eye when operating compared to three-blade rotors. Clearly, the visual impact of turbines diminishes with increasing distance offshore and, in general, it is assumed that the visual impact to observers at sea-level is negligible when wind-farms are located more than eight kilometres from the shore (OWE, 2001). Turbines virtually become invisible at a distance of about 45km from the shore due to the curvature of the Earth's surface (Greenpeace, 2000; OWE, 2001). These distances will be greater when turbines are viewed from elevated viewpoints, but may also be significantly reduced depending upon prevailing weather conditions. Other factors that will determine the significance of any visual effects include (Metoc plc, 2000):

- the scale of the wind-farm;
- complete turbine design (including size, relative proportions of the components and rotor blade configuration);
- overall layout (‘footprint’) of the site;
- whether there are other foci present on the seascape;
- whether there is public access along the shore;
- distance from sensitive receivers; and
- the nature of the adjacent coastline (topography, land use and visual quality).

The visibility of turbines from the shore will also be influenced by the requirements for marking lights and painting. As offshore turbines continue to increase in size, marking lights are necessary in order to avoid collision with vessels (*section 6.7.2*) and low-flying aircraft (*section 6.7.3*). These measures will, however, increase the visibility of wind-farms from shore and may also attract birds, resulting in increased numbers of bird strikes. It is important to note that marking requirements may depend upon turbine size, and that the choice of turbine is often not made at the time of the EIA (OWE, 2001). Consequently, additional marking requirements can change the visual impact of an offshore wind-farm after the EIA has been prepared.

The visual impact is often cited as a determining factor for public acceptance of offshore wind-farms. Moreover, detrimental visual effects could also have potential knock-on effects upon socio-economic issues such as tourism and recreation. A public opinion survey in the Netherlands concluded that visual intrusion was the most important factor related to social acceptance of offshore wind-farms, but would not necessarily result in fewer visits to the affected location (OWE, 2001). Similar results were observed in Germany, where it was concluded that offshore wind-farms would have no negative impacts upon tourism as long as turbines were not sited in near-shore waters (NIT, 2000).[24] Wind-farms can also act as tourist attractions, with onshore visitor centres and boat trips to the installation.

It should be noted that perceptions of landscape and the issue of visual intrusion are entirely subjective matters. As such, there will always be some public resistance to offshore wind-farms, especially for near-shore projects. Attempts have been made to increase social acceptance of offshore turbines. For example, professional designers have been used by several wind turbine manufacturers to enhance the appearance of their machines, and landscape architects are usually involved in the visual assessments of new projects (EC, 1999). The effects of the periodic reflection (glinting) or interruption (shadow flicker) of sunlight have been addressed by careful consideration of turbine siting and of the surface finish of the blades. These phenomena are entirely predictable and their amelioration is easily integrated into wind-arm design at the outset. Furthermore, evidence suggests that public involvement and participation in the planning process can facilitate public acceptance of offshore wind-farms. For example, as a result of visualisations and public hearings held in relation to the Middelgrunden project, the wind-farm layout was changed from three rows with nine turbines to the existing curved profile with 20

[24] Tourists’ answers were based on visualisations where wind-farms with different footprints were presented from different angles and distances.

turbines. The change in the overall footprint of the site and, therefore, the visual impact resulted in increased public acceptance of the project.

6.6.3 Disturbance of seabed and benthos

In general, temporary disturbance of the seabed and benthic communities will occur primarily during the construction (and dismantling) phase. However, any effects on the benthic community could have a knock-on effect on species higher up the food chain and could be significant. Direct loss of marine life and habitat may result from installation of the turbine foundations, as well as indirect effects such as smothering and clogging of benthic organisms by disturbed sediments (Metoc plc, 2000). If excavated material is deposited on the seabed, changes in the substrate surrounding the turbines may also result in long-term changes to the species composition of the benthic community. The effects may be greater for gravity foundations than for monopile foundations due to the larger area of seabed required for the former. Furthermore, the seabed will require preparation for gravity foundations, i.e. loose material will have to be taken away and possibly replaced by gravel. The extent of the effects will also depend upon the type of seabed and site-specific sensitivities such as the seasonal sensitivity of young/larvae and adult organisms, and the recovery rate of any species lost. The re-colonisation rate of the area will be influenced by the hydrography and sediment dynamics of the site (i.e. how rapidly any material settles or is transported from the site), the nature of local benthic communities, and whether contamination has occurred from drilling lubricants (Metoc plc, 2000).

In addition to drilling lubricants, a number of other potentially hazardous chemicals may also be used during the installation process. For example, the release of organic polymers or heavy metals associated with grouting/cementing material could be toxic to marine organisms, and could contaminate seabed sediments thereby preventing re-colonisation of the area (Metoc plc, 2000). The oil and gas industry have agreed a voluntary code of practice (which could soon become compulsory) on the use of such chemicals, and the UK Offshore Chemical Notification Scheme (OCNS) has been developed to provide offshore operators and subcontractors with information on chemicals that should not be used offshore. It is considered that contractors installing offshore wind-farms should subscribe to this scheme and take account of environmental actors when selecting chemicals for use offshore (Metoc plc, 2000).

Experience from the Swedish Bockstigen development suggests that disturbance of the seabed by sedimentation during the construction phase appears to be temporary. Studies of the effects of aggregate extraction around the UK coast seem to substantiate this. These indicate that, provided seabed substrate is not contaminated or the sediment structure does not differ substantially, re-colonisation y bottom fauna communities will start immediately, although full re-colonisation may take at least three to five years (de Groot, 1986; Kenny & Rees, 1994, cited in Metoc plc, 2000). Sediments re-suspended during construction activities may also lead to the release of existing pollutants.

The operational effects of wind turbines are likely to have little or no effect on benthic communities, unless vibration of the turbine tower causes changes in the physical composition of the seabed. As previously noted (*section 6.6.1*), there is little research to quantify the underwater noise emitted by wind turbines, and little is known about the potential effects of vibration upon benthic communities. Observations at the Vindeby offshore wind-farm indicate that the turbines' concrete gravity foundations act as an artificial reef, providing a habitat for bivalves and encrusting organisms (Metoc plc, 2000). It is understood that the flora and fauna of the area has generally improved following turbine installation. However, concrete gravity foundations are likely to be replaced by steel monopile foundations for the majority of offshore turbines in the UK, which provide a very different substrate and less surface area for ecological communities. The foundation itself will also represent a fundamentally different surface from the natural substrate and could, therefore, impact upon species diversity. More significantly, there are large differences between the vibrational behaviour of concrete gravity and steel monopile foundations, which could have a corresponding effect on benthic communities.

6.6.4 Hydrodynamic environment and sedimentary processes

Installation of foundations (seabed preparation, piling and other activities) may cause turbidity around the construction site and downstream of the site. Comparable effects can be anticipated when removing turbine foundations at the end of the wind-farms' service life (Greenpeace, 2000). Deposition of excavated spoil on the seabed could result in changes in the morphology of the area and reduction of local water depths, which could affect navigation and wave climate (Metoc plc, 2000). The flow of water is also likely to be influenced by the introduction of an immovable structure, as a result of diffraction or funnelling of waves and currents between the turbines. This may lead to reductions in the wave energy reaching the coast and changes in local wave patterns. Wave diffraction around gravity base structures is likely to be localised with corresponding local scour effects (Metoc plc, 2000). Local erosion or deposition around the base of the structure may result, depending upon current strength and the resistance of the seabed surface. The effects are likely to increase with the number of turbines installed, depending upon spacing and alignment.

The effects of monopile foundations on sedimentary processes will depend upon the influence that the piles have on local water movements (the 'wake effect'), and whether there are any combined effects such as diffraction or funnelling of waves between the piles due to their proximity to each other. The latter is not considered a significant concern as the requirement to space turbines far apart to prevent wind shadow makes it unlikely that turbines would influence sediment transport processes in this way (Metoc plc, 2000). The 'wake effect', which is defined as the area over which a detectable wake occurs around a structure, is about ten times the diameter of the structure. To reduce scour around monopile foundations this area may need to be covered by gravel or a mattress of artificial seaweed (Greenpeace, 2000).

Detailed modelling will be required to ensure that the wake effects generated by each pile do not interact with each other, and to determine the effects of the development upon hydrography and sediment dynamics. The latter is particularly important if a wind-farm development is proposed on sandbanks (to take advantage of shallow water), as their stability will require assessment.

6.6.5 Emissions

The main environmental benefit of generating electricity from wind power, as opposed to fossil fuels, is the reduction in polluting atmospheric emissions. As well as a significant reduction in CO_2, other polluting emissions such as SO_2, NO_x, CO, methane and particulates, are also reduced. No data was found on the potential emissions savings generated by offshore wind-farms. However, it is reported that a modern 600 kW onshore wind turbine in an average location will, depending upon the site wind regime and hence the capacity factor, prevent the emission of some 20,000-36,000 tonnes of CO_2 from conventional fossil fuel sources during its 20-year design life (EC, 1999).

Table 6.4 compares the amount of CO_2 emitted by various forms of power generation during all stages of a power plant's life cycle. The values (generated by the World Energy Council) are reported to be subject to variation for different countries, but it is evident that wind power reduces polluting emissions by an order of magnitude when compared to conventional thermal power generation (OWE, 2001).

Table 6.4 Comparison of CO_2 emitted by various types of power generation during all stages in a power plant's life cycle

Technology	CO_2 Emissions (Tonnes / GWh)			
	Fuel Extraction	Construction	Operation	Total
Coal-fired[1]	1	1	962	964
Oil-fired	-	-	726	726
Gas-fired	-	-	484	484
Nuclear[2]	~2	1	5	8
Wind	N/A	7	N/A	7
Photovoltaics	N/A	5	N/A	5
Large hydro	N/A	4	N/A	4
Solar thermal	N/A	3	N/A	3
Wood	-1509	3	1346	-160

[1]Conventional plant [2]PressurisedWater Reactor

(*source:* OWE, 2001).

Table 6.5 below estimates the avoided emissions in the EU that would be achieved if wind energy is developed in line with the latest European Wind Energy Association (EWEA) goals.[25]

***Table 6.5* Avoided annual emissions achievable through EWEA goals for wind energy in the EU**

Year	Goals for Installed Capacity (MW)	Production TWh/year	CO_2 Reduction Tonnes/year	SO_2 Reduction Tonnes/year	NO_x Reduction Tonnes/year
2000	8,000	16	14,400,000	48,000	40,000
2005	20,000	40	34,200,000	114,000	95,000
2010	40,000	80	64,800,000	216,000	180,000
2020	100,000	200	134,400,000	480,000	400,000

(*source:* European Commission Directorate-General for Energy, 1999).

If the EWEA's goal for wind energy development were met by 2020, it would be possible to reduce the EU's CO_2 emissions from the energy sector by over 11 per cent, based on the assumptions outlined.

6.6.6 Consumption of energy and materials

Although offshore wind turbines produce no polluting emissions while generating electricity, energy and materials are consumed and emissions are produced during other stages in their life cycle. The typical stages in the life cycle of an offshore wind turbine are broadly similar to those for a WED, as described in *section 5.6.6*. Energy and materials consumed primarily during construction and installation, which are also the stages in the life cycle where most emissions are produced. However, it should be noted that maintenance and decommissioning of turbines may also be energy intensive, as illustrated by the estimated energy requirements of a typical onshore Danish 600 kW turbine during its 20-year life cycle (*table 6.6*).

***Table 6.6* Energy requirements of a typical 600 kW wind turbine**

Process	Energy (MWh)
Manufacture	528
Installation	137
Operation and Maintenance	215
Scrapping (use)	145
Scrapping (recovered)	-204
Total	**821**

(*source:* European Commission Directorate-General for Energy, 1999).

[25] In generating these estimates it has been assumed that specific emissions (Tonnes/TWh) from fossil fuel plants displaced by wind-farms are reduced across the board by 10 per cent of year 2000 levels each decade thereafter, over the entire period covered.

Little information is available on the consumption of energy and materials specifically required for the development of offshore wind-farms. However, it is likely that the energy requirements will be significantly greater for offshore turbines compared to those on land. In particular, there will be a greater demand for energy and construction materials for the deployment of turbine foundations offshore, and energy use by machinery and vessels employed in the construction and installation (and maintenance) of offshore turbines is likely to be higher than on land.

Table 6.7 below shows the breakdown of materials used in the Baix Ebre wind-farm, comprising 27 Ecotecnia 150 kW turbines on a high mountain ridge in Catalonia. The data are derived from a life cycle environmental impact assessment of the wind-arm conducted as part of the THERMIE project for DGXVII (ECOTEC Research & Consulting, 1997).

Table 6.7 Breakdown of components by material type

Material	Total weight (Tons)	Weight per MW (Tons / MW)	Proportion %
Concrete	1847	456	74
Steel / Iron	544	134	22
GRP	49	12	2
Copper	12	3	<1
Gravel	14	3	<1
Aluminium	6	<2	<1
Lubricants	<2	<1	<1
PET	<2	<1	<1
PVC	<2	<1	<1
PUR	<1	<1	<1
Others	<<1	<<1	-
Total	2478	612	100

(*source:* European Commission Directorate-General for Energy, 1999).

Although the quantities of materials are likely to differ in the offshore context, the data provide some indication of the materials used in the construction of an onshore wind-farm. The material requirements are dominated by the concrete and reinforcement for the turbine foundations, and by the steel from which the turbine towers are fabricated. It is also evident that many of the materials are recyclable. However, it is possible that, upon reaching the end of its operational life, a wind-farm could be refurbished by installing new nacelles and rotors on top of the existing towers and foundations (subject to appropriate safety assessment procedures). This would reduce the material inputs for the second-generation wind-farm by over 80 per cent (EC, 1999). However, as offshore wind-farms are relatively new and typically have a design life of 20+ years, the feasibility of such a procedure has not yet been evaluated. Further consideration is given in *section 6.6.7* to the decommissioning of offshore wind-farms.

6.6.7 Decommissioning

Existing offshore wind-farms have a design life of around 20-25 years. As described in *section 6.6.6*, there may be the possibility of refurbishing turbines and re-using existing foundations, but until the viability of such practices has been demonstrated it must be assumed that decommissioning and complete removal of the structure will take place. The Crown Estate has indicated that upon decommissioning it will require the most thorough and acceptable removal of foundations possible. Similarly, MAFF considers that complete removal should be the favoured option on abandonment, in line with the latest requirements under the OSPAR (98/3) Convention for the decommissioning of offshore oil and gas installations.

The most acceptable method of removal will vary on a site-by-site basis, and will be influenced by the seabed conditions and nature of the foundations used. For example, certain forms of foundations, particularly cement or steel gravity, will be easier to remove in their entirety compared to monopile foundations. The latter may need to be terminated at least three metres beneath the seabed, causing additional disturbance to the seabed and benthos (Greenpeace, 2000). Consideration should be given on a site-specific basis when preparing the EIA as to whether or not buried cables should be removed or left in situ.

The general ease by which onshore turbines can be decommissioned in comparison with other generating technologies is often cited as one of the key environmental benefits of wind energy. Clearly, decommissioning procedures will be more challenging in the offshore environment, and may give rise to similar temporary environmental disturbances as experienced during installation. As such, these effects should be well understood through on-going monitoring studies for each individual site, and appropriate mitigation measure can be taken. Complete removal of the wind-farm would allow other activities such as commercial fishing to recommence in areas where they had been previously excluded.

Wind turbines are largely composed of recyclable materials (*section 6.6.6*) and, where possible, options for the re-use or recycling of wind-farm components should be investigated. Consideration should be given at the design stage as to how this can be facilitated, for example through:

- minimising the number of components and ensuring that they are easy to dismantle;
- using recycled concrete scrap as an aggregate in the foundations;
- examining the usability of recycled lubricants;
- labelling precise material composition, especially for alloyed steels; and
- designing rotor blades made of renewable materials, as opposed to GRP.

Studies should address the feasibility of these design options in the marine environment.

6.7 SOCIO-ECONOMIC IMPACTS AND SEA-USE CONFLICTS

As with onshore wind energy, many of the potential long-term impacts of offshore wind-farm development relate more to socio-economic, as opposed to environmental concerns. Some of the concerns associated with the social acceptance of wind-farms, e.g. noise levels and, to an extent, visual impact, are minimised by the offshore location of turbines. However, other potentially more serious conflicts arise when wind-farms are developed at sea, such as the navigational hazard they pose to vessels and aircraft, and their interaction with other legitimate uses of the sea. As with potential environmental conflicts, these socio-economic effects will require assessment on a site-by-site basis.

6.7.1 Interference with radar and radio signals

Any large moving structure can produce electromagnetic interference (EMI). Wind turbines can cause EMI through the reflection of radar and radio signals by the rotor blades, so that a nearby receiver picks up both a direct and reflected signal (EC, 1999). EMI is most severe for metallic materials, which are strongly reflective. Glass-reinforced plastic (GRP), which is used in most modern blades, is partially transparent to electromagnetic waves and is therefore intermediate in its EMI effects. A number of civilian and military communications signals can potentially be affected by EMI, including television and radio broadcasting, microwave and cellular radio communications, and various navigational and air traffic control systems.

In the UK, both the Civil Aviation Authority (CAA) and Ministry of Defence (MOD) have expressed concern over the potential effect of offshore turbines on radar facilities (Metoc plc, 2000). In particular, the MOD considers that if a wind-farm is in the direct line of sight of a radar, the turbines can appear as genuine aircraft targets that could either mask aircraft responses or desensitise the radar within the sector containing the wind-farm. It is understood that the MOD has undertaken a number of trials to determine the extent of interference with radar from wind turbines (OWE, 2001), but these data were not available for this study. If the exact co-ordinates of the wind turbines are known, the radar system operator should be able to compensate for the false signals. However, it is likely that, due to the concern over the potential detrimental effect of offshore wind-farms on radar signals, turbines will be equipped with radar reflectors/intensifiers (Metoc plc, 2000).

Onshore wind turbines have been shown to occasionally cause interference with television and communications systems. This is an important consideration in the offshore marine environment, because radio (mainly VHF radio) is a key communication and safety aid for recreational and other users of the sea, in both large and small commercial craft. Moreover, the power available to small recreational craft for radio operation is limited and any interference with communications could be life threatening. Interference with radio signals is primarily caused by reflections from turbine towers. The effect upon the performance of radio relay links is reportedly greatest for frequencies between 2 and 10 GHz (OWE, 2001).

Similarly, an operational turbine also has the potential to cause interference with microwave links used for communication systems such as mobile phone networks (Metoc plc, 2000). Again, this results from the physical presence of an obstacle situated in the line of a microwave path to path link. This phenomenon may need to be taken into account when siting turbines offshore.

Interference with television receivers is normally rectifiable by a range of relatively inexpensive technical measures, such as the use of more directional transmitters and/or receivers (EC, 1999). This is evident from the number of onshore wind-farms in the UK where turbines coexist with telecommunications systems without any interference.

6.7.2 Navigational hazard

One of the main conflicts of interest arising over the siting of offshore wind-farms is the obstruction and consequent navigational hazard they pose to other sea users. Metoc plc (2000) note that the scale of any development (i.e. the 'footprint' of a group of turbines, the number of such groups in a sea area, and the siting of individual groups in relation to shipping and boat movement patterns), particularly in coastal areas, will all affect the extent to which wind-farms represent obstructions to sea users. Ship lanes clearly represent a limiting factor on site selection for offshore wind-farms, and consultations during the scoping study should identify other areas where turbines could also present a potential navigational hazard to sea users. For example, the MOD has requested that they are fully consulted on proposed developments prior to the formal consents procedure in order to ensure that proposals do not infringe upon any military exercise, danger or operating areas.

However, even when detailed consultations and planning have been undertaken and key sensitive areas have been avoided, a risk will still remain of vessels colliding with turbines (unless they are situated on shallow reefs or on rocky outcrops, in which case turbines may contribute to maritime safety by providing a navigational feature). The risk may be greatest for small recreational vessels, which tend to use shallow coastal waters. Rotation of the operational turbine blades also presents an additional hazard to these craft, particularly those with a tall mast (Metoc plc, 2000). The Royal Yachting Association has requested that sufficient technical details on the design, construction and operation of turbines are provided to sea users to prevent any such incidents.

Should a larger vessel collide with an offshore turbine, it may be assumed that the turbine and foundation would be seriously damaged. However, the risk of severe environmental degradation may not be great, providing the vessel itself is not seriously damaged. The worst case scenario would involve an oil tanker, or a vessel carrying some other noxious cargo, colliding with a turbine. Such an incident could have a potentially devastating effect on the flora and fauna of the area and adjacent shorelines. Oil spillage derived from the turbine itself, however, is not considered to be a major concern, as only small amounts are contained within the infrastructure, although the substation is likely to contain larger amounts of diesel oil. Damage to submarine cables may cause the release of mineral oil insulating the cable but, again, small volumes are involved[26] and the risk of such accidents has been calculated to be very low (one every 32,000 years) (OWE, 2001). Burying the cable will further reduce the risk.

The EIA of an offshore wind-farm should take account of the obstruction and potential navigational hazard offshore turbines pose to other sea users. However, it is difficult to verify the reliability of risk models that have been developed, due to the lack of experience involving collision incidents (OWE, 2001). It is likely that turbines in navigable areas will have to be

---

[26] In a worst case scenario at Horns Rev, the maximum oil leakage from this source would be 4,200 litres (Elsam & Eltra, 2000).

clearly marked and/or lit in accordance with the requirements of the General Lighthouse Authority as well as being equipped with fog signalling devices and radar reflectors/intensifiers (*section 6.7.1*). It is worth noting that the first generation of offshore wind-farms will be located in shallow water, which may minimise the risk of collisions involving larger vessels.

6.7.3 Obstacle to air traffic

It is recognised that offshore turbines could present a potential obstacle to low-flying aircraft. In a report to ETSU, Metoc plc (2000) identifies two classes of low altitude aerial activity that could be affected, namely military low flying and flights by civil helicopters in support of the offshore oil and gas industry. Offshore wind-farm developments in the vicinity of approach paths to coastal airports and MOD Coastal Air Weapon Ranges would, naturally, be prohibited.

The MOD has objected to certain proposed wind-farm development sites, both offshore and on land, on the basis that they would interfere with low flying military aircraft, even though it is reported that many of these sites were not in close vicinity to military airbases or equipment (The Guardian, 31 May 2001). It would appear, therefore, that the objections were based entirely on the potential danger posed by the height of the turbines to aircraft on manoeuvres.

With respect to helicopter movements, there is a need to ensure that offshore wind-farms are visible to helicopter crews, and that turbines do not present a physical obstruction to air navigation. Helicopters servicing offshore installations often fly along predetermined tracks known as Helicopter Main Routes (HMR), which ensures their separation from other aviation activities (Metoc plc, 2000). Whenever possible, helicopters fly well above the upper rotor tip height of turbines, although there are occasions when they are forced to fly at much lower altitudes, e.g. in response to climatic conditions. During inclement weather helicopters may also be forced to operate without visual reference to the surface and are therefore more vulnerable to collision with offshore turbines (Metoc plc, 2000).

The Directorate of Airspace Policy[27] has indicated that in many instances problems caused by conflicting requirements affecting use of airspace can be overcome by negotiation and compromise (Metoc plc, 2000).It is assumed that this may include measures such as appropriate marking and illumination of turbines. In this respect there are already various requirements in different European countries, although in most cases nacelle lights are required as a minimum (OWE, 2001). However, measures that draw attention to turbines such as lights and reflective paint are likely to have a negative aesthetic impact from the shoreline and may even increase the risk of bird strikes – both factors that may reduce social acceptance of offshore wind-farms.

6.7.4 Interaction with the fishing industry

The potential effect of offshore wind-farm development on fish populations has been discussed in *section 6.6.1*. There is a lack of consensus on the extent of the effect that installation and operation of offshore wind turbines has on fish, which is partly attributable to the lack of understanding of the sensitivity of many fish species to the frequency and level of noise emitted by wind-farms. However, it is generally accepted that there is potential for the noise and vibration from turbines to affect the navigation and behaviour of fish.

---

[27] The Directorate of Airspace Policy is a joint service resourced by the Civil Aviation Authority (CAA) and MOD.

Although this is likely to have some negative implications for commercial catches of fish, arguably the main issue of concern to the fishing industry would be the restriction of fishing effort within the vicinity of offshore wind-farms. For example, it may be desirable to establish an exclusion zone around turbines for safety purposes, which could result in the loss of trawling grounds and possibly areas for pot fisheries. Metoc plc (2000) recommends that fishing intensity studies may be required to identify and avoid fishing 'hotspots'. It is believed that this conflict has not to date prevented any projects from being developed, although fishermen are generally well organised and could represent a powerful objection lobby to proposed developments. Potential conflicts with fishing interests can be minimised by:

- avoiding construction of wind-farms in sensitive spawning and nursery areas or other areas with high value for fisheries;
- avoiding construction during spawning periods and during other sensitive times in the life cycle of fish; and
- involving fishing industry representatives in detailed consultations during the scoping phase of the offshore wind-farm.

Further research is also needed into the specific effects of offshore wind-farm development on various types of fishing techniques and fishing activities. This would assist in interpreting site-specific and species-specific monitoring studies to determine the likely effects of changes in fishing intensity applied to the area.

6.7.5 Noise nuisance to humans

Noise from wind turbines arises from the movement of the blades through the air (aerodynamic noise) and the consequent transmission of power and momentum in the nacelle (mechanical noise). Noise may also be generated by the control equipment within the turbine tower (power electronics) (OWE, 2001). Airborne noise propagating across the water could be a source of potential nuisance for humans. The degree of noise effects will be influenced by:

- the type of turbine installed;
- the level and character of noise emitted;
- the distance from the turbines to sensitive receivers;
- barriers located between the turbines and sensitive receivers, which may lead to attenuation of noise;
- prevailing wind directions; and
- background (ambient) noise levels.

One of the benefits of locating wind-farms offshore is that the potential noise source is located away from humans. Nevertheless, it appears that wind power has a reputation for being noisy, a perception that is reinforced by the fact that noise propagates much easier over the sea than over land. There is also concern that turbine manufacturers and project developers may be tempted to place less emphasis upon noise control when turbines are sited offshore. Increases in turbine size and blade tip speed (two-blade rotors rotate more quickly than three-blade rotors and are therefore noisier) may lead to further concerns in this respect. However, noise is being successfully minimised through careful; design and manufacture of the blades, and sound dampening of the gearbox and generator (Metoc plc, 2000).

The noise generated by a wind turbine is normally expressed in terms of its sound *power* level, expressed in decibels (dB(A)).[28] The sound power level at a distance of 40m from a typical onshore turbine is in the range 90-100 dB(A), which creates a sound *pressure* level of 50-60 dB(A)[29], i.e. about the same level as conversational speech (EC, 1999; Metoc plc, 2000). At a distance of 500m from the turbine the equivalent sound pressure level would be about 25-35 dB(A) when the wind is blowing towards the receiver. A wind-farm consisting of 10 such turbines at a distance of 500m would create a noise level of about 35-45 dB(A) under the same conditions. With the wind blowing in the opposite direction the noise level would be up to 10 dB lower (EC, 1999).

It should be noted that these figures are estimates of the noise levels generated by wind turbines on land and may not reflect the situation offshore, as noise propagates differently over water. The only estimate of the noise reaching land generated by offshore turbines has been provided by National Wind Power, which estimates that 50 x 1.5 MW turbines located 5km offshore will lead to a sound pressure level of 28 dB(L_{a90}) at the beach (Metoc plc, 2000). This suggests that turbine noise may not be distinguishable above background levels of noise created by wind and waves and any local industrial/transport noise, although further research is required to confirm these initial estimations.

6.7.6 Impact upon local communities

Social acceptance of offshore wind-farms has already been briefly addressed in *section 6.6.2*, with respect to visual intrusion. While public perception of wind power is often characterised by the NIMBY (‘not in my back yard’) syndrome, this attitude may not be attributable to visual impact alone, and a number of other variables may be involved in determining the general and local public acceptance of specific wind power projects (OWE, 2001). These may include, *inter alia*, local public involvement in the consultation and planning process, and industrial and employment opportunities offered by the development. It has been shown that public acceptance generally increases in a well-informed population, and with direct economic involvement in the project (OWE, 2001). This is illustrated by the Danish approach to onshore wind power development, where wind turbines are owned by locally established private cooperatives. It is reported that this appears to increase local community acceptance of projects as it is, generally speaking, the same people who experience the impacts that receive the financial benefits. The Danish approach to onshore wind-farm ownership is rather unique and is not reflective of the offshore situation, where most wind-farms are owned by utilities. This is also the situation in most other European countries, including the UK, where offshore wind-farms will be owned either by utilities or private consortiums, thus enabling only indirect financial benefits to local communities. An example of this is the JUICE scheme (*box 6.3*).

Acceptance of wind-farm developments by local communities may also be influenced by the industrial and employment opportunities they afford. UK manufacturing has accounted for only 4.9 per cent of the installed UK market for onshore wind energy. However, the size of offshore

---

[28] This is not a measurement of the noise level that is audible to humans, rather of the noise power emitted by the machine.

[29] Sound pressure level is also measured in decibels, and is the magnitude of the pressure variation (in air or water, both of which have different frequencies). Measures of environmental sound are usually made in dB(A), which includes a correction for the sensitivity of the human ear.

turbines makes local manufacture, close to the proposed development sites, the most economic option. Many of the electrical, mechanical and hydraulic components used in turbine manufacturing are already sourced in the UK, including rotor blades for larger offshore turbines. There is, therefore, significant opportunity to expand UK manufacturing capacity, and the skills and equipment necessary for manufacture can be further developed within the home market. In a report to Greenpeace, Border Wind (1998) argues that as it is the offshore elements of wind turbine design and site development that bring about the most significant change in manufacturing emphasis, this demands a greater need for local input and involvement in the overall project. More important, there are economic and logistical benefits to be accrued by establishing manufacturing facilities close to the sea and potential offshore development sites (Border Wind, 1998).

Border Wind estimates that by 2030 the total potential market for offshore wind will be worth £48 billion, with the total market for component supply in the region of £24.9 billion. If this prediction is accurate, not only would there be an expanded market for components but also for the UK assembly of wind turbines (Border Wind, 1998).

It is difficult to forecast how this predicted increase in industrial output would be translated into employment creation potential. Numerous studies have attempted to forecast the employment creation potential of future wind energy development, with widely differing results. The findings vary according to the different methodologies adopted (e.g. based on input-output analyses, or industry surveys), leading to confusion as to how to interpret the figures. There is also the added complication of where the employment will be created. For example, Denmark, which exports around 70 per cent of its turbine manufacture (by MW), will have a higher level of employment than the amount of domestic capacity installed would suggest (BWEA, 2000). There is further complication as some components are imported prior to re-export in assembled units. The European Wind Energy Association (EWEA) Action Plan suggests that 1 MW of wind power creates jobs for 15-19 people (under European market conditions in 1999) (EC, 1999). Border Wind (1998) has compiled an estimate of direct employment in all aspects of the industry: manufacture, project design, installation, and operation and maintenance (*table 6.8*).

The total of 4.5 full-time jobs per MW was derived following consultation with existing developers and offshore operators. As such, it is based upon experience gained from working on onshore and semi-offshore wind-arm sites and may therefore not be representative of offshore wind energy development.

Table 6.8 Estimate of direct employment due to offshore wind-farms

Development Stage	Activity	Full Time Jobs / MW
Project design and development	Marine/ground investigations	0.01
	Site development including permissions	0.10
	Design including structural, electrical & resource	0.02
	Finance	0.04
Component supply	Generators	0.15
	Gearboxes	0.9-0.40
	Rotor blades	0.50
	Brakes and hydraulics	0.04
	Electrical and control systems	0.04
	Towers	0.90
Assembly	Wind turbines	1.00
Installation	Foundation structure	0.30
	Electrical and connecting cables	0.05
	Wind turbines	0.30
	Project management and commissioning	0.11
Operation and maintenance	Management, routine and fault maintenance	0.06
Total		**4.52**

(*source:* Border Wind, 1998).

7 Strategic issues affecting the development of marine renewables

7.1 INTRODUCTION

In addition to the technical and commercial challenges that face specific sub-sectors, the potential for the development of marine renewable energy resources in Wales is also defined by a number of strategic factors that constrain the utilisation of these resources. The key technical, economic and planning/environmental factors that apply across the range of marine renewable energy technologies are considered in the following sub-sections.

7.2 NETWORK CONNECTIONS

The electrical energy produced by any renewable energy device at sea needs to be delivered to the consumer. There are two stages of transmission:

- from an offshore device to the coast; and
- from the coast to the main demand load centres.

While both stages present their own particular challenges, transmission to the coast is principally a technical problem, which has been previously discussed in the context of individual device designs. It is evident that developers have anticipated many of the problems that are likely to be faced when laying and operating electrical interconnections in the offshore marine environment, and have based their solutions on precedents such as the 2,000 MW cross-Channel electricity interconnector, the 20 MW cable across the Pentland Firth to Orkney, and upon experiences from the offshore oil and gas industries (STC, 2001). Transmission problems from offshore devices to the coast are therefore not considered to present insurmountable technical hurdles.

The transmission and distribution of electricity from the shore to the main load demand centres, however, presents a potentially greater problem, one which the Science and Technology Committee on Wave and Tidal Energy believes that individual companies would find almost impossible to solve alone. There are two main technical problems arising due to the limited scope for the existing transmission system to receive additional generating capacity in many areas, and the incompatibility of the existing distribution network to receive output from embedded generation technologies. The present National Grid network was never designed for receiving power from multiple sources as well as delivering it. The difficulties of network connection arguably present the single, most serious problem facing the successful exploitation of marine renewable energy in Wales and the UK as a whole.

The UK electricity supply industry (ESI) has a structure characterised by:
- large-scale generation plants;
- high voltage networks; and
- integrated generation, transmission, distribution and supply functions.

As described in *box 2.1*, transmission is the bulk, often long distance, movement of electricity at high voltages (400 kV and 275 kV) from generating stations to distribution companies and to a small number of large industrial (demand) customers. Ninety-four per cent of generating plant in England and Wales is directly connected to the high voltage transmission network, owned and operated by the National Grid Company (NGC) in England and Wales. The Grid is generally tapered towards its periphery, and was designed to supply electricity from a small number of large power stations at the 'centre' to the rest of the country. Connecting all electricity generators through the transmission system in this manner reconciled the geographic mismatch between generation and demand, and allows use of the cheapest generation available, no matter where it is.

In Wales, the transmission system crosses South Wales from the English border in the east to Pembroke in the west. In North Wales it crosses the border at Deeside, running to Wylfa (Anglesey) via Pentir (Bangor), with an additional connection to Trawsfynydd via Legacy (Wrexham) (SEL, 2001). There are no north-south national grid links within Wales, and the infrastructure in mid-Wales is particularly weak. There is therefore limited scope for connecting medium/large-scale renewable generation schemes (e.g. offshore wind) in this area without major transmission system reinforcement.

This is a problem that also affects other parts of the UK. For example, the transmission lines are particularly weak in the western part of Scotland. Consequently, the Science and Technology Committee on Wave and Tidal Power (2001) reported that Wavegen and Ocean Power Delivery face costs of £500,000 and £1 million respectively merely to pay for the strengthening of the transmission lines necessary to connect their Islay devices to the Grid (*section 7.2.2*).

The provision of electricity to the majority of customers in England and Wales is through the distribution networks, as opposed to the transmission system. Most of the renewable energy developments needed to meet the government's targets are likely to have small generating unit sizes and will therefore find it more cost effective to connect to the lower voltage (from 132 kV to 230 kV), more localised distribution networks. For example, most individual first-generation tidal stream and wave power devices are likely to be smaller than the 300 MW approximate break-even threshold for direct connection to the transmission network. The development of small-scale renewable energy technologies, therefore, is likely to lead to a considerable increase in the demand for 'embedded' electricity generation[30], where small-scale generating units are connected directly to the lower voltage distribution networks. These were designed in the recent past to deliver power from the transmission system to demand customers in a low cost, minimal intervention manner. This clearly runs counter to the traditional model described above where large generating units are connected directly to the higher voltage transmission network, although this may still be the case for large renewable energy schemes, such as offshore wind and tidal barrage projects.

While there is some capacity available on the distribution networks to add further generation, the constraints are significant. The difficulty is compounded by the fact that sites with the

[30] Embedded generation is any plant that is used for generating electricity that is connected to the regional electricity distribution networks. These networks are owned and operated by the Distribution Network Operators (DNOs), the distribution arms of the former Public Electricity Suppliers (PESs) that have been created by the licensed separation of distribution and supply in the Utility Act 2000.

greatest potential for marine renewable energy generation are often situated in remoter parts of the country, near the end of the distribution network. Any generated output, therefore, may also have to travel long distances through the distribution networks to demand load centres. However, system losses may be reduced where the exported energy from embedded generators is absorbed locally.

Sustainable Energy Ltd (SEL, 2001) notes that the distribution systems in Wales have evolved to meet the load demand placed upon them in a given area. For example, in relatively low population density areas such as mid and rural west Wales, the network has a relatively low capability to carry further load and accept generation output. In urban industrial areas such as the North and South Wales coastal belts, loads are relatively much higher compared with rural areas, therefore the electricity distribution network is correspondingly more developed with a higher capacity. Urban networks, however, generally operate with higher fault levels, making it difficult to economically connect embedded generation – see *section 7.2.2* (SEL, 2001).

All existing renewables in England and Wales are embedded, and the NGC expects the majority of renewable energy developments needed to meet the government's targets will also be connected to distribution networks.[31] Major reinforcement of the distribution network may well be necessary to cater for this increase in embedded generation. However, it should be kept in mind that any strategic network strengthening that will increase the amount of load in an area could provide an incentive for economic development, and in particular manufacturing and service activities, which are dependent upon the provision of power. There are therefore economic motivations for supporting network reinforcements in addition to the environmental case for accommodating renewables (SEL, 2001).

In a Technology Status Report on Embedded Generation and Electricity Studies, ETSU (2001d) estimated that in the period to 2010 the current government targets for renewables, if achieved or approached, will result in excess of 20-25 GW of total capacity connected to the distribution networks. This led ETSU to conclude that such a level of embedded capacity cannot be accommodated on the currently configured networks without significant change. Such changes would require the reconfiguration of existing electricity networks into a 'distributed electricity system' that accommodates changed electricity flows. A distributed electricity system combines electricity from large and small generation units. Large power stations and any large-scale renewables, e.g. offshore wind and tidal schemes, remain connected to the high voltage transmission network providing national back up and ensuring quality of supply. Small generators are connected directly to factories and offices and to lower voltage distribution networks. Electricity not used by customers directly connected to small-scale units is fed back into active distribution networks to meet demand elsewhere.

Electricity storage systems are being developed that may be able to store any excess generation. These may also accommodate the variable, intermittent output of some forms of generation, e.g. offshore wind. Nevertheless, studies have shown (and NGC confirms) that the network could readily cope with 10 per cent of electricity produced from wind, as the system already factors in some variations in demand and unpredictable changes in overall generation (Parliamentary

[31] It is important to note, however, that consumers in England and Wales can access renewable energy sources anywhere in the UK and in Europe through interconnections between the high voltage transmission systems.

Office of Science & Technology, 2001). At higher levels however, (perhaps over 20 per cent), intermittence becomes more prominent. Technical responses (inevitably with cost implications) include:

- providing back-up generation facilities;
- wider application of electricity storage technologies to smooth out variable outputs (see *section 7.2.2*); and
- development of distribution networks that can handle the two-way flow of electricity.

7.2.1 Network connection charges

It is likely that future generating plant embedded in distribution networks will contribute a larger proportion of total national generation, considering the government's policy objectives for renewable energy generation. When a developer of an embedded generation project seeks a connection to the distribution network a contractual agreement is required with the DNO. Unlike demand customers, who provide a revenue stream to the DNO via distribution use of system charges (DUoS), embedded generators do not pay a DUoS charge and are, therefore liable to pay the appropriate full cost of the connection. Larger generators (e.g. offshore wind) who are connected directly to the transmission system pay transmission charges only and do not pay DUoS or distribution connection charge.

The full costs of connection payable by an embedded generator currently present a significant financial barrier to new smaller-scale renewable generation because these costs may include any infrastructure changes needed to the network in the location of the connection point to accommodate the generation plant (so-called 'deep connection charges').[32] For example, costs may be incurred in respect of changes to protection or voltage control needed to accommodate the actual anticipated power flows in the system as a result of the connection of the generator. Connecting embedded generators into the distribution network also increases the system 'fault level'. If the increased fault level exceeds existing fault ratings it results in the requirement to change equipment or reconfigure the network. The embedded generator would be charged the full cost of such work. This condition leads to inconsistencies in charging for the connection in different regions of the country. In some cases, where capacity exists, the cost of connection can be low. In other cases where the capacity is constrained, the cost of connection can result in a scheme being uneconomic (ETSU, 2001d).

Sustainable Energy Ltd (2001) notes that due to the nature of the distribution network in Wales, areas of greatest renewable energy potential also coincide with the regions where the grid is weak, therefore the effect of the cost penalty is higher than for other regions of the UK. For instance, its report highlights the area between Aberystwyth and Machynlleth, where no further potential exists for the connection of embedded generation by renewables, in which case reinforcing the 132 kV and 33 kV distribution systems would potentially incur costs of several millions of pounds. Clearly, such costs could not be borne by a small individual embedded generator. There are also many other areas in Wales where a relatively small amount of additional generation could incur a potentially large step increase in network investment.

---

[32] The connection charge may be partly mitigated by the DNO where it can be shown that the replacement of assets have only been brought forward by the actions of the embedded generator (that is a 'time advancement' credit is given to the generator).

These ‘deep connection charges’ fall on the first embedded generator to seek connection to the distribution network. Subsequent generators (with certain exceptions) are not generally faced with these charges. According to ETSU (2001d), this creates an ‘after you’ scenario where generators hold back to avoid the first entrant charges. This clearly imposes a significant constraint on the development of marine renewables in Wales and the ability to achieve renewables targets in general.

7.2.2 Transmission charges

The role of the National Grid Company (NGC), which operates the high voltage transmission network for England and Wales, is limited in respect to the development and operation of most first-generation marine renewables (in particular wave and non-barrier tidal energy). This is because, as previously noted, the generally small-scale nature of these projects means that it will be much more economic for them to connect at lower voltages. As such, the issues associated with the cost of such connections and recovery of these costs through charges to the generators are primarily issues for distribution companies. Nevertheless, larger generating plant (over 300 MW), such as tidal barrier energy schemes and the large-scale offshore deployment of wind turbines, may find it economic to connect directly to the transmission system.

The NGC makes three types of transmission charge to cover the investment, maintenance and operational costs of the Grid. Connection charges reflect the cost of installing and maintaining the assets required for the connection of a generator or demand customer directly to the network. Unlike connections to the distribution networks, transmission connection charges are ‘shallow’ and over only those assets at or very near the connection site. Customers can vary the design of their connections (subject to safeguards), they can choose whether they incur NGC’s regulated rate of return or some other form of financing, and can choose whether to arrange for the construction of these assets themselves or whether NGC makes these arrangements.

Transmissions Network Use of System (TNUoS) charges cover the regulated cost of the transmission network infrastructure assets and their maintenance. As these assets cannot in general be allocated to specific customers, the TNUoS charge shares the cost between all transmission customers who use the system in that year. The charges to individual customers reflect the marginal cost of reinforcement to meet increasing imports or exports from each area of the country. For example, for generators larger than 100 MW, these charges result in a payment from the generator to the NGC in areas where reinforcements will be necessary to accommodate increased exports. A payment is made to the generator by the NGC in those areas of the country where generation offsets the need for transmission investment. Again, due to the nature of the transmission system in Wales and the distance between the potential resource and the load demand centres, the effect of this cost penalty for medium/large renewable generators is likely to be higher than for many other regions of the UK.

Balancing Services Use of System (BSUoS) charges are levied on generators and electricity suppliers participating in the national electricity market, and cover the costs of system operator actions to balance the system including the costs of ancillary services. Generators larger than 100 MW are required to participate in the national market, while smaller generators may choose to do so if they wish. Smaller generators also have available to them a number of options that permit them to participate in the national market without incurring transmission charges.

The NGC does not generally levy charges for embedded generators smaller than 100 MW, so agreements for connection and use of system are not required. However, the NGC is keen to receive information on embedded generators that may have a material impact upon the transmissions system in order to strengthen the network to ensure it remains safe and secure at all times (NGC plc., 2001). In this respect the NGC has facilitated connection and network access procedures for embedded generators by allowing them to have a single point of contact with their host distribution network. This cutting of ‘red tape’ can only benefit marine renewables developers who may be discouraged by the complexity of network access procedures.

Generally, an increasing proportion of embedded generation can be expected to reduce the flow across the interfaces between the transmission and distribution networks, which would delay any requirements for the NGC to reinforce this part of the network. In certain areas, however, it may be possible that there could be electricity exports from distribution networks to the transmission system, and reinforcement would be needed if the level of exports to the transmission system were to exceed the existing capability. This could constrain the further development of embedded renewable generation in certain areas. The NGC is confident, however, that as far as transmission is concerned there are no major issues that would impose a barrier to meeting the government’s immediate (2010) targets for renewable generation (NGC plc, 2001).

Nevertheless, the transmission system will continue to play an important role in the future electricity market even with higher penetration of renewables and embedded generation. It is important, therefore, that action is taken now to ensure that there are no barriers (technical, financial or regulatory) to much larger renewable developments in the future, which could compromise the ability to achieve potentially more challenging renewables targets in the longer term. The adaptation of the Grid to operate alongside significant quantities of embedded generation will also be a significant issue in delivering any long-term cost reductions.

7.2.3 Future potential for embedded generation

There are several potential benefits from the incorporation of embedded generation in the distribution network:

- Significant growth in embedded generation will contribute to fuel diversity and security as it will facilitate diverse forms of generation, including renewables, to be brought on-line that are not reliant upon imported fuel. It will also contribute to the UK meeting its targets for reducing greenhouse gas emissions, as the embedded plant will comprise of low or zero-carbon technologies.
- Embedded generation plant has the potential to reduce overall costs to the consumer in the longer term by providing a more efficient electricity system that generates and delivers power close to the point of use. System losses will also be reduced when the exported energy from embedded generators is absorbed locally.
- Embedded plant (particularly some marine renewables) generally has potentially lower capital costs and can be sized to match a particular level of demand.
- Embedded generating plant can help to reduce the demand on the transmission system. They therefore help to delay or avoid the need to reinforce grid supply points and hence may reduce the charges levied on the host distribution company.
- Similarly, smaller generators reduce the liability of electricity suppliers to pay the TNUoS demand charge. By this means, embedded generators may receive an ‘embedded benefit’ in all areas of the country. However, the benefit tends to be significantly larger in those areas where generation or demand reduction offsets the need for transmission investment. Small generators can also help an electricity supplier avoid BSUoS charges and may therefore be able to negotiate an embedded benefit (NGC plc., 2001). This means that, in many cases, a supplier that provides electricity generated by an embedded generator to its customers, can reduce costs. The increased supply value of embedded generation through these avoided costs could be worth as much as £7 per MWh to the plant operator (ETSU, 2001d).
- Positioning the UK at the forefront of both electricity liberalisation and the development of embedded generation will enhance industrial competitiveness and opportunities in overseas markets. UK companies will be ideally placed to exploit opportunities in developing embedded generation projects and services in other countries.

The mix of embedded generation technologies will, to a large extent, depend on energy market and political issues. The US is a world leader in the development of embedded (or distributed) generation, primarily in response to commercial demands and the poor quality and security of power in a number of states (ETSU, 2001d). This has resulted in an embedded generation market dominated by low-cost, high-reliability fossil fuel plant (predominantly gas-fired). Progress has been slower in Europe because of the generally good standard of power supplies, and market liberalisation has only recently come about in many countries (including the UK). The incentive for embedded generation in Europe has mainly been environmental concern, and this has resulted in wide development of renewable technologies. As shown in previous chapters, these are currently more costly than other forms of generation and rely upon government subsidies to achieve market penetration. ETSU (2001d) believes that the situation in the UK may well move towards that in the US, where renewables benefit from, and are developed alongside, other embedded generation.

If government targets for renewables are to be met, the rate at which new generation must be connected to the distribution systems will need to be increased by a factor of four or five over that which has been achieved in recent years. ETSU (2001d) believes that this will be extremely difficult to achieve within the existing technical, regulatory and commercial framework, and that the environment in which embedded generation currently operates could impose ‘very significant constraints on the ability to achieve the government’s objectives.’ This problem was also highlighted in the RCEP report on *Energy – The Changing Climate* (RCEP, 2000), which called upon the government to review how electricity networks can best be financed, managed and regulated in order to stimulate and accommodate large energy contributions from renewable sources while maintaining reliability and quality of supplies.

Many of the issues relating to connection of embedded generation pertinent to renewable energy generators have been investigated by the OFGEM/DTI Embedded Generation Working Group (EGWG). In its report in January 2001 the EGWG suggested that embedded generation could be facilitate, *inter alia*, through:

- commitment to a coordinated programme of work;
- rewarding reliability and quality of supply, and the connection of renewable and CHP generation; and
- adaptation of electricity networks to encourage significant embedded generation.

Without these changes the EGWG stated that ‘it is unlikely that the level of embedded generation envisaged by the government will be accommodated on distribution networks’ (EGWG, 2001). The work of the EGWG and its outputs will be fundamental in developing a regulatory, commercial and technical framework in the UK within which embedded generation can develop commercially.

The extent of the challenge to generators, developers, and network operators in particular, should not be underestimated. Advance investment by a DNO may be appropriate in anticipation of additional embedded generation (which would also contribute to economic development in the same area), although this would require significant investment and may qualify for structural funding.

While the key aim is to facilitate the achievement of the government’s renewables target by 2010, the key date highlighted by ETSU in the development of fair treatment for embedded generation will be the next distribution price review in 2005. The aim of the programme outlined by ETSU will be to work with OFGEM, government and the industry to facilitate this process and to provide support for relevant research and development projects that can potentially lead to reductions in the cost of connection or the operation of embedded generation. Although this should satisfactorily address regulatory and economic issues, technical works involving reinforcement of the network could still be subject to significant delays.

7.2.3 Alternative to network connection

One alternative to paying for costly network connections, which may be particularly attractive for certain offshore marine renewable technologies, is the production of hydrogen by electrolysis. Hydrogen is a versatile energy vector, providing electricity, thermal and transport energy (Hawkes *et al.*, 2002).

By passing an electric current through water it is separated into its component parts – hydrogen and oxygen. The hydrogen can be stored liquified or compressed up to 700 bar, and periodically collected by ship or pumped ashore. The electrical current required for electrolysis could be generated by the marine renewable device itself. This is a concept that is attracting an increasing amount of attention, and was advocated by the Science and Technology Committee on Wave and Tidal Energy as a potential technology that could be applied to offshore wave and tidal devices. At least two companies, Seapower Ltd, and Tidal Hydraulic Generators Ltd, are considering this. The technology is also being researched by a team led by Professor Hawkes at the School of Technology, University of Glamorgan.

Hydrogen can be generated and used in modular devices at a wide range of scales; at small scale, allowing for embedded power generation with benefits including greater security of supply and use in remote locations (Hawkes *et al.*, 2002). Hydrogen storage, coupled with electricity generation systems, allows smoothing of intermittent electricity supply (e.g. from wind) to provide a 'base-load' supply. In addition, storage offers the prospect of power conditioning, network management support, and reinforcement avoidance if it can be provided at low cost.

With regard to the application of hydrogen technology to marine renewables, the Science and Technology Committee on Wave and Tidal Energy (2001) draws a useful comparison with the smaller, more distant oilfields where it is uneconomical to lay a pipeline. Here the extracted oil is pumped into tanks on the seabed, with a pipe running up to a floating buoy on the surface. The tanks are emptied on a regular basis by a ship, which anchors securely and hooks up to the pipe.

The move towards a hydrogen-based economy[33] will result in an increasing demand for hydrogen technology worldwide. UK, European and global strategy reports all identify hydrogen as the fuel of the future. Promoters of the technology believe the employment implications and, for early adopters, the export opportunities, to be very significant. In a paper presented to the Institute of Welsh Affairs' (IWA) conference on the Welsh Potential for Renewables Energy, Professor Hawkes argued that Wales could be at the forefront of such innovation and could become a supplier of these technologies world-wide. For this to happen, he believes a strategy is required at national level to actively work towards implementation. Although such a strategy is not yet in place, the Government has already signalled its interest in the technology – the 2001 Budget included a 'package of measures…to encourage environmentally friendly fuels and to assist the move towards a hydrogen-based economy' (HM Treasury and DETR press release 07/03/01).

[33] The term 'hydrogen economy' describes the interdependent processes (sustainable production, storage and utilisation) necessary to allow hydrogen to replace fossil fuels.

7.3 LEGISLATION AND POLICY FRAMEWORK

The regulatory framework that is necessary to ensure a responsible approach to the development of marine renewables involves a number of government departments with a range of policy responsibilities. Energy policy is the responsibility of the Department of Trade and Industry (DTI). The Department for Environment, Food and Rural Affairs (DEFRA) has stewardship of climate change policy, but also holds policy responsibility for fisheries, marine nature conservation, habitats and species, and for other aspects of environmental protection. The Department for Transport (DfT – previously the Department for Transport, Local Government and the Regions, DTLR) oversees navigation both at sea and in the air, while the Ministry of Defence (MOD) represents defence interests. Furthermore, the Office of the Deputy Prime Minister (ODPM) is charged with implementation of the European Directive on Strategic Environmental Assessment (SEA), which is expected to apply to the plans for offshore marine renewables development (*section 7.4*).

Given these many policy interests that are likely to be affected by the development of marine renewables, it is important that an integrated approach is adopted for both the strategic planning as well as the consideration of development applications through the consenting process.

The first licensing round for offshore wind has highlighted a number of issues relating to the adequacy of the existing legislative framework for regulating development, and in respect of the application and consents processes and the challenges of integration across government departments. As a result, the government has recently commenced a consultation exercise to identify the elements needed for a strategic planning framework as a basis for future expansion of the offshore wind industry (DTI, 2002e). It is anticipated that many of the elements of the planning framework will apply equally to other marine renewables, such as tidal stream and wave energy which may soon be deployable on a commercial basis.

The ownership of the seabed to a distance of 12 nautical miles and, with the exception of coal, oil and gas, the UK's rights to explore and exploit the Continental Shelf are vested in the Crown Estate.[34] The Estate is managed by the Crown Estate Commissioners (CEC) under the provisions of the Crown Estate Act 1961. The Commissioners have a duty under the Crown Estate Act to maintain and enhance the capital value of the Crown Estate and the income obtained from it. To this end, the Crown Estate grants leases or licenses, as appropriate, to permit developers and operators to make use of the aforementioned rights (Jacobson, 1998). while the Crown Estate is primarily concerned with generating income from the Crown holdings, they check that other permissions have been obtained before granting leases and impose various environmental constraints to protect the site. The Crown Estate is an estate in land; as such the Commissioners' role in managing the Estate is that of landowner, not planning authority or statutory regulator. Nevertheless, the Crown Estate requires that all statutory consents have been obtained before work commences, full public liability insurance and indemnity, and proof that the developer is strong enough financially to meet all obligations. In the first round of wind-farms, 20 developers have entered into agreements with the Crown Estate including a rent provision based on 2 per cent of gross revenue. This is a small fraction of

[34] In the case of oil and gas, the power to license exploration and exploitation throughout the UK, including its territorial waters and on the Continental Shelf, is vested in the Secretary of State for Trade and Industry.

the costs of an offshore project, and has not proved to be a major consideration for the industry (DTI, 2002e).

Development consents and regulatory control of marine renewables developments are matters for the appropriate government departments. The statutory consents required for offshore renewable energy projects are described in *section 7.3.1*. The purpose of statutory consents is to protect affected parties from the adverse effects of development. They also ensure that development decisions are made on the basis of a comprehensive balanced consideration of impacts, and are used to decide whether or not a development is acceptable. If so, the consents process also establishes the conditions under which the development is permitted. Decisions on consents are made by ministers based on assessment of advice from statutory consultees, as well as the wider public consultation process. The government has indicated (DTI, 2002e) that while it is possible to examine each case on its own merits, in the future Strategic Environmental Assessment (SEA) will contribute to sectoral development strategies and regional impact assessment studies. while closely linked, the focus on each development decision is therefore narrower than the process of Strategic Environmental Assessment (SEA) (*section 7.4*), which identifies and assesses environmental impacts at a strategic level, such as the predicted cumulative impact of different development scenarios.

The legal basis under which development rights for marine renewables are allocated is clearly defined only for UK territorial waters, i.e. within the 12 nautical mile limit. In other words, the Crown Estate only has powers to grant a lease for development of wind, wave or water driven generating stations within this area. There is currently no comprehensive legal framework for regulating development of the resource, or for granting developers security over a site, beyond the limits of territorial waters. This has been recognised by the government as a potential constraint upon the future development of marine renewables further offshore (DTI, 2002e). In order that the full potential of offshore renewables can be realised, primary legislation has been proposed to extend the existing regulatory framework beyond the boundary of territorial waters.

7.3.1 The consents process for marine renewables in territorial waters

There are two main legislative routes for the government to grant consent to offshore wind-farms in territorial waters, and developers can currently choose which route is most appropriate to their particular schemes. One possible route is for developers to seek consents under a combination of the Coast Protection Act (CPA), Food and Environment Protection Act (FEPA) 1985, the Electricity Act 1989, and possibly the Town and Country Planning Act 1990.

The alternative approach is for developers to obtain an Order under the Transport and Works Act (TWA) 1992, in conjunction with a licence under the Food and Environment Protection Act 1985. Furthermore a lease must be obtained from the Crown Estate Commissioners to place structures on or pass cables over the seabed or foreshore or to erect structures for economic purposes on the Continental Shelf. It should be noted that the TWA does not apply in Scotland, and presently most marine renewables would be licensed through the Crown Estate Commissioners lease, FEPA, and the Electricity Act 1989. Additionally, marine renewables in Orkney and Shetland may fall under the local authority’s control, since special Acts of Parliament extend their jurisdiction beyond the Low Water Mark in these locations.

The Electricity Act / CPA / FEPA Route

Section 36 of the Electricity Act 1989 requires developers to obtain a consent from the Secretary of State for Trade and Industry for the construction, extension or operation of a generating station of a capacity above the permitted capacity, which for offshore wind and water driven generating stations in the territorial waters of England and Wales is 1 MW. In Scotland, Section 36 consents rest with the Scottish Executive. Section 36 (power stations) and Section 37 (overhead lines) are comprehensive procedures in which the views of the Local Planning Authority, the local people, statutory bodies such as the Environment Agency, Countryside Agency and English Nature/ CCW, and other interested parties can be brought into the decision-making.

Under Section 34 of the Coast Protection Act 1949, consent from the Minister for Transport is required to construct, alter or improve any works below the level of mean high water springs, or to deposit or remove any object or materials from this area. The purpose of the consent requirement is to ensure that marine works will not be detrimental to navigation. The consent process for England and Wales is managed by the DfT, and involves a wide consultation with interested and affected parties. This takes 10-12 weeks if straightforward, but can often be considerably longer (BBV, 2001). Prior consultation with interested parties is recommended and guidance notes have been issued. The Scottish Executive determines applications relating to developments in territorial waters adjacent to Scotland.

Part II of the Food and Environment Protection Act 1985 provides for licensing of the deposit of articles on the seabed. A licence is required for the placing of any structures (other than cables which are exempt) below mean high water springs. The purpose of the legislation is to protect the marine environment and living resources that it supports. An application for a license is made in writing to DEFRA for works within English waters. DEFRA also administers the process within Welsh waters on behalf of the National Assembly for Wales. The Scottish Executive is responsible for licensing developments in territorial waters adjacent to Scotland. Each will take particular care in assessing applications that may have implications for the nature conservation interests of European sites (as defined by the Habitats Regulations 1994).

TWA/FEPA Route

The alternative route is for the developer to apply to the Secretary of State for Trade and Industry for an Order to be made under Section 3 of the Transport and Works Act 1992. The Act introduces a ministerial order-making system in England and Wales for authorising the construction or operation of structures interfering with the rights of navigation, up to the seaward limits of the territorial sea. Construction projects outside harbour areas, formerly the subject of Private Acts of Parliament, will therefore normally have to be approved by an Order under the TWA. The Order can include a provision that specifically extinguishes public rights of navigation over water and can therefore provide a statutory defence against a claim of public nuisance for interfering with navigation rights. This is a longer, more complicated, and much more expensive route than the former, and could trigger a public enquiry. However, it does give the possibility of setting an exclusion zone around the development, and legal protection against being sued for causing nuisance or obstruction. It is unclear whether the Electricity Act/CPA route achieves a similar effect (DTI, 2002e).

By virtue of Section 16 of the Act, the Secretary of State may issue a planning direction under Section 90 (2A) of the Town and Country Planning Act 1990 deeming planning permission to be granted for the works authorised by a TWA Order. As with Section 36 of the Electricity Act, therefore, a developer can request deemed planning permission for ancillary onshore works when applying for a TWA Order for offshore works. The NAW deals with Orders for projects in territorial waters adjacent to Wales. The Act does not extend to Scotland, where developers would need a private bill under sections 28 and 29 of the Scotland Act 1998 (DTI, 2002e).

A study on the legal consents process for the development of offshore wind energy by Bond Pearce Solicitors (2001) has recommended that future wind power schemes should be encouraged to apply for licensing using the TWA consents route, as opposed to the CPA. Arguably, the same is likely to apply to other forms of marine renewables.

7.3.2 Requirements for environmental assessment and consultation

The Environmental Impact Assessment (EIA) Directive (EC Directive 85/337/EEC on the Assessment of the Effects of Certain Public and Private Projects on the Environment, as amended by the Environmental Impact Assessment Directive 97/11/EC) requires an environmental assessment to be made of the effects of certain public and private projects, including energy projects. The Directive is given effect for electricity generation projects in England and Wales by means of the Electricity Works (Environmental Impact Assessment) (England and Wales) Regulations 2000. The Regulations came into effect on 1 September 2000 and update the Electricity and Pipe-line Works (Assessment of Environmental Effects) Regulations 1990. The Regulations implemented some key changes in assessing the environmental impacts of developments, including the introduction of thresholds for overhead power lines.

Under the Regulations all wind-farms, including offshore wind-farms, of more than 50 MW will be considered for EIA on a case-by-case basis. Additionally, offshore wind-farms are now included in Annex II of the amended Directive. This means that any proposal for an offshore wind-farm that is likely to have significant environmental effects has to be subject to environmental assessment and full consultation before consent can be given. It is DTI policy, however, to require EIAs for all offshore wind-farms (DTI, 2002e), and it is almost certain that the same will apply to other forms of marine renewable energy. The EIA should inform the design of the project and should identify measures that will be adopted during the construction and operation of the project to avoid or reduce impacts where practicable.

In addition to meeting the above requirements, developers will have to satisfy the requirements of relevant European legislation that may apply as a result of the legal status of a particular site. For example, the Habitats Directive requires member states to designate sites on land and at sea to form part of the EC Natura 2000 network. This comprises Special Areas of Conservation (SACs) under the Habitats Directive and Special Protection Areas (SPAs) under the Birds Directive. Member states are required to protect any designated sites from activities that may affect their integrity. Although integrity is not defined, it can be regarded as ecological and functional coherence (Metoc plc., 2000). The Habitats Directive is implemented in England and Wales through the Conservation Regulations 1994, which define the duties of the regulator in relation to plans and projects likely to significantly affect designated sites.

Before deciding to give consent to a project that is likely to have a significant effect on a European site (either alone or in combination with other plans or projects), under Regulation 48 the competent authority (as defined in the Habitats Regulations) must make an assessment of the implication of the project in view of the site's conservation objectives. These projects do not need to be situated within the boundaries of the European Marine Site, but might only need to be adjacent to be required to undergo an assessment. A developer applying for a consent for a development within or in the vicinity of such a site should anticipate the need to provide information to the competent authority relating specifically to the assessment of effects on that site. An appropriate environmental assessment will therefore be required for the project alone, but also taking into account other plans and projects in the area, i.e. cumulative impact. First generation marine renewables are likely to be located in areas of relatively shallow water, although developments further offshore may be possible in the future. In the first instance it is likely that the pattern of development will be clustered within regions, particularly if future licensing rounds concentrate development within strategic areas. The deployment of a large number of devices over areas of many square kilometres will give rise to a need to consider the cumulative impact within each region, not only the local impacts of each development on a case by case basis. Given the possible scale of development, cumulative impacts could be significant and would, therefore, need to be incorporated in the planning process.

The final product of an EA is the Environmental Statement (ES). The ES should provide a systematic and objective account of the significant environmental effects to which the project will give rise (Metoc plc., 2000). The preparation of the ES should be a collaborative exercise involving wide discussions with regulators (DTI, National Assembly for Wales, DEFRA, DfT, Environment Agency), statutory consultees (i.e. CCW, government agencies and local authorities), non-statutory consultees (e.g. organisations with a specialist interest in the environment), and the public (through project briefings and public exhibitions), as appropriate. Consultation is seen as possibly the most important stage in the environmental assessment and authorisation process. Although there is no prescribed form for the ES, it must be compliant with the Directive 85/337/EEC and the Regulations implementing the Directive.

In a study of the environmental effects of offshore wind-farms, Metoc plc (2000) recommends that thought should be given to the Environmental Assessment at a very early stage, ideally when the site is being selected so that the environmental merits of practical alternatives can be conducted. If not considered from the outset, environmental issues may well emerge as major problems when a project's design is well advanced, causing possible delay and re-working.

The adoption of environmental assessment procedures at the planning and programming level should benefit undertakings by providing a more consistent framework in which to operate by the inclusion of the relevant environmental information into decision-making. However, the Electricity Works (Environmental Impact Assessment) Regulations 2000 were not developed with offshore marine renewables specifically in mind, and therefore may not cover aspects of this kind of development. A list of potential impacts specifically relating to marine renewables, drawing upon previous and current research in this field, may be useful to both developers and regulators.

7.3.3 Offshore developments beyond territorial waters

As more development takes place within the relatively shallow waters close to shore, the scope for large-scale deployment of renewable energy technologies may be constrained within territorial waters by the lack of available seabed. Furthermore, the cumulative impact of developments in territorial waters may reach levels where further deployment of technologies would be unacceptable. Developers may therefore be encouraged to look further offshore beyond the 12 nautical mile limit where the size of the resource and potential for exploitation may be greater. However, as noted in the introduction to this section, there is currently no comprehensive legal framework for regulating development of marine renewable energy resources beyond the limits of territorial waters. Neither is there a satisfactory legal basis for giving developers security over a site, although developers will be encouraged to investigate sites beyond the boundary of territorial waters in anticipation of future legislation being enacted (DTI, 2002e).

Primary legislation will be necessary to build a comprehensive legal framework to allow development outside territorial waters. In this respect the government has made clear its intention to make an appropriate declaration asserting the UK's sovereign rights in accordance with the United Nations Convention on the Law of the Sea (UNCLOS) in relation to the production of energy from the water, currents and winds in a Renewable Energy Production Zone, and to vest the ensuing development rights with a competent authority. It is proposed that the Renewable Energy Production Zone will extend up to 200 nautical miles from the baselines of the territorial sea (DTI, 2002e)

Legislation will also be needed to revise the consents framework for projects beyond territorial waters, although the DTI notes that some elements of this are already in place (DTI, 2002e). For example, the licensing requirement in FEPA outlined in *section 7.3.1* and Section 34 of the CPA already apply beyond territorial waters. However, the DTI believes that it is highly unlikely that Section 36 of the Electricity Act extends beyond territorial waters. Revision of the legislation will provide developers with the legal assurance of their right to develop renewable energy schemes, both within territorial waters and the Renewable Energy Production Zone. According to the DTI, a decision on the most appropriate body in which the new offshore powers should be vested will be made during the preparation of the legislation, which will also allow the perspective roles of the Crown Estate, DTI and other relevant government departments to be clarified.

As primary legislation would be needed, this is chiefly a consideration for the long-term. However, action needs to be taken now to ensure that there are no delays in the development and deployment of marine renewable energy devices (e.g. floating support structures for offshore wind turbines, and floating wave energy devices) further offshore when the technology has reached maturity.

7.3.4 Proposed changes to the consents process

None of the legislation outlined in *section 7.3.1* was developed specifically within the context of offshore marine renewable energy schemes. Consequently, the government recognises that the various statutory and consents regimes do not fit together seamlessly to form a coherent framework (DTI, 2002e). Specifically, there is duplication of effort between the various consent requirements of different legislative instruments, which is compounded by uncertainties about the time-scales for processing applications, as well as different arrangements for charging of fees and for public consultation. For example, the consenting process under the CPA is different from both the Electricity Act and FEPA, in that it is less formal and structured. At present there is no statutory requirement in the CPA for consultation, except for those elements of the project that are subject to an environmental impact assessment. These issues need to be addressed to remove any disincentive to developers, and to facilitate the development of offshore renewables technology to meet government targets in a responsible way. Efforts to streamline the consents procedure and make it more transparent and accessible for potential developers already include the establishment of an Offshore Renewable Consents Unit (ORCU) by the DTI as a 'one-stop-shop' for developers, whose role is to:

- clarify at an early stage what information the developer has to provide;
- produce a single application form for offshore consents;
- gather all relevant information and distribute it to the correct consenting authority; and
- help to seek solutions to any problems that arise.

Many limitations of the existing framework for applications and consents are not exclusive to the marine renewable energy developments, and affect other marine sectors. In recognising this, the government is undertaking a regulatory review of development in coastal and marine waters, with the aim of streamlining the process and to reduce the overall complexity of the regime. The aims of the study are to (DTI, 2002e):

- identify essential principles to underpin the development regime and assess how far these are currently met;
- make proposals to simplify and reduce the cost and burden associated with existing consent processes in the short-term; and
- make recommendations for longer-term reforms with the objective of delivering sustainable development through a modern, transparent, efficient and effective coastal and marine development system.

The preliminary findings of the study will be reported to Ministers in late-2002, and the government will consult publicly on recommendations in spring 2003.

In addition to the generic shortcomings addressed in the above study, there are also specific concerns relating to the consents process for marine renewables, which were highlighted during the first round of offshore wind-farm licensing. For example, there is some confusion over the extent of the extinguishment of rights to navigation within the territorial sea conferred by the consents routes. As mentioned in *section 7.3.1*, it is not clear whether the Electricity Act and the CPA extinguish public rights to navigation, so developers for whom this is important to their project may be deterred from using this consent route.

The role of the local planning authority (LPA) in respect to marine renewable energy developments also needs to be clarified, particularly with regard to the Section 36 consents process. All marine renewable energy projects are likely to have some impact upon the land – if not a visible impact, then there are likely to be impacts associated with onshore ancillary works. The powers of most local authorities do not extend below the low water mark, therefore it can be argued that there is no relevant planning authority for marine renewables. However, in reality, local authorities can wield substantial powers, as developers require planning consent from the LPA under the Town and Country Planning Act 1990 for the onshore elements of an offshore installation, such as cabling and the construction of an electrical substation. It can object to a proposal and force a public inquiry.

Clearly, the relevant LPA(s) would need to be involved in the consultation process, as they are uniquely placed to bring the local perspective to the decision-making process. However, any effort to streamline the consents procedure should avoid any further unnecessary delays or the addition of further complexity to the regime.

These issues, along with proposed reforms to other aspects of the legislative and policy framework that relate to marine renewables, are the subject of *Future Offshore*, a DTI consultation paper which sounds out on a strategy for a strategic planning framework as a basis for the expansion of the offshore wind industry (DTI, 2002). The more general conclusions and recommendations of this consultation will feed into the recommendations of the wider review of developments in coastal and marine waters. However, the government has made it clear that issues specific to the consents process for offshore wind-farms will be pursued, if necessary, through earlier legislation.

7.4 STRATEGIC ENVIRONMENTAL ASSESSMENT

Strategic Environmental Assessment (SEA) extends the principles of EIA, which is carried out for individual projects, to decision-making at strategic levels. This means that regional impacts associated with the scale of development, or cumulative impacts arising from numerous developments within an area can be taken into consideration. This information is important because it will determine the extent of deployment of renewable energy devices in a given area. The concept is defined in European law by Directive 2001/42/EC on the *Assessment of the Effects of Certain Plans and Programmes on the Environment* (SEA Directive).

The purpose of SEA is to ensure that the environmental consequences of certain plans and programmes are identified and assessed during their preparation and before their adoption. The public and relevant authorities can express their opinions and all results are integrated and taken into account in the course of the planning procedure. After the adoption of the plan or programme the public is informed about the decision and the way in which it was made.

It is proposed that SEA can contribute to more transparent planning for marine renewables by involving the public and by integrating environmental considerations into the decision-making framework. SEA can also be integrated into a wider assessment framework which identifies the social and economic effects of development proposals. This will help to achieve the goal of sustainable development.

The following sections briefly describe the requirements of the SEA Directive, and the potential application of SEA to marine renewables.

7.4.1 Requirements of the SEA Directive

The objective of the Directive is:

> *'to provide for a high level of protection of the environment and to contribute to the integration of environmental considerations into the preparation and adoption of plans and programmes with a view to promoting sustainable development, by ensuring that, in accordance with the Directive, an environmental assessment is carried out of certain plans and programmes which are likely to have significant effects on the environment.'* (European Directive 2001/42/EC).

Member states are required to determine whether plans or programmes are likely to have significant environmental effects either through case-by-case examination or by specifying types of plans and programmes or by combining both approaches. In this respect, the government has already indicated that it expects the Directive to apply to plans for the development of offshore marine renewables (DTI, 2002). The Directive must be transposed into UK law by July 2004.

Where an SEA is required by the Directive, the authority responsible for the plan or programme is required to prepare an environmental report containing relevant information as set out in the Directive. This should identify, describe and evaluate the likely significant environmental effects of implementing the proposed plan or programme, and reasonable alternatives taking into account the objectives and geographical scope of the plan or programme. In deciding the scope and level of detail of the information to be included in the environmental report, the authority responsible for the plan or programme is expected to consult with other authorities with an environmental remit (to be defined by the member states).

In order to contribute to more transparent decision-making and with the aim of ensuring that the information supplied for the assessment is comprehensive and reliable, the draft plan or programme and the environmental report should be made available to authorities with relevant environmental responsibilities, and to the wider public. The detailed arrangements for informing and consulting with the authorities and the public are to be determined by Member States. However, consultation should extend to all parties affected or likely to be affected by, or having an interest in, the proposal, including relevant non-governmental organisations, such as those promoting environmental protection and other organisations concerned. Appropriate time frames should be set to allow sufficient time for consultation and the expression of opinion. Also, the environmental report and the opinions expressed by the relevant authorities and the public should be taken into account during the preparation of the plan or programme, and before its adoption or submission to the legislative procedure.

It is recognised that there could be duplication of effort where the obligation to carry out assessments of the effects of potential plans or programmes on the environment arises simultaneously from the SEA Directive and other Community legislation. In such cases member states may provide coordinated or joint procedures fulfilling the requirements of the relevant Community legislation, although this area may require further clarification to ensure that the procedures adequately cover all potentially important effects while remaining cost-effective. Member states are required to monitor the significant environmental effects of the implementation of plans and programmes in order, *inter alia*, to identify at an early stage unforeseen adverse effects and are able to undertake appropriate remedial action. This is particularly important with respect to marine renewables because, as it is essentially a new industry, many of the potential impacts may be unknown and the extent of other effects cannot be predicted with certainty due to the lack of monitoring data available. Again, the Directive allows for existing monitoring arrangements to be used if appropriate, with a view to avoiding duplication of monitoring effort. Further guidance from the DTI/NAW on monitoring may be required. It may be beneficial if monitoring and research is coordinated and undertaken jointly by all stakeholders.

Although the Directive is yet to enter into force, it is suggested that the SEA procedure could provide helpful support to the development of plans for the expansion of the marine renewables industry, while ensuring that the environmental impacts of deployment of such schemes are kept to a minimum. The DTI appears to have acknowledged the benefits offered by SEA, and has commenced SEA studies on three strategic regions proposed for the next leasing/licensing round for offshore wind-farms (DTI, 2002). Any measures to inform the decision-making process relating to application for consents must be welcomed.

7.4.2 The application of SEA to marine renewables

Although there is no single process for conducting SEA, the overall approach and the methodological principles to be used in applying SEA to marine renewables can be based upon experience gained from the UK offshore oil and gas industries. The first SEA was conducted for this sector in 1999/2000 for an area north-west of Shetland and the DTI has since commissioned a series of SEAs in an assessment of the remaining unlicensed areas of the UK Continental Shelf (DTI, 2002e). These studies provide a large amount of data and information for various offshore areas, which can be used to support marine renewables development and potentially provide significant cost and time savings.

As mentioned in *section 7.4.1*, the government has commenced an SEA process, focusing on three strategic regions (the Thames Estuary, the Greater Wash, and the North-west) proposed for the next leasing/licensing round for offshore wind, the first phase of which is due to be completed in early 2003. A ‘proactive and flexible approach’ has been adopted, which seeks to identify and fill the gaps in the present knowledge base relating to impact uncertainties through a programme of monitoring and research studies. This information will then be used to refine future SEAs, which could be applied to other marine renewables. In future it is likely that the scope will be extended to areas beyond the 12 nautical mile limit and include linked landfall development. However, it is noted that scope does not extend to other onshore facilities linked to offshore energy generation, which may represent a failure to take account of the entire life-cycle of offshore renewable technologies and impacts associated, for example, with manufacture and transportation of devices, and strengthening of the local electricity network to accept further generation. It is important, therefore, that the SEA process informs a wider assessment of the social and economic impacts associated with the development of marine renewables, and incorporates some element of life-cycle assessment for the technology.

It is anticipated that SEA can make valuable contributions to the formulation of a strategy for the development of marine renewbles. These have been identified by the DTI (2002e) as follows:

- identification of environmentally preferred options;

- early identification of areas with presumptions for/against development – this is a key issue as there is a need to avoid the development of the right renewable technologies in the wrong areas;
- production of development guidelines for project design, siting, construction and operational management practices;
- providing information which can inform subsequent project-specific EIAs;
- assessment of cumulative impacts of individual schemes, including any ‘trans-boundary’ impacts;
- identification of decision-making risks arising from lack of data;
- establishing criteria upon which decisions regarding applications for consents can be based; and
- providing recommendations for mitigation measures that can be incorporated into the design and siting of individual projects.

7.5 STRATEGY AND ACTIONS REQUIRED TO DEVELOP MARINE RENEWABLE ENERGY IN WALES

A detailed strategy specifically aiming to optimise the benefits to Wales of the evolving market in marine renewable energy technology is urgently required. In formulating this strategy, it will be necessary for the NAW to work closely with the major offshore wind, wave and tidal energy developers in order to evaluate potential projects and to explore in depth how economic and research and development activity in Wales can be best linked to such projects. Marine renewables present a major growth opportunity in a key sustainable development sector, and it is important that the NAW recognise the potential resource available in Wales and devise a strategy for the sustainable development of the resource. The following sections consider some of the key issues that influence the development of such a strategy.

7.5.1 Benefits to Wales of a Marine Renewables Strategy

Wales has a potentially large renewable energy resource base, due to its climate and geography, and there are commercial and rural development opportunities associated with the development of marine renewable energy technologies. Recognising this potential, the NAW’s intention to develop Wales as a ‘global showcase’ for clean energy production is welcomed, but needs to be carefully managed and orchestrated with long-term planning. With the right approach, Wales could harness some of the massive potential provided by the renewable energy resource base to supply part of its energy needs and be at the forefront of developments in this field.

Development of an appropriate strategy for the marine renewable energy technology sector could also make an important contribution to the creation of long-term and sustainable employment in Wales, not only in the construction, operation and maintenance of offshore schemes, but also in manufacturing and associated industries. The benefits may be particularly evident for industrial areas in proximity to the resource, e.g. Milford Haven, where the geography and existing facilities and skill-base favour development of the resource. Furthermore, development of marine renewables could provide a lifeline to many communities hit by recent job losses in the steel industry in Wales, through manufacturing and assembly of marine renewable energy technologies.

The ultimate aim would be to create a new multi-million pound domestic and export industry for Wales, which would significantly improve employment opportunities in certain parts of the country. This is recognised as being eminently achievable in the report by Sustainable Energy Ltd. (2001), which states: ‘If Wales can select those specific renewable energy technology sub-sectors that provide the best opportunities for sustainable development and competitive technological advantage, and support these sectors by stimulating both supply and demand, then many thousands of jobs can be created with growing export success’.

However, creation of these new economic opportunities will not be achieved without the implementation of a supporting strategy to facilitate the development of marine renewable energy technologies in Wales. As recognised by Sustainable Energy Ltd, future export success for Wales’ renewable energy businesses will largely depend upon the establishment of supportive conditions in the Welsh renewable energy market (SEL, 2001).

In addition to the potential economic benefits provided by developing marine renewable energy technologies, there are also environmental benefits that can be delivered through a marine renewables strategy for Wales. The main benefits are associated with a reduction in CO_2 emissions from conventional fossil fuel power stations. As noted *in section 3.3*, the NAW now needs to position itself so that it can move towards the levels of greenhouse gas emissions that are likely to be needed as part of the global response to climate change. Greenhouse gas emissions targets are likely to become even more stringent beyond the 2012 Kyoto deadline. If targets are to be met, all available renewable energy technologies will need to be exploited, including offshore wind, wave and tidal resources. A precautionary approach therefore suggests that policy action is required now by the NAW to establish a range of future low-carbon energy options, which could benefit from the development of marine renewable energy resources.

Most renewable energy technologies require significant space, mainly because the energy sources they harness are diffuse. Land-based renewable schemes are already facing constraints due to conflicts over land use and lack of suitable sites where planning permission is likely to be forthcoming. Marine renewable energy resources can make a potentially significant contribution to meeting future energy needs, as schemes could be deployed on a much larger scale at sea than on land.

However, it is important to recognise that renewable energy developments, in common with all energy generating activities, are likely to have some environmental impacts although these are generally less significant for renewables than for most other forms of energy generation. Nevertheless, the urgency with which renewables targets must be met should not be a compromise that results in unacceptable environmental impacts upon coastal and marine sites that are selected for development. In other words all effort must be made to avoid the ‘right technology in the wrong location’.

A strategic framework for marine renewables for Wales would encourage a pattern of development which allows optimal exploitation of the available resource while taking account of environmental sensitivities. This approach would also enable an assessment to be made at a strategic level (through a SEA – *section 7.4.2*) of the potential impacts of developments within particular sea areas. This is important because many of the potential impacts, and in particular cumulative impact, of marine renewables development on the environment are not fully understood. It would be useful, therefore, to have a procedure in place that manages these risks.

7.5.2 Role of the National Assembly for Wales

The NAW should be encouraged to continue developing a more positive approach to marine renewable energy generation and to make a commitment to the creation of a competitive marine renewable energy industry for Wales. This opportunity will only be realised if a strong supporting strategy is adopted, backed with sufficient funds to demonstrate its determination. The NAW has already indicated that Objective One funding will be made available for suitable energy infrastructure projects, and may include assistance for renewable energy developers to cover the considerable cost of network connection (DEFRA, 2001). Additional support for research and development is required, so that other schemes can benefit in a similar manner to the innovative Pembrokeshire Tidal Power Scheme, granted £46,000 over two years by Pembrokeshire Coast National Park under the NAW Environment Development Initiative.

Arguably, however, the more pressing need is for more substantial development support via policy statements that make a clear commitment to supporting developments in the marine renewable energy sector. The Science and Technology Committee on Wave and Tidal Energy believes that if such statements were made, marine renewable energy companies would find it much easier to attract funding from private investors who could see a long-term future for the companies. As one witness observed, 'the country that demonstrates commitment at this stage is most likely to be the country that wins the prize of a future major industry' (Seapower, 2001).

The recent Strategic Study of Renewable Energy Resources in Wales by Sustainable Energy Ltd (SEL, 2001) indicated that developers require the NAW to provide a strong lead including national aims and targets for renewable energy. These need to be supported by a positive strategic renewable energy planning framework, regional identification of resources and obligations to enable developers to target suitable areas, within a local, regional and national context.

Beyond declarations of support and the provision of funding, it is debatable, however, exactly how much power the NAW has to effectively support marine renewable energy sources. In this respect the legislative powers of the NAW are even more limited for generating stations at sea than on land. The DTI is currently the coordinating body to facilitate the processing of the consents procedures for all wind and water-driven generating stations above 1 MW capacity in Welsh waters and is responsible for Section 36 consents under the Electricity Act 1989. At present in Scotland only generating stations with a capacity greater than 50 MW require Section 36 consent.

The NAW is formally consulted as part of the consents process, but has no decision-making powers in respect to applications. The NAW has specific devolved responsibilities for Planning and Environmental Issues under the Town and Country Planning Act 1990, and is also the authorising body in respect of the Food and Environment Protection Act 1985, and the Transport and Works Act 1992. Discussions on the possible wider transfer of energy functions to the Assembly are currently taking place (DTI, 2002e). A consistent and seamless strategic framework for offshore development of renewables is essential and improved definition of the role of the NAW is required to ensure that policy formulation and the development of the consents and regulatory process reflects and achieves this.

In this respect there appears to be scope within the NAW's scheme for sustainable development and the emerging Wales Spatial Plan (WSP) to develop a strategic and proactive approach to the development of renewable energy in Wales. In particular it is recognised that the WSP can help to identify and inform, at an early and strategic stage, policy options and broad geographical areas suitable for the development of onshore renewable energy technologies. With this in mind there is cause to support the proposal by CCW for the WSP to be extended to include planning issues within Wales' territorial waters to facilitate the development of marine renewable energy technologies (CCW, 2002). It would also allow the balance between onshore and offshore generation to be considered. Integrating policy and decision-making affecting the terrestrial, coastal and maritime environments would help provide a rational framework for analysing the contribution of Wales' land and seabed to help achieve renewables targets.

7.5.1 Establishment of a Welsh Sustainable Energy Agency

The RCEP report on *Energy – the Changing Climate* (2000) recommended the establishment of an effective executive body charged with carrying forward sustainable energy policies (recommendation 12). The report recognised that there are important functions related to promoting renewable sources of energy that would benefit from a higher profile, sharper focus and better targeting. The report also highlighted the potential for synergy between efforts to promote the development of renewables and efforts to promote energy efficiency. In the commission's view this would be best achieved through the creation of a Sustainable Energy Agency.

The government has, to an extent, taken on board the views of the RCEP, and in May 2002 the first interim meeting of the Renewables Advisory Board was convened. The board is an independent non-departmental public body sponsored by the DTI, which provides advice to government on a wide range of renewable energy issues on request and may also offer other such advice to the government, as it considers appropriate. The aim of the board is to bring together government departments, the renewables industry and the unions to develop mutual understanding of the key issues for the industry both short-term and over the next twenty years, including for example, technology development, barriers to market penetration and export enhancement.

The RCEP (2000) report also recommended that 'the devolved administrations should review and improve their arrangements for promoting energy efficiency and renewable energy, taking into account our recommendation that a Sustainable Energy Agency should be established, and if necessary should seek additional powers in this field' (recommendation 76).

The establishment of a Sustainable Energy Agency for Wales, or a similar body based on the model of the Renewables Advisory Board, could provide an appropriate framework through which an effective strategy for development of renewable energy in Wales could be delivered. The actual delivery of actions and measures within the overall strategy will involve a range of organisations and programmes. Overall coordination will therefore be required, not only to ensure that there is cohesion, but also to ensure that programmes involving the various renewable energy sub-sectors, including marine renewable energy technologies, are initiated.

There have been numerous calls for the establishment of a Welsh Sustainable Energy Agency. Most notably, Sustainable Energy Ltd, in a report to the NAW (SEL, 2001), made the following statement:

> *'Effective strategic leadership will be required if the vast potential offered by development of Wales' renewable energy sector is to be realised. In order to provide this leadership and to coordinate the work of the whole network of relevant organisations and programmes, a Sustainable Energy Agency, directly responsible to the NAW, is urgently required.'*

Sustainable Energy Ltd proposes several options for the establishment of a Sustainable Energy Agency, including contracting the role to the Welsh Development Agency (WDA) or through the formation of a new organisation with its own constitution. Further consultation should seek to identify which option would be most appropriate.

In line with the RCEP's vision, the agency would in essence be a money-moving and promotional body whose principal aim should be to promote the development and implementation of sustainable energy options. It should be required to take account of the environmental, economic and social consequences of its activities. The agency could also take responsibility for funding research and development of marine renewable energy technologies and efficient use of energy. Other potential roles for a Sustainable Energy Agency could include, *inter alia* (SEL, 2001):

- establishment and introduction of targets and liaison with NAW departments, local authorities, etc.;
- coordination of strategic strengthening of electricity networks;
- formulation of a cohesive strategy for marine renewables;
- allocation of a national renewable energy support fund to help provide assistance to projects supported by UK and EU funds;
- formulation, co-ordination and implementation of research programmes to identify and fill gaps in the knowledge base; and
- formulation of public awareness programmes of the benefits of marine renewable energy developments, and dissemination of information.

7.5.4 Development and demonstration of technology

According to the *Science and Technology Committee Seventh Report on Wave and Tidal Energy* (2001) the current level of public spending on wave and tidal energy research is insufficient to give the technology the impetus it needs to develop fully. This is in contrast to offshore wind turbine technology, which has achieved commercial credibility largely due to substantial funding from the government's Capital Grants Programme. The Engineering and Physical Sciences Research Council (EPSRC) is the principal provider of basic, academic-led research funding for wave and tidal energy in the UK. At present wave and tidal technology research receives only a small proportion of the overall funding available to renewable energy research programmes. It is recognised that this is largely due to the fewer applications for funding for wave and tidal energy projects compared to other renewables. Targeted research funding should therefore be made available to encourage research activities in these fields and to attract an increasing number of researchers. This should accelerate technological innovation of wave and tidal energy schemes and bring the technology closer to commercial competitiveness.

It is evident that, in addition to the lack of basic, strategic and applied research in wave and tidal energy, many of the device concepts have not progressed further than the design stages or small-scale prototypes. Relatively few device concepts have advanced to testing of commercial-scale demonstration projects at sea. Consequently, claims relating to the performance and viability of devices, their cost and ability to compete commercially, and their durability in the marine environment cannot be made with any certainty until full-scale units are deployed at sea. Understandably, most investors are unwilling to contribute to such large-scale projects until their commercial credibility has been established (STC, 2001). There is therefore, a strong case for the government to increase the amount of funding available for full-scale wave and tidal energy prototypes, to demonstrate the technology at a realistic scale. The recent announcement (May 2002) of government funding of up to £2.3 million to support the development and demonstration of a series of new WEDs in the Western Isles is welcomed, but this amount represents only a small fraction of the £100 million allocated in 2001 by the government for renewable energy development. Arguably, the funding available should be comparable to that committed to demonstration models in other renewable technologies.

There is widespread support among researchers and developers for the establishment of a National Offshore Test Centre for the development of marine renewable energy technologies. Such a centre would provide smaller companies with the opportunity to trial prototype devices, and enable tests to be carried out on near-market devices. This would accelerate the development process and identify any necessary modifications to devices. Conceivably, the environmental impacts of specific devices could also be studied. Wales could bid for such a centre, based on the technological expertise in the universities and the large renewable resource base found offshore.

8 Conclusions and recommendations

The main observations and findings of the study are summarised below for each chapter. Recommendations are made where appropriate.

Chapter 2 Energy demand and consumption in the UK

- Demand for electricity is likely to increase in the future. This raises concern over diversity and flexibility in the electricity system. The situation is exacerbated by the expected closure of most of the UK's nuclear capacity within the next 10-20 years. An emphasis, therefore, on diversity and environmental sustainability provides an incentive for development of renewable energy resources.

- While the overall energy scene in Wales appears relatively healthy, the long-term future position remains more uncertain. Concerns about future security of energy supply in Wales present a powerful argument for investing in energy efficiency measures and renewable energy generation.

- The scale of future climate change and its effects upon the Welsh environment are uncertain, making adaptation planning difficult. Many experts believe that these changes are irreversible without drastic action, which underlines the importance of taking immediate action to reduce emissions of greenhouse gases.

- Within the context of sustainable development and the review of energy policy in Wales, the opportunity exists for the National Assembly for Wales (NAW) to develop renewable energy policies which will deliver effective protection of the Welsh environment and contribute to tackling the threat of climate change.

Chapter 3 Marine renewable energy resources – current situation and future potential for Wales

- Between 1990 and 1996 the volume of renewables used to generate electricity in the UK grew at an average rate of 8.5 per cent a year and over the last five years growth has averaged 15.5 per cent a year. The growth in electricity generated from renewables, however, has been more erratic because it is influenced by the efficiency of the renewable energy plant. Nevertheless, the average rate of growth in electricity generated from renewables has been around 10.5 per cent a year.

- It is estimated that in 2000, 3.2 per cent of electricity was generated from renewable sources in Wales. This compares favourably with the UK as a whole, for which it is estimated that renewable energy sources provided 2.8 per cent of electricity in the same year. Marine renewable energy generation does not presently contribute to renewable energy in Wales, although offshore wind energy is likely to come online in the near future.

- A precautionary approach suggests that policy action by the NAW is required not to establish a range of future low-carbon energy options that are likely to be needed as part of the global response to climate change. The likelihood of more stringent greenhouse gas emission targets in the future promotes the environmental objective as a strong priority within energy policy.

- If Wales is to reduce CO_2 emissions by 20 per cent of 1990 levels by 2010 in line with government policy, it will need to reduce annual emissions to 8.9 MtC, representing a decrease of 2.3 MtC relative to 1999 levels. If the more challenging RCEP target of a 60 per cent reduction by 2050 is to be achieved, Wales would need to reduce annual emissions to 4.5 MtC (based on 1999 levels), representing a decrease of 6.7 MtC relative to 1999 levels. The significant majority of CO_2 emissions in Wales are associated with energy supply activity or with energy use. The main contribution to achieving these targets must therefore come from changes in the way in which energy is supplied and used in Wales.

- It would appear that the establishment of some form of targets for Wales for reductions in greenhouse gas emissions and for the development of renewable energy in the short (2010), medium (2025) and long term (2050) are matters of priority for the NAW, in order to focus policy measures and provide the impetus for long-term energy planning.

- It is already widely accepted that the 10 per cent target for renewables by 2010 is unlikely to be feasible if sole reliance is put upon onshore renewables, due largely to the conflict over land use. If targets are to be met, all available renewable energy technologies will need to be exploited including offshore wind, wave and tidal resources.

- Deployment of wind turbines offshore will be the only way wind energy can be exploited on a sufficiently large-scale in the future. Other marine renewables such as tidal currents and waves offer higher energy intensity than most renewables and are generally more predictable than onshore renewables.

- Development of marine renewable energy in Wales can make an important contribution to the Welsh economy and bring employment to regions and sectors otherwise deprived of industrial development.

- Wales has a potentially large marine renewable resource base due to its climate and geography. However, the sites with the greatest resource potential may not necessarily be suitable for energy generation. There could be numerous constraints on development, including environmental sensitivities. These factors should betaken into account in future studies that assess the marine renewable resource potential for Wales.

Chapter 4 Tidal energy

- Tidal power can be harnessed either through the energy stored in tidally impounded water, or by extracting energy from the tidal movement of water (tidal streams) using tidal turbines, analogous to underwater wind turbines. The former can utilise naturally occurring tidal basins, for example by building a barrage across an estuary, or by offshore tidal power generation based upon the relatively new concept of constructed offshore tidal lagoons.

- The coast of Wales probably has the most favourable conditions anywhere in the world for tidal power development, due to the high tidal range. These average seven to eight metres on the spring tides in several estuaries, and as much as 11 metres in the Severn Estuary.
- The theoretical potential from tidal energy in the UK as a whole has been estimated to be around 50 TWh/yr, although the present status of technology and financial constraints suggest much of this potential is unachievable. Nevertheless, tidal energy is the most predictable of the marine renewable resources, and variation over the tidal cycles can be predicted with considerable accuracy well into the future.

- Although studies have shown the UK tidal stream resource to be between 31 and 58 TWh/yr, only around 10 TWh/yr could feasibly be exploited, in relatively shallow sites near to high demand for power (providing around 2 per cent of UK electricity demand). Marine currents generated by tidal streams around the Welsh coastline offer as many opportunities as other places in the UK. They represent a viable resource, particularly when focused around headlands or in large estuaries. Sites off Pembrokeshire, the Lleyn Peninsula, Menai Straits and the Severn Estuary may offer development potential.

- Several major potential sites for barrage construction have been identified in the past for the UK, although to date no development has been undertaken. The restructuring of the electricity market has increased the financial risk attached to such projects. It is unlikely that projects such as the Severn Tidal Barrage (STB) would be undertaken by a commercial company in the present liberalised market for electricity. Such projects are unlikely to proceed without government intervention.

- The net environmental effect of barrage development is likely to be site-specific, with some species benefiting at the expense of others. There is limited operational experience of large-scale projects upon which such judgements can be soundly based. Environmental constraints are a key obstacle to the development of the STB, particularly the designation of the Severn Estuary as a SAC as the features for which it has been selected reflect the large tidal range. The context of the STB has also changed in many other ways since the tripartite studies were published more than 12 years ago. Previous work, and in particular the environmental implications, would need to be reviewed in light of new issues that have arisen.

- There may be merit in conventional barrage concepts, but tidal power generated by barrage schemes is unlikely to make any contribution to renewable energy targets in Wales in the short to medium term, and certainly not by 2010. Tidal barrage power may have a role to play in reducing greenhouse gas emissions from power generation in the long term (especially in view of the large amounts of energy that would be available), but given the associated financial, technical and environmental risks, it ought to be as one of the last renewable energy options to be developed.

- Constructed offshore tidal lagoons may offer large-scale energy generating capacity with advantages over conventional barrages. However, it is recognised that many of the environmental effects of the construction and operation of such a scheme cannot be stated with any certainty at present. Detailed modelling of sediment transport and the hydrodynamic environment is required in relation to such schemes. As this is essentially a new technology, the full range and magnitude of environmental impacts may not be known until the first schemes have been built in Swansea Bay and off Rhyl, North Wales.

- Early projects must also demonstrate the functioning of the design and economic performance if outside investment is to be attracted. Careful monitoring of initial projects will indicate the accuracy of projections and actual performance will determine whether future projects will be competitive.

- In future there may be opportunities to further enhance the power output of offshore tidal lagoons through hybridisation with wind power or wave power technology.

- Only limited resources have been available to enable experimentation and development of Tidal Stream Energy Converters (TSECs) – therefore much of the work has so far either been theoretical or small-scale. A number of device concepts have been proposed, but as yet there is no consensus on the best design. Nevertheless, there are already a number of devices at different stages in their development. Their long-term reliability and cost-effectiveness needs to be demonstrated in the marine environment to take the technology forward to commercial reality.

- There is a need to demonstrate tidal stream energy on a large scale to establish its credibility and reduce the perceived risk as rapidly as possible.

- Further studies are required to identify the tidal stream resource available in Wales, including deep-water sites.

- The costs of electricity generation from tidal stream energy schemes are speculative because most devices are still at the research and development stage. However, prices predicted by developers suggest that tidal stream appears close to becoming a viable option within the Renewables Obligation. However, even at a cost of 4-6 p/kWh, tidal stream energy would still be significantly more costly than electricity from a conventional fossil-fuel generating plant. The target is, therefore, for tidal stream to be commercially competitive without the need for market support measures.

- External costs are often not taken into account in the cost comparison of different energy sources, which puts renewables as a whole, and tidal energy in particular, at a disadvantage.

- The limited experience with TSECs enables only an incomplete picture to be formed of their possible environmental effects. Tidal turbines are expected to have a minimal environmental impact, although this cannot be confirmed as the only deployment of tidal stream turbines has been of small-scale prototype devices for short periods. It is likely that many of the impacts would be site-specific and would have to be assessed separately for each scheme. Environmental Impact Assessments (EIAs) performed for specific devices generally do not take account of the cumulative impact of numerous devices deployed in a tidal farm.

- Further research work should address the potential impact of TSECs on marine fauna, and the influences of tidal energy schemes on coastal processes, tidal flows, seabed scouring and sediment transport. Further studies should also address the socio-economic aspects of such schemes.

Chapter 5 Wave energy

- A number of wave energy devices (WEDs) are at different stages in their development and evaluation, but most have yet to demonstrate their long-term reliability and effectiveness in harsh maritime environments.

- At present there are no plans for deployment of wave energy projects in Wales. Nevertheless, Wales has a potentially significant wave energy resource, particularly in the high-energy environments of south-west Wales, which are open to the full force of the Atlantic Ocean. More detailed analysis of the wave energy resource in Wales should seek to identify the full resource potential.

- Oscillating Water Columns (OWCs) such as OSPREY and LIMPET remain the most well developed WEDs, but they may not be the best designs. OWCs may not be suitable for deployment in areas where there is a large tidal range, thereby ruling out many shoreline and near-shore locations, particularly in the Severn Estuary. WEDs may be viable elsewhere on the Welsh coast in areas of high wave energy and low tidal range.

- The future for wave energy is to move further offshore where there is a much larger resource. Unfortunately, offshore devices are still mainly in the research and development stage, with much work needed to tackle key development issues, reduce uncertainty and verify the concepts. Further funding is required for this to occur.

- Shoreline wave energy conversion is technically developed but is some way from being commercially competitive. Very significant improvements in efficiency, capital cost, and operation and maintenance costs are required to change this situation. It is likely to be more cost effective to focus initial development efforts in Wales on smaller WEDs that provide electricity directly to a niche market or dedicated end user.

- The deployment of WEDs could have a varied impact on the environment. The main concerns relate to their visual impact, noise levels, disturbance of seabed and benthos during installation and maintenance, their effects on the hydrodynamic environment and sedimentary processes, and treatment of devices with anti-fouling paints. The socio-economic impacts of wave energy conversion are not significant compared to conventional power stations, or indeed other renewable energy schemes.

- Wave energy is unlikely to make a significant contribution to renewable energy targets and reduction of greenhouse gases in the short-term (2010). It could be an important option for the longer term, as the technology matures and costs are reduced. The NAW should continue to monitor the relative costs, status of development and potential applications of this technology in Wales. A Commission could be established to promote the development of a wave energy industry in Wales.

- The full potential resource of offshore wind energy in Welsh coastal waters has been put at around 79,000 GWh/yr, although other estimates are much higher. However, these may not take account of a number of economic, technical, planning and environmental constraints, which are likely to limit the actual installed capacity.

- The offshore wind energy market in the UK remains substantially influenced by Government policy and incentive/market enablement mechanisms. These mechanisms could provide the support and market stimulation needed for offshore wind to make a significant contribution to the 10 per cent renewables target by 2010.

- Costs for offshore wind-farms are very site-specific and depend on the site location and conditions. It is not clear whether the cost of electricity from offshore wind will be commercially competitive outside the Renewables Obligation. Evaluation of the early schemes will verify the validity of estimated electricity prices. Costs could be reduced with further technological innovation, particularly with regard to the installation of turbines at sea. The target for offshore wind energy is to achieve the same cost of electricity as onshore wind-farms.

- Long-term goals should address siting turbines in more remote/deeper water further offshore, thereby reducing the visual impact from the shoreline and avoiding sensitive coastal areas. This will demand research into the engineering and economic feasibility of floating support structures for turbines.

- With the advancement in tidal stream turbine and wave technology there may also be scope for integrated wind/wave hybrid devices. These could be mounted on support structures (foundations) with extended design lives that allow them to be refurbished and re-used as bases for second-generation devices when the mechanical components are decommissioned.

- The main environmental concerns over offshore wind-farm development relate to the potential impact upon bird populations and migration patterns, and disturbance at bird feeding areas and fish spawning or nursery areas. Unless developments are proposed for very sensitive sites in terms of marine nature conservation, bird populations or fisheries, then the main impact could be visual intrusion on the seascape. Four proposed sites for wind-farm development are in Liverpool Bay, which could have landscape implications for Wales. Visual intrusion may prove to be a particular constraint to wind-farm development in Wales, which relies heavily upon coastal tourism and has a high level of protected coastal landscapes.

- The significance of any potential effect can only be determined in a site-specific context, which would require an evaluation of the baseline conditions and potential changes to them. Further valuable information on the likely environmental impacts of offshore wind energy will become available through the increasing number of EIAs undertaken for specific projects. It is important that this information is widely disseminated and shared in order to strengthen the knowledge base, inform the consents procedure and target areas of research.

- The three offshore wind-farm developments proposed for Wales could provide the basis for Wales to become a key player in the evolving offshore wind energy market. However, it is difficult to identify where further offshore developments within territorial waters could occur. Although much of the Welsh coast may qualify in terms of suitable water depth, development in many areas is constrained by environmental sensitivities and weak access to distribution networks. Further studies are therefore required to identify and evaluate potential sites, and how economic activity in Wales can benefit from such developments.

Chapter 7 Strategic issues affecting the development of marine renewables

- The difficulties of network connection arguably present the single most serious problem facing the successful exploitation of marine renewable energy in Wales and the UK as a whole. There are two main technical problems arising due to the limited scope for the existing transmission system to receive additional generating capacity in many areas, and the incompatibility of the existing distribution network to receive output from embedded generation technologies.

- There are no north-south national grid links within Wales, and the infrastructure in mid-Wales is particularly weak. There is therefore limited scope for connecting medium/large-scale renewable generation schemes (e.g. offshore wind) in this area without major transmission system reinforcement.

- Most first-generation marine renewable energy schemes are likely to have small generating unit sizes and will therefore find it more cost-effective to connect to the lower voltage (132 kV – 230 kV), more localised distribution networks. This is likely to lead to a considerable increase in the demand for ‘embedded’ electricity generation. Major reinforcement of the distribution network may well be necessary to cater for this increase in embedded generation.

- While there is some capacity on the distribution networks to add further generation, the constraints are significant. The difficulty is compounded by the fact that sites with the greatest potential for marine renewable energy generation are often situated in remote parts of the country, near the end of the distribution network. This contributes to the system losses as any generated output may have to travel long distances to reach demand load centres.

- The full costs of connection payable by an embedded generator currently present a significant financial barrier to new smaller-scale renewable generation because these costs may include any infrastructure changes needed to the network in the location of the connection point. These ‘deep connection charges’ fall on the first embedded generator to seek connection to the distribution network. This creates an ‘after you’ scenario that clearly poses a significant constraint on the development of marine renewables in Wales and the ability to achieve renewables targets in general.

- Advance investment by Distribution Network Operators (DNOs) may be appropriate in anticipation of additional embedded generation (which would also contribute to economic development in the area), although this would require significant investment and may qualify for structural funding.

- Alternatives to network connection should be investigated, including the production of hydrogen by electrolysis. Wales could be at the forefront of such innovation and could become a supplier of these technologies worldwide.

- Given the many policy interests that are likely to be affected by the development of marine renewables, it is important that an integrated approach is adopted for both the strategic planning as well as the consideration of development applications through the consenting process.

- All proposals for marine renewable energy projects should be subject to an EIA and full consultation before consent is given. The EIA should inform the design of the project and should identify measures that will be adopted during the construction and operation of the project to avoid or reduce impacts where practicable.

- The possible deployment of a large number of devices in the near-shore environment will give rise to a need to consider the cumulative impact within each region, not only the local impacts of specific developments. Given the possible scale of development cumulative impacts could be significant and need to be incorporated in the planning process.

- A list of potential impacts specifically relating to marine renewables, drawing upon previous and current research in this field, may be useful to both developers and regulators.

- There is currently no comprehensive legal framework for regulating development of marine renewable energy resources beyond the limits of territorial waters (12 nautical miles). The government's intention to address this issue through the creation of primary legislation to establish a 'Renewable Energy Production Zone' is welcomed. Although this is a long-term consideration, action needs to be taken now to ensure that there are no delays in the deployment of marine renewable energy devices further offshore when the technology has reached maturity.

- Strategic Environmental Assessment (SEA) can contribute to more transparent planning for marine renewables by involving the public and by integrating environmental considerations into the decision-making framework. SEA should also be integrated into a wider assessment of the social and economic effects of development proposals. This will help to achieve the goal of sustainable development. SEA should also extend to other onshore facilities linked to offshore developments and should incorporate some element of life-cycle assessment for the technology.

- The urgency with which renewables targets must be met should not result in a compromise that gives rise to unacceptable environmental impacts upon coastal and marine sites that are selected for development. In other words, all effort must be made to avoid the 'right technology in the wrong location'.

- A strategy aiming to optimise the benefits to Wales of the evolving market in marine renewable energy technology is required. In formulating this strategy it will be necessary for the NAW to work closely with the major offshore wind, wave and tidal energy developers to evaluate potential projects and explore how economic and research and development activity in Wales can support and benefit from such projects.

- It is understood that discussions on the possible wider transfer of energy functions to the NAW are currently taking place, and these are welcomed. A consistent and seamless strategic framework for development of marine renewables is essential and improved definition of the role of the NAW is required to ensure that policy formulation and the development of the consents and regulatory process reflects this.

- The NAW should be encouraged to continue to develop a more positive approach to marine renewable energy generation and make a commitment to the creation of a competitive marine renewable energy industry for Wales. This may be best achieved through the establishment of a Sustainable Energy Agency for Wales, or similar body, whose principal aim would be to promote the development and implementation of sustainable energy options.

- It is important that the NAW recognises the potential marine renewable energy resource base available in Wales and how this can contribute to future energy security and diversity needs within the principles of sustainable development. With the right approach, Wales can be at the forefront of developments in this field and reap the potential economic and environmental rewards.

References

AEA Technology (AEAT) (2001) Review of Strategic Study of RE Resources in Wales. Discussion paper for the renewable energy workshop, Newport, 5 October 2001.

Anon (2002) State of the Art: Stingray Tidal Stream Generator. New Review, Issue 52, May 2002, pp.8-9.

ATLAS (a) (website) Tidal Energy.
Available online at: *www.europa.eu.int/comm/energy_transport/atlas/htmlu/tidal.html*

ATLAS (b) (website) Wave Energy.
Available online at: *www.europa.eu.int/comm/energy_transport/atlas/htmlu/wave.html*

Barthelmie, R.J. (1999) Monitoring Offshore Wind and Turbulence Characteristics in Denmark. British Wind Energy Association (BWEA) conference, Cambridge. MEP Ltd., London, 1999.

Bergdahl, C. (1992) Review of Research in Sweden. Workshop on wave energy R&D held at Cork. EUR report 15079EN, 1992.

Binnie Black & Veatch (BBV) (2001) The Commercial Prospects for Tidal Stream Power. Report produced in association with IT Power Ltd. ETSU report T/06/00209/REP. DTI, 2001.

Blue Energy Canada (website) High Density Renewable Energy Breakthrough.
Available online at: *www.bluenergy .com/*

Blue Energy Canada (2001) Memorandum submitted to Science and Technology Committee Seventh Report, Wave and Tidal Energy, Appendix 18. HC 291. The Stationary Office, April 2001, pp.121-125.

Bond Pearce Solicitors (2001) Report to ETSU on the Legal Consents Processes for Offshore Wind Energy Development. Bond Pearce Solicitors, 2001.

Border Wind Ltd. (1996) The Effects of Wind Turbines on the Bird Population at Blyth Harbour. A report to ETSU by Border Wind Ltd. ETSU report W/13/00394/REP, 1996.

Border Wind Ltd. (1998) Building a New Industry for Britain. A report to Greenpeace by Border Wind, Hexam, June 1998.

British Wind Energy Association (BWEA) (website) The website for the UK offshore wind energy industry. Available online at: *www.offshorewindfarms.co.uk*

British Wind Energy Association (BWEA) (2000) Prospects for Offshore Wind Energy. A report to the European Union by BWEA. Contract XVII/4.1030/2/98-395. January 2000.

Celtic Offshore Wind Ltd. (COWL) (2002) Rhyl Flats Offshore Windfarm. Environmental Statement, March 2002.

Countryside Council for Wales (CCW) (2002) Renewable Energy in Wales – Views of the Countryside Council for Wales. EDC 02-02(p4), 16 January 2002.

Craig, J (1999) The Status and UK Resource Potential of Wave Power and Tidal Stream Energy. Paper presented to Joint Irish Sea Forum / CCW seminar on Irish Sea renewable energy resources. Llandudno, 18-19 October, 1999.

Crown Estate (website) Offshore Windfarms, Putting Energy into the UK.
Available online at: *www.crownestate.co.uk/estates/marine/windfarms.shtml*

de Groot, S.J. (1986) Marine Sand and Gravel Extraction in the North Atlantic and its Potential Environmental Impact, with Emphasis Upon the North Sea. Ocean Management, Vol 10, 1986, pp.21-36.

Department for Environment, Food and Rural Affairs (DEFRA) (2001) Climate Change – The UK Programme. Cm 4913. The Stationary Office, February, 2001.

Department of Business, Economic Development and Tourism (DBEDT) Hawaii (2001) Feasibility of Developing Wave Power as a Renewable Energy Resource for Hawaii. Response to HR8, State of Hawaii, 2001.

Department of Trade and Industry (DTI) (1999) New & Renewable Energy – Prospects for the 21st Century. Department of Trade and Industry, March 1999.

Department of Trade and Industry (DTI) (2000) Energy Paper 68: Energy Projections for the UK. December 2000.

Department of Trade and Industry (DTI) (2001a) Energy Trends – Section 6: Renewable Energy. December 2001. Available at: *www.dti.gov.uk/energy/inform/energy_trends/dec_01.pdf*

Department of Trade and Industry (DTI) (2001b) Sustainability Through Diversity: Prospects for the UK Oil and Gas Suppliers Industry, PILOT. April 2002.

Department of Trade and Industry (DTI) (2001c) Offshore Wind Energy Fact-Sheets. DTI Sustainable Energies Programmes, June 2001.

Department of Trade and Industry (DTI) (2002a) Digest of United Kingdom Energy Statistics 2002. The Stationary Office. July 2002.
Available online at: *www.dti.gov.uk/energy/inform/dukes/index.shtml*

Department of Trade and Industry (DTI) (2002b) Energy Consumption in the UK. The Stationary Office, July 2002.

Department of Trade and Industry (DTI) (2002c) UK Energy In Brief. The Stationary Office, July 2002.

Department of Trade and Industry (DTI) (2002d) Wilson announces £2.3m boost for wave energy. DTI press release 20/05/02. Available online at: *www.dti.gov.uk/*

Department of Trade and Industry (DTI) (2002e) Future Offshore. Consultation paper on a strategic planning framework for the major expansion of the offshore wind industry, 22 November 2002.
Available online at: *www.dti.gov.uk/energy/leg_and_reg/consents/future_offshore/*

Doody, P. (2001) The Coast of Wales. Coastal Guide Country File – Wales. In: EUCC Coastal Guide. Available online at: *www.coastalguide.org/index.html*

Duckers, L. (1998) Wave Energy. In: Renewable Energy – Power for a Sustainable Future. Open University. Available online at:
www.openuniversity.edu/StudentWeb/t625/update/wave.htm

Economic Development Committee (EDC) (2002) Targets for Renewables. Paper presented to EDC by Committee Secretariat. EDC 05-02(p6), 6 March 2002.

ECOTEC Research & Consulting (1997) Life-Cycle Environmental Impact Assessment of THERMIE. ECOTEC Research & Consulting, Energy Unlimited, GOPA Consultants, Synergia, 1997.

Elsam & Eltra (2000) Horns Rev Offshore Wind-Farm. Environmental Impact Assessment. Summary of EIA Report. Prepared by Elsamprojekt A/S (Tech-Wise).
Available online at: *www.elsam.com/havmoller/pdf/Resume_eng.pdf*

Embedded Generation Working Group (2001) Final Report January 2001.
Available online at: *www.dti.gov.uk/energy/egwg/report.htm*

Engineering Business (EB) Ltd. (2002) Stingray Tidal Power Generator. The Engineering Business Ltd. Report M02-003-01.ADT, January 2002. Available online at: *www.engb.com/*

Environment & Resource Technology (E&RT) Ltd. (1994) Environmental Assessment of the Proposed OSPREY Wave Energy Device for Dounreay, Caithness. Report No. 93/060/R1, January 1994.

Environment Trust (2001) Memorandum submitted to Science and Technology Committee Seventh Report, Wave and Tidal Energy, Appendix 19. HC 291. The Stationary Office, April 2001, pp.125-128.

ETSU (1996) Tidal Energy – DTI R&D Programme 1979 – 1994. ETSU Report R-96. Energy & Technology Support Unit, DTI, 1996.

ETSU (1999) New & Renewable Energy: Prospects for the 21st Century, Supporting Analysis. ETSU Report R-122. Energy & Technology Support Unit, DTI, March 1999.

ETSU (2001a) Technology Status Report, Tidal Stream. A report by ETSU as part of the DTI's Renewable Energy Programme. Energy & Technology Support Unit, DTI, June 2001.

ETSU (2001b) Technology Status Report, Wave Energy. A report by ETSU as part of the DTI's New and Renewable Energy Programme. Energy and Technology Support Unit, DTI, March 2001.

ETSU (2001c) Technology Status Report, Offshore Wind Energy. A report by ETSU as part of the DTI's New and Renewable Energy Programme. Energy and Technology Support Unit, DTI, January 2001.

ETSU (2001d) Technology Status Report, Embedded Generation and Electricity Studies. A report by ETSU as part of the DTI's New and Renewable Energy Programme. Energy and Technology Support Unit, DTI, May 2001.

European Commission (EC) (1999) Wind Energy, The Facts; Volume 4 – The Environment. EC Directorate-General for Energy, Brussels, 1999.

Eyre, N. (1995) Externalities of Energy – ExternE Project Volume 6 – Wind and Hydro. European Commission DGXII, Science, Research and Development, JOULE, Report no. EUR16525EN, 1995.

Ferguson, M.C. (ed) (1998a) OPTI-OWECS, Volume 4 – A Typical Design Solution for an Offshore Wind Energy Conversion System. Final report on JOULE III contract JOR3-CT95-0087 for the Commission of the European Communities, Delft, the Netherlands Institute for Wind Energy, 1998.

Ferguson, M. (1998b) Support Structure Concepts for Offshore Wind Turbines. Proceedings of the 1998 Twentieth BWEA Wind Energy Conference, 'Wind Energy – Switch on to Power'. Available online at: *www.owen.eru.rl.ac.uk*

Fraenkel, P. (1999) The Role of Marine Current Energy as a Potential Contributor to Future Energy. Written evidence for House of Lords Sub-Committee on Energy, March 1999.

Fraenkel, P. (2001) Memorandum submitted by Marine Current Turbines Ltd. to Science and Technology Committee Seventh Report, Wave and Tidal Energy. HC 291. The Stationary Office, April 2001, pp.43-50.

Friends of the Earth (FoE) Cymru (2002) Severn Barrage out-performed by tidal lagoons, Greens advise Assembly. FoE Cymru press release, 11/02/02.

Fujita Research (website) Fujita research report – Electricity from the sea with a LIMPET. Available online at: *www.fujitaresearch.com/reports/limpet.html*

Greenpeace (2000) North Sea Offshore Wind – A Powerhouse for Europe. Technical possibilities and ecological considerations. A report to Greenpeace by Suker *et al*., October 2000.

Hawkes, F.R.; Dinsdale, R. & Hawkes, D.L. (2002) Future Technologies – Hydrogen. Presentation to the Institute of Welsh Affairs (IWA) Conference on the Welsh Potential for Renewable Energy, Llanberis, 19 September 2002.

Henderson, A.R. & Patel, M.H. (1998) Floating Offshore Wind Energy. Proceedings of the 1998 Twentieth BWEA Wind Energy Conference, 'Wind Energy – Switch on to Power'. Available online at: *www.owen.eru.rl.ac.uk*

Hydrographic Office (1993) West Coasts of England and Wales Pilot. Twelfth edition. Hydrographic Office, Ministry of Defence (MoD), 1993.

Innovation and Sustainable Growth Division (ISGD) (2001) EDC Energy Review: Energy in Wales Overview Paper. EDC 12-01(p4), 17 October 2001.

Institute of Biology (2001) Memorandum submitted to Science and Technology Committee Seventh Report, Wave and Tidal Energy, Appendix 17. HC 291. The Stationary Office, April 2001, pp.118-121.

International Centre for Island Technology (ICIT) (1995) Feasibility Study of Tidal Current Power Generation for Coastal Waters. Report for Regional and Urban Energy Programme of the EU, DGXVII, 1995.

Interproject Service (website) IPS OWEC Buoy System. Available online at: *www.ips-ab.com/Working%20princliple.htm*

IT Power (website) Providing Sustainable Energy Solutions Through Innovation and Dedication. Available online at: *www.itpower.co.uk/*

Jackson, K. (2002) Moving Towards an Energy Policy for the UK. Power Engineering Journal, Vol 16, No. 2, April 2002.

Jacobson, N. (1998) The Role of the Crown Estate in the Development of Offshore Windfarms. Proceedings of the 1998 Twentieth BWEA Wind Energy Conference, 'Wind Energy – Switch on to Power'. Available online at: *www.owen.eru.rl.ac.uk*

Jamieson, M. (2002) Wave Energy Exploitation in UK Waters. Undergraduate dissertation, Department of Earth Sciences, Cardiff University, 2002.

Kenny, A.J. & Rees, H.L. (1994) The Effects of Marine Gravel Extraction on the Macrobenthos: Early Post-Dredging Re-colonisation. Marine Pollution Bulletin, Vol. 28, No. 7, pp.442-447.

Kerlinger, P. (2001) Avian Issues and Potential Impacts Associated with Wind Power. Development in the Nearshore Waters of Long Island, New York. Prepared for AWS Scientific, Curry & Kerlinger, L.L.C. New Jersey, October 2001.

Krohn, S. (2001) Offshore Wind Energy: Full Speed Ahead. Danish Wind Energy Association. Available online at: *www.windpower.org/articles/wres/offshore.htm*

Larsson, A.K. (2000) *Försökanläggning för Hausbaserad Vindkraft I Nøgersund* (Offshore Wind Pilot Project in Nøgersund). Cited in Offshore Wind Energy Europe (OWE) (2001) Concerted Action on Offshore Wind Energy in Europe (CA-OWEE) Final Report. Contract NNE5-1999-562, Institute of Wind Energy, Netherlands, December 2001.

Lowther, S. (2000) The European Perspective: Some Lessons from Case Studies. Proceedings of the Third National Wind / Avian Planning Meeting, San Diego, CA, May 1998. National Wind Co-ordinating Committee, Washington, DC.

Marine Current Turbines Ltd. (MCT) (website) Electricity From the Sea.
Available online at: *www.marineturbines.com*

Metoc plc. (2000) An Assessment of the Environmental Effects of Offshore Wind-Farms. ETSU Report W/35/00543/REP. Report to Energy and Technology Support Unit, DTI, 2000.

Mirko, P. (2001) Ocean Wave Power EPRI Technical Report. Draft report prepared by Sea Power & Associates on behalf of Electric Power Research Institute (EPRI), August, 2001.

Mitchell, C. (2002) What Does the Energy Review Mean for the Renewable Energy Sector? New Review, Issue 52, May 2002.

Mitson, R.B. (ed.) (1995) Underwater Noise of Research Vessels. ICES Co-operative Research Report No.209. Copenhagen, 1995.

National Assembly for Wales (NAW) (2002a) Review of Energy Policy in Wales. Part 1: Renewable Energy. Economic Development Committee (EDC) report for consultation, April 2002.

National Assembly for Wales (2002b) Sustainable Development Indicators for Wales, 2002. Statistical Bulletin SB36/2002. National Assembly for Wales, March 2002.

National Environmental Research Institute (NERI) (1998) Impact Assessment of an Offshore Wind Park on Sea Ducks. National Environmental Research Institute (NERI) Technical Report No.227, 1998.

National Grid Company (NGC) plc. (2001) Memorandum submitted to Science and Technology Committee Seventh Report, Wave and Tidal Energy, Appendix 36. HC 291.
The Stationary Office, April 2001, pp.170-174.

Network for Alternative Technology and Technology Assessment (NATTA) (undated) Overview of the La Rance Tidal Barrage. In: La Rance Tidal Power Barrage. NATTA Technical Paper 3, Open University, Milton Keynes.

Newton, M.J. & Hopewell, P.D. (2002) Costs of Sustainable Energy Generation. Power Engineering Journal, Vol 16, No. 2, April 2002.

N.I.T. (*Institut für Tourismus und Bäderforschung in Nordeuropa*) (2000) *Touristische Effekte von On- und Off-shore Windkraftanlagen in Shleswig-Holstein* (Effects on Tourism from On- and Offshore Wind Turbines in Shleswig-Holstein). Cited in: Offshore Wind Energy Europe (OWE) (2001) Concerted Action on Offshore Wind Energy in Europe (CA-OWEE) Final Report. Contract NNE5-1999-562, Institute of Wind Energy, Netherlands, December 2001.

NWP Offshore Ltd. (2002) North Hoyle Offshore Wind Farm Environmental Statement, Non-Technical Summary. NWP Offshore Ltd., Bourne End, Bucks, 2002.

Ocean Power Delivery Ltd. (OPD) (2002) Wave energy company Ocean Power Delivery secures £6m funding package. OPD press release 20/03/02. Available online at: *www.oceanpd.com/*

Offshore Wind Energy Europe (OWE) (2001) Concerted Action on Offshore Wind Energy in Europe (CA-OWEE) Final Report. Contract NNE5-1999-562, Institute of Wind Energy, Netherlands, December 2001.

Open University Energy and Environment Research Unit (2001) Memorandum submitted to Science and Technology Committee Seventh Report, Wave and Tidal Energy, Appendix 6. HC 291. The Stationary Office, April 2001, pp.93-97.

Osborne, P. (2000) Electricity from the Sea.
Available online at: *www.fujitaresearch.com/reports/tiodalpower.html*

Palmer, C. (undated) Offshore Wind Farms. Available online at: *www.seascape-energy.co.uk*

Parliamentary Office of Science and Technology (POST) (2001) UK Electricity Networks. Postnote No.163, October 2001.

PB Power (2001) Electrical Network Limitations on Large Scale Deployment of Offshore Wind Energy. ETSU Report W/33/00529/REP/1. DTI/Pub URN 01/773. Department of Trade and Industry, 2001.

Pearson, S.F. (2001) Memorandum submitted to Science and Technology Committee Seventh Report, Wave and Tidal Energy, Appendix 8. HC 291. The Stationary Office, April 2001, pp.97-102.

Performance and Innovation Unit (PIU) (2002) The Energy Review. The Cabinet Office, February 2002.

Probert, P.K. & Mitchell, R. (1979) Nature Implications of Siting Wave Energy Converters off the Outer Hebrides. Report No. 15, Nature Conservancy Council (NCC), 1979.

Probert, P.K. & Mitchell, R. (1983) Environmental Implications of Wave Energy for the Outer Hebrides and Moray Firth. Ocean Engineering, Vol 10, 1983, pp.459-469.

Richardson, N. (2001) Severn Barrage Back in the Frame. In: AGENDA – Journal of the Institute of Welsh Affairs (IWA). Winter 2000/01.

Ross, D. (1995) Power from the Waves. Oxford University Press, January 1995.

Ross, D. (1998) Wave Power – The Story Continues: A Compilation of Reports from Renew on UK Policies and Programmes. Volume II of the Wave Power in the 90’s Series. NATTA, April 1998.

Royal Commission on Environmental Pollution (RCEP) (2000) Energy – The Changing Climate. Twenty-Second Report, CM 4749, June 2000.

Salter, S. (1993) Changes to the 1981 Design of Spine-based Ducks. Proceedings of the First European Wave Power Conference, Edinburgh, 21-24 July 1993.

Salter, S.H. (2001) Memorandum submitted by Prof. S.H. Salter (Edinburgh University) to Science and Technology Committee Seventh Report, Wave and Tidal Energy. HC 291. The Stationary Office, April 2001, pp.19-28.

Science and Technology Committee (STC) (2001) Seventh Report, Wave and Tidal Energy. HC 291. The Stationary Office, April 2001.

Seapower (2001) Memorandum submitted to Science and Technology Committee Seventh Report, Wave and Tidal Energy, Appendix 25. HC 291. The Stationary Office, April 2001, pp.145-148.

SEAS (2000) Rødsand Offshore Wind-Farm. Environmental Impact Assessment Summary Report. Available online at: *www.seas.dk/*

Severn Tidal Power Group (STPG) (undated) The Severn Barrage, Renewable Energy for the Next Century. Severn Tidal Power Group c/o Sir Robert McAlpine Ltd., Hemel Hempstead.

Shetland Times (05/09/00) Wave Scheme Takes a Step Forward. The Shetland Times, 05/09/00.

Sjostrom, B.O. (1993) The Past, Present and Future of the Hose Pump Wave Energy Converter. European Wave Energy Symposium, Edinburgh 1993.

Still, D. (1996) The Birds of Blyth Harbour. In ‘Birds and Wind Turbines: Can they Co-exist?’ Proceedings of a seminar organised by ETSU for the DTI, 26 March 1996.

Sustainable Energy Ltd. (SEL) (2001) Strategic Study of Renewable Energy Resources in Wales. Draft report to the National Assembly for Wales, Cardiff, 2001.

Syred, N. (2002) A Discussion Paper on Energy Policy in Wales Following a Review of the Most Relevant Literature Available in Wales, the UK and Europe. Paper presented to the Economic Development Committee, National Assembly for Wales. EDC 03-02(p7).

Thorpe, T.W. (1999) A Brief Review of Wave Energy. A Report produced for the DTI, May 1999.

Thorpe, T. (2001) Wave Energy – Current Status and Developments. Available online at: *www.nesea.org/buildings/images/current%20status%20and%20developments.htm*

Thorpe *et al*., (1998) Benign Energy? The Environmental Implications of Renewables. International Energy Agency, 1998.

Tidal Electric Ltd. (website) Tidal Electric – The Technology. Available online at: *www.tidalelectric.com/technology/index*

Tidal Electric Ltd. (2001) Memorandum submitted to Science and Technology Committee Seventh Report, Wave and Tidal Energy, Appendix 10. HC 291. The Stationary Office, April 2001, pp.105-107.

Trapp, T. (2002) Developing and Building the Stingray Tidal Stream Generator. The Engineering Business Ltd., UK, 2002. Available online at: *www.engb.com/*

Trapp, T. & Watchorn, M. (2001) EB Development of Tidal Stream Energy. The Institute of Marine Engineers (IME) MAREC 2001 Conference, February 2001.

Tucker, V.A. (1996) A Mathematical Model of Bird Collisions with Wind Turbine Rotors. Journal of Solar Energy Engineering, Vol 118, pp.253-262.

Tulp, I.H. *et al*. (1999) Nocturnal Flight Activity of Sea Ducks Near the Wind-Farm Tunø Knob in the Kattegat. Bureau Waardenburg, report nr.99.64, Utrecht, 1999.

Turnpenny, A. (2001) Memorandum submitted by Fawley Aquatic Research Laboratories to Science and Technology Committee Seventh Report, Wave and Tidal Energy, Appendix 2. HC 291. The Stationary Office, April 2001, pp.86-90.

Turnpenny, A.W.H.; Struthers, G. & Hanson, K.P. (1998) A UK Guide to Intake Fish-Screening Regulations, Policy and Practice. Report by Fawley Aquatic Research Laboratories Ltd. & Hydroplan to DTI. ETSU report H/06/00052/00/00, 1998.

Turnpenny, A.W.H.; Clough, S.; Hanson, K.P.; Ramsay, R. & McEwan, D. (2000) Risk Assessment for Fish Passage Through Small Low-Head Turbines. Report to DTI by Fawley Aquatic. ETSU report H/06/00054/REP, 2000.

Ullman, P.W. (2002) Offshore Tidal Power Generation: A New Approach to Power Conversion of the Ocean's Tides. Available online at: *www.tidalelectric.com/technology/index.html*

Watchorn, M. & Trapp, T. (2000) Tidal Stream Renewable Offshore Power Generation (TS-ROPG). Available online at: *www.engb.com/Downloads/m0200301.pdf*

Wavegen (website) Available online at: *www.wavegen.co.uk/*

Wavegen (2000) Latest news on Limpet 500 – wave power competition heralds a new era. Wavegen press release 20/11/00. Available online at: *www.wavegen.co.uk/*

Wells, A. & Langston, D. (2001) Memorandum submitted by Wavegen to Science and Technology Committee Seventh Report, Wave and Tidal Energy. HC 291. The Stationary Office, April 2001, pp.50-53.

Whittaker, T.J.T. *et al*. (1992) The UK's Shoreline and Nearshore Wave Energy Resource. Report WV 1683, ETSU, 1992.

Winter, A.J.B. (1979) Some Calculations from the Met Office Model. Report to Wave Energy Steering Committee, WESC (79) DA84, July 1979.

WWF-UK (2001) Offshore Wind Energy. Marine Update 49. December 2001.