THE ENVIRONMENTAL IMPACTS AND DEVELOPMENTAL CONSTRAINTS OF TIDAL CURRENT ENERGY GENERATION

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Acknowledgments

Many people have travelled this roller-coaster of a journey with me and the following ironic statement has stayed with me throughout:

"The only way to find out how to do a PhD is to do one. Therefore all advice is useless".

I can honestly say that though this statement is fundamentally true, in my case it is not a definitive truth. Over the last few years many people have either been directly or indirectly involved in my journey in writing this thesis. I say journey because it is one. A journey that starts with a slow beginning and which gradually builds momentum until it ends some years later with you wondering where the years have gone. It is a journey to explore not only your intellectual potential but it is also a journey that defines your capacity for determination and commitment, as well as the patience and dedication of others around you, and I have to say, not all advice given has been useless!

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I know you would be proud!

Abstract

The thesis discusses the environmental impacts and developmental constraints of tidal current energy. Using an iterative approach and drawing upon a number of different methodologies the thesis attempts to evaluate the development potential of tidal current energy in terms of the resource and identify the potential environmental impacts. In addition, it attempts to identify the barriers to development that may be preventing the growth of the industry. The thesis also assesses further research requirements in terms of environmental and social barriers to development, focusing on an environmental impact methodology and its importance in tidal current energy development.

Over recent years there has been a significant acceleration in tidal current energy research and development. The key challenge is for technologies to reach full commercialisation. The thesis investigates present market and industrial accessibility and due to institutional and environmental barriers, concludes that commerciality will be hard to achieve if such 'barriers' are not broken. However, the skills and capability base in the UK offshore industry and indeed the renewable energy sector is significant and this should be utilised accordingly. This vision of commercialisation needs to be sustained and a culture of forward thinking needs to be continuously cultivated. In essence, the UK cannot afford to miss this opportunity, both in terms of R&D status, economic stability, energy diversity and security of supply and in time export potential.

The thesis identifies key environmental issues concerning tidal current energy development using a site-specific case study and highlights the misconception that renewable energies are without environmental impact. It is clear that some are well understood within the realm of other offshore industries, however, some are relatively unique to this type of development and the need for further research is evident in these areas, in order to dispel the environmental impact uncertainties that exist. The thesis also demonstrates that there are 'process gaps' within Environmental Impact Assessment and attempts to develop an environmental impact assessment framework to aid the tidal current energy development process.

Abbreviations and Acronyms

ACORD	Advisory Council on Research and Development
AD	*Anno Domini*
AHP	Analytical Hierarchy Process
AREG	Aberdeen Renewable Energy Group
AWCG	Active Water Column Generator
BEEO	Best Environmental and Economic Option
BERR	Department for Business Enterprise and Regulatory Reform
BP	British Petroleum
BPEO	Best Practical Environmental Option
BWEA	British Wind Energy Association
CCL	Climate Change Levy
CE	Crown Estates
CEC	Commission of European Communities
CEFAS	Centre for Environment, Fisheries and Aquaculture Studies
CFD	Computational Fluid Dynamics
CM	Consequence Model
COWRIE	Collaborative Offshore Windfarm Research into Environment
CPD	Continued Professional Development
CRADA	Co-operative Research and Development Agreement
CREAM	Computer-aided Rapid Impact Evaluation And Management
DEAT	Department of Environmental Affairs and Tourism
DEFRA	Department of Food, Environment and Rural Affairs
DOE	US Department of Energy
DTI	Department of Trade and Industry
EA	Environment Agency (now Natural England)
EAP	Environmental Assessment Process
EB	Engineering Business
EC	European Commission
ECOTECH	Ecotech Centre
EERU	Energy and Environment Research Unit
EI	Environmental Impact
EIA	Environmental Impact Assessment
eia	Energy Information Administration
EMEC	European Marine Energy Centre
EPRI	Energy Power Research Unit
ES	Environmental Statement
ESPOO	Convention on Environmental Impact Assessment in a Transboundary Context
ETSU	Energy Technology Support Unit
EU	European Union
EUREC	European Energy Centres Agency
FEPA	Food Environment Protection Act
FREDS	Forum for Renewable Energy Development Scotland
FRS	Fisheries Research Services
GIS	Geographical Information Systems
GNN	Government News Network
HC	House of Commons
HEP	Hydro Electric Power
IAIA	International Association for Impact Assessment
ICIT	International Centre for Island Technology
IEA	International Energy Agency
IEMA	Institute of Environmental Management and Assessment
IMO	International Maritime Organisation
INTRA	INTer-parameter Relationship Analysis
JNCC	Joint Nature Conservation Council

KORDI	Korea Ocean Research and Development Institute
LCA	Life Cycle Analysis
LPC	London Power Company
m/s	Metres per second
MAREC	Marine Renewable Energy Conference
MARPOL	International Convention fro the Prevention of Pollution from Ships
MCA	Maritime and Coastguard Agency
MCEU	Marine Consents and Environment Unit
MCT	Marine Current Turbines
MHD	Magneto Hydro Dynamic
MIS	Marine Information Systems
MNR	Marine Nature Reserve
MP	Member of Parliament
MPA	Marine Protection Area
MSP	Member of Scottish Parliament
NaREC	New and Renewable Energy Centre
NASA	National Aeronautics and Space Administration
NETA	New Electricity Trading Arrangements
NFFO	Non Fossil Fuel Obligation
NHA	National Hydropower Association
NNR	National Nature Reserve
NOREL	Nautical and Offshore Renewable Energy Liaison Group
NYPA	New York Power Authority
NYSERDA	New York State Energy Research and Development Authority
NYU	New York University
OECD	Organisation of Economic Cooperation and Development
OFGEM	The Office of Gas and Electricity Markets
ORCU	Offshore Renewables Consents Unit
OREEF	Offshore Renewable Energy Environmental Forum
OWEN	Offshore Wind Energy Network
PCZ	Preferred Conservation Zone
PIU	Performance and Innovation Unit
PV	Photovoltaic
RAG	Research Advisory Group
REZ	Renewable Energy Zone
RGU	The Robert Gordon University
RIAM	Rapid Impact Assessment Methodology
RLD	Regional Landscape Designation
RO	Renewables Obligation
ROC	Renewables Obligation Certificate
RPA	Renewable Power Association
RSPB	Royal Society for the Protection of Birds
RTT	Rotech Tidal Turbine
SAC	Special Area of Conservation
SCARCOST	Scour Around Coastal Structures
SE	Scottish Executive
SEA	Strategic Environmental Assessment
SEDC	Sustainable Energy Development Office
SEERAD	Scottish Executive Environment and Rural Affairs Department
SEn	Scottish Enterprise
SEPA	Scottish Environmental Protection Agency
SIA	Social Impact Assessment
SIAM	Spatial Impact Assessment Methodology
SIF	Significance Impact Factor
SMART-ALEC	Statistical Measurement for Assessing Regional Trends – And Long-term Environmental Consequences
SME	Small – medium Enterprise
SNH	Scottish Natural Heritage
SPA	Special Protection Area

SPREG	Scottish Parliament Renewable Energy Group
SRO	Scottish Renewables Obligation
SSSI	Site of Special Scientific Interest
STC	Science and Technology Committee
STC	Science and Technology Select Committee
SUPERGEN	Sustainable Power Generation na Supply Initiative
SWREA	South West Renewable Energy Agency
TBT	Tributyltin Triphosphate
THGL	Tidal Hydraulic Generators Ltd.
TWA	Transport and Works Act
UCS	Union of Concerned Scientists
UEK	Underwater Electric Kite
UK	United Kingdom
UKCS	UK Continental Shelf
UKOOA	UK Offshore Operators Association
UN	United Nations
WEC	World Energy Council
WWF	World Wildlife Fund

Units of Power

(with relevance to thesis)

W	Watt
Wh	Watt hour
MW	Megawatt
kW	Kilowatt
kWh	Kilowatt hour
GW	Gigawatt
TW	Terawatt

1 MW	1000 kW
1 kW	1000 W
1 GW	1000 MW
1 kWh	1000 Wh

Nomenclature

$P = \frac{\rho V^3}{2}$	Power of density
V^3	Velocity cubed
ρ	Density
$E = \frac{D^2}{8} \cdot \mu \cdot \rho \cdot \pi \cdot V_{R^3}$	Potential energy capacity
D	Diameter of rotor (metres)
μ	Assumed efficiency
V_R	Rated velocity ($m.s^{-1}$)
$D_{number} = \frac{A_{surface}}{D_L . D_W}$	Number of devices that can be installed within a site
$A_{surface}$	Seabed area
D_L	Diameter length
D_W	Diameter width
$S_{capacity} = E \times A_{surface}$	Overall energy capacity
$\frac{d\,p\,i\,n}{e}$	Inanimate environmental impact
$\frac{d^y\,p\,i\,n}{e^x}$	Animate environmental impact
$\frac{p\,i}{d\,e}$	Human environmental impact
Length of cable X Diameter of cable	Area of seabed affected by cable
$K_D = H / H_0$	Diffraction coefficient
H	Wave height
H_0	Initial or deep water wave height
(θ)	Angle of incidence
r	Radius vector
L	Incident wavelength
$C_R = H_R/H_0$	Reflection coefficient
$C_T = \sqrt{1 - C_{R^2}}$	Transmission coefficient
$S = \frac{f}{2} \rho U_{tide}^2 B \cdot L \left\{ 1 + \frac{2}{3} \frac{d_{min}}{d} \right\}$	Total flow shear force
$F = 10 \cdot \frac{1}{2} \rho C_D \left(U_{tide} \sqrt{\frac{d_{min}}{d}} \right)^2 d_{min} \cdot D$	Total current force
f	Bottom friction factor
d_{min}	Minimum depth at shed lines
D	Diameter of one device support structure
L	Length of shed line
B	Width of shed line

Contents

Page

FIGURES

TABLES

APPENDICES

"You see, we should utilise natural forces and thus get all our power. Sunshine is a form of energy, and the wind and tides are manifestations thereof. Do we use them? Oh No! We burn up wood and coal, as renters we burn up the front porch for fuel. We live like squatters, it's not as if we own the property".

Thomas Edison, 1916

CHAPTER 1

Research Background

1. RESEARCH BACKGROUND

1.1 Energy and the Environment

1.1.1 The Energy Situation

The bulk of the worlds energy demands are currently met from non-renewable energy sources and the global population has been estimated to grow from around 6 billion in 1999 to nearly 7.5 billion in 2020, which is an approximate rise of 25 percent (EIA, 2002). However, its rate of growth is predicted to slow down to just over 1 percent (%) per annum (pa) in the latter part of the projection period. The EU share in world population is expected to decline from 6.8% in 1992 to 4.8% in 2020 and 4.2% in 2030. Though predictive estimates are notoriously inaccurate and can be subject to extreme change (Charters, 2001), it is clear the problem of increased population growth and the need for energy still remains. The world energy consumption 24-year forecast (2001-2025) has been projected to increase by 54%, with the world demand for electricity growing by approximately 2.3% annually between 2001 and 2025 from 13,290 Billion kW in 2001 to 23,072 Billion kW in 2025 (EIA, 2004)(**Appendix 1**).

It is also clear that the energy mix for both total energy consumption and energy for electricity generation are predicted to be predominantly that of non-renewable means. In 2001, the total world energy mix favoured oil (**Table 1**). The energy mix however, for electricity generation forecasts are predicted to be quite different (**Table 2**), where the primary means of generating electricity is forecast to be coal, natural gas, with renewables being third in the projected world energy mix.

Despite UK energy consumption decreasing by approximately 2.3% between 1999 and 2000, trends are likely to increase overall (BP, 2001), with natural gas and the nuclear industry predominating (DTI, 2001).

Table 1: World Energy Mix for Energy Consumption (EIA, 2004).

Energy Type	World % (2001)	Projected World % (2025)	% Difference
Oil	38.7	40.6	+1.9
Natural Gas	23	25	+2
Coal	23.8	22.1	-1.7
Nuclear Energy	6.5	4.3	-2.2
Renewable	8	8	0

Table 2: World Energy Mix for Consumption by Electricity Generation (EIA, 2004).

Energy Type	World % (2001)	World % (2025)	% Difference
Coal	38	37.4	-0.6
Renewable	19.7	19.2	-0.5
Natural Gas	18.4	25.2	+6.8
Nuclear Energy	16.3	11.7	-4.6
Oil	7.6	6.5	-1.1

1.1.2 Environmental Implications of Energy Resources

Energy use is central to most activities conducted by man, but it is also the primary cause of many environmental problems experienced, whether globally or in a local context. Such problems are not just associated with global warming, acid rain or ozone depletion, but are also related to issues, such as air quality and the physical impact associated with drilling and mining activity, including production and refining. These are just some of the environmental issues resulting from the use of fossil fuels by the industrialised nations. Since the 1990's however, governments have taken the threat of global warming and climate change increasingly seriously. The nuclear energy industry and the oil industry also involves a risk to human and environmental health (EERU, 1997) and the uncertainties regarding fossil fuel reserves have also taken a priority (Elliott, 1997), leading to further concern relating to the socio-economic implications with respect to the environment as a whole. The DTI have considered examples of such implications in a recent report (DTI, 2002), such as energy supply and demand and fuel poverty. Much evidence suggests that the future environment will be negatively impacted if it continues to be degraded in the present fashion with respect to present resources and usage of energy (Dincer, 2000).

There has always been an intimate relationship between energy, the environment and the need for sustainable development. However, despite the emergence of environmental issues in the 1960's and the 1970's, highlighting long-term problems (Elliott, 1997), it has only been since the 1980's that a relationship between energy use and environmental impact has received attention (Dincer, 1999). Energy use is no doubt a key driver in the issue of environmental impact and it is evident that as the need for energy use increases, the adverse impacts on the environment will also increase if measures are not taken to slow or prevent such an increase.

It seems clear that if energy needs are to be met with minimal environmental damage there will have to be a world-wide drive to not only conserve and improve efficiency of energy use, but to also create a sustainable and 'clean' energy future. A number of potential solutions to environmental problems have been highlighted (Dincer 2000; Dincer & Rosen, 1999). These include energy conservation through improved energy efficiency, a reduction in fossil fuel usage and an increase in renewable energy resources and technologies to name but a few. For example, in the recent Energy White Paper (DTI, 2007) it is believed that the Energy Efficiency Action Plan and both the 2000 and 2008 Climate Change Programmes will deliver a reduction in the UK's carbon dioxide emissions of 16% below 1990 levels, where 40% of this improvement will be by energy efficiency measures.

The primary factor for determining such future energy development, however, will be the continued maintenance and introduction of legislation and policy with regard to the environment, energy issues, sustainable development and environmental protection. Over the past decade or so there has been a world-wide effort to address these issues with increased legislation and policy.

1.1.3 International and EU Energy and Environmental Policy

United Nations Convention on Climate Change

In 1992, members of the United Nations (UN) recognised and agreed to meet the challenge of the 'Greenhouse effect' and associated problems like climate change due to the use of fossil fuels and consequent pollution. It took just over two years to negotiate an agreement and on March 21st 1994, 185 countries ratified the Convention on Climate Change and subsequently became legally bound by it.

The convention establishes a framework and a process for agreeing future actions between countries on issues concerning the environment. There were, however, no set tasks or rules laid down. This promoted a certain degree of uncertainty regarding actions to be taken. Consequently though, countries could collaborate and agree on and adopt specific actions when necessary. Countries collectively agreed to develop programmes to slow climate change and encourage scientific research. Developed countries however, and members of the Organisation of Economic Cooperation and Development (OECD) were obligited to take the lead in such programmes and in turn took on a greater responsibility than other countries that ratified.

The convention also supported the concept of 'sustainable development', by encouraging and developing methods for using critical natural resources at a rate no faster than they can be replaced. The convention also called for the development and the sharing of knowledge with respect to environmentally clean and renewable energy technologies and an emphasis on educating people about climate change and associated effects and ways in which cultures and behaviour needs to change.

Kyoto Protocol

In 1997, governments responded to increasing pressure by adopting the Kyoto Protocol. Basically a protocol is an international agreement that stands on its own but is fundamentally linked to an existing treaty and in this case it was the convention outlined above. The protocol builds upon existing principles. Further commitments were added however, which are more detailed in comparison, reflecting specific legally binding targets and actions.

EU and Member State Response

As a response to the Kyoto Protocol, the EU made its own international agreement to reduce harmful emissions by 8% and with this commitment a number of other targets and frameworks have been introduced.

The promotion of renewable energy sources is a high priority throughout the EU to help in the challenge against climate change. EU renewable policy is based on the White Paper (EC, 1997) and its aim is to double the share of renewable electricity generation from 6% to 12% by the year 2010.

In the past, national legislation inhibited the uptake of renewable energy technologies because generally electricity supply was provided through single national energy utilities and independent producers had limited access to power supply markets.

As a continuous process the EU is now moving towards a more liberalised market both within and between EU states, creating greater competition and freer access for independent producers, especially those in the renewable market. As a result, electricity prices for consumers decreased. This in turn however, made it more difficult for renewable energy technologies to compete with conventional fuel mechanisms (**Section 7** details this).

The EU Directive on the *promotion of electricity from renewable energy sources in the internal market* (EC, 2001) addressed this problem. The aim was to create a common framework to promote an increased contribution of renewable energy resources to electricity production. All EU countries were required to set national targets to achieve the 2010 target and were consequently free to decide the methods involved i.e. financial support, feed-in tariffs, green certificates etc. (Meyer, 2002; Midttun & Koefoed, 2002).

1.1.4 UK Renewable Energy Policy

There have been a number of key documents and papers discussing and reviewing UK energy policy and funding (Elliott, 1996, 1997, 1999 and 2000; Mitchell, 1995; Scottish Enterprise, 2002 and DTI, 2000, 2001e, 2002b). However, the most definitive paper to date is a review of UK renewable energy policy by Conner (2002).

Historical Perspective

A key driver in the UK renewable energy research and development effort was that of the oil crisis in the 1970's. In the late 1970's wave energy was the most favoured form of renewable energy and received considerable government support. Following the 1982 review by the Advisory Council on Research and Development for fuel and power (ACORD) a re-assessment of wave energy occurred and subsequently funding and the prospects of wave energy development were curtailed. Since then the ACORD report has been scrutinised and in a more recent report (STC, 2001) openly admitted that it was a mistake that wave energy efforts were stopped (Elliott, 1989; Conner, 2002).

The focus from that point was the land-based wind industry and over the years this has developed into offshore projects with encouragement from other leading countries, such as the USA, Germany, Denmark, Sweden and the Netherlands. Wind energy flourished in these countries, but the attraction of wind energy in the UK was less positive, and reflected poor funding, the need for privatisation and new policies to govern renewable energy development. In the 1980's the Non Fossil Fuel Obligation (NFFO) was introduced (Scottish Renewables Obligation existed in Scotland) bringing a renewable energy support mechanism. Mitchell (1995) reviews the NFFO process in detail. Ironically the original NFFO was created out of the need to find a means of supporting the nuclear industry. Central to achieving policy goals and targets 5 NFFO's were set up, but short and long term draw- backs prevented them from going any further (Conner, 2002; Mitchell, 1995).

Current Policy

The basis of the UK renewable energy policy was achieved in the Energy Paper 55 (DTI, 1988) and the main aims of the policy were to;

- Stimulate the full economic exploitation of alternative energy resources in the UK;
- Establish and develop options for the future;
- Encourage UK industry to develop capabilities for domestic and export markets.

These policy goals were also reflected and expanded upon in another Energy Paper (DTI, 1994). In the year 2000 with the government's commitment to adopt the renewables obligation (DTI, 2000a), changes were made to the key aims and these form the basis of the current renewable energy policy;

- To assist the UK to meet national and international targets for the reduction of emissions, including greenhouse gases;
- To help provide secure, diverse, sustainable and competitive energy supplies;
- To assist the renewables industry to become competitive in home and export markets and, in the doing so, provide employment.

In terms of targets the *Renewable Obligation Statutory Consultation* (DTI, 2001e) provides clear definition. UK renewable energy targets are set at 10% of all UK electricity generation and must be provided by renewable technology by 2010, with further specific targets of 3% by March 2003 and 10.4% by March 2011. A further report (PIU, 2002) has suggested a more ambitious target of 20% renewables by 2020 should be set and this has been approved, along with targets of 5% by 2005 and 10% by 2010 (DTI, 2004).

The Scottish Executive is also duly committed in the promotion of renewable energy development in response to environmental and security needs. This commitment and strong commercial interest can been seen in the 18% renewable generation target set for 2010. An initial longer term target of 30% by 2020 was set, but the Scottish Executive has increased this to 40% (DTI, 2004).

The central mechanism to meet these renewables obligation targets lies in a wide range of new instruments put forward called the Renewables Obligations (RO) or Renewables Obligation (Scotland). The new Renewables Obligation and associated Renewables (Scotland) Obligation came into force in April 2002 as part of the Utilities Act (2000). These have been put forward in an attempt to maximise competition within the support mechanism, whilst guaranteeing a minimum level of installation of new capacity. It requires power suppliers to derive a specified proportion of the electricity they supply to their customers from renewable energy (as stated above). A price cap, limits the cost to consumers and this obligation is guaranteed in law until 2027.

Renewable energy generating companies receive Renewables Obligation Certificates (ROCs) for each MWh of electricity generated. These certificates can then be sold to suppliers, in order to fulfil their obligation. Suppliers can either present enough certificates to cover the required percentage of their output, or they can pay a 'buyout' price of approximately £30/MWh for any shortfall. All proceeds from buyout payments are recycled to suppliers in proportion to the number of ROCs they present.

ROCs have traded as high as £47/MWh but there is no guarantee that they will remain at this price. ROCs have increased the profitability of renewable energy generation, especially as certificates have sold for more than the power itself. This is especially true for wind, which was already producing electricity at competitive prices. The Non-Fossil Purchase Agency Ltd. administers the trading of ROCs. The Renewables Obligation has just been extended to rise to 15% by 2015 (BWEA, 2006).

At present, UK policy favours on- and offshore wind, landfill gas and bio-energy. However, since the Binnie, Black and Veatch report (DTI, 2001b), more and more attention is turning towards the marine renewables, such as wave and tidal current energy (DTI, 2001c; 2001d; and STC, 2001) and it is quite clear that within Scotland where such resources predominate there is a feasible potential for commercialisation. However, recently The South West Renewable Energy Agency conducted research into the development and exploitation of wave and tidal energy in the region, recommending that a Strategic Environmental Assessment (SEA) of the South West be undertaken, along with resource assessment activities, including identification of key locations and their energy capacity (SWREA, 2003). All in all, it is quite clear that tidal current energy has a growing interest and increasing prospects of becoming commercialised throughout the UK.

1.2 Environmental Impact and Constraint Research: Scope of Work

With increased concern over global and local environmental implications with respect to the present world energy mix, uncertainty of the extent of fossil fuel reserves and the need for sustainable energy supply, the recognition of the importance of renewable energy development is rapidly increasing throughout the world. Such recognition has been found at all levels from public concern to government interest, with the introduction of policy and legislation on a national and international level. This will enable an increase of renewable energy technologies within the electrical energy mix, reduction in harmful emissions and the encouragement of a 'cleaner' and sustainable environment throughout.

There is however a dichotomy of responsibility with respect to the global environment and the need to protect and sustain our 'local' environments. The recognition for sustainable development and clean technology doesn't stand-alone, because there has also been a parallel increase in environmental policy, legislation and formal procedure to protect the environment from unwarranted detrimental impact through all areas of human development and action. Renewable energy development is by no means an exception, despite the obvious global benefits. Generally, there has been a growing awareness and consideration of environmental impact due to development in the marine environment. Overall this has been slow to mature compared to land-based development. Efforts have been mainly concerned with the prevention of marine pollution (shipping issues, waste management, oil and gas production related environmental concerns etc.), the sustaining of natural marine resources and coastal protection schemes, where MARPOL and other international bodies and industries have been heavily involved. Despite the fact that Environmental Impact Assessments (EIA) are required by European and most national legislation where there is the possibility of environmental impact, far too often these and the mitigation procedures recommended are not adequate for the complex marine environment and the developments proposed.

With all these issues in mind, this thesis focuses on the following major themes:

- tidal current energy and its relationship to the environment;
- a review of the existing methodology employed to identify environmental impacts with respect to potential development, especially within the marine environment;
- the development potential for tidal current energy and the barriers that hinder such development;
- Research and development that focuses on the mitigation and assessment of environmental impact with respect to tidal current energy development; and

- Environmental impact framework/guidelines and EIA methodology specifically related to tidal current energy and other marine related developments.

Tidal Current Energy and Environmental Impact

It is probably a common misconception to think that *any* renewable energy source is environmentally benign. Over recent years limited concern has been expressed with respect to the potential impacts of renewable energy on the environment (Clarke, 1993, 1994; Elliott, 1997; IEA, 1998; Abbassi and Abbassi, *et al.*, 2000; UCS, 2002). However, with the increasing need for a higher renewable energy status this concern seems to have been largely ignored in the hope that the positive implications and significant global environmental benefits of such energy technology would override these concerns. With increased deployment of renewable energy systems, such as on- and offshore wind, a heightened awareness of environmental problems has surfaced, proving to be an obvious constraint to their development. If these energies are to fulfil their potential, these issues need to be addressed and tidal current energy generation is no exception, especially with the vast resource that is available within the UK and other parts of the world.

There have been few generic studies and reports approaching the topic of the environmental impacts of marine renewable energy but some have approached quite specifically the issues concerning offshore wind (ETSU, 2000; Marine Institute, 2000) and the offshore wind farm consents process (DTI, 2003). There is, however only one specific study relating to the environmental impacts concerning tidal current energy (DTI, 2002a), despite the significant amount of positive research and development within technological and economical aspects.

A handful of reports have expressed a need for environmental impact research within the context of marine renewable energy in order to overcome deployment constraints and uncertainty (Boud, 2002; DTI, 2001b; 2001c, 2002; Pontes & Falcão, 2002, Dacre, 2002; Ball, 2002; Wilson & Downie, 2003 and Band, 2003). With this in mind and an increased pressure for renewable energy electricity supply there is a direct need to establish and understand the environmental problems faced by tidal current energy and therefore in turn find ways to mitigate and reduce these environmental uncertainties within tidal current energy developmental history.

Environmental Impact Assessment Methodology

At present there is a broad selection of EIA methodology available to generate both generic and site specific assessments of developmental impact for a broad and varied range of potential human development. Most processes are subjective and open to interpretation and most methods when they are employed usually reflect the scope of the study and the extent of the methodology that is current at the time. Though there is some form of transparency related to the methodology used, more is needed to enable increased consistency throughout the EIA process, ensuring that the complexity of the issues and problems raised is highlighted for specific methods of development and development locations.

Due to the slow introduction of tidal current energy and the fact that such technology is predominantly at prototype and experimental stage, just a handful of assessments have been carried out. These were largely to establish the environmental impacts of a site-specific nature with respect to feasibility studies (ICIT, 1994; Dacre, 1999; Dacre & Bullen, 2001; Dacre, 2003) and environmental appraisals for demonstration projects (Lowther, 2001; Pomfret & Smith, 2002). Recently, an environmental impact statement has been prepared for the Lynmouth SeaGen Array (MCT Ltd.), along with a number of high level scoping reports for MCT Ltd. and Tidal Electric Ltd. for projects in UK waters (*pers comm.* Keith Welford and Robert Lily, DTI). Research is also ongoing using a quantitative approach to compare environmental impacts for a number of forms of renewable energy, including tidal current energy (Clarke, 1993, 1994; Clarke, 2002, *pers comm.*). The assessments conducted by ICIT (1994) and Dacre (1999) were generally descriptive and subjective with very little transparency and definitely warranted some further consideration in terms of reasoning and analysis. Though the studies conducted by Dacre and Bullen (2001) and Dacre (2003) were subjective and open to interpretation, the method did establish consistency through clear definition. The simplicity of the method did not detract however from the fact that assessing impacts and the interactions of those impacts and the environment is a complex process (**Sections 4** and **5** detail this methodology).

Through conducting the Pentland Firth study (Dacre & Bullen, 2001) it was highlighted that tidal current energy technology does have its unique, but diverse environmental problems and considerations, despite also having some generic ones that compare with other marine or offshore renewable energies. It also became apparent working through the EIA process used that in terms of tidal current energy a standardised EIA framework and methodology for assessing potential environmental impact would be beneficial, especially with respect to future potential development. These sentiments have also been iterated since then in terms of the future development of marine energy systems (Dacre *et al.*, 2002; Lowther, 2002; Harper, 2002; Wilson & Downie, 2003; Band, 2003 and CCW, 2006).

Tidal Current Energy Development

With UK Government targets having been set to provide 20% of energy through renewable sources by 2010 and Scottish targets of 40% by 2020 and with the continued effort of reducing carbon emissions by 60% by 2050 (PIU, 2002), the need for positive development in new technology is paramount and evidently advocated by government policy and remit. Diversity of energy resources has also been strongly advised to sustain an effective security of supply throughout the future (HC, 2002a).

It has been well documented that tidal currents throughout the UK and Europe represent a significant sustainable energy resource and it is widely accepted that tidal current power could supply energy to the UK and the EU. The House of Commons Science and Technology Select Committee has stated recently that the UK can no longer afford to neglect the potential of tidal energy and has suggested that the UK tidal current energy resource could fall between 31 and 58TWh per annum (Science and Technology Committee, 2001). Similar opinion was also stated in more recent government debate (HC 2002a; 2002b).

In the past few decades, especially in more recent years tidal current energy technology research and development has progressed. Technology is still, however, at an early stage of development with companies and research institutions working to develop technology that is both economically and technologically sound. There is little doubt, however, that such energy devices will move beyond the experimental and prototype stage and will, subsequently, become serious market contenders with respect to other new and renewable energy sectors. However, while other energies have been able to establish a foothold in the market, such as wind, hydro and nuclear, the prospect of tidal current energy technologies seems to be taking longer to gain that same foothold, despite the encouragement from government and key stakeholders.

Throughout the thesis development, the latter trends became more apparent and fundamentally related to environmental impact issues with respect to the socio-economic environment. The Pentland Firth study (Dacre & Bullen, 2001) began to touch on these issues, but the development and market potential study (Dacre, 2002) highlighted the fact that tidal current energy was a few years behind other renewable or new energy technologies and subsequently addresses the complex reasons why. A study conducted by AEA Technology for the Scottish Executive (Boud *et al.*, 2002a) also discussed opportunities for marine energy in Scotland, but predominantly touched on the synergies and potential of wave power.

In its report *Sustainability through diversity: Prospects for the UK oil and gas suppliers industry*, (DTI, 2001d), the DTI identified tidal current power as having a close fit with skills possessed by suppliers to the offshore oil and gas industries. The potential diversification of these and the shipping industries into the offshore renewable energy market has been an important consideration, especially in areas of design, fabrication, installation, operations and maintenance. Such diversification and development could widely stimulate a number of employment opportunities and potential economic growth, as well as providing a basis of a major new industry with export potential. However, at present it is unclear how and to what extent this will emerge and the implications this has. Research primarily focused on Scotland, investigating the industrial skill and capability that could be applied to the development of tidal current power, the market potential it has and, in general, the socio-economic implications that may arise with respect to industry, manufacture and the Scottish economy and culture.

1.3 Aims and Objectives

1.3.1 Aim(s)

i. To determine the environmental impacts and constraints of tidal current energy extraction and assess the methodology that governs the identification of such impacts.

ii. To ascertain the environmental constraints and developmental barriers associated with tidal current energy extraction and develop further research needs to accommodate and mitigate such barriers.

1.3.2 Objectives

i. Evaluate the resource and development potential of tidal current energy.

ii. Identify the environmental impacts and constraints of tidal current energy extraction and evaluate the importance of such impacts within the context of a potential development.

iii. Identify barriers to the development of a tidal current energy extraction industry.

iv. Assess the need for further research requirements with respect to specific areas of environmental impact and tidal current development.

v. Evaluate existing environmental impact assessment methodology and develop a standardised scoping methodology for assessing potential environmental impacts of tidal energy schemes.

1.4 Outline of Thesis

The thesis is structured as follows. The thesis development has been summarised as a conceptual diagram in **Figure 1**.

Chapter 1 - Research Background: explains and sets the scene to the research project, highlighting the current energy situation, government and legislative influence, the role of tidal current energy and the scope of work drawing upon the needs of environmental impact assessment and the role of this in tidal current energy development and the contribution of the thesis to related work.

Chapter 2 - Resource and Development Potential: discusses the resource and development potential of tidal current energy, focusing on the development and market potential of such an industry in Scotland.

Chapter 3 - EIA and Tidal Current Energy: explains the EIA process and the general role of EIA in the development process. Discusses current EIA methodology and builds upon the importance of EIA in the context of tidal current energy.

Chapter 4 - Identification of Environmental Impacts and Constraints: using two case studies constructed throughout the thesis lifetime and current EIA scoping methodology this chapter identifies the potential environmental impacts and constraints of tidal current energy development.

Chapter 5 - Assessment of Environmental Impacts and Constraints: discusses the implications of the potential impacts identified within the context of the case studies as previously described in chapter 4.

Chapter 6 - Assessment of EIA Methodology: Critically assesses the methodology used in chapter 4 in relation to other offshore EIA's and briefly addresses the need for further EIA development with respect to tidal current energy and development within the marine environment.

Chapter 7 - Barriers to Development: drawing upon key issues and elements of previous chapters the barriers to the development of tidal current energy were identified.

Chapter 8 - Environmental Impact Research Development: drawing upon the identification results the chapter discusses and presents in detail the environmental interactions associated with tidal current energy development and forms the basis of future research needs. Subsequent chapters draw upon some of these research needs.

Chapter 9 - EIA Framework Development: builds upon EIA process needs discussed in chapter 6 within the context of tidal current development. The derivation of a standardised comparative EIA framework and methodology for the assessment of tidal current energy development is also discussed.

Chapter 10 - Discussion and Conclusions: presents the overall discussion and conclusions, giving a critical analysis of the thesis in terms of methodology used and results obtained.

Chapter 11 - Recommendations: discusses further recommendations.

Chapter 12 - References and Bibliography: lists all sources referenced and used for the thesis.

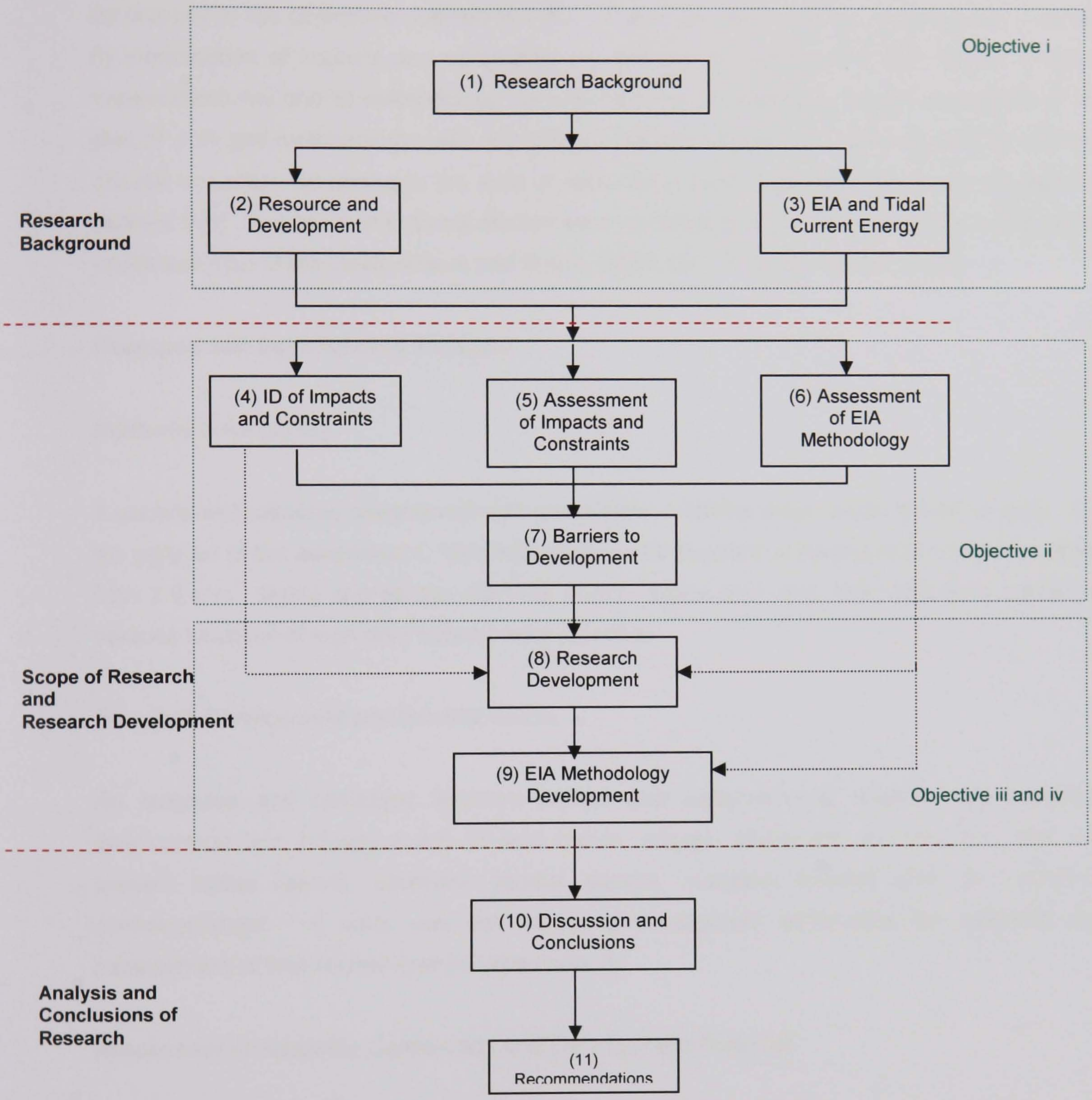


Figure 1: Schematic Representation of Thesis Development and Layout

1.5 Plan of Work

To achieve the overall aim, the plan of work was divided into five distinct areas of study, which correspond to the objectives outlined in 1.3.2. These are; resource and development potential (i) identification of impacts and constraints (ii), barriers to development (iii), further research requirements (iv) and EI methodology development (v). Following is a brief description of the plan of work and methodology used, but detailed methodological description can be found in the chapter or section pertaining to the area of research in hand throughout the thesis (section 1.4 outlines this). A number of external studies were commissioned which contributed to the overall scope and plan of the thesis (Dacre and Bullen, 2001; DTI, 2002 and Dacre, 2002).

Resource and Development Potential

Resource Assessment

A generalised resource assessment was undertaken to define major areas of tidal velocity. For the purpose of the assessment, 'high tidal areas' were denoted as having tidal velocities greater than 2.0 m/s. Using appropriate maritime charts, tables and other tidal data from numerous sources locations of high tidal velocity were identified.

Research Development and Industry Status

An extensive and continued literature review was undertaken to establish the research, development and industry status of tidal current energy, taking into account both past and present status reports, academic journal papers, company internet sites and personal communications. A table was devised to chronologically summarise the research and development of tidal current energy (**Appendix 8**).

Assessment of Resource Contribution and Development Potential

Throughout the course of this research area (Dacre, 2002) a consultative process was used to determine the following:

- Development, design and manufacturing capability for tidal current technology
- Assessment of diversification potential to establish a tidal current energy sector
- Identification of key issues that may significantly inhibit the development process

A number of key organisations, companies and developers were contacted to aid in this process. Contact was conducted through research group individuals, as well as using the contract services of a market analyst group, Systems Insight Ltd., specialising in technical aspects of industry. Methods included telephone and direct interviews, e-mail and letter.

Consultation areas are summarised in **Table 3**.

Developers and stakeholders were contacted to establish an overview of the problems associated with the development of tidal current energy and to discuss the potential capability of Scotland for development. Those developers not already associated with tidal current energy were also approached regarding their willingness to diversify into the tidal energy sector. A handful of organisations associated with the environment, legislation and finance were also consulted with respect to opinions on potential barriers. Industrial consultees were divided into those actively involved in or who have an interest in renewable energy and those that had no specified interest. All were approached regarding developmental barrier issues, which could be related to reasons why companies are not diversifying. Those approached with no specified interest in renewable energy development were asked questions relating to their willingness to diversify into the tidal current energy sector (**Appendix 2**).

By using information generated from the resource assessment and assessing electricity consumption statistics, energy mix and market structure, key areas of interest and potential for tidal current energy were identified, along with an overall assessment of development and market potential.

Identification of Impacts

A study funded by Scottish Enterprise (Dacre and Bullen, 2001; Dacre *et al.* 2002) formed the basis of this research. A second study (Dacre, 2002), outlined above (page. 17) was used to build upon the potential socio-economic impacts associated with tidal current development.

Initially the study was to identify all potential environmental impacts, problems and constraints associated with potential tidal current energy development using current environmental impact (EIA) methodology. Identification of impacts was derived from known theory within the context of the marine environment and related issues and an initial significance was established for each potential impact. Sources used included academic theses, consultant reports, academic books and journals and personal communication. A consultative process was also critical to the study and the validity of the conclusions drawn (**Table 4**). This included contact via e-mail, letter, telephone and direct interviews. Sources were critically analysed and evaluated and related to the development location of the Pentland Firth, Scotland.

Table 3: Summary of Organisations Contacted [Source: Dacre, 2002].

Organisational Area		Consultees
Developers	Tidal Current Energy	The Engineering Business - Tony Trapp RVco - John Hassrad (Imperial College, London) MCT Ltd. - Peter Fraenkel
	Other	Wavegen Ocean Power Delivery University of Plymouth Energy Unlimited
Key Stakeholders		Scottish Hydro Electric Industrial and Power Association Seapower Department of Trade and Industry (DTI)* Scottish Executive* Crown Estates*
Industrial	Interest in RE	AEA Technology* ANGLE Technology Ltd BAeSEMA British Power (BP)* Brown & Root McDermott MacKellar Engineering Ltd Merpro Ltd Scot Waste. Cadagon Consultants Dales Engineering Green Electricity Marketplace Ltd Medlock Ltd. McGregor Energy Services Richard Morris Assoc.
	No specified interest	AJT Engineering Ltd Forsyths Ltd Lothian Engineering S&D Fabricators Ltd Scotland Electronics Isleburn Group Lewis Offshore Ltd MacGregor Energy Services Wood & Davidson Ltd
Environmental		Joint Nature Conservation Council (JNCC) Royal Society for the Protection of Birds (RSPB) Scottish Environmental Protection Agency (SEPA) World Wildlife Fund (WWF) BMT Cordah* Environment Agency* Friends of the Earth* Environmental Consultant (Dr Bob Earll)*
Other		Burness Solicitors Masons Scotia Energy Wright, Johnston & MacKenzie Centre for Alternative Technology*

* Directly contacted by Systems Insight Ltd.

Barriers to Development

By using information generated through the two consultative processes described and a detailed literature search the barriers to development were identified and discussed.

Further Research Requirements

Drawing upon the identification process and initial significance of impacts, methodology was employed to extend the results further and establish further research need, to subsequently enable quantifiable results and further understanding of key potential environmental impacts. The study commissioned by the DTI (2002) formed the basis of this research and methodology.

Constraint issues and routes to commerciality were also discussed drawing upon research initiated and funded by Scottish Enterprise (Dacre, 2002).

Table 4: Summary of Key Consultations [Source: Dacre and Bullen, 2001].

Project Area	Organisation Consulted	Purpose
Legislative Framework/Designations	Scottish Natural Heritage Scottish Environmental Protection Agency Joint Nature Conservancy Council Scottish Executive	Information and advice on current legislative issues and designated areas etc.
Physical Environment	Proudman Oceanographic Laboratory British Oceanographic Data Centre Scottish Natural Heritage British Geological Society Orkney Islands Council - Env. Unit Scottish Environmental Protection Agency	Information/data and advice on the physical environment covered by the project proposal - tidal data etc. for the purpose of baseline data
Biological Environment	Scottish Natural Heritage Marine Conservation Society Sea Mammal Research Unit Gatty Marine Laboratory Orkney Seal Rescue Centre Orkney Islands Council - Env. Unit Orkney Field Club Royal Society for the Protection of Birds Scottish Environmental Protection Agency Peter Evans, Zoology Dept. Oxford	Information and advice on the biological environment influenced by the project.
Socio-economic Environment	Orkney Island Council (Dept. of Harbours) Pentland Coastguard Thomas & Bews Ferries Harbour Office, Scrabster HM Coastguard, Wick Fathoms, Wick Northern Lighthouse Board Orkney Fisherman Association Orkney and Caithness Enterprise Co. John O'Groats Ferries Creel Fisherman, John O'Groats Scottish & Southern Energy North Coast Marine Adventures Marine Lab, SERAD Sea Fisheries Protection Agency, Thurso Crown Estates, Edinburgh Wavegen, Inverness Maritime and Coastguard Agency (Mr Colin Brown)	Information/advice reflecting the key issues associated with the socio- economic environment
Other	Marine Laboratory, Aberdeen Scottish Coastal Forum	General consensus of proposal and report structure

Development of EIA Framework

From the initial EIA, a critical examination was undertaken to assess the methodology used and a comparison was made with other methodologies currently available. Methodological needs were established with respect to the EIA of tidal current energy development, forming a standardised EIA framework and methodology for assessing and comparing potential environmental impacts of such developments. This was established by drawing upon existing methodology and will, it is hoped be adapted to suit the needs of offshore and coastal tidal current projects and perhaps in time be adapted to meet the needs of other marine development opportunities.

1.6 Thesis Contribution

In terms of thesis outcome, four direct beneficial contributions can be highlighted, not only concerning the development of tidal current energy, but also with respect to EIA methodology:

i. A greater understanding of the potential environmental implications of tidal current energy and therefore a general assessment of the environmental integrity of tidal current energy systems.

ii. An understanding of the development potential of tidal current energy and the developmental barriers faced, concerning such a new energy industry.

iii. The scoping and establishment of research and developmental needs to sustain tidal current energy interest and market potential.

iv. The development of a standardised EI framework and methodology for the assessment of potential site-specific tidal current developments.

From these direct contributions a number of indirect outcomes can also been established, which are as follows:

i. A reduction in uncertainty with regard to the environmental integrity of tidal current energy, therefore allowing barriers to development, especially with respect to the consents process in this area being reduced or removed;

ii. Research will provide an adequate mechanism to ensure mitigation through technological design and environmental management and prediction;

iii. With developmental barriers being removed through the reduction in uncertainty and the process of mitigation the commercialisation of tidal current energy can potentially become more of a reality, in turn creating a significant contribution to the renewable energy resource and producing further beneficial social and economic impacts;

iv. Though there are unique environmental implications associated with tidal current energy, there are commonalties with other offshore and coastal industries and ventures, such as other marine renewables and therefore it is anticipated that research will provide and enhance knowledge and understanding of environmental issues that may be common to all;

v. A standardised environmental impact framework and methodology will enable a transparent and consistent assessment of potential impacts for comparing different sites using the same tidal current system or comparing different systems with respect to the same site, creating an effective decision tool to aid the consents and deployment process and;

vi. With the development of such a framework and methodology in time it has the potential to be adapted for other offshore and coastal projects creating the same consistency when assessing a specific project or a number of options.

CHAPTER 2

Resource and Development Potential

2. RESOURCE AND DEVELOPMENT POTENTIAL

2.1 Identification of Potential Resource

2.1.1 Tidal Current Characteristics

The tides are the consequence of the simultaneous action of the gravitational forces of the moon and sun and the revolution of the earth and moon; earth and sun, causing a tidal rise and fall (**Figure 2**). Tides also cause horizontal water movements termed tidal currents. The characteristics of currents (velocity and direction) vary markedly over horizontal distances of hundreds or even tens of metres, but over depths of only a few metres.

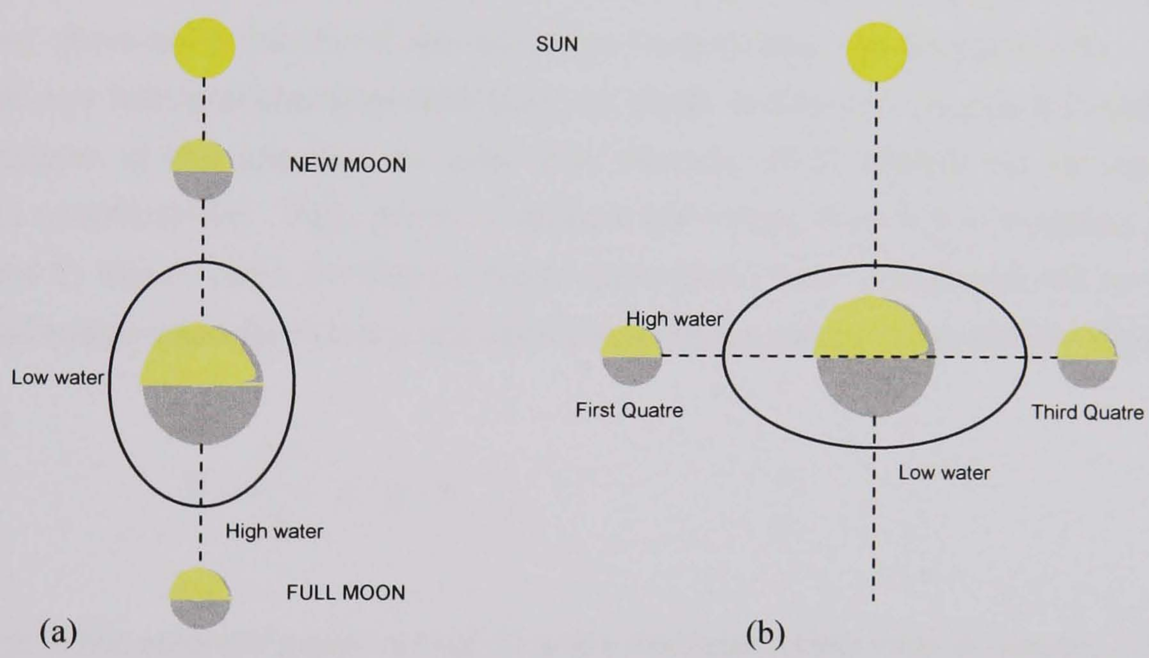


Figure 2: Gravitational Forces of the Sun, Moon and Earth. *(a) Spring tides occur at times of new and full moon. Range of tide is greater than average since solar and lunar tractive forces act in same direction. Neap tides occur at times of first and third quarters. Range of tide is less since solar and lunar forces act at right angles.*

The power generated by tidal currents is generally proportional to the cube of the current velocity. Away from the coast, current speeds are generally less than 0.1 m s^{-1}, however, tidal currents are at their strongest in narrow passages, straits and in shallow areas around continental shelves, where it is usually more practical to extract the energy. Energy output for tidal energy currents is strongly dependent on the magnitude of the tidal velocity present. The peak velocity on a mean spring tide should be greater than 1.5 m s^{-1}. The extraction of tidal energy is of most interest where sites >1.5 m s^{-1} current velocities present.

There have been a number of studies to assess the resource of marine currents throughout the world (ETSU, 1993; CEC, 1996; CEC, 1998; Boud, 2002 and SE, 2001). The following section will attempt to evaluate a number of sites throughout the world in terms of estimated power density and energy output potential.

The power density (*P*) in water currents can be calculated as follows (1):

$$(1) \qquad P = \frac{\rho V^3}{2}$$

Where V^3 is velocity cubed and ρ is the density of water. The density of water is assumed to be 1025 kg.m^{-3}.

Energy output computations for this section are based on those used by ETSU (1993). The purpose of this calculation is to determine the energy output obtainable at a particular site. However, there are a number of site-related constraints that may be applicable. These include physical and technical characteristics such as, depth and type of energy generator used. For the purposes of this exercise, an axial rotor diameter of 20 metres will be used (MCT Ltd. concept specifications). With structure support technology research in progress (**Appendices 3, 6 and 7**) that in effect diminishes depth constraints, these constraints will be limited. The potential energy capacity (rated power) of a single device can be calculated as follows (2):

$$(2) \qquad \mathrm{E} = \frac{D^2}{8} \cdot \mu \cdot \rho \cdot \pi \cdot V_{R^3}$$

Where E is the potential power output, D is the diameter of the rotor in metres, ρ is the density of the water, μ is assumed efficiency and V_R is the rated velocity (m.s^{-1}).

With respect to the energy output calculations various assumptions were also made. These were as follows:

1. Rated velocity is the velocity at which the device reaches maximum (rated) output. For the purposes of the calculations, the rated velocity is assumed to equal 85% of the maximum surface velocity at mean spring peak.

2. For some tidal current energy generation devices, it is possible to have more than one device within each depth band i.e. 3 devices deployed vertically at depth point of 50m. For the purposes of the calculations, the number of devices within each depth band will be 1, as the device selected for the purposes of the calculations is only designed to have one device within a depth point.

3. Efficiency (of rotor) (μ) is assumed to be 30% (0.3). This is the proportion of incident flow power that would be converted into power output. Taking gearbox and generator efficiencies into account efficiency has been calculated to be between 28% (DTI, 2001) and 40% (EPRI, 2006). The theoretical maximum value of efficiency is approximately 60% (0.593) according to Betz law. Due to the discrepancies between values, an approximate average was used for the Pentland Firth study.

The number of devices (D_{number}) that could be installed at a particular site can be calculated as follows (3):

$$(3) \qquad D_{number} = \frac{A_{surface}}{D_L . D_W}$$

Each device is allocated a seabed area ($A_{surface}$) related to rotor diameter. Lateral spacing of the turbines is assumed to be 2 diameters, with a downstream spacing of 20 diameters to allow wake recovery of the free stream velocity (refer to page 106 for diagram).

Therefore assuming all the devices within a site are the same size, the overall energy capacity for each site can be calculated as follows (4):

$$(4) \qquad S_{capacity} = E \times A_{surface}$$

In terms of results, energy capacity will be summarised in MW and then subsequently converted to GWh/year and TW/h per year, where it is assumed that operation is all year (365 days or 8760 hours). Navigational, depth and other site constraints have not been taken into account therefore all computations are assumed to be maximum values and may seem extremely high. Computations of general areas, such as Orkney, Shetland and the Western Isles are solely based on estimated area calculations, again not taking into account the latter constraints. Areas that have no area measurement have been calculated over 1 Km^2 for convenience and comparability. They are therefore a measurement of energy density only.

A summary of the energy computations can be found in **Appendix 3**. A number of sites known for their high tidal velocities were used for resource comparison, including sites in the UK, Europe (Italy, Netherlands), Australia, Asia, Canada and the USA. Though the fjords of Norway are strong contenders for potential tidal current energy generation sites, comparatively little was known about the characteristics of such sites when the resource estimates were generated. All estimates are comparable to previous resource assessment material (CEC, 1999, 1996: DTI, 2001; ETSU, 1993; SE, 2001) not withstanding differences in computation parameters such as rotor diameter and site constraints. A report commissioned by the Carbon Trust (Black & Veatch, 2005) details and compares the potential tidal current energy resources from various reports highlighted in this chapter, including the reports conducted by Dacre & Bullen (2001) and Dacre (2002). One of the important results of this review, was the inconsistency of estimates due to the simplicity of some resource calculations and the complexity others. In addition, the many assumptions necessary to estimate power capture realistically also added to the inconsistency of past energy resource estimates. The most common methodology used, now termed the 'farm' method appeared to have major limitations. This method adopted a 'windfarm' approach, estimating a tidal stream site's resource by considering the number of turbines within a grid-like formation, where the 'extractable energy' depended upon the number of devices deployed. The number of devices, however, were a function of the size of turbine, the device's efficiency and the size of the proposed site. The major limitation of this methodolgy is that the energy within a tidal stream site is broadly fixed by the flow entering the upstream cross-sectional area of the site, and therefore has a limit that is not taken into account by this "farm" methodology .

In the approach adopted by Black and Veatch (2005) an alternative approach to the 'farm' tidal stream resource analysis was used, known as the 'flux' analysis. This has also been adopted by resource research conducted by Strathclyde University (Strathclyde University, 2005). The Flux Method considers the percentage of total energy in a site that can be extracted without significant alteration to flow speed. The Robert Gordon University (RGU) have also been researching the 'extractable resource' of tidal current energy (Melville *et al.*, 2001; Couch & Bryden, 2004; Bryden *et al.*, 2005). Results showed that it is not possible to purely base resource estimates on the whole of the natural flow, as energy extraction causes reduction in flow speed and subsequently reduces the overall energy flux of the body of water. This implies that resource estimates would be significantly lower than previously suggested. In addition, capital investment per unit energy extracted would be higher than suggested by energy estimates based only upon the undisturbed flow. From analysis conducted by Bryden *et al.*, (2005), extraction of 10% of the energy in an undisturbed channel causes a speed reduction of 3%. The authors suggest that 10% could be considered a 'rule of thumb' limit to acceptable energy extraction in this case. Further studies by RGU (Couch & Bryden, 2004), however, suggest that up to 50% extraction could be possible in areas where the flow has more freedom within its elevation boundary conditions without significant effect. Such modelling is theoretical and requires validation against physical experiments.

The approach adopted by the Pentland Firth study was on a 'farm' resource analysis and therefore was therefore based on the number of turbines that could be used within a given area, consequently basing the resource estimate on the whole of the natural flow within the area, not accounting for energy reduction. Further analysis using the 'flux' approach would be required to gain a more realistic estimate of the Pentland Firth resource, but modelling this is out-with the scope of this thesis. However, if the 'rule of thumb' figures of 10% and 50% stated above are used then more realistic estimates of the potential resource in the Pentland Firth could be

8.21TW/h and 41.06TW/h per year respectively. Though these estimates are significantly lower than those described in **Appendix 3**, the Pentland Firth is still a potentially significant contender for tidal current energy generation.

Through the research conducted by Black and Veatch (2005), a 'Significance Impact Factor' (SIF) was developed. The SIF represents the percentage of the total resource at a site that could be extracted without significant economic or environmental effects. The 'available resource' (resource that is likely to be technically available prior to the imposition of more practical constraints) is therefore defined as the product of the 'total resource' and the SIF. The SIF is thought to vary with different types of site and it has been suggested that an indicative 20% SIF for all sites would result in an upper limit for 'available resource'.

2.1.2 Potential Tidal Current Energy Locations

Worldwide

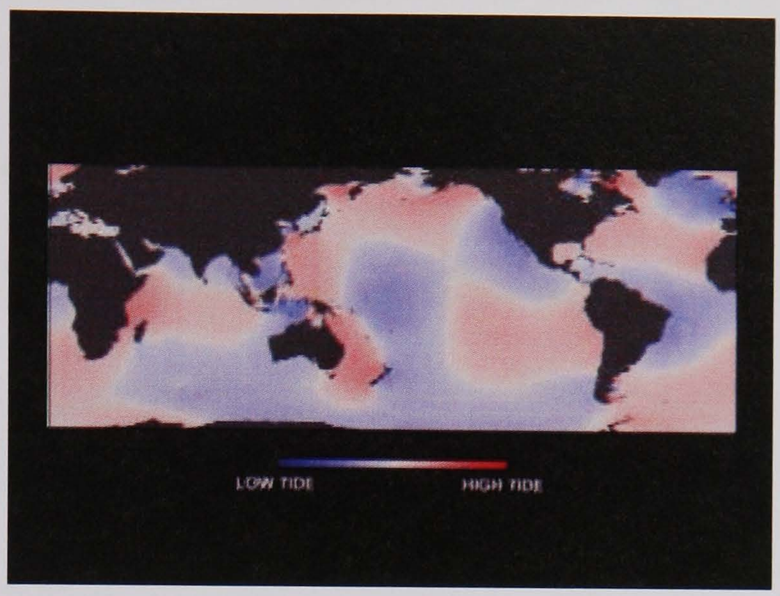


Figure 3: World-wide High and Low Tide (Source: NASA)

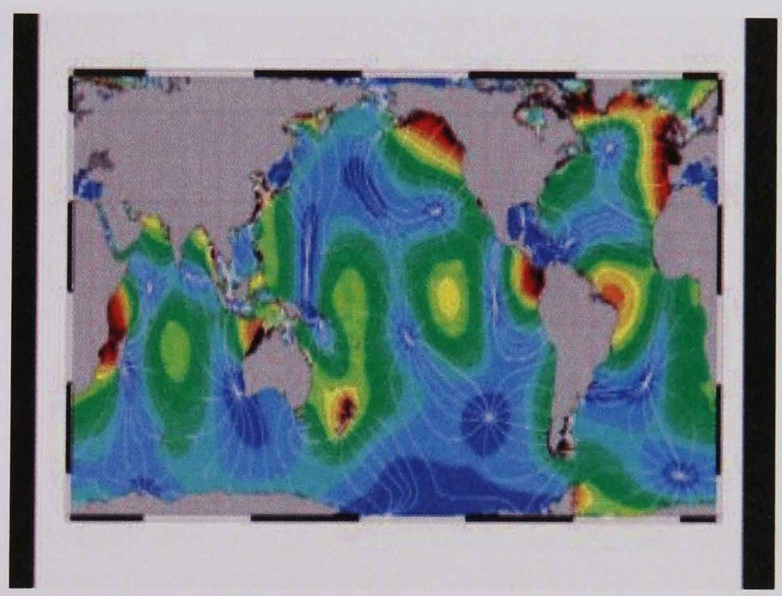


Figure 4: Typical High Current Velocity Areas (Source: NASA)

The predictability of tidal stream currents is also an advantageous factor when considering exploitation. Throughout the world there are significant areas of high and low tidal level (**Figure 3**), in addition to areas of high tidal velocity, which usually occur along coastal regions where water depth decreases, where islands have formed and where there are straits and narrows. **Figure 4** shows (in red) some typical high current velocity areas throughout the world. Locations with high potential have been highlighted in China (with a potential 7000 MW available), the Philippines, Japan, Australia, Northern Africa and South America, as well as Canada and some areas in North America. As yet, few studies have been carried out to determine the global marine current resource, however, Isaacs and Seymour (1973) estimated the total power of ocean current to be 5TW, though this figure is generally unrealistic if you take into account practical constraints and issues of harnessing such energy. Other estimates have brought the figure down to 450 MW (WEC, 2002), but again this figure is also unrealistic in today's terms, where estimates are in the order of 3000GW, though it is estimated that only 3% of available energy is located in areas suitable for power generation (Douglas Westwood Ltd.,2002). Other sources have also estimated the global resource of tidal current energy, including 'Blue Energy', a Canadian based development team and the 'Green Energy Study for British Columbia (Triton Consultants, 2002). Despite this there is a huge power potential throughout the world. **Appendix 3** and **Table 5** compares specific sites throughout the world.

Table 5: Comparison of Power Density over 1 Km^2 for Key Locations Worldwide

Location	Max Velocity (m/s)	Energy Capacity (MW)	TW/h per Year
Pentland Firth, Scotland	8	1067.88	9.35
Yell Sound, Scotland	2.57	35.4	0.31
Blue Mull Sound, Scotland	3.08	60.94	0.53
Straits of Gibraltar	3.6	97.31	0.85
Torres Strait, Australia	3.6	97.31	0.85
Naruto, Japan	4.63	207.01	1.81
Seymour Narrows, Canada	7.2	778.48	6.8
Active Pass, Canada	3.08	60.94	0.53
Deception Pass, USA	4.11	144.80	1.26

Europe

In Europe, marine currents are of special interest within the UK, Ireland, Norway, Greece, France and Italy. Within these countries a total of 106 promising sites have been identified and it has been estimated that using present day technology these sites could supply 48 TWh/y to the European electrical network (Boud, 2002). Locations include sites with respect to the inland fjords of Norway, the Bosporus (between the Black Sea and the Mediterranean), some of the narrows between the Greek Islands, the Baltic Sea and the Straits of Gibraltar.

Scotland and the UK

It has been reported that sites around the UK have current velocities between 1.75 m s^{-1} and 5.25 m s^{-1} (approx. 3.4 - 10.4 knots) and a total of 25 sites were potentially identified with a combined energy output of 58 TWh/y (ETSU, 1993) (**Figure 5**). The CEC (1996) report identified a total of 42 UK sites with a combined annual output of 31 TWh/y. Sites included, Shetland, The Pentland Firth, the Orkney Isles, West Coast, Galloway and Wigtown (Scotland); Rathlin (N.Ireland); Cornwall, the Bristol Channel and Portland Bill (England), the Channel

Islands and the Menai Straits (Wales). The Pentland Firth together with the Orkneys and the Channel Islands were estimated to contain 70% of the total resource, while Galloway, Wigtown and Rathlin is reported to contain approximately 15%. Both reports, however, outline their potential sites with respect to different conditions. For example, the ETSU report excludes sites with water depths less than 20m and 70% of the ETSU report output was from sites with a water depth greater than 50m (60% for the CEC report) (DTI, 2001). In a 2004 study by Robert Gordon University for the Marine Energy Group (MEG) of the Forum for Renewable Energy Development in Scotland (FREDS), estimates were made for key areas of interest within the SEA study area. Estimates for the Pentland Firth ranged from 101GW/h for 2005 and 4,827 GW/h for 2020 (SE, 2006a).

With respect to the studies conducted by Dacre & Bullen (2001) and Dacre (2002) many potential sites have been highlighted within Scotland. Probably the most promising site highlighted is that of the Pentland Firth which is situated between the north of Scotland and the Orkney Isles. A study looking at the feasibility of tidal development in the Pentland Firth was conducted using present technology (developed by MCT Ltd.).

Figure 5: Map Showing Potential Tidal Current Energy Sites in the UK and Northern Europe.

Initially, it has been calculated that electricity could be generated with a rated capacity of 350 MW to 2 GW, which is the equivalent of approximately 3 TW/h and 17 TW/h per annum respectively (Dacre and Bullen, 2001). These calculations were generated using maximum and minimum depth constraints. Calculations conducted for the Dacre (2002) study far exceeds these figures; however, such figures have no constraints applied and are therefore the absolute maximum that could be generated. For example, the energy capacity for the area of the Pentland Firth reached 82 TW/h calculated from an average current velocity of 4.5m/s. **Table 6** and **7** summarises other potential key areas in Scotland.

When compared to recent tidal energy resource studies, this estimate is unrealistic. The Black and Veatch Pentland Firth estimate using flux methodology with a SIF of 20%, updated site parameters is 8.9TWh/y. These results also compare to some initial RGU results, that estimate 7TWh/y (Black and Veatch, 2005).

Table 6: Potential Areas in Scotland and Northern Ireland for Tidal Current Energy Generation

Location	Velocity (m/s)	Installed Capacity (MW)	TW/h per Year
Pentland Firth	4.5	9374	82
Hoy Sound	2.57	59	0.52
Westray Firth	2.3	570	5
Rathlin Island	3.08	2468	21
Mull of Kintyre	2.05	303	2.65
Yell Sound, Shetland	2.57	12	0.11
Total		**12786**	**111.28**

Table 7: Other Potential Sites in Scotland and Northern Ireland for Tidal Current Generation. [Figures are calculated using 125 devices only]

Location	Velocity (m/s)	Installed Capacity (MW)	TW/h per Year
North Fair Isle	2	16.68	0.14
Firth of Lorn	2	16.68	0.14
East Lewis	2	16.68	0.14
Fall of Warnes	3.34	77.71	0.68
Strangford Narrows	3.6	97.31	0.85
Mull of Galloway	3.08	60.94	0.53
Sound of Islay	2.37	35.40	0.31
Blue Mull Sound, Orkney	3.08	60.94	0.53
Total		**382.34**	**3.32**

2.2 Research Development and Industry Status

2.2.1 Historical Perspective

Tidal power is one of the earliest forms of renewable energy exploited by man and records indicate that before AD 1100 tide mills were operating along the coasts of the UK, France and Spain. Charlier in his book 'Tidal Energy' (1982), along with more recent publications (King, 1997; Charlier, 1997; Charlier & Menanteau, 1997 and Charlier, 2003) accounts the history of such exploitation in detail. Widely used for many centuries, tide mills and other forms of renewable energy were gradually displaced by the cheaper and more convenient fossil fuels, such as coal, oil and gas. Nonetheless, the concept of tidal energy has long since enticed inventors and engineers over the past 150 years (Johannsson, 1993).

There are two main forms of tidal power generation systems, but it has generally been the perception that tidal power consists of large barrage schemes. Tidal barrage schemes operate in a similar way to hydropower by trapping water behind a barrage across the mouth of an estuary or strait and using the head difference (tidal range) as the tide changes to produce energy. There are four types of system, which are available: ebb generation, flood generation, two-way generation and multiple basin schemes. At present there are a number of schemes operating, which include La Rance, France (240 MW_p[1]), Annapolis Royal, Canada (18 MW_p) and Murmansk, Russia (0.4 MW_p). Other projects and developments include Hoengg, Switzerland (1.5 MW), Weinzodl (8.4 MW) and Vienna (5 MW), Austria and Jebel Aulia Dam (30 MW), Sudan. Turbine manufacturers presently active include Sulzer Esher Wyss STRAFLO®, HydroMATRIX, EAML Engineering Co. and ALSTOM (SEDO, 2001). Such schemes however carry very high capital costs and potential environmental impact, reason enough to prevent the implementation of schemes in the UK, despite over 100 feasibility studies having been undertaken ranging from power outputs of 20 to 20,000 MW. Detailed feasibility studies carried out between 1983 and 1991 include Loughor, Conway, Wyre, Dunddon and the Severn Estuary (ETSU, 1989).

The use of energy created through tidal current velocity represents an alternative resource. The UK Department of Energy (Den) at the 1981 UN Conference on New and Renewable Sources of Energy (Nairobi), selected wind and tidal current energy as those most likely to provide a substantial contribution to UK electricity generation by the early 21st century (Taylor, 1983).

[1] MW_p denotes 'peak output in MW'

2.2.2 Research and Development

Previous R&D Status Reports and Reviews

There have been a number of studies and reports conducted to evaluate and review the status of tidal current technology and assess future research and development needs. Key past studies include an early study conducted by ETSU (ETSU, 1993) and the CENEX study (CEC, 1996). Since 1996 a number of other publications have been published (DTI, 1999; DTI, 2000; DTI, 2001; DTI, 2001b; STC, 2001; and SE, 2001), of which the publication "The Commercial Prospects for Tidal Stream Power" by Binnie, Black & Veatch (BVV) in association with IT Power Ltd. (DTI, 2001) is probably the most authoritative. Reports prepared by AEA Technology plc (Boud, 2002) for the International Energy Agency and Scottish Enterprise (SEn, 2005) are at present the most recent, but with respect to technology status do not actually supersede previous work, though future research and development needs are expressed in a little more detail, including procurement and supply chain strategies. With reference to these publications, reports and the addition of further 'desk-top' research, a summary of the technological status of tidal current energy and its research and development can be ascertained.

Review of Existing Technology

There have been several types of tidal current energy mechanisms proposed for enhancing tidal currents for the generation of electricity and there are some at present that are currently under development either at an experimental or prototype stage. At present it is clear that devices do work, but a 'best option' has yet to be identified (DTI, 2001b). As the development of technology progresses, however, the selection of technology may in time become site specific taking into account environmental characteristics and design criteria, enabling the matching of technology to site specific environments.

At present there are two forms of tidal current system: those that are associated with tidal fences (designed to operate in the open sea with the aid of a 'blocking' structure) and those that are free-stream and can operate on an individual or group basis (modular). Most systems under research and development are modular concepts (**Table 8**).

Tidal fences usually consist of vertical mounted blades within a structure that blocks and guides the flow towards the blades and therefore have very similar environmental constraints and impacts to tidal barrage systems. Blue Energy, Canada and Tidal Electric Ltd are probably the only two companies involved in this type of exploitation and aims to make such schemes commercially viable by using a Darrieus turbine – at present its cost effectiveness has yet to be proven (*Sink or Swim*, 1998; Elliott, 2000).

Tidal Electric Inc[2]., USA are also researching similar technology using the concept of a circular dam located offshore and using low-head hydroelectric generation equipment (Ullman, 2002).

Table 8: Tidal Current Energy Concepts

Tidal Fence Concepts	Modular Concepts	
Tidal Electric Ltd 'tidal fence' Blue Energy Ltd 'tidal lagoon'	MCT Ltd Seaflow MCT Ltd Seagen EB Stingray Lunar Energy concept Aquamedies J A Consult concept Cycloidal system SMD Hydrovision, TidEl Hammerfest Strom, Blue Concept Tidal Generation Ltd. concept RTVL/SSE (Neptune) Scotrenewables Statkraft Tidal Hydraulic Generators Sea Power Group	Hydroventuri Gentec Venturi POLO Underwater Kite EXIM Helical Turbine Open-centred turbine Verdant concept Hydrohelix concept Oceantecs, Mermade Kinetic Energy Systems WWTurbine Subsea Energy (Scotland) Underwater Electric Kite Tidal Sail

Tidal current schemes using 'free-stream' tidal turbines on the other-hand are thought, by some, to have lower environmental impact and lower capital costs as they require less material to build and deploy and they also have less technical complexities.

Since 1979, much research has gone into the development of tidal current energy technology, primarily by the efforts of Peter Fraenkel, the founder of the recent Marine Current Turbines Ltd. (MCT Ltd.). At the time working for IT Power Ltd., Fraenkel, along with Peter Musgrove (Reading University), believed that the most straight forward system would be that of an underwater equivalent of a windmill, using a vertical axis rotor (Taylor, 1983). In an article reported in the New Scientist (Webb, 1993), David Wardle of Engineering and Power Development and Peter Fraenkel (IT Power Ltd.) explained that tidal current power was a 'long term possibility', however admitted it could be a number of years before such technology would make a significant contribution. A decade on, the research, development and commercial viability of tidal current technology has progressed considerably.

Tidal current energy devices can be described mainly in two parts: the support structure and the mechanism that extracts the energy from the currents, which in most cases is known as the turbine, but other mechanisms do exist.

The support structure is designed to keep the turbine stable with respect to the seabed and its navigational position. Crucially, it is the integrity of the support structure and its mooring that

[2] www.tidalelectric.com

governs the life and security of the tidal current energy system. A number of support structure types have been developed and considered. These include, floating, semi-submersible and fixed mounted structures (**Appendix 4, 5, 6 and 7**). At present research is underway to develop a support device that has no depth or installation restrictions at the Robert Gordon University. A recent paper describes and compares support structure technology, concluding that there is not one concept which clearly surpasses the others in all areas. Different devices are suited to different financial models and environmental conditions. Consequently it is likely that a number of device concepts will succeed in the industry (Orme and Masters, 2006).

A majority of tidal current energy devices that have been proposed are very similar to that of wind energy devices, however, the characteristics of such turbines are varied and there are various rotor options that have been considered. These include axial (horizontal), Darrieus (vertical), Savonius, Panomones and Helical (Gorlov & Rogers, 1997) (**Appendix 4, 6 and 7**). The Active Column Water Generator (AWCG) and 'Stingray' type mechanisms developed by The Engineering business are different to that of conventional type turbines. In order to extract energy from the tidal currents hydroplanes are used, however, they are nonetheless effective mechanisms for extracting energy (Watchorn, 2000; EB 2002a; EB 2002b; Trap 2002; Trap & Watchorn, 2001). Each rotor type may include different configurations, such as single, twin or multiple rotors: fixed or variable rotor speed or fixed or variable pitch rotor blades. Devices are also being explored which use augmentors or that are ducted to create a funnelling effect, thereby concentrating the energy and increasing tidal velocity flow through the rotor, thus in theory harnessing more energy capture from the tidal currents themselves (Meade, 2002; Ponta & Dutt, 2000).

Research and development is a continuous process within all aspects of tidal current energy technology to reduce concept uncertainties with respect to long-term reliability and efficiency, installation and support structure techniques, device spacing, electrical connection issues and non-technical issues, such as environmental impact and resource availability.

With the establishment of the European Marine Energy Centre (EMEC)[3] in Orkney, the importance of research and development within the marine energy sector has been driven forward, where the process of marine energy devices from the prototype stage into the commercial market place becomes a closer prospect. The centre is the first of its kind to be developed anywhere in the world. It provides an opportunity for developers to test prototype devices in intense tidal conditions. To date, Government and other public sector organisations have invested around £15 million in the creation of the centre and its two marine laboratories.

[3] www.emec.org.uk

The New and Renewable Energy Centre (NaREC)[4] is an organisation that has been set up to bring substantial benefits to the UK's new and renewable energy industry. NaREC is a Centre of Excellence, fast-tracking concept evaluation, feasibility studies and prototype evaluation and testing through to early commercialization and is another indication of the facilities available to tidal current energy developers.

Table 9 (pp. 69) summarises the key developers and concepts available at this present time. **Appendix 8** summarises the technological development and research, highlighting the continued and growing interest in this concept of renewable energy.

[4] www.narec.co.uk

2.2.3 Industry Status

There is a wide combination of support structures and rotor type configurations, and in the early stages of the thesis, the most advanced devices and significant market contenders are those proposed and recommended by MCT Ltd. (UK), The Engineering Business Ltd. (UK) and Hammerfest Strom AK (Norway). However, recently proposed concepts by Lunar Energy Ltd. and Renewable Technology Ventures Ltd. have also become market contenders.

Marine Current Turbines Ltd., UK[5]

Originally the MCT Ltd. concept developed by Peter Fraenkel was a single axial flow turbine rotor on a mono-pile, where the rotor and power train could be raised above sea level for maintenance was proposed. However, further studies by MCT Ltd. indicated that it would be more cost effective to install two turbine rotors on each pile rather than a single rotor with the same capacity (Figure 1). The Binnie, Black and Veatch independent review (DTI, 2001) discusses this concept in more detail. A demonstration project 'Seaflow' (300kW) at Lynmouth, North Devon is underway. The demonstration project has performed better than expected so far, reaching its 300kW rated power, and consistently providing a rotor efficiency of 40% or more. The energy capture has also been 25% better than anticipated. MCT Ltd. is also in the progress of launching a programme to develop a successor to 'Seaflow', called 'SeaGen', which will consist of an array of 12 grid connected twin rotor devices – the next stage towards the development of a commercial tidal current turbine (**Figures 6 and 7**)(International Ocean Systems, 2004).

Figure 6: MCT Ltd. 'Seaflow' Demonstration Device, Lynmouth, Devon.

[5] www.marineturbines.com

MCT Limited currently has plans to install another full scale tidal current turbine in April 2006 in the Strangford Lough Narrows, Ireland. It is hoped the system will be installed for the duration of between two and five years before being decommissioned (MCT, 2005).

In addition, MCT Ltd. is also investigating the potential for a commercial tidal energy farm in waters off the Anglesey coastline. MCT Ltd. expects to complete an initial consultation period by October 2006 and begin a comprehensive Environmental Impact Assessment (EIA), offshore and onshore, thereafter. It is expected that the EIA could take up to 10 months to complete whilst consultations with interested parties will be on-going. Once the EIA has been completed, MCT will determine whether or not the waters off Anglesey are a suitable location for an array and whether the necessary consents should be sought. Subject to planning approval and financing, a tidal array could be operational by 2009.

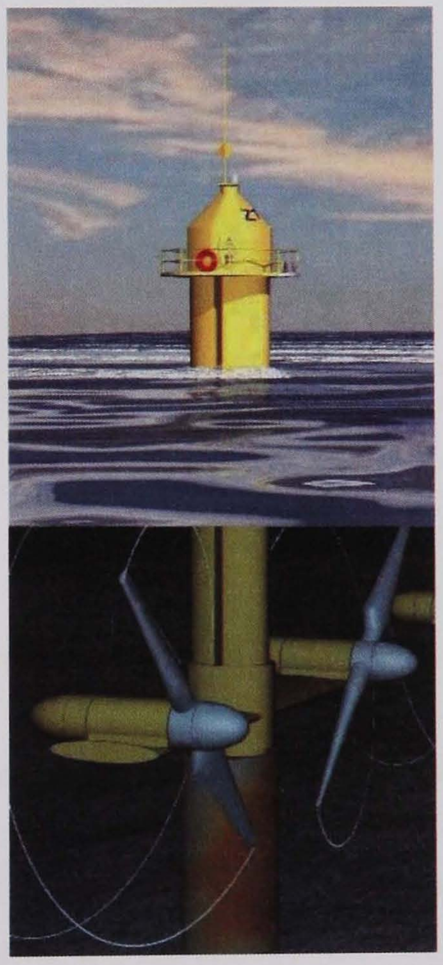


Figure 7: Artists impression of the MCT Ltd. Concept - two-turbine rotor on a monopole, known as SeaGen.

The Engineering Business Ltd., UK[6].

Phase 1 of The Engineering Business 'Stingray' project demonstrated that the concept is technically robust, commercially viable and cost-comparable with other tidal current systems. It has also become apparent that further validation of mathematical, physical and cost models is

[6] www.engb.com

required for further clarification of Stingray's capabilities and a demonstration device was the next logical step (DTI, 2002).

The Engineering Business's 'Stingray' is now at the demonstration stage and a device has been deployed in the Yell Sound, Shetland (**Figure 8**). 'Stingray' is a simple concept consisting of a hydroplane which has its attack angle relative to the approaching water stream varied by a simple mechanism. This causes a supporting arm to oscillate which in turn forces hydraulic cylinders to extend and retract. This produces high- pressure oil that is used to drive a generator (EB, 2002c).

Figure 8: Artists Impression of the Engineering Business Concept - 'Stingray'

The 150kW Stingray system was successfully demonstrated in Yell Sound of 2002. A report, discussing phase 3 of the development of Stingray concluded that technology is technically viable for the generation of electricity at a potentially commercially viable unit energy cost and that many viable sites exist for the technology (DTI, 2005). However, further development of the system has been put on hold. The difficult decision is not a result of technical issues, but that of economics. To ensure the profitability of 'The Engineering Business', the application of skills to projects that will ensure the long viability of the company is paramount and the further development of Stingray is at present commercially unattractive. Despite the significant support from the DTI, NaREC and Shetland, the timescales and investment involved in taking Stingray to commerciality much investment is required and The Engineering Business cannot continue to sustain the project on a non-profit basis (DTI, 2005; EB, 2005). However, if adequate funding becomes available, the development of the 'Stingray' project may recommence.

Subsea Energy (Scotland) Limited[7]

Subsea Energy is a relatively new company within the tidal current energy sector and have only been active since 2003/04. At present, the company are in the process of developing a 'novel' tidal current turbine, which utilises existing North Sea oil industry equipment and skills. It is anticipated that prototypes will be progressed over the next 2 to 3 years.

The "Aquamedies" concept has been developed to operate in rivers, estuaries and offshore tidal zones. It is a modular system and basically comprises selected components from existing subsea well technology, which includes an anchor module, a subsea alternator module and a rotor module, using a helical-shaped rotor blade similar to the Gorlov design. Over the next few years, Subsea Energy is hoping to finalise design and gain sea-test permissions at EMEC, Orkney in the view of developing a full-scale prototype (Morse, 2004).

Lunar Energy Limited[8]

Since 2003, Lunar Energy Ltd. in conjunction with Rotech Engineering Ltd. has been working on a marine renewable energy concept. With use of a ducted turbine it fell within the type of concepts already prominent within tidal current energy industry research and development. An environmental scoping study was commissioned by the company, despite its developmental infancy (Dacre, 2003). Continued research development has aided the progression of the technology and in early 2005, a grant was awarded from the DTI to help further develop the 'Rotech Tidal Turbine' (RTT), which uses an innovative duct system to extract maximum power from tidal flows. A 1MW prototype is due to be commissioned at the European Marine Energy Centre (EMEC), Orkney in early 2006. If testing is successful, the next step will be to progress to larger pre-commercial deployments (GNN, 2005) and it is anticipated that a Lunar RTT 5000 system will be commercially operated by 2008 (Lunar Energy Ltd., 2004). Lunar Energy Ltd. and Rotech have just secured backing from the german engineering group, Bosch for its 1MW prototype (Gow, 2006).

The Rotech Tidal Turbine (RTT) comprises a ducted rotor which extracts the tidal-flow energy to drive hydraulic pumps and motors, which will use environmentally benign hydraulic fluids. A generator housed within the subsea unit is then activated. As well as obviating the need for a conventional mechanical gearbox, the use of hydraulics (technology transfer from other marine sectors) allows all the electrical components to be located in an airtight chamber with no rotary seals, which enables extended periods between servicing.

[7] www.sub-seaenergy.com

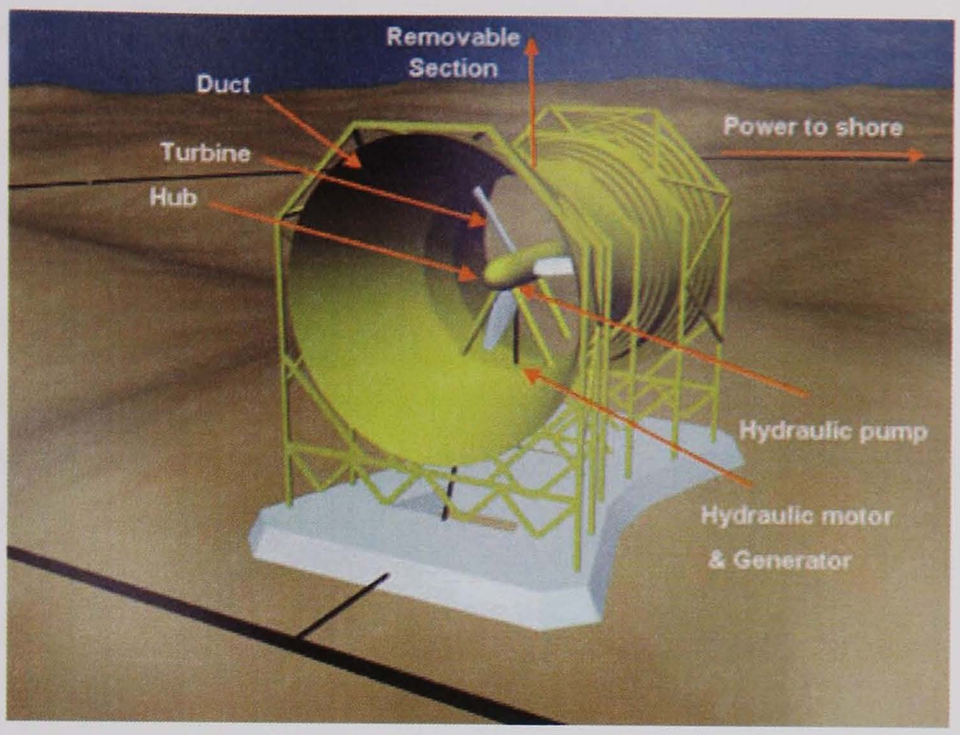


Figure 9: Lunar RTT 1500

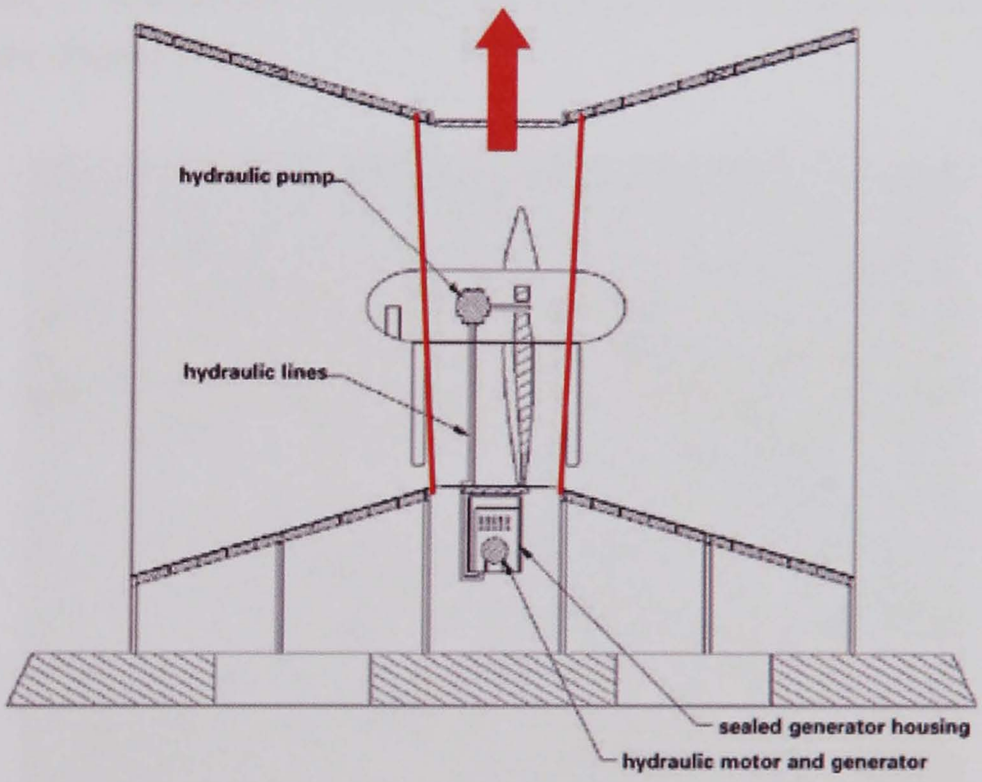


Figure 10: Schematic representation of the Lunar RTT

The ducted rotor is bi-directional and the turbine blades are symmetrical. In-sensitive to off-turbine axis flows of at least 40 degrees, the duct removes the need for a complicated yawing mechanism to rotate the device as the tide turns, thereby allowing the device to be positioned directly into the flow. As a consequence, Lunar Energy maintain that by using a ducted turbine, expensive design, construction and maintenance is mitigated. It is also thought to remove the need for blade pitch control. The venturi shaped duct accelerates the fluid through the turbine, increasing the energy that can be captured by turbine blades of a given diameter. This keeps the size, and hence manufacturing and operation and maintenance costs, of the complex

[8] http://www.lunarenergy.co.uk

moving components to a minimum. The use of a duct also ensures that the fluid always flows perpendicularly through the turbine itself, unlike an un-ducted turbine where the fluid passes through the turbine at whichever angle the turbine is presented to the flow. In 'straightening' the flow, the use of a duct ensures that the turbine operates at its most optimum efficiency in all flow conditions. The duct is also said to have another benefit in that it protects the tips of the blades of the centrally mounted turbine.

Furthermore, the duct offers greater augmentation of power during off-turbine axis flows. It has been proven that the power actually increases as the flow moves away from the turbine axis, peaking at around 25 degrees angle-off.

J A Consult, UK

The system developed by J A Consult is a semi-submersible concept that is considered to have the potential for energy capture in deep water tidal streams with relative insensitivity to severe sea states. . A detailed description of the system can be found in J A Consult (2004). The concept is based on downstream rotors that are tethered by a swing-arm and supported by a buoyant structure (**Figure 11**).

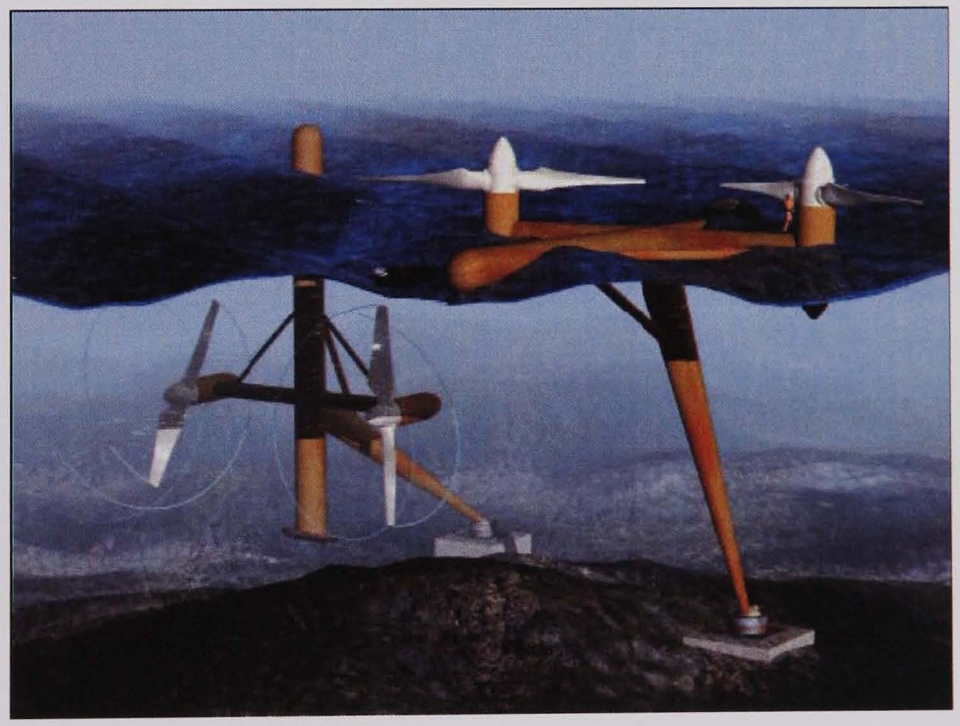


Figure 11: Artists impression of Potential 500 kW Turbines (J A Consult, 2004)

The arrangement in **Figure 11** shows two 14m diameter contra-rotating twin turbines, together rated at about 500kW and operating in 30m water depths. The turbine on the left is operating downstream of its seabed anchor, supported by an air-filled vertical spar buoy. The blades are stall-regulated, avoiding the complexity and cost of pitch systems. The turbine is free to pitch, yaw and roll as the water stream changes in speed, direction and turbulence. Stability is ensured by the righting tendencies of the spar buoy. As the tide changes direction, the turbine swings through 180 degrees, using deflectors that ensure the grid connection cable tends to unwind.

The second turbine (to the right) has been raised to its maintenance position. This is done by pumping air into the spar buoy so that it lifts the turbine up out of the water, flipping it on to its back so that the rotors are pushed up above sea level where they can be inspected and maintained. After maintenance, the spar buoy is partially flooded so that the rotors return to their operating position. This is also the procedure adopted for float-out installation and removal of the turbines.

J A Consult envisage the system being deployed in deeper waters, such as in the 60 – 80m water depths of the Pentland Firth. It is understood that multiple rotors will be needed to maximise energy capture while keeping blade size within reasonable limits. **Figure 12** demonstrates what such a 2.5 MW turbine might look like, with an equivalent rated wind turbine (the largest currently in production) alongside for comparison.

Figure 12: J A Consult concept compared with a wind energy turbine.

A study was conducted in 2004 to demonstrate the practicality of this concept by monitoring, operating and assessing a 1.5m diameter river turbine in the river Thames off Chiswick Pier in West London (**Figure 12**).

After a successful study, J A consult anticipate that further research and development will continue.

Figure 13: Initial J A Consult model for the Thames test

SMD Hydrovision, UK[9]

TidEl is the result of 30 months of development to produce a reliable method of capturing tidal current energy. Hydrovision, are confident that the device:

- is economical to install, operate and decommission.
- requires no support structure
- generates electricity at prices comparable with wind power

Drawing on over 30 years of underwater vehicle innovation, the device is completely novel in that it floats and is submerged and restrained to the seabed using a mooring arrangement. As the potentially damaging effects of large waves pass overhead with little impact on the performance of the generator, the system is designed for the typical loads rather than the storm loads; saving on weight, size and of course cost.

The generator is free to move in line with the direction of the tide, and this enables the device to follow the tide backwards and forwards as it changes direction twice a day, without the need for additional controls to re-orientate it.

A 1:10 scale scale system partly funded by the DTI has successfully completed a seven week trial program at the New and Renewable Energy Centre (NaREC) in Blyth. Extensive offshore testing is being has been carried out in hope that the system would be ready for commercial use by the end of 2006.

[9] http://www.smdhydrovision.com/

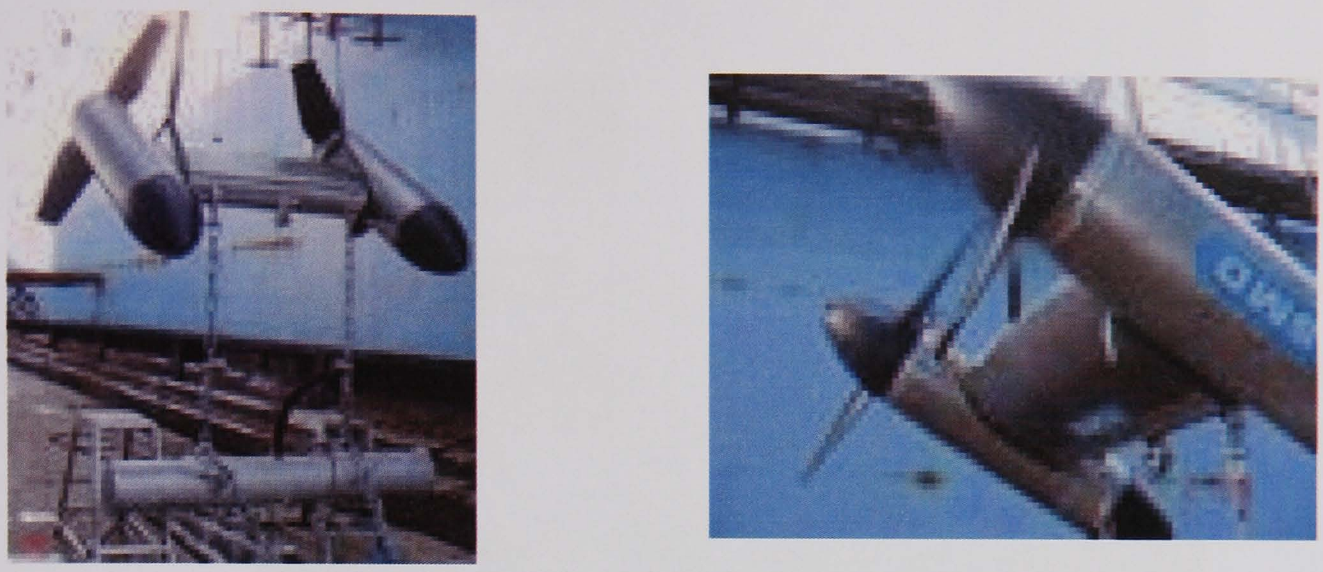


Figure 14: SMD Hydrovision TidEl Concept.

Hammerfest Strom AK., Norway.[10]

Hammerfest Strom AK installed an axial type turbine, known as 'The Blue Concept' in the Norwegian Strait of Kvalsundet, near Kvalsund (Hammerfest Strom, 2002). The concept is not dissimilar to the MCT Ltd. design (Figure 6 and 7). The predominant design is that of 2 or 3 blades with pitch control mechanisms. The concept has an installed capacity of 300kw, with an estimated energy output of 0.7GWh per year. A proposed 20-device tidal current power project in the Strait of Kvalsundet is estimated to deliver 32GWh per year.

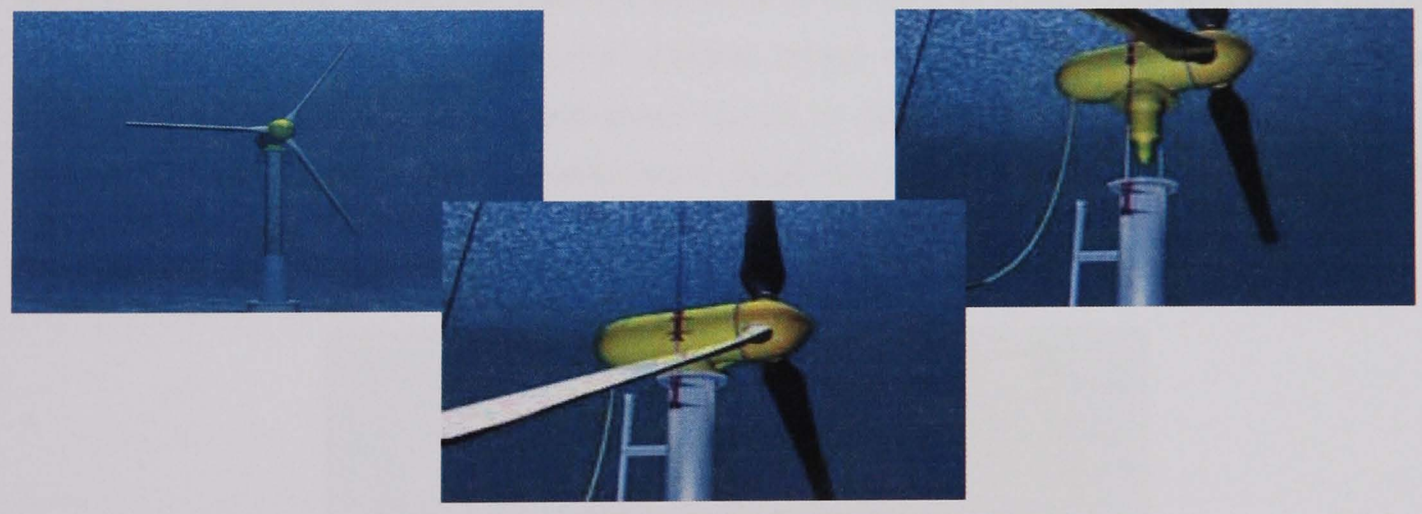


Figure 15: 'The Blue Concept', Hammerfest Strom AK. [Source: Hammerfest Strom, 2002]

10 www.e-tidevannsenergi.com

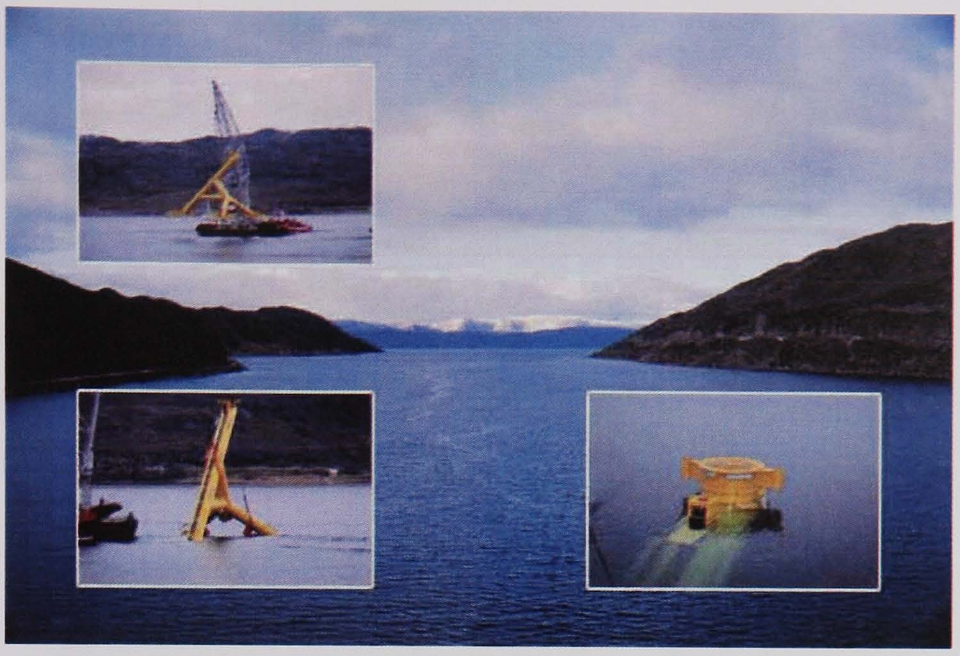


Figure 16: Installation of the monopile structure for the 'The Blue Concept', Kvalsundet, Norway. [Source: Hammerfest Strom, 2002]

Oceantecs, UK[11].

Oceantecs provide offshore service solutions to the submarine cable and oil and gas industries, but are currently researching and developing a tidal current turbine, 'Mermade'. One of 'Mermades' characteristics is its ability to be mounted both vertically and horizontally, with little or no effect on performance. It is also suitable for shallow waters and can be utilised in the open sea, rivers and lakes, where sufficient water flow is generated. Another potential advantage is that the 'Mermade' has the potential to be used in conjunction with other offshore or subsurface structures, such as wind turbines, bridge supports, jacket legs etc. It is also a modular system, capable as a stand alone device or forming an array of many devices. At present, the 'Mermade' is still in development stage, but a scale model is currently undergoing dry and wet testing.

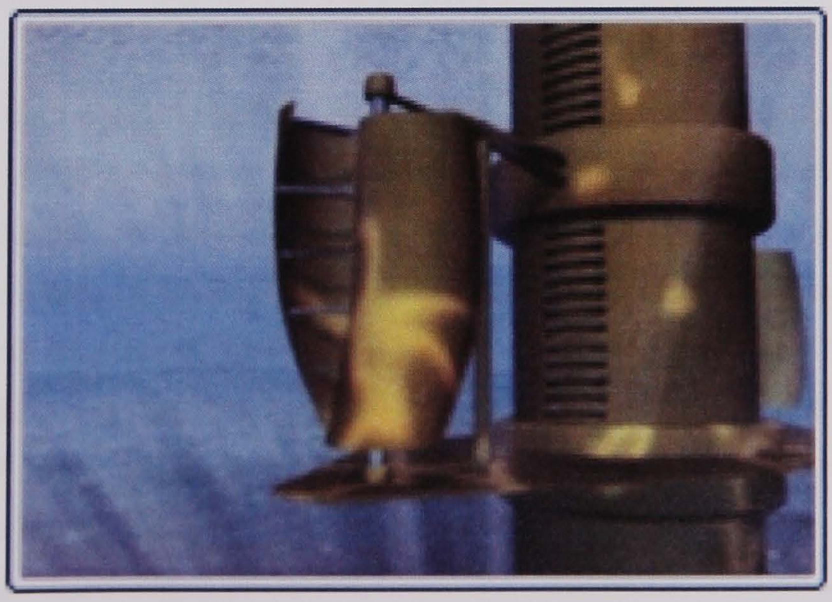


Figure 17: Mermade Concept

Tidal Hydraulic Generators Limited, UK[12]

Tidal Hydraulic Generators Ltd (THGL) have developed a turbine system to convert the tidal flow of sea water into 'industrial' energy. The system has been primarily designed to generate electricity.

An axial-type prototype has been successfully tested in the Cleddau estuary with plans to build a 3.5MW turbine system for the Ramsey Sound in Pembrokeshire, Wales. The Ramsey Sound is 45 – 60m deep and has a 3m/s (6 knot) maximum flow.

Figure 18: Artists impression of the THGL Concept

HydroVenturi Limited (formerly known as RVco Ltd.), UK and Canada[13]

Venturi (Rochester Venturi) reflects the founder of the system and the principles governing the approach. By accelerating tidal water flow through a choke (venturi), Bernoulli's principle dictates that the water pressure within the venturi becomes lower than ambient. The resulting pressure gradient is then harnessed to drive a conventional turbine.

The technique is said to concentrate the low-density energy in tidal currents into a more rapid flow of a smaller quantity of water to the shore (**Figure 19**). HydroVenturi have claimed to maintain 24% efficiency. At present little is known about the concept itself, however a demonstration device has been deployed in the Alexander Dock, Grimsby and in the River Humber and has been capable of generating 25kW. According to a report conducted by Triton Consultants Ltd. (2002) the concept is extremely attractive for tidal power extraction in British Columbia. However, there has been little information about the concept available to allow any defendable evaluation to be made.

[11] www.oceantecs.com
[12] www.thglimited.com

Figure 19: 60kW Demonstrator, Alexander Dock, Grimsby [www.hydroventuri.com]

However, more recent news has suggested that plans are being made for a pilot project off San Francisco. The system is planned to be placed adjacent to an existing oil platform in San Pablo Bay. However, lack of investment by potential investors has placed the project on hold (San Francisco Government, 2004).

Tidal Generation Limited[14], UK

Tidal Generation Limited was set up in 2005 by a team that has been involved in the tidal energy industry since its inception. TGL's staff had key roles in the first successful UK tidal turbine project, led by IT Power Limited and installed in 2003.

Tidal Generation Limited (TGL) is developing a 1MW fully submerged tidal turbine (**Figure 20**). On the basis of comprehensive techno-economic modeling, TGL believe their device will generate electricity costing 8-9p/kWh for initial farms, falling to 5-6p when the technology is sufficiently well established for projects to attract competitive interest rates. This is at the lower limit of estimated costs quoted by a recent carbon trust report (Black and Veatch, 2005), using the same basis of calculation, which gave central estimates in the range 12p to 15p kWh.

TGL has a five year technology development programme from prototype through to commercial product. A feasibility phase has been completed, and it has been established that the technology is feasible and has the potential for a significant cost advantage over other offshore marine renewables currently under development.

[13] www.hydroventuri.com
[14] www.tidalgeneration.co.uk

The concept design phase has now commenced, and it is hoped that TGL will be able to confirm the detailed technical feasibility and the cost of the device. This work is being carried out with the aid of a grant from the South West Regional Development Agency.

Once the concept design is complete, the company plan to install a 500 kW prototype at the European Marine Energy Centre in the Orkney Islands, which will provide enough energy to supply 300 homes

Figure 20: TGL Concept – Fully submerged tidal turbine

Scotrenewables[15], UK

The Scotrenewables tidal turbine (SRTT) system is an innovative free-floating rotor-based tidal current energy converter, which has been under development for over three years.

The concept in its present configuration involves dual counter-rotating horizontal-axis rotors driving generators within sub-surface nacelles, each suspended from separate keel and rotor arm sections attached to a single surface-piercing cylindrical buoyancy tube. The device is anchored to the seabed via a yoke arrangement and compliant mooring system. A separate flexible power and control umbilical then connects to a subsea junction box. The rotor arm sections are hinged to allow each two-bladed rotor to be retracted so as to be parallel with the longitudinal axis of the buoyancy tube, giving the system a transport draught of under 4.5m at full-scale to facilitate towing the device into harbours for major maintenance.

The free-floating SRTT combines many of the design principles behind the "Pelamis" wave energy converter currently under development by Ocean Power Delivery (OPD), and much of the existing technology from the wind energy industry. Some of these key principles include a

15 www.scotrenewables.com

focus on survivability, use of existing proven equipment, standardisation of components, off-site maintenance and quick mooring and electrical connection and disconnection using modest vessels.

Swan Turbines[16], UK

Swan Turbines is an 8 partner consortium led by Swansea University. The concept is a gearless axial flow turbine. The gearless low speed generator offers a high efficiency over a range of speeds with minimal maintenance demands through the use of novel structural topologies and the incorporation of an adapted Permanent Magnet Generator (PMG) (Orme and Masters, 2004).

Offshore specialists CB&I John Brown transferred standard offshore technology and operations to form the basis for a new support structure concept. In collaboration with Swansea University, using rotor dynamic modelling, the concept was designed to allow simple installation and maintenance retrieval in both shallow and deep water and to minimise vibrations, hence increasing the maintenance period.

A yawing mechanism is used for maximum flow capture and the use of patented materials, developed by Corus will form the gravity base.

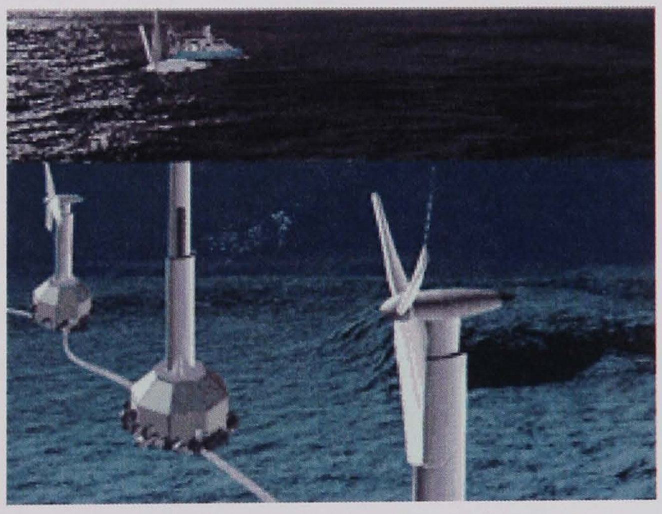


Figure 21: Swan Turbine Concept

Statkraft[17], Norway

Statkraft is in the process of developing and testing a tidal power plant based on a floating, anchored steel structure which will generate electricity via four large turbines driven by marine currents. The turbines and generators will be placed under the water line and can be easily brought to the surface for maintenance. Because it is a floating power plant, Statkraft believe

[16] http://www.swanturbines.co.uk/
[17] www.statkraft.com

there will be no large-scale permanent disturbance to the sea floor, and the project will have minor environmental impact.

In 2004, Hydra Tidal signed an agreement with Statkraft for the joint development and construction of a full-scale demonstration plant – the MORILD project. The main objective of the MORILD project is to demonstrate the technical constraints, functionality and overall efficiency of a full-scale, operational tidal power plant.

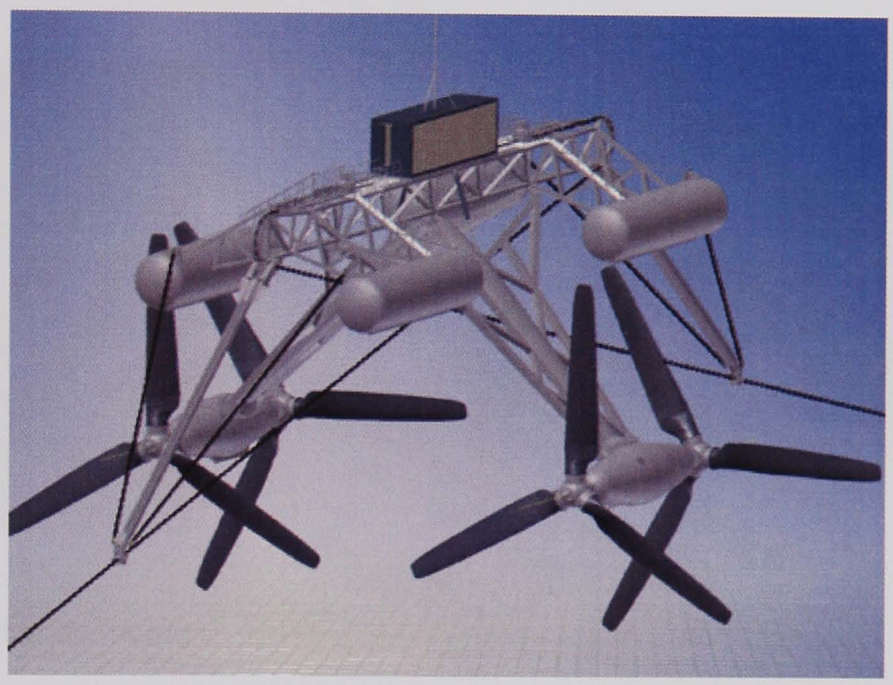


Figure 22: Floating tidal energy device based on the Hydra Tidal design.

Another project objective is to construct, test and operate a working demonstration plant at a representative site in Kvalsundet in Tromsø, Norway. Power output to the grid is estimated to be approximately1 MW/3–5 GWh. The first demonstration device is being designed for minimum risk with regard to structural stress at dimensioning offshore conditions (100-year wave). This plant will establish the basis for optimised engineering, design criteria and further technology improvement on the route to commercialisation and competitive, renewable energy production.

Blue Energy Ltd., Canada[18]

The concept introduced by Blue Energy Ltd. is basically an ultra-low head underwater device. Such a concept can be used in modules or as a 'tidal fence'. It has been claimed that using vertical axis turbines is advantageous due to the fact that the gearbox and electrical system can be placed above the water line. To date six prototypes of the turbine have been built and tested under the National Research Council of Canada. Blue Energy Ltd. proposed planning a prototype demonstration located near the Seymour Narrows. They have also proposed the potential combination of tidal fence power with other structures, such as bridges. Such proposals are interesting issues and may provide cost sharing and cross-discipline advantages

(Triton, 2002; Davis, 1997). Information availability is limited however interests have been noted with a view in developing the concept at Bailiwick, Guernsey to enable the islands to become independent with respect to energy supply. The Guernsey environment department have made no firm commitment and are exploring their energy policy and other device options (Mann, 2004). In addition, the Company has proposed the development of a four-kilometer long tidal fence between the islands of Samar and Dalupiri in the San Bernardino Strait in the Philippines (Blue Energy Ltd., 2006).

Figure 23: Blue Energy Concept: Tidal Fence (Left) and Turbine (Right)

UEK Inc., USA[19]

The UEK Inc. (Underwater Electric Kite) concept is a hydrokinetic energy conversion system that can be installed in a river or marine environment. The concept consists of a self-contained semi-buoyant turbine that is suspended like a 'kite' within a tidal stream. The UEK has a ducted turbine design, enhanced by a flared skirt at the end of the short penstock, called an Augmentor ring. The water flow is deflected outward by the Augmentor ring and creates a low pressure immediately behind the turbine. The core of water directly in front of the short penstock is accelerated and is intercepted by the turbine's blades and discharged into the low pressure at the back of the UEK System. The total flow cross-section reached by the Augmentor ring effect reappears accelerated in front of the turbine. The result is that the existing kinetic energy from the hydraulically affected cross section is converted into electricity. They are more efficient when a number of turbines are used (UEK Corp, 2002; Triton, 2002; www.uekus.com)..

There have been a number of projects within river environments, including the DeQew hydropower plant, St. Catherine, Ontario; Chitokoloki Mission Hospital Project on the Zambezi River, northeast Zambia; and the Puerto Legnizamo y La Tagua demonstration project on the Caqueta River, Amazon Basin, Colombia, South America.

[18] www.bluenergy.com
[19] www.uekus.com

With respect to tidal applications, a site at the Indian River Inlet, Delaware, displays the second fastest tidal water velocity in the eastern coast of the US (over seven knots) and UEK Delaware LP, formed in 2005, plan to develop this project, headed by David Rickard, PE and Philippe Vauthier, General Partners.

The UEK System tidal turbine is designed to operate in both tidal flow directions with the same efficiency as the river turbine's design. The tidal system development is currently underway and is known as the 'Bi-Directional Hydroturbine Assembly for Tidal Deployment'. Ninety percent of the tooling is already manufactured and UEK is ready to build the first unit of this new machine in its Maryland facility. The Delaware Indian river project is at the preliminary permitting stage at the moment. The development will include the installation of a pilot unit for demonstration purposes, followed by the installation of a 25 twin Tidal UEK Systems in the inlet representing an agglomerated installed capacity of 10MW. The twin units have a dimension of 3m in diameter x 6.7m width x 3.5m long and will develop 400kW each in a water velocity of 3.6m/s.

Figure 24: Underwater Electric Kite

Sea Power Group[20]

Sea Power Group started research and development with different renewable energy concepts about 15 years ago. Initially, the company started with wave power concepts, but over the last 8 years the group have been initiating tidal current energy development in the form of the EXIM tidal and stream turbine. Following successful tests at the Ship Design and Research Institute in Gdansk, Poland, a commercial joint venture has been formed on the Shetland Isles together

[20] www.seapower.se

with Delta Marine, Lerwick. In Shetland Island tests, the device delivered 3kW in tidal speeds of around 2.5m/s (Pettersson & Langström, 2003).

Research and development has continued for the Exim device and plans are underway to site a pilot power station in Blue Mull Sound, between the islands of Yell and Unst, Shetland. Manufacturing of the system has already taken place in Lerwick, Shetland. The production target is 160,000kWh/year. However, further tests are being carried out using a workboat to calculate how much power the Exim system potentially could generate. It is anticipated that the pilot project may be connected to the grid at Cullivoe Pier, on Yell, but as yet no information has been released concerning talks with Scottish and Southern Energy, Shetland Islands Council and Shetland Enterprise (Press and Journal, 2005).

The EXIM device consists of a Savonius turbine, mounted under a buoy that is anchored to withstand rotation with the moving current. The bottom part of the turbine is equipped with a weighting mechanism to allow the device to stay vertical.

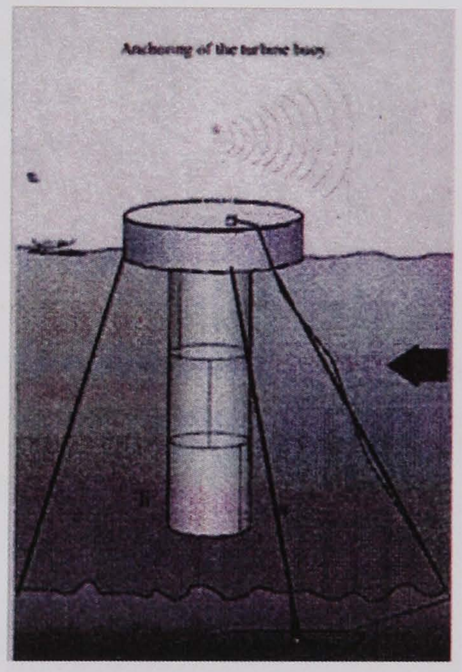


Figure 25: EXIM Tidal Turbine

Tidal Sail AS, Norway[21]

Tidal Sail AS is a relatively new company, based in Norway and working in collaboration with the University of Hertfordshire. The Harmonica Model principle can be compared with a set of vertical blinds under water, which are being pulled from a start to an end station by the tidal current. A 'magazine' at the start station deploys sails at certain intervals; at the same time as the end station 'magazine' is detaching and collecting arriving sails. Huge sails are fixed to long cables under water, which are pulled by the tidal stream, to feed a generator, which in turn produces electricity. Tidal Sail believe that this way of generating electricity is more efficient

[21] www.tidalsails.com

than any other already existing method of generating electricity from tidal stream. All component technologies required to generate electricity using the Harmonica Model are commercially available and well known in established industries.

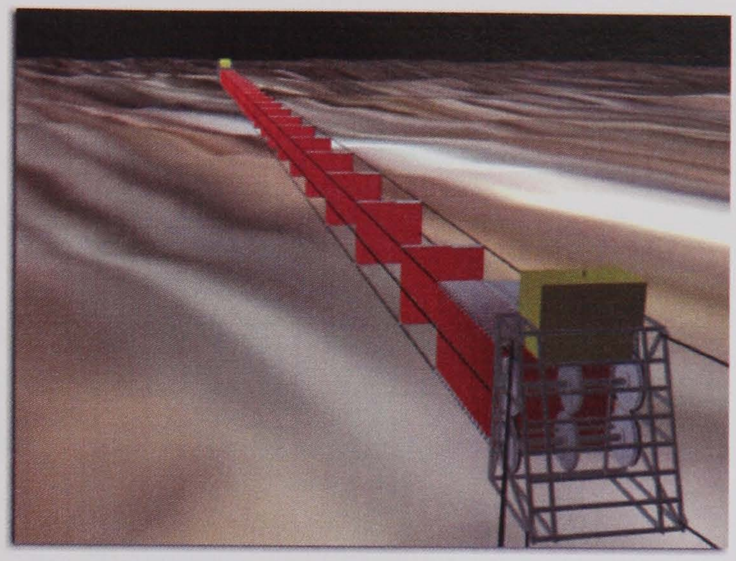


Figure 26: Image of Tidal Sail's Harmonica Concept

The system is expected to extract around 28% of the power within a tidal site. At present, a team from the University of Hertfordshire are using CFD-modelling (Computational Fluid Dynamics) to predict the behaviour of the concept in water.

Tidal Sail AS have already received a Norwegian Patent in May 2006 and completed tank testing at the University of Hertfordshire. It was planned to have a prototype design completed by August 2006. In addition, Tidal Sail AS also have ambitious goals to have grid connected prototype by 2008 and to have commercially available devices within Norway and the UK by 2009 and the USA, Canada and South East Asia from 2010. The company also hopes to have 2 commercial 'farms' in the UK by 2010.

Helical Turbine (Alexander Gorlov)[22]

This rotor was first developed in 1994/95 and is a variation of the Darreius rotor that was originally patented in 1931 (Gorlov and Rogers, 1997). The helical arrangement of the rotor blades eliminates pulsation common to the Darreius rotors, resulting in a faster, more uniform turning in relative slow tidal current velocities. Between 1994/5, 20 small 3.5 inch diameter rotor turbines were demonstrated and tested and proved to have a 50% higher efficiency than the Darreius type rotor (Gorlov and Rogers, 1997). During 1996 another series of demonstrations were conducted in Cape Cod Canal, Massachusetts, where current speeds ranged from 0 to 3.25 knots (1.7 m s^{-1}) and reversed direction at least four times a day. Rotor diameters used were 0.6m in diameter and were supported by pontoon-type structures. At 0.5 m s^{-1} the system was able to produce 4.5 watts of power and at nearly 1 m s^{-1}, 47 watts. At current speeds of 1.4 m s^{-1} 200 watts of power was generated. It must also be noted that power increased expotentially with increased current speed (Gorlov and Rogers, 1997). The power capacity of the helical rotor can easily be increased by adding more helical turbine modules (Gorlov, 1998) and a large-scale project was under research and development to generate power from the Gulf Stream near Florida (EERU, 2003).

GCK Technology, a Texas-based renewable energy company has bought the worldwide rights to the turbine. At present it is in the process of installing a permanent turbine array in the Uldomok Strait off the southwestern coast of South Korea (***See page 65***).

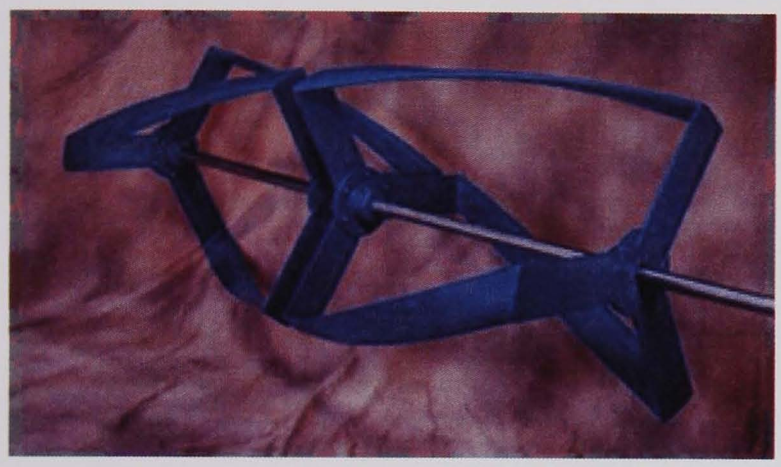


Figure 27: Gorlov Helical Rotor

Openhydro (formerly Florida Hydro Power and Light) USA[23]

Another company with a tidal current energy concept that has interests in the Gulf Stream is Florida Hydro Power and Light. The Open-Centred Turbine is a submerged wheel of blades anchored to the sea floor. The Open-Centred Turbine was developed specifically for the dynamics of the Gulf Stream. In the 1990's, using standard Kaplan and Francis turbine designs, NASA found that they were not cost effective enough to produce electricity at fossil fuel costs. With this is mind Herbert Williams set out to design a device specifically for ocean currents, recognising the need for cost effectiveness and the need to overcome scalability problems. Removing the central shaft of a conventional turbine altogether to eliminate drag and designing a continuous series of blades in a ring-shape, the Open-Centred Turbine was created.

The viability of the turbine concept was tested using a small-scale prototype in 1995, which was a 3m diameter blade in the St. Johns River in North Florida, exceeding expectations by producing 12.7kW, instead of the predicted 10.4kW. It also produced a 25% power efficiency increase over more conventional turbines and this was verified by design analysis conducted by an Alaskan company.

[22] www.gcktechnology.com
[23] www.floridahydro.com

In 2001, a second prototype was constructed, with a 3.1m diameter blade and tested in the Gulf Stream, Atlantic Ocean and results were similar to the previous prototype. Florida Hydro then proceeded to test and analyse the device and results led to the support for commercialising the technology, however, due to US market and financial problems, it became an unlikely candidate for strategic partnership. Since then, the US Naval Surface Centre's Carderock Division agreed to pursue a Co-operative Research and Development Agreement (CRADA) to bring the technology to commercialisation. CRADA aims to refine the entire system using more sophisticated marine engineering technology.

The production device is designed to produce 3MW of electricity and is approximately 72m in length. Each device features two counter-rotating turbines of 32.3m in diameter. Each turbine was designed to be deployed in 60m of water off the coast of Florida. Sea tethers anchored the device and flotation stabilised each unit. In 2000, the sea trials off Palm Beach, Florida were successful and electricity was generated in 2003. In 2004, Openhydro negotiated the acquisition of the world technology rights to the Open-Centre Turbine from Florida Hydro and a grid connected Open Centred Turbine was installed at EMEC.

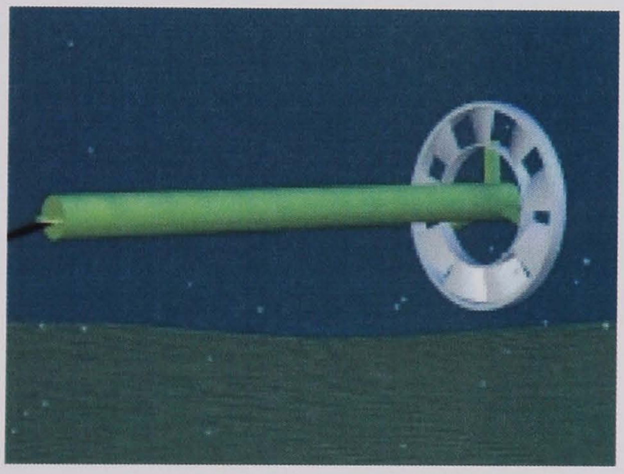
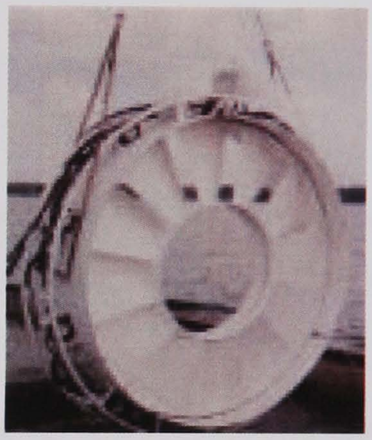



Figure 28: Open-centred turbine

Verdant Power, Virginia USA[24]

After more than two years of personally financing research and testing of prototype turbines, the management team formed Verdant Power in March 2000. The team began development of a product in 1998 by funding the fabrication of a prototype turbine. The prototype, a ducted twin-turbine system, was produced and tested in October 1999. In May 2000, the system was demonstrated at DeCew Falls Generating Station in conjunction with Ontario Power Generation.

Work continued with another concept, a free-flow turbine system, created in collaboration with the New York Power Authority (NYPA) and New York University (NYU). The core of this system is a "conformal" three-blade rotor design. This constant-speed blade design has the highest

[24] www.verdantpower.com

rotor performance versus water current speeds of all the rotors tested by Verdant. Studies sponsored by NYPA, New York State Energy Research and Development Authority (NYSERDA), Consolidated Edison, NYU, and the U.S. Department of Energy included model tests of various design parameters under controlled water channel conditions. Based on these tests and further rotor and nacelle model tests, a full-scale prototype was designed, fabricated, and tested in Pakistan. The results of this power generation testing confirmed the data obtained in the model testing.

In December 2002 and January 2003, Verdant Power successfully deployed a prototype turbine system in the East River in New York City. The system was tested in Chesapeake Bay in the autumn of 2002. The first phase of the project was conducted in cooperation with the New York State Energy Research and Development Authority (NYSERDA), New York Power Authority (NYPA), Columbia University, the Department of Energy's Idaho National Engineering and Environmental Laboratory (DOE INEEL) as well as the Oak Ridge National Laboratory (DOE ORNL), the Electric Power Research Institute (EPRI), the Hudson Valley Technology Development Center, the U.S. Navy's David Taylor Model Basin, and the National Hydropower Association (NHA).

Situated on the Eastern side of Roosevelt Island in tidal currents reaching 2.05m/s, the demonstration unit was deployed from a double-hulled vessel specially designed and fabricated for Verdant Power.

The surface-mounted axial flow turbine, with 10-foot diameter rotors, generated up to 16 kW of power. A yaw system allowed the system to rotate and capture energy from both ebb and flow tides.

Verdant Power has been issued a preliminary permit for the project and site by the Federal Energy Regulatory Commission. The Company received a $500K grant from NYSERDA for this $1.5 million, first stage of the three-stage project. Verdant Power has also been awarded an additional $500K from NYSERDA for the next phase, currently underway. In addition to its assistance with local and state permitting and licensing issues, NYSERDA is expected to provide Verdant Power with additional funding over the next four years as the build-out progresses to the project's ultimate goal of a 5 to 10 megawatt development.

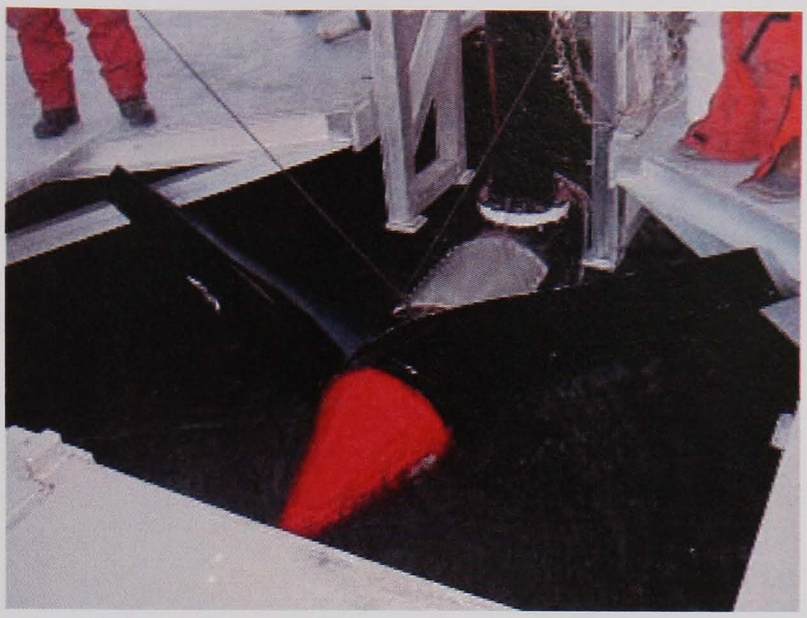


Figure 29: Verdant Axial Flow Turbine

The first units are hoped to be installed by summer, 2006. The development, shown in green (**Figure 30**), is approximately 1 mile long by 270 feet wide, and 30 to 40 feet deep. It is estimated that the development will consist of several hundred turbine units, mounted on mono-piles affixed to the bottom of the tidal basin. Columbia University is one of several groups, including the Roosevelt Island Operating Corporation and Green Mountain Energy Company that have expressed willingness to buy power generated from this site. Verdant Power expects to complete this $20 million East River project, including power conditioning and grid connection, within four years. The Company is also conducting a survey of additional potential sites in and around New York City, California, Canada and the UK.

Additionally, in partnership with GCK Technology, Verdant Power is in the process of developing a tidal site in Massachusetts. The project will represent the first field test of an integrated water to wire system. It will use the Gorlov Helical Turbine, from GCK Technology in conjunction with an operating platform - including drive-train, generators, and power conditioning systems - developed by Verdant Power.

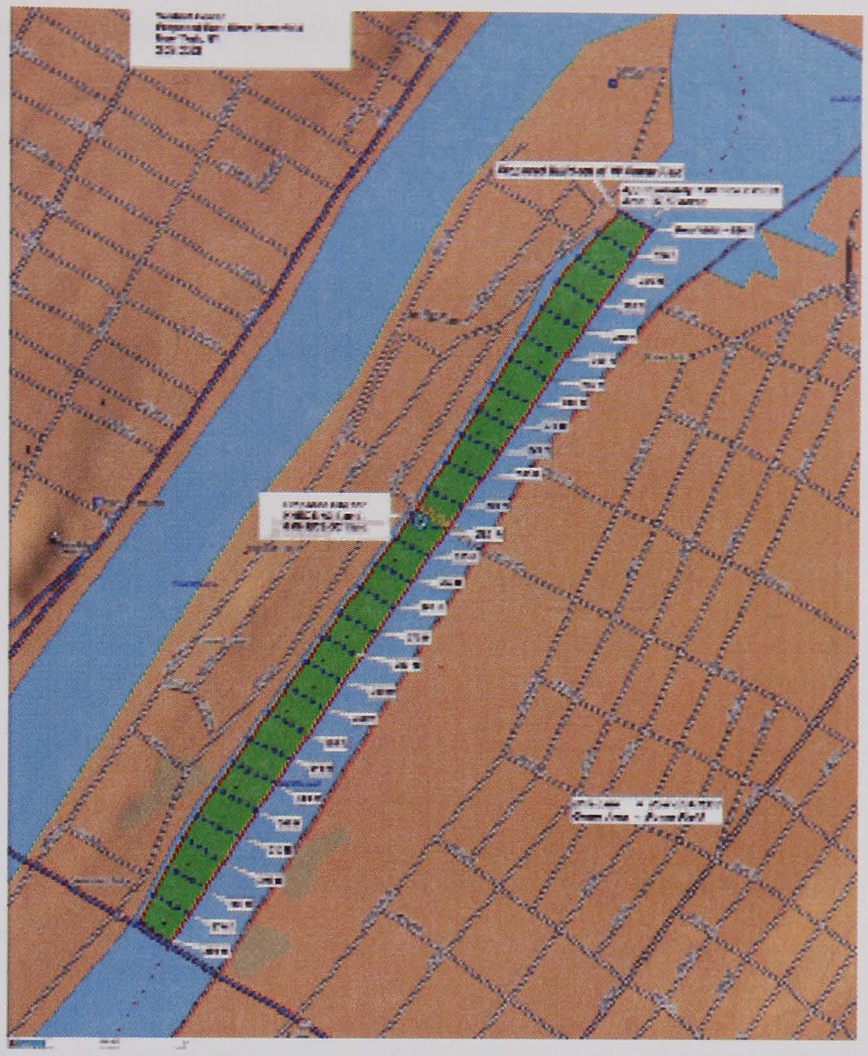


Figure 30: East River Project, New York City

Kinetic Energy Systems, USA[25]

Kinetic Energy Systems have developed a number of concepts designed to harness tidal current energy.

The Bowsprit Generator design is based on free flow hydrodynamics, which is used to construct bowsprits on ships. The designs aim is to increase the efficiency of the current-driven turbine by 3 to 12%. Due to the low or null drag coefficient, it is envisaged that the Bowsprit Generator will be attached to the hulls of large ocean-going ships or in conjunction with the new electric drive pods now being used to drive and steer new cruise ships, to offset internal electrical generating costs. In addition, generators can be placed on pedestals fixed to the bottoms of rivers, channels, or ocean, or attached to docks, bridges, ship hulls, pilings or tethered by anchor where depth is a problem or anywhere omni directional current flows. It is estimated that a stationary 600 kW Bowsprit Generator with a 10 meter turbine diameter, 2 m/s (4 knots) current, at 45% efficiency will generate 2,332,800 kWh per year.

The Hydrokinetic Generator was designed to house generators from 5 kW to 4.5 MW or, the largest in existence. The generator makes use of hydrodynamic principles in its design which will increase the efficiency of the generator from 3 to 15%. It is anticipated that this generator can be used in rivers, streams and, ocean currents, or in conjunction with the offshore wind turbine for multiple renewable resources. It is estimated that a 600 kW will generate approximately 3,369,600 kWh per year, with 15m turbines, a 2m/s (4 knots) current, at 65% efficiency.

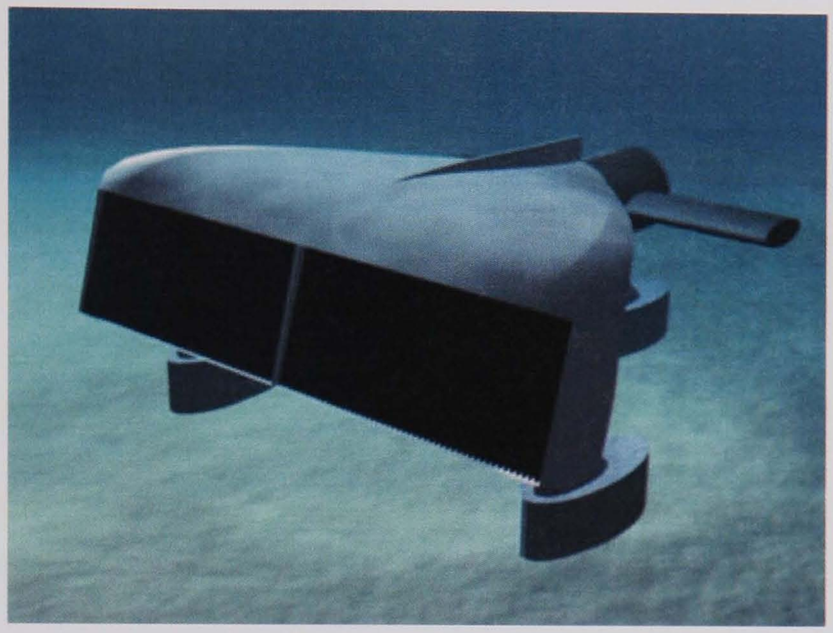


Figure 31: Hydrokinetic Generator

A third concept, the Tidal Generator is based on free flow hydrodynamics for regions that have flood and ebb tides. This multi-directional concept contains two sets of turbine blades. As the tide flows inward the inward turbine blades opens to maximum rotor diameter while the outward turbine closes into the outward cone-shaped hub to create a hydro dynamically clean surface for water to flow without drag. The centre diameter is 75% of the diameter of the turbine blades at full rotor extension for stability.

It is estimated that a 600 kW Tidal Generator with a 10 meter turbine blade diameter, 2 m/s (4 knots) current, at 35% efficiency will generate 1,814,400 kWh per year.

In addition to the generator concepts developed, the Offshore Energy Platform was designed to house a typical offshore wind generator with an underwater current driven generator attached to the structure below the surface, thereby utilizing one platform for dual energy sources. The platform's wind turbine capacity range is from 600 kW to the largest 4.5 MW generators on the market today. The surface generator capacity below would range from 600 kW to 4.5 MW.

It is anticipated that the combined dual systems would generate 5,702,400 kWh per year. The efficiency of both generators would run at 55%.

[25] www.kineticenergysystems.com

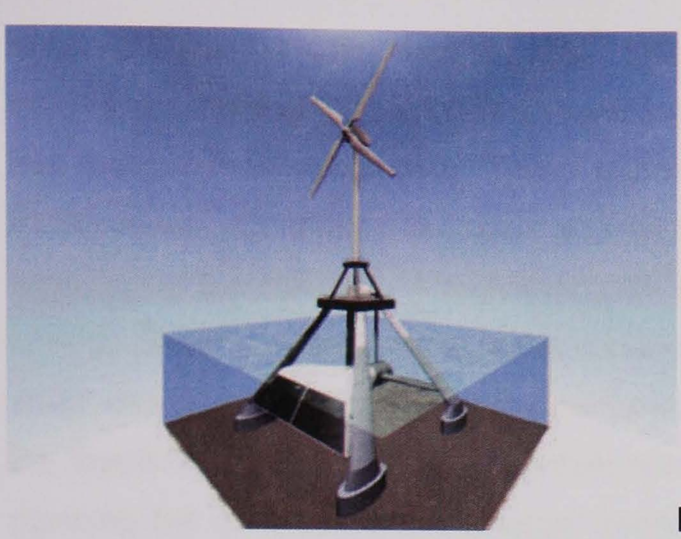


Figure 32: Offshore Energy Platform

Neptune Systems, Netherlands[26]

Neptune Systems is a 'technostarter' company active in the development and manufacture of tidal energy converter systems based upon magneto hydro dynamic (MHD) concepts.

The concept is based on the direct interaction between a magnetic, electric and fluid flow field, discovered by Faraday in 1832: When a conductive fluid moves through a magnetic field, electrical power is generated directly, inside the fluid volume. Though this principle has been studied extensively for generation of electricity from high temperature gases (plasma's) as a topping cycle in electricity power plants, its application for direct conversion of ocean and tidal currents is new. In this marine application, the sea water itself is the conductive fluid. A static antenna-like structure generates the magnetic fields and at the same time taps the electrical power from the fluid current.

Through its research and development, Neptune Systems showed that the most favourable configuration found is a single (or alternatively multiple Helmholz) solenoid, super conducting DC-coil. By using super conduction Ohmic losses are eliminated. The power necessary to drive the cryo-cooler is considerable less than the electric power produced. The concept resembles a dynamo, the sea water being the rotor and the antenna the stator (**Figure 33**).

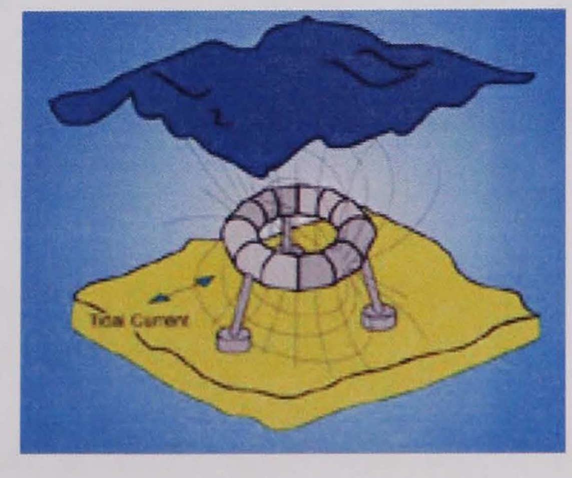


Figure 33: Magneto Hydrodynamic Concept

[26] http://www.neptunesystems.net

Neptune Systems state that the main advantage of the MHD-conversion is the absence of moving mechanical (drive-train) components, which make contemporary systems vulnerable and maintenance demanding. These aspects are especially important in the hostile (marine) environment. Continued research and development is underway to gain more insight in the feasibility of the concept. A technical audit was organised with 6 known experts within the field of MHD, super conduction and super conductive magnet technology, power electronics, and salt water chemistry. The concept was determined to have no technical barriers expected to block the feasibility of Neptune MHD current conversion. Neptune Systems are in the process of planning the development of a larger prototype to further assess the technical and economic feasibility of the Neptune tidal current converter system (Neptune Systems, 2006).

Water Wall Turbine Inc[27], USA

Little is known about this recent concept. The system has been developed for extracting energy from ocean and freshwater currents by Marek Sredzki, Lodewyk Botha and Grace Sredzki. Consisting of a light superstructure, it is claimed that it can produce over double the energy production per m^2 than any other renewable technology and that it can produce significant power output in any depth, including 300m+. Such claims do not seem to have been publically or academically substantiated.

Other Tidal Current Concepts and Research and Development

Oxford Oceanics have been developing a system to co-exist with coastal defence mechanisms and Don Cutler, founder of the former engineering company, Tekflo in Weymouth has also been developing his ideas and is presently looking to form associations with an existing developing company who has experience in securing finance for tidal energy projects. Cutler believes that he can secure cost effective tidal power by innovatively placing existing turbine designs inside large bore underwater pipes using oilrig technology (Science Daily, 2004).

QinetiQ have also been developing a system over recent years, termed the Cycloidal system, which comprises a number of blades orientated parallel to the axis of rotatation and perpendicular to the plane of rotation. The system uses lift and drag force to enable rotation. A prototype is not yet ready as the concept is still at the very early stages of development and still undergoing modelling (DTI, 2004).

Scottish-based Greenheat Systems are developing a tidal stream turbine to generate and store energy, known as the Gentec Venturi (Mackay, 2006).

Researchers at the University of Southampton have also developed a tidal current energy system that is believed to be much more simplified than most existing designs. The present

[27] www.wwturbine.com

prototype is just twenty-five centimetres across and the research team now plan to design a larger model with improved propeller blades that will further increase the efficiency of generating electricity. All being well, the team envisage the generator becoming commercially available within five years (EPSRC, 2006).

An investment of £650,000 from the Scottish Executive has ensured that a hi-tech tidal underwater turbine demonstrator (twin axial rotor monopole device) will be built at the European Marine Energy Centre (EMEC) in Orkney. The £8 million 'Neptune' project, developed by Scottish and Southern Energy's wholly-owned subsidiary Renewable Technology Ventures Ltd, is supported by the ERxecutive, the Department of Trade and Industry, Highlands and Islands Enterprise (Scottish Executive, 2006).

In Italy, the ENERMAR concept has been deployed in the Straits of Messina and is basically a cross-flow three-blade turbine mounted on a floating platform (Pontes & Falcão, 2001). A French project has also been operating off the North coast of France. Hydrohelix Energies have been piloting a 60W model, but hope to increase this to a large-scale demonstration of 4 turbines. Each turbine is 8 metres in diameter and can generate 1MW of electricity (Environline, 2003). Clean Current (Power Systems) have undertaken design studies on a ducted horizontal axis turbine. It is envisaged that a 1-metre diameter model will be tested in towing tank facilities at BC Research, ready to finalise a 3-metre design that will be installed at Race Rocks, Victoria, Canada (Triton, 2002).

A number of other research initiatives have also been set up throughout the world, within China, Korea and the USA. The Northwest Indian College, Washington have been conducting feasibility studies for the potential application of renewable energy technologies for tribes in the Northwest and considered tidal current energy as important potential resource, after calculating the potential power from a number of sites (Bledsoe, 2001). With respect to Korea a study on 'Ocean Energy Utilisation' was initiated in 2001 after some simple feasibility studies were conducted in previous years. The core of research has been in technological development, including precise prediction modelling techniques for tides and currents and site characteristic assessments for proposed sites. Design and manufacture techniques of turbine generators has also been an important research element. Other core research includes optimisation techniques for current power generation and design and construction of tidal power developments. However, the site of Uldolmok, the strait with the strongest tidal currents in Korea (approximately 6.5 m/s) is also under investigation. In-situ experiments with helical type turbine designs have been conducted, with plans to develop a 1000kW 'tidal farm', to be completed by 2006. The potential power capacity of this site is approximately 90,000 to 130,000kW, with the annual duration of energy to be 6,900 hours, generating an annual output of 240GWh (KORDI, 2001; KORDI, 2004).

Renewable energy development in China has become an important strategy over recent years and the industry itself has grown steadily, notably in solar water heating. Other technologies are also rapidly moving towards commercialisation and with a vast coastline, including offshore islands tidal current energy is no exception. At present, one tidal current development has been under construction, with an installed capacity of 70kW (Zhang *et al.*, 2003) and a number of research projects are taking place, including that of the pilot Kobold turbine, developed by Italy-based Ponte di Archimede and the Guangzhou Institute of Energy Conversion (China Daily, 2005).

Melbourne-based Woodshed Technologies[28] has been granted a UK patent for a novel marine energy technology that relies on the rise and fall of a water body, as opposed to the horizontal movements of tidal currents. The Tidal Delay® tidal power technology utilises existing natural land formations and creating a tidal barrier, using proven hydro-electric technology. Woodshed technologies hopes to develop and implement the concept in the UK (Woodshed Technologies, 2005). In addition, another Australian-based company, Marine Energy Power has also been developing tidal power technology and has plans to demonstrate their system on the west coast of Scotland in 2006 and have already commissioned Edinburgh University and RGU to survey the UK coastline to find optimal sites for the system. It is hoped that fully commercial systems will be contributing to the national electricity grid by 2007 (Magee, 2005).

Related Research Activities

Over the years there has been a number of research activities associated with tidal current energy development and the applications that could potentially be derived from such power generation. The Robert Gordon University (RGU), Aberdeen have been at the forefront of this research, developing an optimisation program for tidal current development and conducting resource assessments, feasibility and market potential studies. Support structure research and development is also very much underway with respect to Prof. Ian Bryden's 'Snail' concept. The technology is particularly beneficial with respect to the minimisation of existing depth constraints associated with the deployment of tidal current energy devices and in its uniqueness of having a very minimal environmental footprint and no sub-seabed engineering requirements. Such technology uses six hydrofoils, which can rotate through 172° and automatically adjust to the direction of the tide, creating a powerful down-force, rending the structure totally stable, but can be later recovered from the seabed by pumping air back into the cylinders (Bryden, *pers comm.*).

[28] http://www.woodshedtechnologies.com.au

Figure 34: Prototype support structure for seabed mounted tidal current turbines (The Sea Snail)

The University of St. Andrews are investigating a new micro-electrolyte technology, which uses hydrogen to store and transport energy in the form of a chemical fuel. If research is successful, the technology will increase the practicality of energy gained from remote renewable sources (i.e. tidal current power) by allowing energy to be moved to more urban locations. A joint research project with The Robert Gordon University is currently developing a more effective way of generating and storing power generated by tidal current energy. It is anticipated that hydrogen can be generated electrochemically from any surplus capacity and stored within integral tanks of the tidal energy system. The hydrogen would then be utilised for conversion to electricity for the grid or local demand when tidal energy output was low, enabling a more stable output.

CJ Day Associates have been actively involved in the research of options of installing tidal turbines through existing marine industry activities to reduce costs for early trials and demonstrations of tidal current technologies. Such options investigated were the use of buoyage infrastructure and fixed navigation marks (ETSU, 2001).

Table 9: Summary Matrix of the Principal Tidal Current Energy Technologies

Type	Developer	Device Name/Description	Design Characteristics				Depth Range (min/max)	Operational Limitations	Deployment Limitations	Estimated time to market
			Size	Weight	Blade Speed	Capacity				
Single horizontal axial rotor with monopile support	**Marine Current Turbines Limited (MCT)**	**SEAFLOW –** fixed mounted structure. A twin turbine is currently being developed known as SEAGEN.	Rotors – 15 to 20m in diameter with 3m diameter monopole support, but dependant on depth. Pile Diameter, 4.14m, 5.39m and 6.01m respectively. Pile length, 58.55m, 73.55m, 86.05m Rotor clearance required for Seabed: 12m Surface: 4m	Varies depending upon installation weight and height: 284Te (30m) 590Te(40m) 888Te(50m)	Ranges from 10-20rpm	Proven 300kW using single turbine Second , third generations could reach 500-1000kW dependant on tidal flow	Between 30m to 50m	**Min. Current Speed** Not Stated **Max. Current Speed** >4m/s	Horizontal device spacing limited to x2 rotor length and vertical spacing limited to x10 rotor length. Structures can also be installed using zigzag configuration. Installation requires a vertical pile to be drilled into underlying seabed geology.	Commercial series of installation splanned for 2006 with each module generating between 750 to 1200kW. This will utilise two 16m diameter turbines.
Hydroplane with seabed mounted support	**The Engineering Business Ltd**	**STINGRAY** Hydroplane concept. Uses a hydroplane which has its attack angle relative to the approaching water stream	Length: 25m Width:20m Max height: 26m	300Te (500Te including gravity base/ballast)	Cycle time – 20sec or 3rpm	Timed average output gained from sea trials is 90kW with peak output of 290kW	Up to 100m	**Min. Current Speed** 1m/s **Max. Current Speed** 2.9m/s (Optimal – 2m/s)	None immediately identified	EB were preparing for Phase 4: 5MW farm comprising 10x500kW systems, however R&D economic considerations have put project on hold at present.

Type	Developer	Device Name/Description	Design Characteristics				Depth Range (min/max)	Operational Limitations	Deployment Limitations	Estimated time to market
			Size	Weight	Blade Speed	Capacity				
Ducted horizontal axial rotor with gravity foundation support	**Lunar Energy Ltd.**	**LUNAR RTT 1500** This system features a ducted turbine, fixed to the seabed via gravity foundation	Can be scaled to suit site. 1MW unit is 21x27m	1200Te	Not Stated	Commercial Unit: 1.5-2.5MW 5MW in planning stage	>35 and <150m	**Min. Current Speed** 2.06m/s	**Device spacing** Envisaged to be in clusters of 3 and each cluster will be 20-30m a part	Prototype not yet available, first trial scheduled for 2005 Commercial operation possible for 2006
Helical Turbine	**Subsea Energy (Scotland) Ltd**	**AQUAMEDIES** Modular system that comprises selected components from existing subsea well technology in addition to a helical-shaped rotor blade.	10m high and 4m wide	10Te	Not Stated	Prototype: 0.5MW installed capacity	>20m	**Min. Current Speed** >1m/s	None immediately identified	Prototype system – 2005; Commercial by 2006/7
Horizontal axial rotor with semi-submersible support	**J A Consult**	**SEMI-SUBMERSIBLE** Free-swinging downstream device. Turbine is held buoyantly in the water by a fixed float.	1.5m diameter	Blade weight – 2.3kg	60-70rpm	None immediately identified	None immediately identified	**Min. Current Speed** 0.4-0.5m/s **Max. Current Speed** >0.8m/s	None immediately identified	Currently at demonstration stage using scale model
Cycloidal Concept	**QinetiQ Ltd.**	**CYCLIODAL SYSTEM** Comprises of a number of blades orientated parallel to the axis of rotation and perpendicular to the plane of rotation. Uses lift and drag force to enable rotation.	Optimal system has 6 blades, with blade span of 4m and a disc diameter of 4m	Not Stated	Not Stated	Not Stated	Not Stated	**Min. Current Speed** >1m/s **Max. Current Speed** >4m/s	None immediately identified	Only at modelling stage

Type	Developer	Device Name/Description	Design Characteristics				Depth Range (min/max)	Operational Limitations	Deployment Limitations	Estimated time to market
			Size	Weight	Blade Speed	Capacity				
Horizontal axial rotor with surface mounted support	**SMD Hydrovision**	**TidEl** Bouyant submersible concept based on an axial type rotor blade.	Typical device has 2x18m blades spaced at 22m. Each power train mounted in a 8m long, 2.5m diameter pod	70Te		1MW	For deep water up to a limit of 200m Shallow water 50-80m	**Min. Current Speed** 2.3m/s (optimum) **Max. Current Speed** >5m/s	**Device spacing** 75m across flow and 200m downstream **Seabed geology** All range of soil types and solid rock	First demonstration farm to be running by 2007 – commercial systems after this – Planning commencing now.
Horizontal axis rotor with augmentor	**UEK Inc., USA**	**UNDERWATER ELECTRIC KITE** Uses semi-bouyant turbine that is suspended like a 'kite' in the water column. Also has augmentor feature and 2-counter rotating turbines.	5m long, 5.5m wide and 3m high Blades – 2.4m diameter	2.5Te	31.4RPM in 2.05m/s to 55RPM in 3.6m/s	0.5m/s = 1.1kW	>6m (Not suitable for deep water)	**Min. Current Speed** >4m/s **Max. Current Speed** 7m/s **Max. Wave Height** Approx. 1.8m	**Device spacing** Generally, 2-turbine diameters – have software to work this out based on a number of parameters **Seabed geology** Hard sand is the best substrate and bare rock is the worst. Depends on cost.	Commercial system already available.
Darrieus, semi submersible	**GCK Technology Inc., USA**	**HELICAL TURBINE** This is a variation of the Darrieus rotor.	Standard unit is 1m in diameter and 2.5m in length, but size can be changed to suit different scenarios.	91kg		At 1.5m/s capacity is 1.56kW to 7.7m/s where capacity reaches 188kW	Minimum depth, 1.2m. No maximum depth.	**Min. Current Speed** 1.5m/s	Can be installed vertically and horizontally in the water column.	Pilot projects going a head in Massachusetts, Maine and Long Island and also in South Korea.
3-blade horizontal axis rotor	**Verdent Power, USA**	**Verdant axial flowr turbine**	Scalable to suit different scenarios	Not Stated	32rpm	36kW	Up to 30m	**Min. Current Speed** 1.54m/s **Max. Current Speed** 7m/s	None immediately identifiable	Expect to have pre-commercial installation of 6 devices (150kW to 200kW) by 2005

2.3 Market Status and Opportunities

2.3.1 General Overview

Within the European Union, companies are amongst the world leaders with respect to developing renewable energy technologies and this trend is forecast to expand, especially with the challenges set to meet the EC Directive to double the share of renewable electricity by 2010. Therefore, there is increasing confidence that markets in the sector will improve their competitive edge and this could be particularly significant for SME's. Within the world market EU companies are significantly active and many are already established, especially in wind, hydro and PV industries.

2.3.2 Renewable Energy Market

For Scotland, the energy industry has been dominated by its natural resources where oil and gas have provided sound economic activity that is set to continue. However, these resources are finite and cannot be sustained continuously. With this in mind and the key drivers set out in **Section 1.1.4**, it is necessary for Scotland to take a broad, long-term view concerning Scotland's and indeed the UK's energy requirements.

According to a Scottish Enterprise report (SEn, 2001) the renewable energy electricity industry in Scotland has been under review and it generally concluded -

- the market for renewable energy technology is maturing throughout the UK;
- the Scottish market shows signs of greater stability;
- the need to fulfil waiting and prospective projects presents a significant market opportunity;
- new technology also presents significant opportunity;
- market demand for 'green electricity' and benign alternatives is increasing and is expected to be a sustainable demand for the future.

According to the Scottish Executives Environment Group report 'Do a Little, Change A lot' (SE, 2002), Scotland's potential for further renewable energy development is massive. There is also a strong commercial interest in Scotland's resource, which are the keys to exceeding the 18% renewable energy target for 2010. It is estimated that by 2010 the world renewable energy market will be valued at approximately £400 billion. It is assumed that wave, tidal and ocean thermal energy will hold significant prospects within this market, especially in the longer-term timescale compared with offshore wind and other renewable energy resources (Douglas-westwood, 2000).

It is a recognised view that renewable energy development has started at a very low base and if the importance of such schemes were pro-actively engaged 20 years ago the country would be in a better position to develop quickly and realistically. Due to the vision of Tom Johnston[29] Hydroelectric generation has become a renowned, stable and efficient industry; as has the wind industry, which initially had been classified as a technology least likely to be commercially viable (Connor, 2002). Both technologies make a relatively high contribution to Scotland's electricity demand at present. This vision now needs to be taken further forward with respect to diversifying into other realms of renewable energy technology, especially Tidal Current Energy and other marine renewables.

2.3.3 Tidal Current Energy

Tidal current energy is perhaps one of the newest renewable energy concepts to be taken seriously by the government, following recommendations from both the Binnie, Black and Veatch report (DTI, 2001) and the Science and Technology Select Committee (STC, 2001).

Currently, there are no commercial operating systems anywhere in the world. The primary market for such systems would ultimately be electricity generation at grid level or into a regional or local distribution network. Tidal Current Energy systems are particularly attractive for island and remote community situations, especially those that are willing to accommodate 'community ownership' projects. Most technologies are modular systems and can accommodate high and low level scenarios.

With respect to commercial competitiveness the Government has developed plans to ensure a competitive option throughout all the renewable energy technologies. The introduction of the Scottish Renewables Obligation (SRO) is in place to ensure electricity suppliers provide at least 10% of their electricity from renewable energy sources by 2010. Renewable energy technologies are also exempt from the Climate Change Levy. The long-term target for tidal current technology is to be commercially competitive without subsidies or other market support measures and therefore, the price of electricity generation needs to be in line with other new and renewable technologies. By present day standards this price needs to be the region of 2.5p/kWh.

[29] Tom Johnston was appointed Secretary of State for Scotland in 1941. He set up the North of Scotland Hydro-Electric Board in 1943. Once WWII was over, the board started building hydro-electric power stations and dams throughout the North of Scotland. Tom Johnston was interested in developing hydro-electric power in order to provide electricity to remote part of the Highlands. This was achieved by selling surplus supplies to England and the money generated was used to extend the national grid into the Highlands and Islands. At the end of the war very few Highland homes had electricity but by the 1970s, over 90% of homes were connected.

Electricity price estimates for the leading market contenders at present fail to meet this target. The Engineering Business Ltd. has estimated their concept to produce anywhere in the region of 4-14p/kWh. MCT Ltd however, have produced estimates in the region of 4.56p/kWh (DTI, 2001), which is lower than the cost quoted in the 1993 ETSU report with unit costs approaching 17.9p/kWh (ETSU, 1993). Using the MCT Ltd. concept, the Pentland Firth report estimated costs at 2.5-2.8p/kWh for 100 turbines. Such estimates are dependent on a number of factors, including tidal velocity and depth (Dacre & Bullen, 2001), but it is also evident that with optimum site characteristics and the number of turbines devisable within the possible constraints of an area electricity costing could be competitive, if not exceed that competitiveness.

With increasing interest in renewable energy commercial activity in this sector has grown rapidly with respect to energy companies and manufacturers. A typical example of this activity is the expansion of interest in renewables by Shell, the largest oil company in the world with the formation of 'Shell International Renewables'. Investment is mainly with respect to Photovoltaics and biomass with the aim to capture 10% of the market over the next 10 years.

With respect to tidal current energy a significant arrangement has been achieved with London Power Company (LPC) investing £3M in the developer MCT Ltd. and is set to become a strategic partner in its future projects.

2.4 Potential Market and Resource Contribution

2.4.1 Identification of Potential Market

When assessing the potential market for Scotland it was important to understand electricity generation statistics within a wider context of energy use throughout the European Union. Through the resource assessment key countries with a tidal current energy generation potential were highlighted, which included areas in Scotland, England, Italy, France, Portugal, Australia, Japan and Canada.

2.4.2 Electricity Consumption, Energy Demand and Consumer Cost

Electricity consumption for the UK in the year 2000 was approximately 345 TW/h and the electricity generated from renewables reached 3.8%, which compared to other EU countries is relatively low. With the introduction of renewables directive, national targets have been formulated throughout the EU. As **Table 10** illustrates, EU states have widely different levels of renewable energy use and therefore have different national targets for 2010.

Table 10: Summary of Electricity Generation Statistics for 2000.
[Source: www.eia.doe.gov ; ECOTEC, 2002]

Country	Electricity Consumption (TW/h)	Cost (P/KWh)	Installed Capacity (GW)	RE Generation		% of Total Demand from RE	2010 RE Target
				Hydro	Other		
Austria	54.8	n/a	14	41.4	1.7	78	78
Belgium	78.1	n/a	14	0.5	1.2	2.17	7
Denmark	33.9	3.1	13	n/a	5.7	16.8	30
Finland	82	1.3	16	14.5	8.7	28.29	32
France	408.5	n/a	110	66.7	3.8	17.25	21
Germany	501.7	2.2	109	19.6	17.6	7.41	13
Greece	**46.1**	**1.3**	**10**	**3.3**	**0.9**	**9.1**	**21**
Ireland	**20.8**	**1.75**	**4**	**0.8**	**0.3**	**5.2**	**13**
Italy	**283.7**	**2.2**	**67**	**44**	**7.5**	**18.15**	**25**
Luxembourg	6.2	1.77	n/a	0.1	0.1	3.2	6
Netherlands	100.7	1.98	21	n/a	4.7	4.66	9
Portugal	**41.1**	**2.1**	**11**	**11.2**	**1.8**	**31.63**	**40**
Spain	201.2	2.1	46	26.4	6.1	16.15	30
Sweden	139.2	n/a	34	77.8	3.9	58.69	60
UK	**345**	**1.75**	**72**	**5.2**	**8.2**	**3.8**	**8**
Australia	**188.5**	**n/a**	**43**	**17.2**	**3.5**	**10.98**	**n/a**
Japan	**943.7**	**3.1**	**229**	**86.6**	**18.5**	**11.13**	**30**
Canada	**499.8**	**n/a**	**111**	**352.7**	**9**	**72.36**	**n/a**

Renewable energy sources in the UK provide approximately 3.86% of the total electricity supply and to meet the 10% target by 2010, approximately 10,000MW of additional renewable generation will be required (DTI, 2004a).

The electrical generation mix for Scotland is predominated by nuclear energy, coal and hydro and oil has been largely replaced by gas. Hydro accounts for 9.9% of the electrical generation and other renewable energy sources include wind and landfill, bringing the overall renewable percentage to 10% (SE, 2001). It is expected, however, that this figure will be increased to 18% by 2010, however there is thought of bringing that figure to 40% by 2020 (DTI, 2004a).

2.5 Industrial Capability in Scotland

2.5.1 Background

Throughout Chapter 2, it has been highlighted that the renewable energy industry has significant potential for Scotland, especially those areas that have a large capacity for renewable energy resource, such as the north and West Coast of Scotland. This section will therefore concentrate on the existing and potential skills base and capability of industry within Scotland and in turn assess the needs and requirements, if any with respect to the development of tidal current energy in Scotland.

For the purposes of this section it will be useful to establish the definitions of 'skill' and 'capability' within the context of the following discussion. "Skill' can be defined as the expertise or experience a company has and 'capability' can be defined as the competency or ability of those skills to achieve a desired end, whether it be within a manufacturing or service context etc.

Scotland in general has been long regarded for its engineering skills and innovation capability. Today a majority of this is reflected in the innovations and research development in the country's universities and colleges, as well as its strong, diverse industrial base. There are many indigenous companies that operate in Scotland with a wide range of capabilities and skills.

The northeast in particular has been the focus for developing such industries and it has been excepted that the area is well placed to exploit renewable energy technology and tidal energy has been no exception with the existing engineering and research base. It was estimated that the world market would be approximately £1 bn/yr, which was defined as a medium to high development potential (DTI, 2001c).

Diversification Potential

Scotland has been recognised over the years as having a high concentration of oil and gas support services, a strong shipbuilding history and a wealth of engineering and manufacture capabilities. Within these and other offshore sectors, it is thought that such companies have a wide range of skills and capabilities to meet the requirements of a new renewable energy industry. It has been recommended that companies need to act now, while oil prices are high and the resources are there to help develop new business opportunity.

Renewable energy in Scotland is seen to be the top prospect for future development, especially with the expected growth over the next 10 years. However, it seems at present Scotland's core renewables capability is limited with some 200 companies listed on the Scottish Enterprise database as participating or wanting to participate in one way or another. It is thought such impartiality will change with adequate promotion and encouragement to diversify into the renewable market.

Tidal Current Energy Requirements

There are a number of skills and service requirements associated with potential tidal current development. Some can be associated with the oil and gas industry, but most are associated with the offshore industry in general, leaving much scope for the exploitation of these sectors for the development of tidal current energy. Requirements are summarised in terms of the developmental stages needed for the establishment of a tidal current energy project (**Table 11**).

Table 11: Summary of Tidal Current Energy Developmental Requirements

Development Stage	Skills and Expertise Required	
Project Development	*Strategy and Business Planning* *Project Management* *Cost Awareness and Control* *Training* *PR*	*Environmental Assessment and Baseline Studies* *Site Optimisation* *Offshore Survey* *Legislation and Consents* *Finance/Funding* *Civil and Offshore Consultancy*
Construction	*Design* *Fabrication*	*Manufacture* *Logistics and Transport*
Deployment	*Transport of Device* *Installation Equipment* *Safety* *Offshore Personnel* *Grid Connection*	*Underwater Services* *Project Man./Inspection* *Pipeline/Cable Laying* *Drilling* *Landfall Engineering*
Operations	*Offshore Repair/Maintenance* *Sub-station personnel* *Remote Diagnostics/System Support*	*Navigational Safety* *Environmental Monitoring/Survey*
Decommissioning	*Transport of device* *Offshore equipment/services* *Offshore personnel*	*Underwater services* *Project Man./Inspection* *Safety*
Post- operation	*Environmental Monitoring* *Impact Analysis*	

2.5.2 Company and Industrial Skills Base and Capability

Identification of Skills Base

By using and consolidating a number of existing databases[30] a skills base index was created (**Appendix 9**). This constitutes a number of key organizations and companies that are already involved or interested in the renewable energy sectors, as well as a number of marine-based companies that have the potential to diversify their skills and expertise into the tidal current energy industry. This database is by no means exhaustive and there is much scope for addition of information and database development as knowledge in this field is increases.

The following sections make reference to Scotland, as apposed to the UK as a whole. Discussion is based on research conducted by Dacre (2002), but many of the conclusions drawn may also reflect the UK as a whole.

Assessment of Company and Industrial Skills Base and Capability

When comparing the tidal current energy industry requirements (**Table 10**) with those skills already associated with a number of companies in Scotland (**Appendix 9**) it can be seen that much of an overlap already exists and there is no question that the skills base is already in Scotland.

Scotland already has strong engineering and manufacturing skills with expertise across a number of disciplines, which has already established itself in electronics and the oil and gas sector. There is no reason why such skills can't be applied to the marine renewable energy sector. The oil and gas and shipping industries are an added strength because they are well developed and have invaluable experience in the marine sector. The existing infrastructures and diversification potential also make such industries strong contenders for marine renewables.

Industrial capability has a slightly different scenario and one that needs to be addressed if a tidal current energy industry is to take hold within Scotland. Though there is evidence of industrial capability among some companies, a majority of industry simply doesn't have any. Most companies that are involved in the marine or oil and gas industry are suited to those requirements that are primarily one-off or that are small in number. The tidal current energy concepts are looking to be highly repetitive and therefore companies have not got the capability required for mass production techniques that may be suited for the tidal current energy industry.

[30] Scottish Chambers of Commerce Business Directory; Renfrewshire Business Directory; H&I Business Directory; RE Directory; UKOOA; Aberdeen City Council Business Guide; Oil & Gas Directory; South Ayrshire Council Business Directory; Energy Source Guide; Glasgow City Council; Shetland Business Directory; Fife Business Directory; RE-online; Edinburgh Business Directory; Industrial and Power Association; Operators & Suppliers International On-line; SPREG; James &James; and Oceanology 2004.

In relation to this, companies also haven't the capability of reducing costs so readily as the tidal current energy industry may need, especially for small-scale production as needed at the start of any development. **Chapter 7** covers these difficulties in more detail.

Potential of Diversification to Tidal Current Energy Technology

With reference to the database in **Appendix 9**, there are already a number of companies with an interest in the renewable energy sector. The consultative process reflected similar responses. Generally, companies recognise the need and importance for diversification into the renewable energy sector in light of the slow decline and fluctuating oil and gas industry, as well as the increasing renewable energy industry. Many companies recognise that the skills and experience they have lend themselves well to serving the renewable energy industry and have targeted such for potential diversification opportunities. All in all the drive is there to diversify, but companies also responded with reasons why this wasn't possible at this time and why they are hesitant to pursue opportunities in the renewable energy industry and these are discussed further in **Chapter 7**.

2.6 Assessment of Resource Contribution and Development Perspective

2.6.1 Resource Contribution

It is clear that Scotland has a massive potential resource in tidal current energy generation to meet not only the needs of Scotland, but other parts of the UK as well.

The resource from the Pentland Firth alone could potentially meet Scotland's requirements, where demand is approximately 35TW/h per annum. The use of further sites could far exceed Scotland's electricity demand. For example, with respect to the UK's electricity demand of 345 TW/h per annum (ECOTEC, 2002), Scotland's resource could potentially generate at least 34% of this demand. On a European level this would be a contribution of nearly 5%. Where Kyoto targets are 8% and 12% respectively for 2010 this is a massive contribution far exceeding the agreed targets. For Scotland alone this far exceeds any 2020 targets of 30 or 40%.

The consensus seems to be that all EU member states have adequate provision and policy for meeting EU and national targets and are all committed to meeting these needs and beyond, whether it be through internal means or energy export. With the potential exceeding the demand it is important to note that Scotland also has the capacity to export energy to countries that have a shortage of supply or who lack the resources for renewable energy generation.

By continuously improving capability and exporting technology and expertise to the EU and world areas of interest the resource contribution of tidal current energy is of great value to overall electricity demand.

2.6.2 Development Perspective

The development of a tidal current energy industry isn't that far removed from the beginnings of the wind industry. Over the past 15 years or so, the wind energy industry has grown relatively consistently. The key to Denmark's wind energy success was to create a 'market pull' mechanism that allowed the technology to be developed and compete against more mature technologies. As a result, Denmark now has 50% of the world market.

The tidal current or marine energy industry is probably at a similar point to where the wind energy industry was 15 years ago. It has been recognised by researchers, key stakeholders and Government-bodies that it has a huge market potential. However, since then, global environmental needs and the recognition of climate change has increased, making development opportunities and the need for rapid growth paramount. Over the next 2 or 3 years it has been invisaged that around £70m of investment and funding will be committed to marine energy research (Boud, *et al.*, 2002a). It is unknown what proportion of that will fund tidal current energy research and development. However, there was (and still is) an optimism that Scotland is becoming the base and world leader in technology that is fast developing, thus, creating a strong tidal and marine energy industry within Scotland and the UK. For much of industry and the economy, success of a venture is measured through employment figures, but success goes far beyond this. There are many more benefits and positive measurables that can be linked to the growth of such a new technological industry and it is this perspective that must be built upon and enhanced.

CHAPTER 3

Environmental Impact Assessment and Tidal Current Energy

3. EIA AND TIDAL CURRENT ENERGY

3.1 The Role of EIA

All activities cause an impact on the environment, but any development activity with the aim of benefiting mankind shall serve its purpose only if it is compatible with the environment (Abassi and Ayra, 2004). In ecosystems not directly influenced by human perturbations, such activities have an impact within the natural variability of the ecosystem and are subsequently assimilated into the natural scheme of things. Human-induced projects, on the other-hand have the potential to cause impacts which may disturb ecological balance beyond the ecosystems natural variability and capacity. However, it wasn't until the late 1960's that the realisation of this began to unfold. At the same time, the science of environmental impact assessment began to develop and by the 1970's environmental impact assessment emerged as a major branch within the realm of environmental engineering (Abassi and Ayra, 2004) and in the 1980's there was renewed vigour in the expansion of EIA, where political recognition of reconciling development with the environment and increased awareness of sustainable development continued to increase (Morgan, 1998).

> *"The purpose of EIA is to improve decision making and to ensure that the project options under consideration are environmentally sound and sustainable"*
>
> World Bank Operational Directive (1991)

With the increasing awareness that human activities are altering natural cycles and systems and that the risks and impacts associated with project development are actually significant in terms of changing and affecting those natural cycles, the role of EIA has become crucial. Since the 1970's, Governments have began insisting on environmental impact assessment as a pre-requisite for licensing new projects, both on land and in the marine environment. In the UK, Environmental Impact Assessment (EIA) is a procedure or process required under the terms of Directive 97/11/EC on assessment of the effects of certain public and private projects on the environment and also under Directice 92/43 on the conservation of natural habitats. An EIA is an obligation that must fall into compliance with various regulations that implement these Directives.

Environmental impact assessment (EIA) is generally a tool to help authorities to make decisions with respect to project approval (Leknes, 2001), providing a basis for design and planning, taking into account the potential environmental impacts, constraints and benefits and providing key mitigation methods for managing significant impacts and risks from development projects and associated activities. Essentially, the EIA process links the environment and the potential development aiming to mitigate against significant negative environmental impacts. In recent years the adoption and adaptation of EIA has continued to expand, bringing changing perspectives on what constitutes sound performance (Sadler, 1996) and in addition what methods are best employed to individual project needs. There have been numerous guidelines to describe and facilitate understanding of EIA and its process including that written by Petts (1999), Roe *et al.* (1995), Department of the Environment (1995), European Commisssion (2001), Scottish Natural Heritage (2002), and Institute of Environmental Management and Assessment (IEMA) (2004) to name but a few.

3.2 The EIA Process

The process attempts to ensure maximum protection for the environment by early consideration of a proposal's impact before construction takes place. An associated function of this is to collect, collate and disseminate data on the proposal and its implications, increasing information, understanding and awareness of the proposed development and its surrounding environment and the interactions between them. It is becoming a *multi-purpose* process with increasing emphasis on sustainable development.

Therefore, the purpose of this Environmental Assessment Process is:

- Screening – determine whether or not a proposal is subject to an EIA, and if so determine the level of detail to which assessment needs to be applied;
- Scoping – identify issues and impacts that are likely to be important and establish terms of reference for EIA;
- detail the proposed development action, outlining alternative action, including the preferred or most environmentally benign option for achieving the proposal objectives;
- describe and investigate the area of influence i.e. the receiving environment;
- identify and predict, where possible the likely impacts and their interactions;
- investigate those impacts and their probable response, including the determination of their relative importance/significance, especially residual impacts (impacts that cannot be mitigated);
- discuss any mitigation requirements – establish necessary measures to avoid, minimise or offset predicted impacts and incorporate into environmental management plan; and
- discuss recommendations, future research and monitoring procedures and follow up such procedures and monitor impacts of development and the effectiveness of any mitigation that was required.

Thus, providing:

- a resource, enabling environmental concerns to be integrated into the project planning and design activities, safeguarding ecological and physical processes and heritage areas, as well as providing a management tool to avoid irreversible or unacceptable loss and deterioration of the natural and/or socio-economic environment;
- a tool to ensure development is adjusted to the potentials and capacities of the resource base and in addition optimising the natural resource under consideration,

allowing conservation issues and management opportunities to be integrated where necessary;

- the impetus to achieve high standards of environmental performance, especially within the legislative framework;
- a resource to help address concerns of the general public and organisations that are directly or indirectly involved, including addressing concerns related to the disruption of people and traditional lifestyles; and
- a resource to create confidence that the project is being implemented in the correct manner, taking into account possible issues that may implicate the project.

Through the above, the environmental impact assessment can be used with regard to the following principal functions, focusing on separate processes or comprising areas of specific specialisation:

- a planning tool to minimise adverse impacts that the project could potentially cause, thus, providing the best environmental option in terms of project options and location of development (EIA);
- to aid the systematic process of addressing the environmental considerations and consequences of proposed policy, plan and programme initiatives, integrating both environmental and sustainability factors into the development of government policy-making (SEA);
- an instrument for decision-making, to decide whether a potential project is acceptable from the point of view of its costs, e.g. determining the best economic option (BEEO);
- it can be used as an instrument for decision-making with respect to determining the best practical project option and best practical location (BPEO);
- the process can also be formulated to reflect solely social impacts within a Social Impact Assessment (SIA); as well as,
- a provision to evaluate risk and provide technology assessment.

Each function integrates the process of environmental impact assessment for meeting different project needs. A project may only require a general environmental impact assessment, involving discussion of project alternatives and the assessment of environmental and socio-economic implications. In itself, this is a comprehensive process. However larger, more complex projects may also require further assessment with regard to project and economic options, as well as a purely ecological impact assessment. Irrespective of the assessment emphasis, they all adhere to the same processes and provisions set out above. **Figure 35** demonstrates the environmental assessment process.

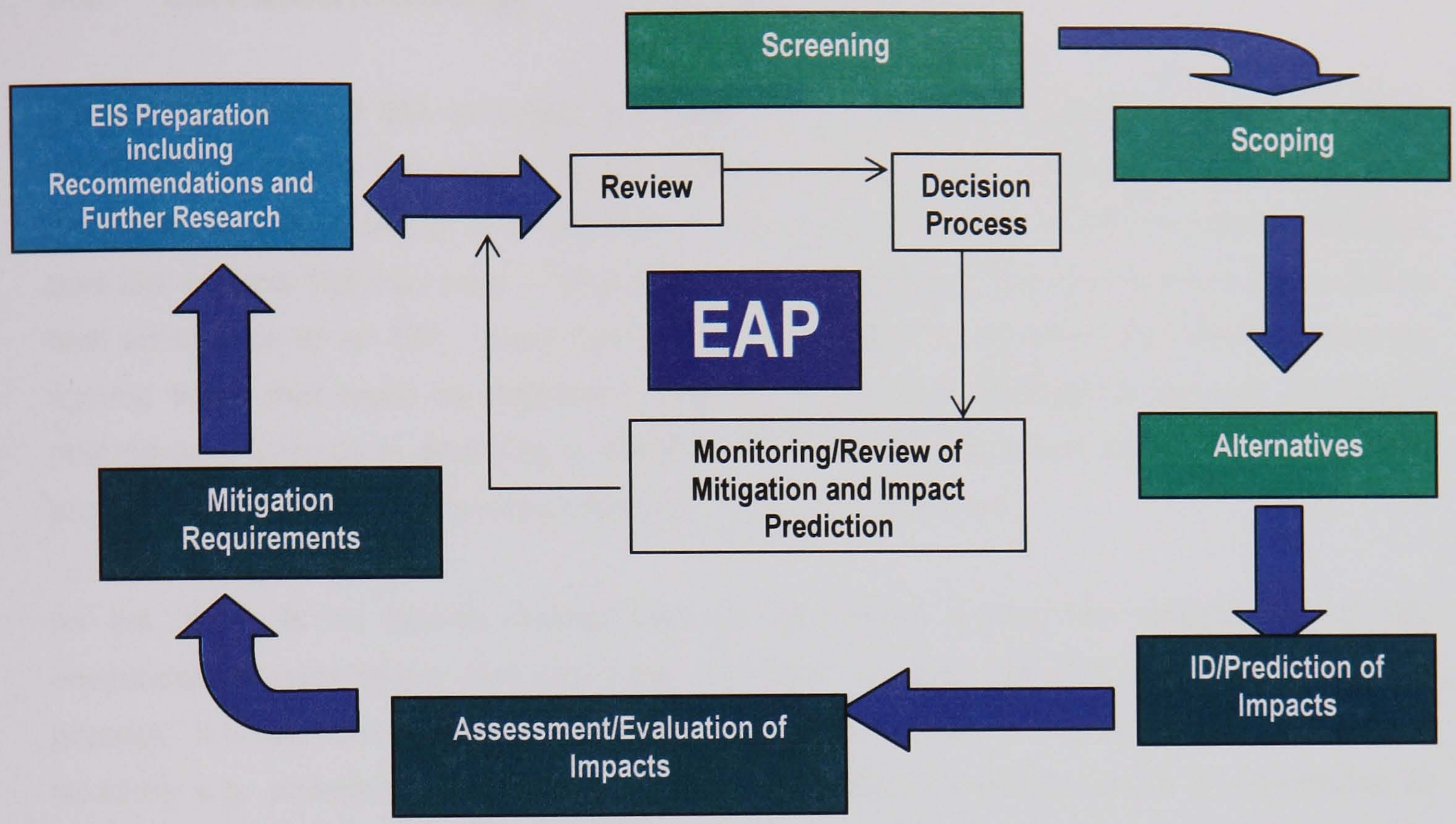


Figure 35: The Environmental Assessment Process [Adapted from Dacre and Bullen, 2001].

3.3 EIA Methodology

Since the science of EIA emerged, a myriad of techniques and methodologies have been developed to assess the impact of environmental parameters. However, most have been developed to assess one or other parameter. Very few methods exist for integrating numerous potential impacts that may pose a risk to the natural variability of the environment and resolve a final summation of an EIA. Such summation is essential to establish the beneficial impacts against those that could be potentially negative. It is also essential to be able to have a methodology integral in providing a decision tool to enable a choice to be made regarding project alternatives and determining suitable sites for development.

As yet, there is no proven methodology to, objectively enable the identification of key environmental parameters and associated potential impacts that may occur within an EIA process. It would also be helpful if a methodology could be established to produce a hierarchal structure e.g. arranging key parameters and associated impacts in order of importance or severity of potential environmental impact. Such a methodology would enable a greater understanding of the nature and influence of various parameters, providing a tool to determine which ones could be potentially dominant in their 'impact role' and those which were peripheral (Abbasi, 2004).

There are a number of methodologies commonly employed in the environmental impact assessment process and many have been frequently used and described (Bisset, 1988; Canter, 1996; Morgan, 1998; Al-Rashdan *et al.*, 1999; Wathern, 1999; Abbasi and Ayra, 2004) and these are:

- Ad-hoc approaches;
- Checklists;
- Overlays;
- Matrices;
- Delphi

3.3.1 Ad-hoc

Such methods provide qualitative assessment of the total impact associated with a project development. Simply the method suggests the broad areas of possible impacts and the general nature of these potential impacts. For example, consideration of each environmental area and identifying the nature of the impact upon it in terms of 'no effect', 'problematic', 'short term' and 'long term'. This approach has very little quantification or precision.

3.3.2 Checklists

This approach combines a list of potential impact areas under consideration with a qualitative assessment of the individual impacts. Checklists facilitate rapid assessment of environmental impacts. They do not, however, provide cause and effect links and an overall interpretation of overall impact. Unlike, the method described above, it does facilitate a systematic approach despite having the common disadvantages of being qualitative and subjective.

3.3.3 Overlay

The Overlay approach relies on a set of maps encompassing environmental characteristics for a project area. Maps are overlaid to produce a composite characterisation of the project environment and impacts are identified by noting impacted environmental characteristics that occur within the project boundary. The method is particularly useful for screening alternative sites when scoping a development project, as its approach is incapable of quantifying or indeed identifying potential impacts. However, Geographical Information Systems (GIS) and Marine Information Systems (MIS) have taken this method beyond the capability of paper-based maps, allowing hypothetical scenarios to be analysed within the process of problem solving and, or gaining some insight into 'worst-case' scenarios with respect to project development. A new GIS-based EIA methodology, known as Spatial Impact Assessment Methodology (SIAM) has been developed (Antunes *et al.*, 2001).

3.3.4 Matrices

Of all the approaches employed in the process of environmental impact assessment, the use of matrices is the most predominant method (Abbasi and Ayra, 2004). As described in Section 2.3.2, checklists can be characterised as 'one dimensional' in their approach to impact identification, however, matrices can be at least 'two dimensional', not only by identifying potential impacts, but also giving some indication of magnitude of likely impacts, as well as having the ability to vary its approach. This can be dependent on the project development and the type of impacts likely to occur, but matrices can be developed where some measure, albeit subjective, can be ascertained, such as duration, importance, probability and even feasibility of mitigation. In some cases (**Chapter 4**) the significance of impacts can be estimated by integrating each 'dimension'. Though matrices are still qualitative and somewhat subjective, they do help to understand the complex interactions between the project development and environment. In addition, the interactions between each environmental component can also be determined and in doing so, can be applied to more comprehensive assessments, such as cross-impact analysis and modelling techniques.

3.3.5 Delphi Approach

Delphi is a method that is predictive, systematic and iterative and is based upon expert independent contribution (Mohorjye and Aburizaiza, 1997). In its most simplistic form it is a carefully designed series of questionnaires, where the objective of employing Delphi is to derive a consensus of opinion. Statistical techniques are often employed to analyse, combine or average responses. Results are often integrated into further questionnaires until a consensus of opinion is identified. Delphi is often used to forecast technological, social or policy events. Though the procedure is relatively robust and replicable in statistical terms, the method contains insufficient information about environmental problems in general and is predominantly used in the early stages of EIA to identify potential impacts and the information generated is often incorporated into other methods (Abbasi and Ayra, 2004).

3.3.6 Other Methodologies and Research

There are numerous other methods that have been and are still being used and some that are still emerging or are under development. The concept of environmental impact assessment methodology is a continuous process and constantly under development to improve and better aid the decision making processes that constitute environmental impact assessment. Lawrence (1997) details and assesses the relationship between EIA-theory and practice and determines that it is essential to enhance the practice of EIA and ultimately protect the environment.

Content Analysis, a method using known literature in order to identify project activities and their potential impacts is still being used, especially in cases where previous projects in similar settings have already been conducted. Survey methods are also being used to collect opinion and assess human perception, but such methods are generally not used for environmental assessment purposes, unless there is an aspect of a project that has an important 'human' element.

Weighting, ranking and other quantitative methods are also continuously being developed and are used in various contexts to evaluate environmental impact.

A weighting method was first proposed in 1978 by Sondheim which consisted of ranking and weighting matrices, however like many methods proposed it neglected to incorporate inter-relationships among variables (Abbassi and Ayra, 2004). Since then a number of methodologies have emerged using enhanced methodology, such as the wide range of multi-criteria analysis (MCA) methods (Cavallaro and Ciraolo, 2003; Goyal and Deshpande, 2001; Al-Rashdan *et al.*, 1999; Sankoh, 1996) and impact tree analysis methods (Abbassi and Ayra, 2004). MCA methods recognise the interactive nature of environmental components and impacts by determining overall preferences among alternative options, where the options accomplish several objectives. In MCA, objectives are specified and corresponding attributes or indicators are identified. The actual measurements of indicators are often based on the quantitative analysis (through scoring, ranking and weighting) of a wide range of qualitative impact categories and criteria. MCA provides techniques for comparing and ranking different outcomes, even though a variety of indictors are used. However, though there are key advantages in the use of MCA, in the fact the method allows quantitative and qualitative data to be combined and the range of multiple impacts can be used, there are also some key disadvantages. For example, there are no clear criteria for selecting impacts; there is a risk of double-counting categories and there is always the potential for arbitrariness within the scoring of the qualitative impacts and within the weighting of the overall impacts with respect to relative importance. Bearing this in mind, for the methodology to be reliable and valid, the method has to either make allowances for lack of scientific accuracy and practical viability or work hand-in-hand with scientific expertise to establish impact parameters and weighting criteria.

Impact tree analysis methods or network methods have been developed to determine or recognise the interactive nature of environmental components and in turn identify secondary and tertiary impacts. In doing this, it allows the identification of impacts by selecting events as they might be expected to occur. However, a key drawback is in the fact the networks do not necessarily achieve the degree of detail necessary for an informed decision-making process. In addition, detailed impact networks can be too complex to be really useful.

A fuzzy logic approach has also been applied to MCA and decision tree approaches to improve the integration of variables that have in the past not been quantified (Boclin and de Mello, 2005). Analytical Hierarcy Process (AHP) approaches first developed by Saaty (1980) have also been revised and implemented (Dey, 2002).

Modelling approaches (using both non-computerised and computerised means) have also been developed over recent years and though they are a powerful means of environmental impact analysis they are also notoriously time-consuming and expensive. In addition, complex issues may not always be adequately represented in a model, where factors may not be suitable to quantify and where critical thought would be a fundamental factor in the analysis of a component's environmental impact significance. Such modelling approaches include the Rapid Impact Assessment Matrix (RIAM) (Pastakia and Jensen, 1998; Jensen *et al.*, 1998), INTRA (INTer-parameter Relationship Analysis)(Arya and Abbasi, 2001), SMART-ALEC (Statistical Measurement for Assessing Regional Trends – And Longterm Environmental Consequences) and CREAM (Computer-aided Rapid Impact Evaluation And Management) to name but a few (Abbassi and Ayra, 2004).

RIAM is probably the emerging methodology that is the most applicable within the context of this thesis. The others listed gravitate towards land-use, urbanisation and sustainability impact issues, though some elements of each method could be utilised within a purely EIA context. RIAM is a tool to organise, analyse and present the results of an EIA and is based on a standard definition of assessment criteria, as well as the means by which semi-quantitative values for each criterion are collated to provide an independent score for each condition e.g. the impacts of project activities are evaluated against the environmental components, and for each component a score (using defined criteria) is determined. A clear advantage or even disadvantage of this method lies within its accuracy and transparency related to the values ascribed by the assessor and the level of expertise they have or obtained. If the level of expertise is high, then the accuracy will reflect this. However, the accompanying report, where all scoring justifications are recorded enables any qualitative assumptions made to be interpreted accordingly.

3.3.7 Conclusion

Section 3.3 has clearly demonstrated that there are a vast number of EIA methodologies that have been developed or are in the process of being developed and the list is not exhaustive. The section only really touches on the key methodologies that have been developed to provide some understanding of the mechanisms there are to aid the environmental impact assessment process. Some methodologies are very simplistic, however as more understanding of the complexities of environmental impact has emerged, so has the complexities of EIA methodology to aid the decision-making processes involved in environmental impact identification and assessment.

With respect to the methodologies that have been applied within the context of this thesis, a combination of simple methods has been used such as checklists and matrices. Throughout the thesis, however, conceptual diagrams and consequence models have been formulated, which in some ways reflect an *impact tree*, identifying impacts as they might occur but also providing a means of identifying component and impact inter-relationships. **Chapter 9** further discusses EIA methodology in the context of tidal current energy and the development of an EIA tool.

3.4 EIA in the Context of Tidal Current Energy

3.4.1 General Context

There has been a growing awareness of environmental issues and the need to conserve, preserve and sustain our environment (Carter, 1995). This is primarily due to the growing awareness that our environment 'does matter' and that human activity is altering the natural cycles and systems on an unprecedented scale. In addition, awareness has grown in relation to EIA itself, where the importance of such has become a paramount tool that can be used effectively in providing a basis for taking into account design and planning issues. Any constraints highlighted, can then be incorporated into the design and planning stage of a development, enabling mitigation of potential impacts and risks for development projects. However, relatively little consideration of the environmental impact process has been aimed at developments in the marine environment in terms of methodological and process development, even though the first environmental assessments were undertaken for the North Sea oil and gas industry and other coastal development (Budd, 1999).

Echoing the opinion of Gray (1999), one of the main contributors to this lack of consideration has been the lack of faith in the role of science in protecting the marine environment and the lack of willingness to apply the methods used to demonstrate the effects of development on the marine environment. Over the years, EIA within the marine environment has been simply a paper-based exercise, where predictions are simply a subjective assessment. However, the development of EIA methodology to ensure its robustness, objectivity and accuracy for developments within the marine environment is in use in some areas of assessment, such as chemical risk assessment using the Chemical Hazard Assessment and Risk Management (CHARM) or Dose-related Risk and Effect Assessment Model (DREAM) and software to enable the prediction of the movement and quantity of drill cuttings dispersal and other pollutants. Though CHARM has been around for a while, it is still the modelling technique that is used throughout the UK oil and gas industry (both by operators, FRS, CEFAS and BERR) to conduct the chemical hazard assessments on chemical products offshore for all installations, pipelines and well operations.

Other EIA techniques employed to mitigate potential problems require a 'feedback' system or environmental monitoring approach that incorporates environmental indicators to determine detrimental problems. Further methods however, need to be formulated to enable further control over potentially environmentally damaging activities. Though it is acknowledged that 'science' does not necessarily expel 'uncertainty', 'uncertainty' can be mitigated if appropriate strategies and frameworks are in place. In addition, by incorporating scientific methods into EIA, 'uncertainty' may become eradicated as questions regarding the extent of environmental impact are answered. In some respects, EIA's need to make quantitative predictions of the impacts expected and their overall significance. These then need to be tested by properly designed monitoring programmes which have the ability to detect the changes expected. This may be a generalised view but, in terms of tidal current energy, this level of understanding is paramount to its successful development as an energy source. At present, their seems to be many 'uncertainties' regarding its impact on the marine environment, thus, by dispelling such uncertainties and understanding the functions governing the environmental processes underpinning the potential environmental impacts of tidal current energy, an appropriate balance can be found between technology and the very environment it uses to harness the energy needed to operate.

Despite the difficulties associated with marine environmental impact assessment, and the increasing progress of marine renewable development (including Tidal Current Energy), the need to investigate the potential environmental impacts of such energy to ensure maximum protection for the marine environment is becoming more apparent. Subsequent chapters of the thesis prove that this is a complicated issue and may even determine the success or failure of marine renewables in general in becoming a major energy source.

All renewable energy technologies use natural energy flows and generally do not generate pollution or carbon dioxide in the operational stage of their lifetime, however they do produce local impacts and tidal current energy is no exception. Therefore, it is imperative that any impacts associated with tidal current energy technology should be minimised and any remaining impacts should be within the realm of natural variability when possible and justified in the fact that such development will be contributing towards minimising global environmental impact overall and creating a sustainable source of energy.

3.4.2 EIA and Renewable Energy Research

Over recent years, the awareness of the potential environmental impacts of renewable energy as a whole has increased further. The likely adverse environmental impact of renewable energy has been discussed in detail by a few authors (Abbasi and Abbasi, 2000; Dincer, 1999 and IEA, 1998).

An early key researcher, who has been examining the environmental impacts of renewable energy, is Alexi Clarke from the Open University Technology Policy Group. Clarke (1993; 1994) has been developing a methodology for comparing the relative impacts of renewable energy sources and one of the key factors influencing the relative scale of impact is the proportion of energy extracted from the natural energy flow, whether it is heat from the sun or energy from waves and tidal currents. Though such energy extraction would not result in global inbalance, the potential to have a significant effect has been highlighted with respect to local or even regional ecosystems. Clarke's theory states that "*the effects of higher or lower natural energy flux densities will be different for different sectors of the environment*". In summary:

- Inanimate/geomorphic activity increases as energy flux density levels increases, therefore, changes to the inanimate environment are expected to vary proportionally in relation to energy flux density. Such a scenario is commonly seen in high energy environments i.e. marine environment. For example, if energy flux density levels increases (e.g. tidal velocity increases), geomorphic (e.g. sedimentation) will also increase. However, this relationship is more complicated than this generalised theory.
- Animate (living organisms) environmental activity is expected to peak at a particular energy flux density and remain at a 'plateau' and then decline rapidly. It is expected, therefore, that the ecological environment or specific components thereof will have an optimum energy flux density before a change will occur. For example, this may be illustrated by the response to tidal energy velocities in the marine environment. Individual organisms are adapted to fairly narrow changes in energy velocities and so where there is a change, organism activity will remain at a 'plateau' until it reaches its optimum or peak velocity where changes to the organism will occur.
- Human environmental activity is expected again to have an optimal energy flux density.
- Due to the fact that the inanimate and animate relationships with energy density flux are so different, a conclusion was made that the impacts of harnessing natural energy sources will be linked to both.

Clarke (1994) also states that key environmental impacts are derived from the following:

- Abstraction of Energy – where environmental impact depends on the fraction of energy in the flow that is abstracted.
- Changed Conditions – aside from abstraction. There are expected to be changes from pressure, temperature, flow rate etc., which the process of energy conversion has caused. These changes are a result of the type of technology and the mode of conversion.
- By-products – these are considered to be secondary effects, such as turbulence, cavitation or noise etc., which can be mitigated or avoided through technological design.
- Basic resource consumption – defined as land-use which will depend on energy flux density.

Clarke (1994) continues to describe the following key factors that define the overall conversion process:

- Amount of Energy in Flow – this is dependent on the volume flow and energy flux density
- Ability of Technologies to harness flow – depends on nature of flow and the ability to 'focus' the flow
- Efficiency of Device – the more efficient the device the greater the amount of energy it can extract and according to Clarke, the less environmental impact will occur. This statement by Clarke hinges on the theory that in environmental terms, efficiency might be defined as energy capture with the least consequences and side effects. In this case, energy conversion should be as direct as possible, devices ideally having one conversion process. Taking the example of tidal current energy generation, energy conversion is direct with only one conversion process e.g. kinetic energy of tidal flow to mechanical energy. Whereas, hydro-electric energy with a dam has an initial conversion process of energy of river flowing into to damn (kinetic to potential energy), then conversion of potential energy to kinetic energy through turbines to produce mechanical energy. Clarkes theory suggests the more energy conversions, the more potential environmental impacts.

From the theories outlined above, Clarke proposed five key factors that are relevant to environmental impact from renewable energy technologies:

- Energy Flux Density (of natural energy flow) (d)
- Proportion of Energy Flow Extracted (p)
- Overall Efficiency of Conversion Device (e)
- Number of Conversion Processes (n)
- Degree at which flow is subject to 'channelling' (degree to which energy flux density is increased (i or Δd)
- In addition, five sub factors were also seen to be relevant:
    - Proportion of Flow Abstracted (pa)
    - Proportion of Flow Intercepted (pi)
    - Efficiency of each conversion process (c_e)
    - External Conversion Processes (in flow) (c_x)
    - Internal Conversion Processes (in device) (c_i)

By using these terms, Clarke proposed that three types of environmental impact can be described for a renewable energy source and their associated conversion technologies. An illustration is shown below using a hydro electric power (HEP) system as an example:

- Inanimate Environmental Impact = $\frac{d\,p\,i\,n}{e}$

The inanimate environmental impact is said to change in relation to the product of the energy flux density of the flow, the proportion of the flow that is abstracted, the additional augmentation of the energy flux density at the device and then inversely by the efficiency of the conversion.

- Animate Environmental Impact = $\frac{d^{y}\,p\,i\,n}{e^{x}}$

In general terms the impacts on the animate environment are proportional to the product of energy flux density of the flow (to the power of y, a value to express the discontinuous relation of energy flux density to the animate environment), the fraction abstracted, the augmentation of the energy flux density and inversely the efficiency of the abstraction process (to the power of x to express the effects of efficiency on the animate sector).

- Human Environmental Impact = $\frac{p\,i}{d\,e}$

Human impact varies inversely in relation to the product of the energy flux density, and the efficiency, and in relation to the product of the proportion abstracted and the augmentation of the energy flux density.

Clarke explains these equations in terms of a hydro electric power system. For example, change to the inanimate processes (physical processes) is in proportion (expotentially) to the energy flux density, since the greater the energy flux density, the greater the inanimate activity, especially in terms of sedimentation. In the case of HEP, the degree of augmentation refers to dams etc. whose purpose is to increase the energy flux density across the device. The expression 'e' for efficiency of energy extraction, refers to the fact the greater the efficiency of energy production, the less the impact per unit of power there will be. Therefore, environmental impact will vary inversely with this factor. However, in the case of research conducted by Black and Veatch (2005) and RGU (Couch and Bryden, 2004), the 'Significance Impact Factor' (SIF) represents the percentage of the total resource at a site that could be extracted without significant environmental impact. With this research in mind it is more likely that the greater the efficiency the greater the environmental impact per a unit of power. **Section 2.1.1** explains this in greater detail.

When applying the inanimate equation for HEP, it is evident that with respect to Clarkes theory, the value of the energy flux density (d) is relatively high compared to other renewables, such as wind, solar and biomass. The proportion of energy flow extracted (p) and degree of augmentation (i) is a value that is dependent on the selection of technology proposed. Overall efficiency (e) should always be as high as possible, but is dependent greatly on the technology proposed and subsequently dependent on (d) and (i).

With respect to tidal current energy technology, similar values could be used as HEP. Though most devices do not have augmentation, it is apparent with respect to Clarke's theory that tidal current energy systems would have an impact on the inanimate (physical processes, such as tidal velocity and sedimentation) environment due to its high (d) and (p) values. For comparison, wind would have an imperceptible inanimate impact due to its low values of energy flux density and the proportion extracted.

It is apparent that the nature of the natural energy flow will need to be taken into account in the process of selecting, designing and locating tidal energy systems. In particular there is a need to relate the way in which specific technologies interact with the natural energy flows in their local contexts (Clarke, 1994; Elliott, 1997). In his research, Clarke (1994; 1993) concentrated on comparing different forms of renewable energy technology, such as solar, biomass, hydro-electric and geothermal, but the concepts formulated can be applied to all forms of energy extraction. The analysis that is described in Clarke's work has not yet been validated. In conclusion, Clarke states, while general levels of impact may be predictable using the technique formulated by his research, environments are extremely complex and it is very difficult to fully anticipate impacts on the environment.

3.4.3 EIA in the context of Marine Renewables

Within the marine renewables sector, offshore wind has gained relatively significant interest with respect to potential environmental impacts, though much research is still to be instigated. Presently, a number of research initiatives are in progress funded by the Offshore Wind Energy Network (OWEN) and the Collaborative Offshore Wind Farm Research into Environment (COWRIE) funding agency. Research projects include the assessment and effects of electromagnetic fields, noise emissions and benthic studies with respect to offshore wind energy. With respect to tidal current energy, the Sustainable Power Generation and Supply Initiative (SUPERGEN), a large collaborative programme of research dedicated to tackling the large challenges of sustainable power generation and supply has a marine consortium, aiming to develop marine energy technologies, including that of tidal current energy technology. Some of the research underway includes analysing the interaction between technologies, as well as the associated mooring technologies and the marine environment. In addition, the European Renewable Energy Centres Agency (EUREC) published a report detailing renewable energy research priorities (EUREC, 2005). Among a number of research and development targets were those associated with the environmental impact of marine energy technology.

Awareness of environmental impacts and marine energy has also grown in recent years within key stakeholder and Government groups. Scottish Natural Heritage published a report on the potential environmental impacts of marine renewables, including that of tidal current energy (Wilson and Downie, 2003). The World Wildlife Fund commissioned a similar report (Ball, 2002) and Pelc *et al.* (2002) have also contributed to the awareness of the potential impacts of tidal current energy. However, probably the most definitive work that has been carried out is that commissioned by the DTI and includes an earlier and less detailed assessment (ETSU, 1993) and also more in depth scoping and feasibility studies with respect to the potential environmental impacts of tidal current energy (DTI, 2002; Dacre, 2002; Dacre *et al.*, 2002; Dacre and Bullen, 2001). All the reports referenced highlighted a need for further environmental impact research, both in terms of the physical and biological environment and in terms of the socio-economic environment.

3.4.4 EIA and Tidal Current Energy Generation

In conclusion to this chapter, Environmental Impact Assessment is an important process in the development of Tidal Current Energy due to the intimate association of the technology and the potential effects it may have on the 'natural' and 'human' energy flows already described by Clarke (1993; 1994) and the potential subsequent ecological, physical and socio-economic implications that may arise (Wilson and Downie, 2003; Ball, 2002; Pelc *et al.*, 2002; DTI, 2002; Dacre, 2002; Dacre *et al.*, 2002; Dacre and Bullen, 2001).

The importance of comprehensively identifying potential environmental impacts associated with tidal current energy are summarised below:

- Tidal current energy is obtained through the natural energy flows of the marine and/or coastal environment. These flows contribute significantly to the maintenance and functioning of such environments and abstracting energy will modify them;
- Tidal Current Energy technologies often harness the *mean* energy flow and therefore require a large number of devices, which may in turn contribute to significant environmental impacts;
- Tidal Current Energy technology is site specific and therefore the potential environmental impacts will also be specific to those sites or types of location that optimise the tidal current energy generation;
- Tidal Current Energy sources will be limited by the capacity of the environment to accommodate potential impacts, as well as by the amount of extractable energy;
- There is more than one type of tidal current energy device, each potentially having unique environmental impacts. There is thus, a need to compare the technologies available for the purposes of strategic decision-making with respect to assessing potential development projects or specific locations.

CHAPTER 4

Identification of Environmental Impacts and Constraints

4. IDENTIFICATION AND ASSESSMENT OF ENVIRONMENTAL IMPACTS AND CONSTRAINTS

4.1 Introduction

The process of identifying the potential impacts and constraints of tidal current energy development began with a generic knowledge of the marine environment and the natural processes associated with such an environment. It became clear that much research had been conducted with respect to effects of the marine environment on offshore structures and development, but little research had been associated with the impacts of offshore structures on the marine environment itself. Research has been limited to aspects of the oil and gas industry and coastal protection development. In the case of studies relating to human impact on the marine environment these were mainly associated with the effects of Tributyltin Trisphosphate (TBT) with respect to shipping, over-fishing problems and pollution issues mainly with regard to the oil industry and illegal dumping of waste. However, effects of structures and disturbance of seabed on benthos have also been studied in some detail with regard to offshore industries, such as, the oil, gas, fishing and aggregate industries and are widely referenced throughout the oil and gas Strategic Environmental Assessment reports (DTI, 2007).

An offshore structure can be defined as one that has no fixed access to land and which is required to stay in position in all weather and offshore conditions (Chakrabarti, 1994). There are many types of offshore structure, but most common of all are those that support the exploration and production of the oil and gas industry and those used for coastal protection projects. There are many however, that have been designed to derive power from the ocean such as wave and tidal energy systems. Other structures include those that are associated with the offshore wind industry. It is the purpose of this chapter, to outline some of the potential effects marine structures have on the marine environment, specifically relating to tidal current energy technology using the following case study.

4.2 Context of the Case Study

4.2.1 The Pentland Firth Study

The project (Dacre & Bullen, 2001; Dacre *et al.*, 2002) represented collaboration between The Robert Gordon University (RGU), The International Centre for Island Technology (ICIT) and Marine Current Turbines Ltd., funded by Scottish Enterprise.

The purpose of the overall project was to determine the potential of economic generation of electricity using the tidal current resource of the Pentland Firth, which lies between the Scottish mainland and Orkney. The potential development constituted the construction of tidal current turbine clusters that would exploit the naturally rapid current flows within the Pentland Firth, providing an alternative source of electricity generation. It is an on-going project with a number of phases, including the identification of environmental and social constraints that may limit the geographical location of the tidal current energy development, economics and efficiency, hydrodynamic modelling and parametric design (Bryden, *et al.*, 2000)

Phase 1 of the project was a study to establish the environmental feasibility of tidal current development within the Pentland Firth, taking into account the physical, ecological and socio-economic environment of the Pentland Firth and immediate surrounding areas. In effect, the study constituted an environmental statement, which predicts how a development will affect the natural and socio-economic environment and discusses any mitigation or further research that may be needed in order to support consent applications proposed by the project collaborators. This phase of the project provided a means to identify the potential impacts and constraints of a development within a real context and generate conclusions of the potential environmental impacts associated with such a development, which constituted site specific, as well as generic environmental impact considerations.

4.2.2 Development Potential Study

A further study (Dacre, 2002) primarily focused on Scotland, investigating the industrial skill and capability that could be applied to the development of tidal current power and the market potential of such industry development. The study also focused on the general benefits that may be accomplished with respect to industry, manufacture, the Scottish economy and in turn its culture. This study provided greater clarification of the socio-economic impacts and constraints involved in the process of tidal current development and were subsequently integrated to provide a more detailed approach and view of the potential impacts initially identified in the Pentland study.

4.3 Description of the Proposed Development

4.3.1 Development Objectives

The primary objective of the proposed development was to exploit tidal current energy within the Pentland Firth through tidal current energy devices for the economic generation of electricity. It was anticipated that with the large area of the Firth and the strong tidal current regime, a relatively large installation could be developed overall, using smaller 'clusters' within the most suitable areas of the Firth. At present, there are no other developments on such a scale throughout the world, though, as discussed in previous chapters, few demonstration projects are underway. At the beginning of the project, it was thought that if the overall project demonstrates that the development is feasible in all facets, such as, economic, technical and environmental, then it is possible that commercial exploitation could follow within five to ten years.

The proposed development involved the construction of tidal current turbine clusters. These are designed to utilise the naturally rapid current flows to provide an alternative source of electricity generation.

The overall project involved the following:

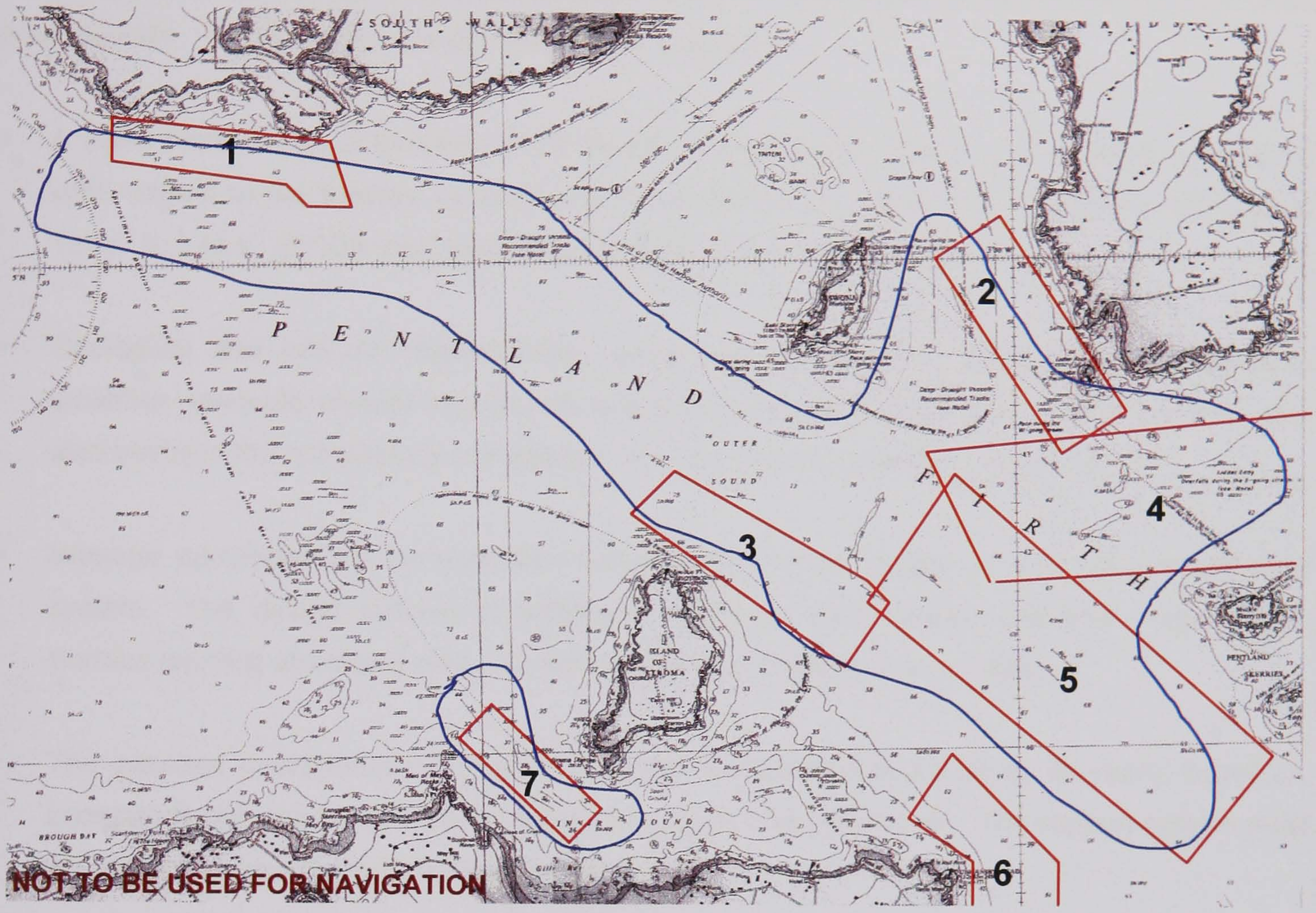
- installation of Tidal Current Turbines
- installation of new cables within the turbine cluster
- installation of new cables from the turbine cluster to a landfall site

The project also considered the modification of the Dounreay Nuclear Power Plant site if this were to be the finalised landfall site for cables and grid connection.

4.3.2 Area and Scale of Development

The area of the proposed tidal current energy project is within the Pentland Firth, which is situated between the Scottish mainland coastline and the Orkney Islands (**Figure 36**).

In a study conducted by the Energy Technology Support Unit (ETSU) in 1993 the Pentland Firth was said to be the site with the greatest potential. Within the study, sites were selected that had mean spring velocities of over 4 knots (2.06 $m.s^{-1}$) and depths over 20m. In the ETSU study funded by the UK Department of Trade and Industry (DTI), the Pentland Firth was identified as being the single most attractive site in the UK for large-scale tidal current development. If tidal currents are to represent an important source of energy in the UK, the potential of the Pentland Firth cannot be ignored. Within parts of the Pentland Firth, mean Spring currents can be in excess of 6 $m\ s^{-1}$ (12 knots) and even 8 m s $^{-1}$ (16 knots) have been recorded, but, Spring current speeds of 4.5 m s $^{-1}$ (9 knots) are common place. Even the latter figure is 50% higher than that used for the Blue Mull Sound, Shetland, which produced the most optimistic cost-estimate results in the North Isles study (Bryden & Bullen, 1994). This in effect represents a three-fold increase in power density.



Reproduced from Admiralty Chart 2162 by permission of the Controller of Her Majesty's Stationary Office and the UK Hydrographic Office.

Figure 36: The Pentland Firth showing the potential Tidal Current Energy sites identified in Dacre and Bullen (2001).

It has been initially calculated that using the concept recommended by Marine Current Turbines Ltd. (MCT) electricity could be generated with a rated capacity of 350MW to 2GW, which is the equivalent of 1TW and 7TW hours per annum respectively. This would fulfil approximately 300 to 2000 full time direct employment opportunities over the project lifetime.

The scale of the development will be dependent on the number of suitable areas that are within the Pentland Firth, but it is envisaged that at least one cluster of turbines could be installed. However, ideally a number of small clusters would be more efficient with respect to total energy output and costs.

4.3.3 Technological Considerations

Site Criteria

The selection of technology was predominantly based on the environmental characteristics of the proposed site. The following design criteria were considered:

- A water depth range of between 20-50 metres was advisable due to environmental constraints with respect to the present technological base available. Tidal current velocities of between $1 m.s^{-1}$ to $5 m.s^{-1}$ (2-10 knots) were also considered for the same reason.

- Geological and seabed characteristics were also an important consideration in order to establish adequate layouts for tide-mill arrays and the foundation type. This information was also useful in the consideration of siltation, erosion and sedimentation concerns.

- Weather conditions are an important consideration in the design of any support and rotor system. The design needed to withstand maximum storm waves and tidal surge forces. Surface piercing structures also needed to withstand maximum wind loads.

- The intended operational life of such systems is estimated to be 25 to 30 years, therefore, accessibility for maintenance and repair procedures was paramount. The support system must be designed to accommodate these needs.

- The location of the landfall site was also a consideration and needed to be in close proximity to the tide-mill arrays or to the nearest site suitable.

Selection of Technology

The technology used for the proposed project was based on the concept developed by Marine Current Turbines Ltd. (MCT), of which a demonstration project 'Seaflow' has been successfully completed in an area near Lynmouth, North Devon, with further developments being considered off Anglesey (refer to page 38). At the time this concept was the most advanced. Originally, a single axial flow turbine rotor on a mono-pile was to be used, where the rotor and the power train could be raised above sea level for maintenance. However, further studies by MCT Ltd. indicated that it would be more cost effective to install two turbine rotors on each pile rather than a single rotor with the same capacity. The technology in question was not suited for deep water due to engineering constraints, such as drilling capability and structural integrity issues, as well as the associated costs involved. Installation of turbines in deep water produces more costly electricity and it is clear that extrapolating for deeper depths additionally results in even higher costs (Prof. Peter Fraenkel, *pers comm.*).

The proposed concept was a 2-bladed, twin axial flow turbine mounted onto a mono-pile founded into the seabed. The support structure (mono-pile) is estimated to be 5m diameter and the diameter of the rotors will be approximately between 15m and 20m. The mono-pile itself would be installed from a jack-up barge equipped with a drilling rig. Once installed the pile would be grouted into position. Basically the design consists of 5 main components. These include the rotors, power train, mono-pile, pod and the power generation and transmission system.

Spacing of the turbines can be very dependent on the area in question, however in general the recommended spacing of the turbines was as follows:

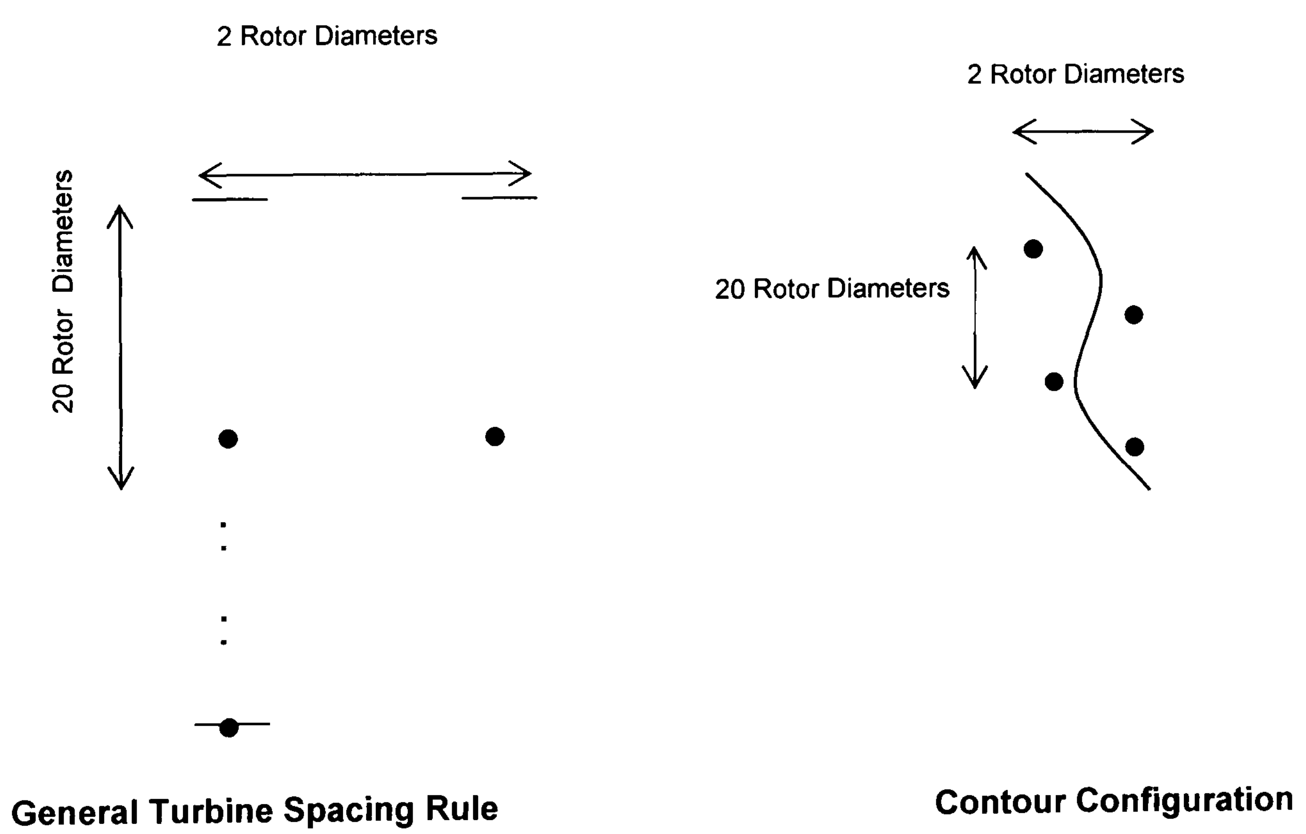


Figure 37: General Turbine Spacing and Configuration

It has been proposed that a good spacing arrangement consists of each turbine being spaced 2 rotor diameters apart with a 20 rotor diameter spacing arranged for turbines situated down-stream (DTI, 2001). However, for the area of the Pentland Firth it was envisaged that turbines would be placed along an appropriate depth contour in a zig-zag configuration, preventing total blockage of the channel and providing a better format for shipping exclusion zones.

4.4 Scoping of the Project

Impacts and constraints were identified and assessed using common EIA approaches, the full purpose of which was discussed and illustrated in **Chapter 3**.

Scoping involves the identification of issues that are associated with the proposed project and aims to achieve a focus on those issues and prioritise key processes within the project that may have a potential impact on the local environment.

4.4.1 Sources of Information

In order to scope for such a project, key organisations and interest groups were consulted to establish priority environmental issues concerning the project. Consultation was either through letter, e-mail, and telephone or through meetings. Consultees included JNCC, SNH, harbour and port authorities to name but a few. To establish a credible report, reliable and up to date information was essential. Many sources of information were used and consulted for subsequent evaluation and analysis. A summary of key consultations can be found in **Table 4** (pp.20).

4.4.2 Assessment of Activities

The scope of activities to be considered within the project that could have a potential impact on the environment is outlined in **Table 12**. They encompass most of the processes needed to accomplish the proposed development.

Table 12: Activities Considered within the Study

Process/Activity	Description
Initial Transportation	Movement of installation equipment and device parts
Installation	All activities/operations associated with the installation of the devices.
Installation of Cables	All activities associated with the laying of cables, including land-based construction activities
Operations and Maintenance	Includes all facets of the installed device in operation i.e. structure, rotor, generation of electricity etc.
Decommissioning	All activities/processes associated with the removal of devices at the end of their field life

4.4.3 Description of the Environment

The environmental assessment process relates the major activities that are associated with a proposed project to the environment in which they occur. With respect to this project, the environment was defined as a system, with combination of inter-related attributes that as a whole make up the physical, ecological and socio-economic conditions of the projects' surroundings.

Physical Environment

Within the report, the physical environment constituted these areas:

- the physical components of the air, water and land; and
- the processes that underpin those components.

Ecological Environment

Within the report, the ecological environment constituted:

- the biological components, such as the fauna and flora that are influenced by the physical environment.

Socio-economic Environment

Within the report the socio-economic environment constituted these main areas:

- recreation and tourism;
- commercial activities;
- industrial activities; and
- the people and communities that are influenced by these activities

In order to establish an impact assessment it is necessary to characterise the 'baseline' or 'pre-project' state of the surrounding environment. The purpose was therefore to describe the 'baseline' by presenting an overview of the physical and socio-economic environments of the project area. The following table (**Table 13**) details the environmental components that were considered and **Table 14** provides a summary of the environmental baseline conditions. This provided the basic context for the identification and assessment of environmental impact. A detailed description of the Pentland Firth environment can be found in Dacre and Bullen (2001).

Table 13: Environmental components considered

Type of Environment	Environmental Component
PHYSICAL	Coastal Geolography and Geology/Sediment Onshore Geology Sediment Transport Water Turbidity Water Characteristics (bathymetry, tides, wave climate, salinity, temperature, underwater sound) Climate and Atmosphere
ECOLOGICAL	Coastal and Marine Habitats Fauna and Flora Designated and Protected Areas
SOCIO-ECONOMIC	Shipping and Navigation Commercial Fisheries Activity Seabed Communications Dredging, Spoil, Burial Sites and Industrial Discharges Oil and Gas Fields Military Activity Marine Archaeology Recreation and Tourism Electrical Grid Infrastructure Technological Base

Table 14: Summary of the Environmental Baseline Conditions of the Pentland Firth [adapted from Dacre & Bullen, 2001].

Type of Environment	Environmental Component	Baseline Conditions
Physical	Coastal Geography and Geology	Coastal geology is relatively uniform, formed primarily of Middle and Upper Devonion (Old Red Sandstone), which are sedimentary rocks. Geography is variable where the coastline consists of high cliffs, low rocky shores and enclosed coastlines.
	Offshore Geology and Seabed Sediment	Solid geology comprises middle Devonion rocks. Very exposed with bedrock outcrop due to high tidal velocities. Sediments characterised by sand and gravels and are known for high biogenic carbonate content. To the east and west of the firth, sand waves are common over large areas.
	Sediment Transport	Due to high tidal velocities the Pentland Firth is almost entirely scoured. A shed line exists between Stroma and Swona with sediment being carried west to east. Where tidal velocities decrease, sand and gravel is deposited to form the 'Sandy Riddle'.
	Water Characteristics (bathymetry, tides, wave climate, salinity, temperature, underwater sound)	Coastline is >20m deep reaching approximately 60m 5km from the coastline. Within the firth there are several banks with depth contours of 65m encircling each. Deep pockets of 100m also exist. The area has a mean tidal range of 3m. Strong tidal currents predominate reaching speeds in excess of 4.5m/s. Mean wave period is approximately 4-6 seconds. Salinity is relatively constant throughout the year. Mean surface temperatures in the summer and winter are 12.5 and 8.5°C respectively. Ambient sound levels are thought to be normal ambient conditions of 90dB re 1μPa.
	Water Turbidity	Due to the tidal characteristics of the Pentland Firth, there are high percentages of suspended sediment, therefore turbidity would be high.
	Climate and Atmosphere	Area has strong winds. Approximately 75% of the year the area has an hourly mean wind speed of 4m/s, with winds greater than 8m/s occurring for over 25% of the year.

Table 14 Continued: Summary of the Environmental Baseline Conditions of the Pentland Firth [adapted from Dacre & Bullen, 2001].

Type of Environment	Environmental Component	Baseline Conditions
Ecological	Coastal and Marine Habitats	Coastal and marine habitats include cliffs, coastal sand dunes, shingle shorelines and the seabed, where the seabed is dominated by scoured bedrock.
	Seabed Fauna and Flora	Due to the high tidal velocities, very specialised benthic communities occur. The exposed habitats of the area around the coast of the Scottish mainland are known to be rich in sea squirts and sponges, especially *Dendrodoa* and *Clathrina* respectively. Laminarian kelps extend down to a maximum depth of 25 metres below chart datum, usually with *Alaria esculenta* present at exposed sites and *Saccorhiza polyschides* at more sheltered areas. Common fauna species include Dead Man's Fingers *Alcyonium digitatum*, the Feather Star *Antedon bifida* and Scallops *Pecten maximus*. To the east, Duncansby Head seems to act as a distribution boundary for intertidal 'southern' species that do not actually occur on the east coast. These include the upper shore barnacle *Chthamalus montagui*, the gastropod *Littorina neritoides* and the topshell *Gibbula umbilicalis*. Where currents are strong south of the Scapa Flow and Sound of Hoxa extensive communities of Hydroids and Bryozoans occur with soft coral growth and the coarse sands of the area are characterised by the Sea Cucumber (*Neopentadactyla mixta*) and in deeper water the Brittle Star *Ophiocomina nigra*. At Switha, which is characterised by steep sloping bedrock, there is a dense kelp *Laminaria hyperborea* forest that extends to 20 metres depth, which also supports dense growths of soft coral, such as Dead Mans Fingers. Maerl is also present around Switha. Where there is increased current flow attached species dominate. Due to the extreme fast flowing currents and the substrata available in the Pentland Firth, it can be assumed that less species will occur deeper into the firth. However, without any benthic survey data this cannot be fully concluded No rare species have been found within the area of the proposed project.
	Seabirds	It must be noted that the area is internationally important for seabirds and is one of the most important regions in Europe for offshore seabirds and is especially important for cliff- and island

		nesting birds. The near shore waters of the area hold vulnerable concentrations of birds throughout the year. Guillemots, Razorbills and Kittywakes are the most abundant and widespread of all the bird species found in the area, which is one of the most important breeding areas in Scotland. The Razorbill numbers account for 20% of the worlds population. There are also notable concentrations of Fulmar, Cormorant, Gannet, Shag, Skua, Tern and an array of gull species
	Marine Mammals	The Harbour (Common) Seal *Phoca vitulina* and the Grey Seal *Halichoerus grypus* both breed within the area of the Pentland Firth and the area accounts for a large percentage of the UK population. The most common species that have been recorded are the Harbour Porpoise *Phocoena phocoena*, Bottlenose Dolphin *Tursiops truncatus*, Minke Whale *Balaenoptera acutorostrata* and the White-beaked Dolphin *Lagenorhynchus albirostris*. The White-sided Dolphin *Lagenorhynchus acutus*, Killer Whale *Orcinus orca* and Long-finned Pilot Whale *Globicephala melas* usually occur offshore, but have been known to venture nearshore. The Risso's Dolphin *Grampus griseus* is often sited within the Pentland Firth area and the north of Orkney.
		The Pentland Firth Islands SPA consists of the small uninhabited islands of Swona and Muckle Skerry situated in the Pentland Firth between South Ronaldsay and mainland Scotland. The SPA supports a nationally important breeding population of Arctic Tern *Sterna paradisaea,* which qualifies the area for such status. Non-qualifying interest includes an overall bird breeding assemblage, which regularly supports about 7700 individuals of 16 species. Switha SPA is a small island east of South Walls and includes the whole island. The island qualifies due to its internationally important wintering population of Greenland Barnacle Geese *Branta leucopsis.* Approximately 1120 individuals are present annually, representing 4% of the British population. Other SPAs are located on the North Caithness Cliffs. These include the areas of John O'Groats to Duncansby Head, Dunnet Head, Holburn Head and Red Point Coast. This is again due to important populations of bird species. Within the area Special Areas of Conservation (SACs), Biogenetic Reserves and Ramsar sites have not been designated at this time.

Table 14 Continued: Summary of the Environmental Baseline Conditions of the Pentland Firth [adapted from Dacre & Bullen, 2001].

Type of Environment	Environmental Component	Baseline Conditions
Socio-economic	Shipping and Navigation	Vessels transiting the Firth use two navigation routes – the central (main) navigation channel is known as Outer Sound, while the channel between Stroma and Caithness is known as Inner Sound. Whilst the bulk of large through traffic will remain within the Outer Sound, the Inner Sound is also regularly used by fishing vessels, smaller cargo ships and occasional pleasure craft. Traffic density is approximately 140 vessels per week. Around 22% of the vessels carry cargoes classified as hazardous material.
	Commercial Fisheries Activity	The very nature of the fast-flowing channel restricts development of both demersal and pelagic fish species effort, and consequently static gears targeting shell-fisheries form the predominant activity. Generally there are around a dozen full-time boats working from the Caithness side and a similar number working from Orkney.
	Seabed Communications	Seabed electricity power cables linking Orkney to the Scottish mainland from Dunnet Bay are routed west of the Firth to avoid areas of high currents. Likewise there are no seabed telecommunications links in the Pentland Firth area.
	Dredging, Spoil, Burial Sites and Industrial Discharges	Currently there are no sites where dredging for marine aggregates takes place in North-East Scotland. Dredging in the Pentland Firth area would appear to be technically unfeasible. There is a designated (human) burial at sea site located off Dunnet Head. The largest trade discharges in the region of the Firth are associated with the UK Atomic Energy Authority's (UKAEA) site at Dounreay, which now acts as a depository for radioactive material. Radioactive particles discharged from the complex have been regularly found in seabed sediments and on nearby beaches. In 1997, as a precautionary measure, The Scottish Office imposed an order prohibiting fishing and the removal of seafood within a 2km radius of the Dounreay sea pipeline.
	Oil and Gas Activity	A review of current oil and gas licenses has indicated no licensed Operator Blocks within the Pentland Firth (Blocks 11/9 and 11/10). The nearshore locations and the nature of the underlying geology are not commensurate with the exploration of hydrocarbons, and any future interest in these blocks is unlikely.
	Military Activity	There is a designated military practice area at Cape Wrath off the north west coast (approx. 60 miles west of Dunnet Head). This area is still in use as an air force target practice area. There are no naval exercises carried out within the Pentland Firth

		area. Submarine movements around the UK are designed to minimise possible interactions with fishing vessels and when transiting the Pentland Firth, such vessels would be required to be on the surface.
	Marine Archaeology	Their database revealed 45 identified wreck sites within the Pentland Firth area. This list was reduced to 32 by considering only those sites within the geographic confines of the study area. The majority of wrecks lie in close proximity to coasts and skerries having become grounded due to navigational error (e.g. the majority are concentrated around Duncansby Head, but also around Stroma and Pentland Skerries – both situated along the route of the main navigation channel).
	Recreation and Tourism	The scenery, coastline and wildlife of the north of Scotland, including the Pentland Firth, is a major feature in attracting tourists to the area. Much of the recreation, however, tends to be on an informal basis with little infrastructure to support it. The scenic value of the Pentland Firth is appreciated from both Caithness and Orkney coastlines with several purpose built viewing areas and car-parks.
	Electrical Grid Infrastructure	The UK power system is characterised by a 400-275-132kV grid transmission system, which by a series of step-downs in voltage through bulk electricity points delivers power to lower voltage distribution networks. A 275 kV line links Dounreay, close to the Pentland Firth coastline, with Inverness. The grid in the coastal areas adjacent to potential Pentland Firth tidal development areas (between Dunnet Head and Duncansby Head) is of 11 kV rating. The nearest 33 kV lines are at Dunnet Bay where 2 subsea cables leave to connect Orkney to the grid. Between Thurso and Dounreay there is a 132kV line. The 275kV connection at Dounreay was established to accept nuclear-generated electricity into the grid. Generation of electricity no longer takes place at the plant following the closure of the 3 reactors at the site.
	Technological Base	The technological bases of both Orkney and Caithness are similar, with the major population centres providing market town service industries, support services and transport and communication infrastructure.

4.4.4 Identification of Key Deployment Activities

In order to identify and assess the interactions between the project activities and the environment, the key stages of deployment process were considered and related to the processes within the environmental components (**Table 15**).

Table 15: Key Stages of Deployment Activities Considered

Key Stages of Deployment	
Transportation	▪ Movement of installation equipment ▪ Transportation of foundations/towers/nacelles/blades etc.
Installation	▪ Physical presence of installation equipment ▪ Piling foundations (if required) ▪ Grouting/cementing of material during installation ▪ Disposal of spoil from drilling (if required) ▪ Minor fuel/oil leaks
Installation of Cables	▪ Cable installation (trenching ops/laying on seabed) ▪ Construction activities - land based
Operations and Maintenance	▪ Overall structure presence ▪ Rotor effects ▪ Extraction of tidal current energy ▪ Routine maintenance/emergency repairs ▪ Physicality and Ops of grid connections ▪ Overall generation of electricity
Decommissioning	▪ Physical removal of pile/tower/nacelle/blades etc. ▪ Disposal ▪ Presence of decommissioning vessels

4.4.5 Legislative Framework and Consents Process

The Scottish coastline is an important resource in terms of its beauty, wildlife and habitat, as well as a working environment, where people depend upon such for the traditional and new industries of the sea and coastline. Such activities include fishing, the oil industry and tourism, which all have an effect on the environment as a whole and the area of the Pentland Firth is no exception.

While recognising the importance of renewable energy development it is also important to find a balance between local conservation, the protection of the marine environment and harmony between anthropogenic users and new development. Therefore, it is essential that planning guidelines, statutes and obligations are adhered to. In the case of the Pentland Firth, any development is subject to the requirements of applicable Scottish, UK and EU legislation, as well as a number of International treaties and agreements.

Over recent years, the planning and environmental consents process for marine renewables has been under review and both the UK Government and Scottish Executive have put forward a consultation process to underpin this and to amend such consents process to align with the EIA Directive. The Draft Regulatory Impact Assessment was also initiated to view such amendments and review the options being explored by the DTI. The DTI have recently produced Guidance on Consenting Arrangements in England and Wales for a Pre-Commercial Demonstration Phase for Wave and Tidal Stream Energy Devices (Marine Renewables) (DTI, 2005) and the BWEA have also provided a summary of key legislation and consents (BWEA, 2005).

At present, unlike other offshore industries, the marine renewables have two processes which reflect developments in English and Welsh waters and developments in Scottish waters.

A detailed summary of key legislation can be referred to in **Appendix 10**. It is common to find overlaps in the stages of development with respect to applicable legislation. The summary is also applicable to a majority of offshore development scenarios.

Planning and Consents Process

Scottish Waters

Currently, Planning Advice Note 45 (Revised 2002), PAN 45 should be read in conjunction with the National Planning Guidelines, NPPG 6. In summary, PAN 45 details the characteristics of the main types of electricity generation developments using renewable energy sources likely to be deployed in Scotland. The revised PAN 45 replaces the 1994 version. NPPG 6 provides details of Scottish

Executive policy on nationally important land use and planning with respect to renewable energy developments.

With respect to offshore renewable developments in spring 2001 a new statutory order specifying a generating capacity threshold for offshore wind or water driven technology of 1MW has brought all developments into the scope of Section 36 of the Electricity Act 1989. With a view to this change, such developments also fall within schedule 2 of the EIA regulations and are therefore subject to a full EIA.

Within Scottish Waters, it is the responsibility of the Energy Division (ED) of the Scottish Executive to convene a meeting of all consenting authorities with the developer to discuss site specific consent requirements and scoping of an environmental statement, such as the Rural Affairs Division (RAD), and Transport Division etc.

The Food Environment Protection Act (FEPA) provides the licence for the depositing of structures/articles (not cables) on the seabed below mean high water springs. Its purpose is to protect the marine environment, human health and other sea users and the ED will send separate applications plus an Environmental Statement to FEPA and to the Rural Affairs Division (RAD). Particular care is taken in assessing applications that may have detrimental environmental implications. It is the ED's responsibility to implement the EC Council Directive 85/337/EEC on EIA, which is in turn part of the FEPA process. Fisheries liaison is also required through the Model Clauses of Licence HSE Offshore Safety Division Operations Notice 3. Installation itself requires adherence to a number of guidelines with respect to transportation of equipment and structures and activities such as, disposal of spoil, rock dumping etc.

English and Welsh Waters

The DTI has established the Offshore Renewables Consents Unit (ORCU) to serve as a focal point for development applications and to promote a co-ordinated approach to administer consents required by developers. The ORCU has the responsibility in handling applications under both the Electricity Act 1989 (EA) and the Transport and Works Act 1992 (TWA).

ORCU has been initiated to work closely with the Marine Consents Environmental Unit (MCEU), which constitutes DEFRA's marine environment branch and DfT's Ports Division. In addition, the Environmental Resources Development Unit (ERDU) is also consulted with respect to proposed offshore renewable energy developments.

Offshore renewable development on Crown Estates marine estate requires the granting of a lease by the CE.

Consenting requirements can be site dependent, however, there are a number of generic consents that are required for all potential developments. These include:

- Electricity Act 1989 – Section 36
- Food and Environment Protection Act – Section 5
- Coast Protection Act 1949 – Section 34
- Town and Country Planning Act 1990 – Section 90
- Transport and Works Act 1992

To bring smaller developments within the remit of the EA and thus subject to the EIA regulations, the EA was extended to cover all offshore developments above 1MW capacity.

For England and Wales there are two consent routes available to developers:

- Electricity Act/FEPA/CPA route

Where the principal consents required include the:

  - Electricity Act 1989
  - FEPA 1985
  - Coast Protection Act 1949

And other consents may include the:

  - Town and Country Planning Act 1990
  - Electricity Act 1989
  - Water Resources Act 1991

Wildlife and Environmental Protection

There is an extensive legislative framework concerning wildlife and environmental protection, which can be relatively complex.

As stated in section 3.1, the CEC will not issue a lease until they are satisfied that all statutory consents have been obtained. Therefore, the proposal has to comply with the requirements of the EIA Directive (97/11/EC). Furthermore, all proposals that may affect a site designated under the Habitats Directive (92/43/EEC) and the Birds Directive (79/409/EEC) are required to be subject to an appropriate assessment under regulation 48 of the Conservation Regulations 1994.

Through the Habitats Directive and the Birds Directive member states are required to designate sites to form part of the EC Natura 2000 network. The implementation of the Habitats Directive (92/43/EEC) in offshore waters was started in 2000 and various habitats and species can be put forward as having conservational importance and are listed in Annex I and Annex II of the Habitats Directive. **Table 16** lists those habitats and species likely to be found in UK waters.

Table 16: Habitats and Species found in UK Waters listed in Annex I and II of the Habitats Directive.

Habitats Listed in Annex I	Species Listed in Annex II
Estuaries Lagoons Large shallow inlets and bays Submerged or partly submerged sea caves Sandbanks which are slightly covered by sea water all the time Mudflats and sandflats not covered by sea water at low tide Reefs Submarine structures made by leaking gases	Grey seal - *Halichoerus grypus* Common (or harbour) seal - *Phoca vitulina* Harbour porpoise – *Phocoena phocoena* Bottlenose dolphin - *Tursiops truncatus* Otter - *Lutra lutra* Loggerhead turtle – *Caretta caretta* Lamprey – *Petromyzon marinus* Sturgeon – *Acipenser sturio* Shad – *Alosa spp.*

Other non-statutory designations were also highlighted. Though these are not legally binding, they are seen as important areas with respect to wildlife and environmental conservation and protection and in some cases such areas require consultation with relevant statutory agencies before the commencement of any development on or adjacent to the area concerned.

Role of Statutory Agencies

Essentially for developments in Scottish waters, it is Scottish Natural Heritage (SNH) and the Scottish Environmental Protection Agency (SEPA) that are responsible for providing advice on policies for or affecting nature conservation and environmental protection. SNH are primarily responsible for establishing and managing designated areas and for disseminating information about conservation and advising on ecological change. Research is also commissioned in support of these duties. SEPA are mainly responsible for environmental protection in Scotland and Fisheries Research Services (FRS) is consulted with respect to fisheries and chemical risk issues for Scottish waters.

English and Welsh statutory agencies include English Nature (EN) and the Countryside Council for Wales (CCW) respectively. The Centre for Environment, Fisheries and Aquaculture Science (CEFAS) is the English equivalent to FRS.

The Joint Nature Conservation Committee (JNCC) is currently advisor to the government on wildlife issues, undertaking national and international work on behalf of all UK statutory agencies.

4.5 Environmental Impact Identification and Significance

The purpose of the identification process is to provide the following:

- establish the most likely environmental effects;
- ensure compliance with regulations;
- distinguish between positive and negative, large and small, temporary and permanent, reversible and irreversible impacts; and
- identify possible secondary, indirect, cumulative, as well as direct effects.

The identification of environmental effects and impacts is probably one of the most critical steps in the whole environmental feasibility process. When considering such impacts it is important to use a systematic approach. All in all this helps to review all the main aspects of the proposal with respect to the environment and helps the process of differentiating the important issues from those that are less important, as well as providing consistency.

Within the context of the Pentland Firth study, the EIA method was not formulated to produce specific answers (i.e. full quantification of potential impacts), but in effect gives a systematic appraisal of a wide variety of information and data collected, formulating a non-quantitative prediction of potential environmental impacts.

The following sections outline the methodology used to identify those aspects of the proposed project that were thought to have a potential environmental impact, whether it be within the physical or ecological environment or in a socio-economic context. The methodology consists of the following:

- Identification of key interactions;
- Likelihood and magnitude associated with those interactions; and
- Identification of the most significant issues within the project

4.5.1 Identification of Key Environmental Interactions

The interactions between the project activities and the environment were initially identified in list form then summarised using a matrix system (**Figure 38**). Where the project activity has the potential to cause an impact to the environment a '•' indicates this. This provided a simple representation of the project and the environmental interactions, providing a basis for determining possible implications of project impacts and effects on the various environmental components. However, the matrix itself has an inability to take account of the fact that environmental components may be affected through more than one environmental pathway and by more than one aspect of the development. In reality, potential impacts are a complex web of interactions. Hence, it fails to draw upon the additive, synergistic or neutralising affect some interactions may have. A simplified conceptual diagram has been included (**Figure 39**) to illustrate the inter-relationship and hence, the complexity of potential impacts within the marine 'natural' environment. In addition, a conceptual diagram illustrating the interactions of the socio-economic environment (**Figure 40**) has been developed and should be taken in the context of a working diagram. With this in mind, adjustments and modifications could well be made in the future as more knowledge is gained in the field.

4.5.2 Significance of Impacts

Having provided an initial assessment of the project activities and the physical, ecological and socio-economic components they may affect, it was necessary to provide focus and priority on each interaction. This was established by applying significance, using the following criteria set out in the following sections. These pertain to the various pressures that influence the environmental management of a development and include the following criterions:

- Environmental Risk: the core of impact assessment has been the scientific prediction of possible impacts. However, there are many areas where the consequences are unknown or cannot be established due to lack of scientific knowledge. Society's expectations of what is acceptable can also be based on perceptions rather than environmental integrity. There have also been instances where science has failed to recognise potential threats and the public domain to some extent has lost faith in the ability of science;
- Legislation and Policy: overall this bridges the gap between scientific knowledge and consultative requirements. However, the significance of regulation in an area may be very different from the significance arising from a scientific or consultative origin.
- Consultative Concerns: the need to obtain a 'licence to develop' is recognised as being a highly important procedure in any project. Consultative views may still be subjective and even emotionally driven, more than being objective, but they are nevertheless important.

Definitions for establishing significance in each of these criterions were related to:

- Magnitude and likelihood of event leading to environmental impact;
- Level of legislation and policy requirements; and
- Level of importance expressed by those consulted.

There is no doubt that this process was still subjective and open to interpretation, but this method does provide consistency through clear definition. Every method holds its inherent advantages and disadvantages and the choice reflects the scope of the case study at the time.

4.5.3 Environmental Impact Assessment

The environmental impact within each environmental interaction, was assessed by determining the likelihood (i.e. temporary, long-term), the magnitude, the importance of legislation and policy and the importance of consultative concerns.

Likelihood and Magnitude

Likelihood

In order to determine the likelihood of occurrence a score between 1 and 5 was allocated (**Table 17**). Those scores that are low are most likely to occur in the construction and decommissioning phase where impacts are most likely to occur once or twice for a relatively short period of time. Those that are designated a moderate to high level are those activities that may affect an environmental component more than once in a year due to seasonal influences and breeding sensitivities. Interactions given a level 5 are expected to influence the environment on continuous or near continuous basis, causing an irreversible change of environmental components over time.

Table 17: Determination of Likelihood

Occurrence	Level
Continuous	5
High	4
Moderate	3
Minimum	2
1 off event	1

Magnitude

Magnitude of each potential impact was rated with respect to shades for easy reference. Some effects were considered to be positive and were subsequently included. It must be noted, however, that regulatory authorities in some countries do not recognise 'environmental change' as positive in any instance. In addition, it should be noted that spatial scale of impact influence has not be considered within magnitude significance because such spatial influence is project dependent and site specific and as such, spatial influence cannot be accurately identified unless site specific surveys and modelling studies have been carried out to determine zones of influence.

The overall environmental significance for each component with respect to likelihood and magnitude levels is shown in **Table 18**.

Table 18: Levels of Magnitude

Magnitude Level	Definition
5 Severe	Impacts in the local environment are considered to be long-term, with poor potential for recovery. Effects are unpredictable as yet, but may cause permanent change to local environment. Protected areas would also be under threat of such damage and include all types of designated area. Long term detrimental effect on infrastructure and local people. High impact on other sea users.
4 Major	Impacts are considered medium term, with recovery expected to be likely within 2 to 5 years. May have effect on internationally or nationally protected species, designated sites and habitats. Possible effect on infrastructure and local residence. Impact on sea users.
3 Moderate	Impacts leading to short-term damage with recovery expected within 2 years. May have effect on protected local important sites. Mitigation and remedy possible with consultation. Possible nuisance may be caused, but only over the short-term.
2 Minor	Changes caused by impact are within the scope of natural variability, but are potentially detectable
1 Neglible	Impacts and changes caused are unlikely to be detected or measurable
+ Positive	Some aspects of the project may act as an enhancement to the area, whether within a physical, biological or socio-economic scenario i.e. benefit to the local, regional and national economy; tourism etc.

Phase	Project Activity \ Environmental Component	Climate/Atm	Tidal currents	Wave climate	Salinity	Temperature	Ambient noise	Sedimentation	Seabed	Water turbidity	Water quality	Coastal Env.	Benthos	Pelagic org.	Demersal org.	Plankton	Vegetation	Seabirds	Pinnipeds	Cetaceans	Desig. Areas
		PHYSICAL ENVIRONMENT											BIOLOGICAL ENVIRONMENT								
INSTALLATION PHASE	Transport of installation equip.	•					•														
INSTALLATION PHASE	Physical presence of install equip								•		•		•	•	•			•	•	•	
INSTALLATION PHASE	Piling foundations						•	•	•	•	•		•	•	•			•	•	•	
INSTALLATION PHASE	Grouting/Cementing							•		•	•		•	•	•			•	•	•	
INSTALLATION PHASE	Disposal of spoil							•	•	•	•	•	•	•	•						
INSTALLATION PHASE	Minor fuel/oil leaks							•	•		•	•	•	•	•	•	•	•	•	•	•
INSTALLATION PHASE	Installation of foundation/tower etc						•	•	•	•	•	•	•	•	•			•	•	•	
INSTALLATION PHASE	Installation of cables						•	•	•	•	•	•	•	•	•		•	•	•	•	•
INSTALLATION PHASE	Land based Activities						•	•				•					•	•			•
OPERATIONS PHASE	Overall structure presence		•	•			•	•	•	•	•	•	•	•	•	•		•	•	•	•
OPERATIONS PHASE	Rotor effects		•	•			•	•	•	•	•	•	•	•	•	•		•	•	•	•
OPERATIONS PHASE	Extraction of tidal energy		•					•	•	•	•	•	•	•	•	•					•
OPERATIONS PHASE	Routine maintenance/repair						•			•	•		•	•	•			•	•	•	
OPERATIONS PHASE	Physicality/Ops of grid connection						•					•					•				•
OPERATIONS PHASE	Overall generation of electricity	•																			
Decom	Presence of decomm vessels	•					•		•									•	•	•	
Decom	Physical removal of structure		•				•	•	•	•	•	•	•	•	•	•		•	•	•	
Decom	Disposal										•	•									

Phase	Project Activity \ Environmental Component	Commercial Fishing	Shipping/Navigation	Cables/Pipes	Oil/Gas fields	Military Activity	Marine Archaeology	Tourism/Recreation	Tech/Ind Base	Grid infrastructure	Local residence	Local infrastructure	Policy and Consents	RE Awareness	Tech/Ind Experience	Employment	Energy Industry/Exp
		SOCIO-ECONOMIC ENVIRONMENT															
INSTALLATION PHASE	Transport of installation equip.	•	•			•		•	•		•	•			•	•	
INSTALLATION PHASE	Physical presence of install equip	•	•			•	•	•	•		•	•			•	•	
INSTALLATION PHASE	Piling foundations	•		•			•		•						•	•	
INSTALLATION PHASE	Grouting/Cementing	•	•				•	•	•						•	•	
INSTALLATION PHASE	Disposal of spoil	•	•				•		•			•			•	•	
INSTALLATION PHASE	Minor fuel/oil leaks	•					•	•			•	•			•	•	•
INSTALLATION PHASE	Installation of foundation/tower etc	•	•	•		•	•	•	•		•	•			•	•	
INSTALLATION PHASE	Installation of cables	•	•	•		•	•	•	•			•			•	•	
INSTALLATION PHASE	Land based Activities							•	•		•	•			•	•	
OPERATIONS PHASE	Overall structure presence	•	•			•	•	•			•			•			•
OPERATIONS PHASE	Rotor effects	•	•			•	•	•									
OPERATIONS PHASE	Extraction of tidal energy					•			•					•			
OPERATIONS PHASE	Routine maintenance/repair	•	•			•		•	•		•	•			•	•	•
OPERATIONS PHASE	Physicality/Ops of grid connection							•	•	•	•	•			•	•	
OPERATIONS PHASE	Overall generation of electricity								•	•	•		•	•	•	•	•
Decom	Presence of decomm vessels	•	•			•		•	•		•	•			•	•	
Decom	Physical removal of structure	•	•			•	•	•	•	•	•	•		•	•	•	
Decom	Disposal							•	•						•	•	

Figure 38: Project Activities and Environmental Interactions Matrix

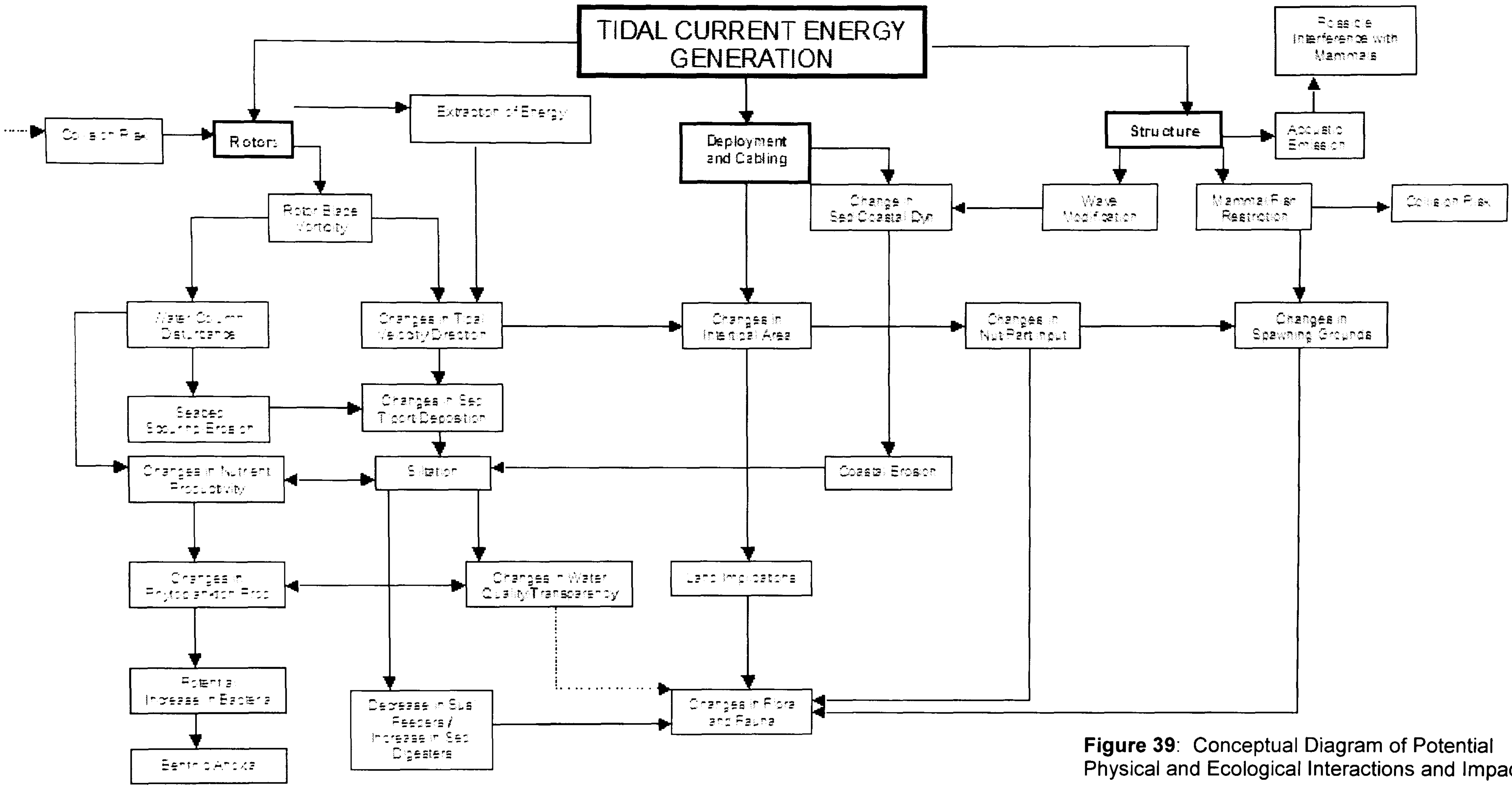


Figure 39: Conceptual Diagram of Potential Physical and Ecological Interactions and Impacts

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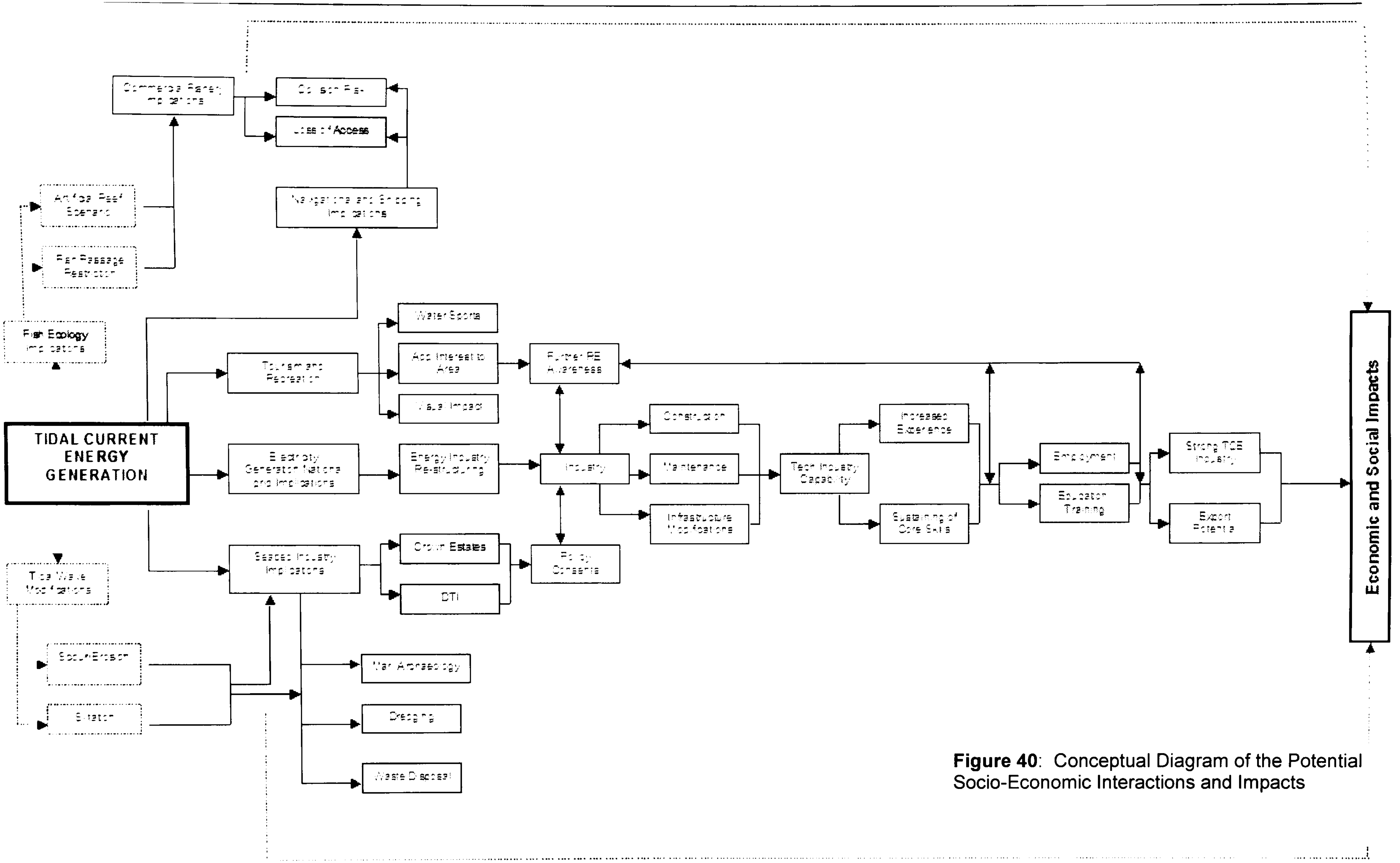

Figure 40: Conceptual Diagram of the Potential Socio-Economic Interactions and Impacts

Phase	Project Activity \ Environmental Component	Climate/Atm	Tidal currents	Wave climate	Salinity	Temperature	Ambient noise	Sedimentation	Seabed	Water turbidity	Water quality	Coastal Env	Benthos	Pelagic org.	Demersal org.	Plankton	Vegetation	Seabirds	Pinnipeds	Cetaceans	Desig. Areas
		PHYSICAL ENVIRONMENT											BIOLOGICAL ENVIRONMENT								
INSTALLATION PHASE	Transport of installation equip.	1					1														
INSTALLATION PHASE	Physical presence of install equip								1		1		1	1	1			1	1	1	
INSTALLATION PHASE	Piling foundations						1	1	1	1	1		1	1	1			1	1	1	
INSTALLATION PHASE	Grouting/Cementing							1		1	1		1	1	1			1	1	1	
INSTALLATION PHASE	Disposal of spoil							1	1	1	1	1	1	1	1						
INSTALLATION PHASE	Minor fuel/oil leaks							1	1		1	1	1	1	1	1	1	1	1	1	1
INSTALLATION PHASE	Installation of foundation/tower etc						1	1	1	1	1		1	1	1			1	1	1	
INSTALLATION PHASE	Installation of cables						1	1	1	1	1	1	1	1	1		1	1	1	1	1
INSTALLATION PHASE	Land based Activities						1	1				1					1	1			1
OPERATIONS PHASE	Overall structure presence		5	5			5	5	5	3	3	5	5	4	4	1		4	4	4	5
OPERATIONS PHASE	Rotor effects		5	5			5	5	5	5	5	5	5	3	3	1		3	3	3	3
OPERATIONS PHASE	Extraction of tidal energy		5					5	5	5	5	5	5	5	5	1					2
OPERATIONS PHASE	Routine maintenance/repair						3			3	3		3	3	3			3	3	3	
OPERATIONS PHASE	Physicality/Ops of grid connection						5					5					1				1
OPERATIONS PHASE	Overall generation of electricity	5																			
Decom	Presence of decomm vessels	1					1		1									1	1	1	
Decom	Physical removal of structure		1				1	1	1	1	1	1	1	1	1	1		1	1	1	
Decom	Disposal										1	1									

Phase	Project Activity \ Environmental Component	Commercial Fishing	Shipping/Navigatio	Cables/Pipes	Oil/Gas fields	Military Activity	Marine Archaeology	Tourism/Recreation	Tech/Ind Base	Grid infrastructure	Local residence	Local infrastructure	Policy and	RE Awareness	Tech/Ind	Employment	Energy Industry/Exp
		SOCIO-ECONOMIC ENVIRONMENT															
INSTALLATION PHASE	Transport of installation equip.	1	1			1		1	1		1	1			1	1	
INSTALLATION PHASE	Physical presence of install equip	1	1			1	1	1	1		1	1			1	1	
INSTALLATION PHASE	Piling foundations	1		1			1		1						1	1	
INSTALLATION PHASE	Grouting/Cementing	1	1				1	1	1						1	1	
INSTALLATION PHASE	Disposal of spoil	1	1				1		1			1			1	1	
INSTALLATION PHASE	Minor fuel/oil leaks	1					1	1			1	1					
INSTALLATION PHASE	Installation of foundation/tower etc	1	1	1		1	1	1	1		1	1			1	1	1
INSTALLATION PHASE	Installation of cables	1	1	1		1	1	1	1			1			1	1	
INSTALLATION PHASE	Land based Activities							2	2		2	2			2	2	
OPERATIONS PHASE	Overall structure presence	5	5			2	1	3			3			4			4
OPERATIONS PHASE	Rotor effects	2	2			2	2	2									
OPERATIONS PHASE	Extraction of tidal energy						2			5				5			
OPERATIONS PHASE	Routine maintenance/repair	3	3			3		3	3		3	3			3	3	3
OPERATIONS PHASE	Physicality/Ops of grid connection							1	1	1	1	1			3	3	
OPERATIONS PHASE	Overall generation of electricity								2	5	3		2	3	3	3	3
Decom	Presence of decomm vessels	1	1			1		1	1		1	1			1	1	
Decom	Physical removal of structure	1	1			1	1	1	1	1	1	1			1	1	
Decom	Disposal							2	1						1	1	

Magnitude Level			
Severe	Moderate	Negligible	
Major	Minor	Positive	

Likelihood Level		
5 Continuous	3 Moderate	1 1 off event
4 High	2 Minimum	

Figure 41: Likelihood and Magnitude Significance Matr

4.5.4 Legislation and Policy

The project collaborators and everyone involved should be committed in conducting all activities in accordance with applicable legislation and policy, whether under international obligation or under local policy. When considering the significance of legislation and policy, priority was given to those scenarios and activities that affected legislation controlled areas. However, it must be stated that with less prioritised situations legislation should still be adhered to and measures should always be taken to minimise risk of detrimental environmental impact, despite any risk being low.

Table 19: Significance of Legislation and Policy

Legislative/Policy Scenario	Level
Clear legislative and policy driven obligations including permissions, planning, consents, waste management, conservation and protection etc. that must be specifically adhered to.	3
Certain obligations with respect to acquiring permissions and informing other parties may be involved. Activities potentially affecting the integrity of international obligations with regard to conservation and biodiversity, where the project should be compliant.	2
Project specific activities that could potentially be affected by non-statutory designated areas, which should be considered carefully, whereby all measures should be undertaken to minimise or avoid detrimental impact.	1

4.5.5 Consultative Concerns

Consultation and discussion was an important process within the environmental assessment and a wide range of organisations and individuals were contacted throughout the environmental study. A list of all contacts made can be found in **Table 20**. The level of concern regarding each issue was split into three categories:

Table 20: Significance of Consultative Concerns

Concern Categories	Level
There is a widely held concern, which corresponds to feeling that project activity will have a long-term effect and measures will have to be taken to mitigate that concern.	a
Local concern, where issues have been raised with moderately to low impact potential issues	b
Issues that may affect individual people and, local businesses that can be mitigated fully. Where concerns have been raised with issues that are deemed non-impact specific.	c

Complete overviews of the concerns expressed by the organisations contacted are addressed in **Chapter 5**. However, following is a summary of those concerns expressed:

- Scottish Natural Heritage (SNH) expressed concern about the implications of construction and the disturbance of breeding seabirds and the affect construction activities may have on adjacent areas; there was also concern regarding the precautionary principle of monitoring and the cumulative effect with adjacent operations, such as the Flotta terminal and other human operation.

- Concerns were expressed with regard to the effect on Cetacean movement and migration within the area due to the possible acoustic emissions from tidal current energy devices; collision risk was also a concern.

- The Orkney Seal Rescue Centre also expressed concern with respect to Seal collision with blades and the effect construction activities would have on breeding Seals.

- The Royal Society for the Protection of Birds (RSPB), indicated concern again about the implications of construction on breeding birds and also suggested there was a slight concern with regard to diving birds in the vicinity of a development.

- There was concern about the possible landfall site being situated near Dounreay nuclear power plant and possible radioactive substances within the sediments surrounding the area and the potential contamination issues this may have through the construction phase of a development.

- Harbour authorities showed particular concern with problems associated with the established traffic patterns and navigational difficulties commonly encountered within the Firth.

- Concern was also expressed with the possible reduction of the already limited navigational channels that exist and the effect this would have on ship operation and fishing boats.

A matrix indicating legislation and consultative significance is shown in **Figure 42**.

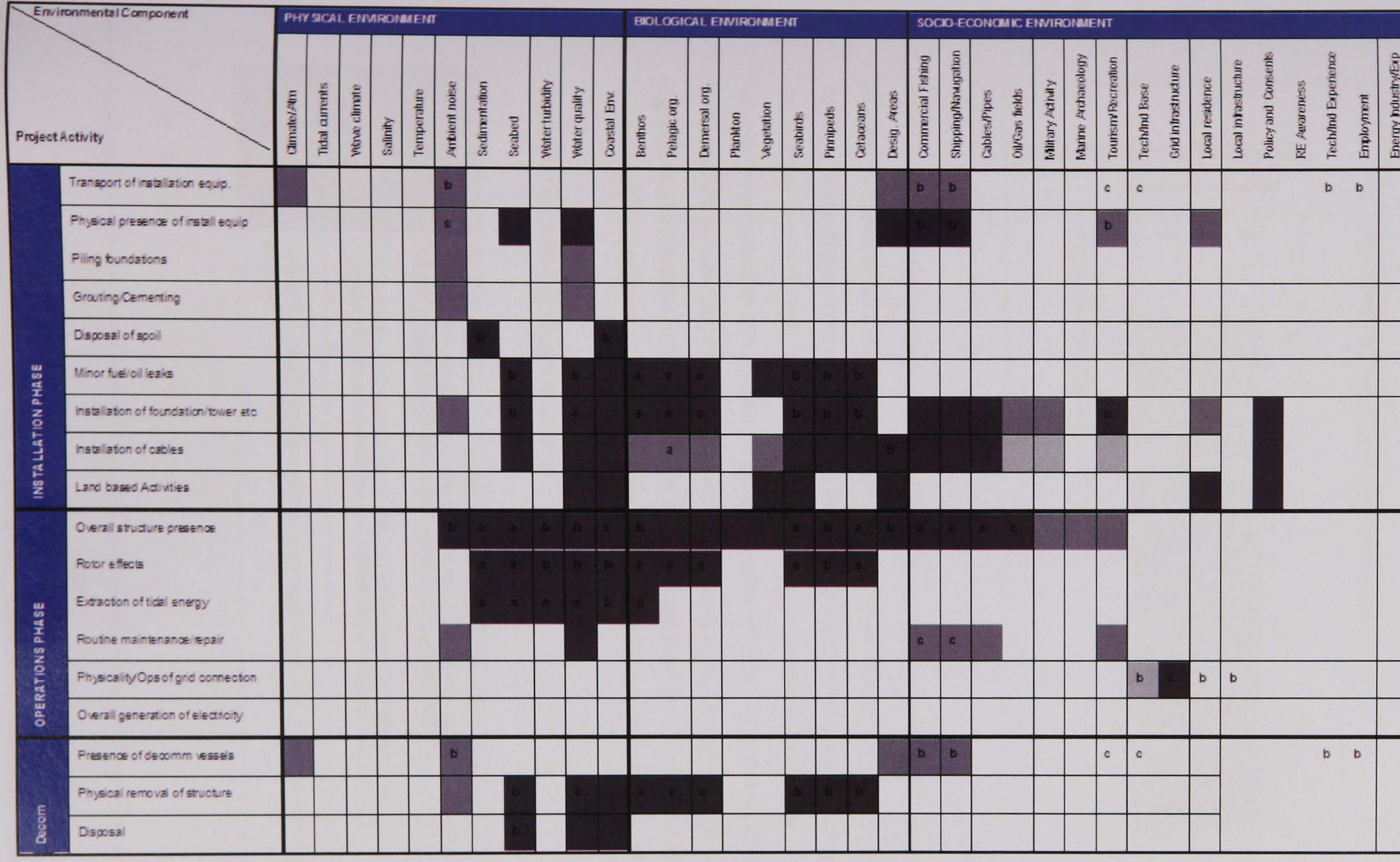

Figure 42: Legislative/Policy and Consultative Concern Significance Matrix

Legislative/Policy Scenario	
Clear legislative and policy driven obligations including permissions, planning, consents, waste management, conservation and protection etc. that must be specifically adhered to.	3
Certain obligations with respect to acquiring permissions and informing other parties may be involved. Activities potentially affecting the integrity of international obligations with regard to conservation and biodiversity, where the project should be compliant.	2
Project specific activities that could potentially be affected by non-statutory designated areas, which should be considered carefully, whereby all measures should be undertaken to minimise or avoid detrimental impact.	1

Concern Categories	
There is a widely held concern, which corresponds to feeling that project activity will have a long-term affect and measures will have to be taken to mitigate that concern.	**a**
Local concern, where issues have been raised with moderately to low impact potential issues	**b**
Issues that may affect individual people, local businesses that can be mitigated fully. Where concerns have been raised with issues that are deemed non-impact specific.	**c**

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4.5.6 Combined Significance

In order to establish an overall significance the following criteria were used to construct an overall significance matrix:

Table 21: Overall Significance for Project Interactions

Increase in Leg/Policy Sig. ↑

Increase in Magnitude Significance →

	1	2	3	4	5	
3	L	M	M	H	H	a
2	L	M	M	M	H	b
1	L	L	M	M	H	c
	1	2	3	4	5	

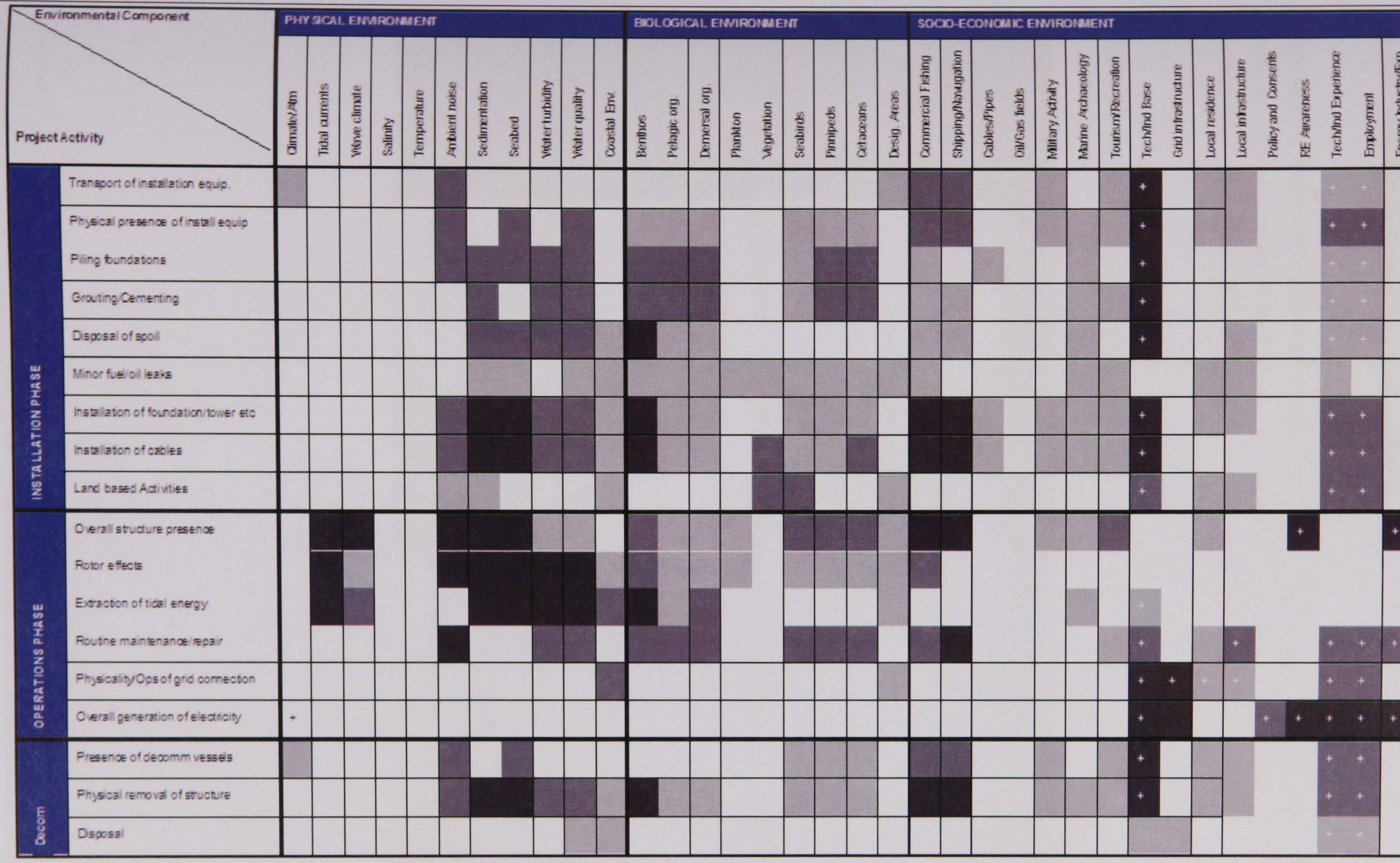
Increase in Likelihood →

Increase in Consultative Concern ↑

Overall significance has been expressed as low, medium and high. High significance has been applied to areas where increased magnitude and likelihood of an impact interaction occurs, as well as high consultative concern and legislative significance. However, where the latter are low and the former are still high, this also denotes a high overall significance. A moderate significance covers those areas in the middle range of the above table. Low overall significance predominantly corresponds to low magnitude and likelihood significance, as well as low consultative concern and legislative significance, however, where the latter are high and the former still low, this also denotes a low overall significance. An overall significance matrix can be viewed in **Figure 43**.

Table 22: Overall Significance Criteria

High	Denotes continuous or high/moderate occurrence, with potential level 5 and 4 magnitude, where impacts are unpredictable as yet and need further investigation. Impacts may have a level 3 or 2 legislation significance and a high level of concern is evident.
Moderate	Moderate to 1 off event status, with moderate to minor potential magnitude, but may be questionable. Impacts may have a varied level of legislative significance and concern
Low	Likelihood levels may be variable, but magnitude is thought to be neglible or positive. Low level of concern.



High | Medium | Low

Where a '+' sign is used, this denotes a potential positive impact.

Figure 43: Overall Significance Matrix

4.5.7 Key Environmental Concerns

With respect to the identification process the key environmental interactions that have been recognised as being of particular concern, are summarised in **Table 23**. Full discussion of environmental impacts and related environmental benefits are discussed in the following chapters.

Table 23: Summary of Environmental Concerns

	Environment Type	Main Concerns	Other Concerns
Installation	Ecological	Benthos Seabird disturbance Pinniped disturbance	Vegetation
	Physical	Ambient noise levels Water turbidity and quality Seabed disturbance Overall impact on coastal env. Designated area disturbance	
	Socio-Econ	Fishing Shipping and navigation constraints	Impact on other users
Operations and Maintenance	Ecological	Seabirds Pinnipeds Cetaceans Benthos	
	Physical	Tidal current movement and intensity Wave climate Ambient noise levels Sedimentation/Seabed disturbances Water turbidity and quality Overall effect on coastal environment	Designated area disturbance
	Socio-Econ	Fishing Shipping and navigation constraints Grid Infrastructure	Tourism Other Users

CHAPTER 5

Assessment and Evaluation of Environmental Impacts and Constraints

5. ASSESSMENT AND EVALUATION OF ENVIRONMENTAL IMPACTS AND CONSTRAINTS

5.1 Introduction

In this chapter the environmental impacts and constraints are discussed in detail with respect to the proposed area of the Pentland Firth and the baseline conditions that were considered (**Chapter 4**). Some measures of mitigation and remedy have also been discussed, which have provided a framework of recommendations detailed in the Pentland Firth report (Dacre & Bullen, 2001).

It is probably fair to say that any potential environmental implications would not be significantly discernible for the experimental, prototype or odd deployed device. However, this is entirely dependent on the sensitivity of the area. For example, in areas which have been designated to provide environmental protection, any development may be deemed to have a significant environmental impact. In the long term, it is envisaged that devices will be deployed in clusters within an area and it is this centralisation, like that of many other renewable energy methods, that has the potential for environmental impact beyond the natural variability of the area.

Within the context of the Pentland Firth study and the thesis in general, an 'impact' and a 'constraint' can been defined as follows: -

- **Impacts**: are defined as those responses and changes in the behaviour of the environmental system as a result of a proposed project or development that are above and beyond the natural variability that may occur; where the environmental system encompasses the physical, ecological and socio-economic conditions (Chapter 4).

- **Constraints**: are defined as those issues that have a direct effect on the tidal current turbine site selection i.e. environmental factors that may restrict the deployment process of the devices, such as those of a technical nature. These can occur within the physical, ecological and socio-economic components of the environment. However, some constraints are likely to overlap with potential impact issues.

Like any potential environmental impact or constraint, physical, ecological or socio-economic considerations depend solely on the proposed area for any offshore or coastal development. Therefore, even though there are some commonalties between broad sites, each development and site is unique in its own right and careful site selection and consideration is needed for any given proposal.

The probability of accurately predicting all environmental impacts is considered to be relatively small. It is a known fact that the more knowledge gained about the environmental system in question, the more complex the interactions and processes that govern their response to the perturbations become. The coastal and offshore environment is probably the most dynamic of all environmental systems and so all potential impacts that are discussed are based on the current understanding of the form and dynamics of the environmental processes that are in place. For the purpose of this chapter, specific regard has been given to the environment of the Pentland Firth. Some, socio-economic impacts and interactions however, are transboundary which not only reflect the localised area in question, but also within a broader context and generally reflect Scotland and beyond. These impacts were highlighted within the research conducted for the market study (Dacre, 2002) and have been termed 'barriers' to development and are detailed in **Chapter 7**.

Over the period this research has been conducted, research into marine development and environmental impact has increased, primarily with the introduction of offshore wind projects. Consequently, Bruns & Steinhauer (2004) have produced a review of the current and future environmental impact research of offshore wind in Germany, Denmark and the UK. Earlier reports (ETSU, 2000; Marine Institute, 2000) have been superceded by later research into the environmental implications of offshore wind including ETSU (2002), DTI (2002), DTI (2003). The introduction of Collaborative Offshore Wind Energy Research Into the Environment (COWRIE) has further enhanced environmental impact research with respect to offshore wind farms. Research continues to be conducted primarily with respect to potential noise, electromagnetic fields, bird interaction and visual impact. In addition, a number of wind farm projects have also been developed and these have provided invaluable impact research and monitoring reports. These include those associated with Horns Rev, Scroby Sands, Blythe, Gunfleet and London Array to name but a few.

Though the concept of offshore wind is very different to tidal current energy generation and there are very different environmental implications for development, there are also some generic ones. In response to the recent research conducted, the assessment and evaluation of the potential impacts of tidal current energy will utilise the research to inform and enhance that evaluation in order to better understand the potential impact implications.

5.2 Assessment of the Physical Environment

The physical environment constitutes the air, water and land and the processes that underpin those components. Within the baseline study detailed consideration was given to tidal current and sediment characteristics. A conceptual diagram (**Figure 39, pp.125**) illustrates some of the potential physical and ecological impacts and interactions of a potential tidal current energy project. In terms of environmental impact there are a variety of potential direct and indirect issues that may occur and in terms of potential ecological impacts there are a number of issues that may be the direct result of changes in the physical environment. These will be discussed in **Section 5.2.2**.

In terms of the processes that are related to the physical components there are a number of coastal and offshore processes that may occur or be affected as a result of a tidal current energy development. These include:

- Direct disturbance of the seabed and sediment re-distribution;
- Tidal currents and wave climate;
- Sediment transport and seabed morphology;;
- Scouring of sediments;
- Water quality changes and turbidity; and
- Underwater sound (ambient noise).

5.2.1 Direct Disturbance of Seabed and Sediment Re-distribution

With any offshore or coastal development, installation and the cabling involved will inevitably affect the seabed. The installation and decommissioning phases are assumed to create the most direct adverse impact with respect to seabed disturbance. Impacts of this nature, however, are predicted to be short-term and very local, concentrating around the structure and cabling areas. The degree of impact is very dependent on the type of structure, cables and installation methods used and the characteristics of the sediment being disturbed. For instance the finer the sediment and the stronger the prevailing current, the more widely the sediment will be re-distributed and entrained in the water column. The seabed in areas of high tidal velocity is usually characterised by rocky outcrops, boulders and cobbles, rather than fine, sandy sediments.

It is inevitable with the placement of structures on the seabed and the need for cabling that the seabed will be affected. The installation stage of the programme will be the most crucial, as this is undoubtedly the phase in which the most direct adverse impacts will occur, with respect to drilling, piling and cable laying etc., which is dependent on the method of support structure chosen and the method of installation used. Bearing the area of the Pentland Firth in mind, most of the offshore seabed is rock outcrop and this poses an added concern in terms of construction. For each activity, sediment disturbance and related seabed impacts will be very short term with local effects concentrating only at the specific device sites and along stated cable routes. Even if the energy devices themselves were not fixed in a mono-pile fashion such impacts would still occur, but may not be on such a severe scale. It is important that careful consideration of the area and the methods used for installation and cabling should reflect the need for as little disturbance as possible. Directional drilling could be advantageous in this respect for monopole type installations or if possible a deployment and installation method that minimises such seabed disturbance.

For example, with respect to cable-laying, the area of seabed affected can be calculated as follows:

(6) Length off cable X Diameter of cable

Calculations for a 4" cable (7) and a 48" cable bundle (8), with a length of 5km can be calculated as follows:

(7) $5000\text{m} \times 0.1016\text{m} = 508\text{m}^2$

(8) $5000\text{m} \times 1.22\text{m} = 6100\text{m}^2$

If the cables were to be trenched and the assumption was made that the area between the top of the cable and the seabed is 0.75m and the cable was 12", the area of disturbance can be calculated as follows:

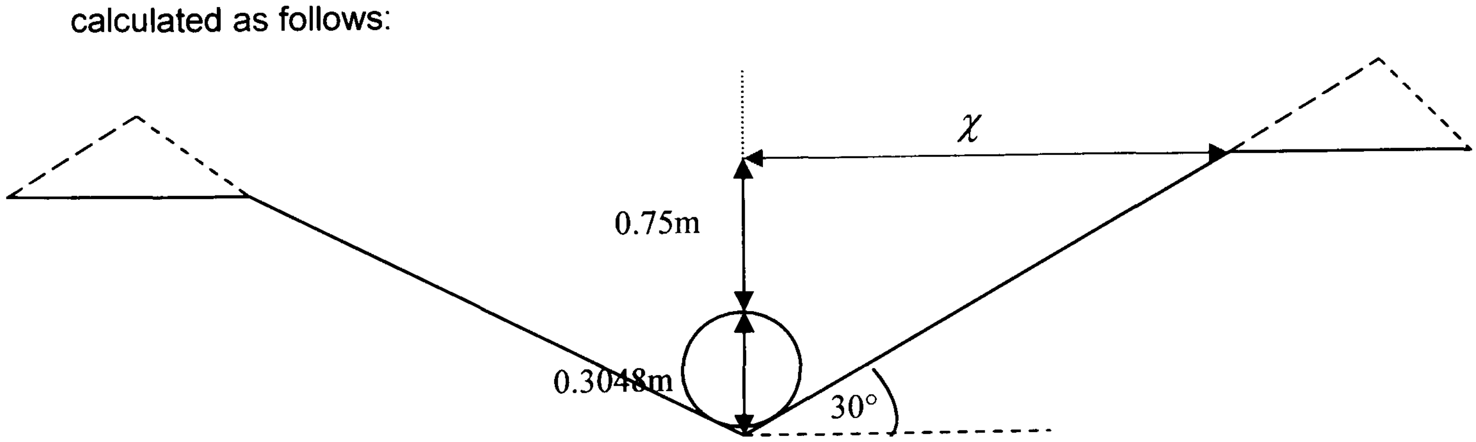


Figure 44: Cross-section of a trenched cable

(9) $Tan60^\circ = \chi / 1.0548$, where χ is half the trench width

$\chi = 1.827\text{m}$

The disturbed zone width (1.827m X 3) = 5.481m width = 3χ

Therefore, a 5.481m disturbed zone width X 5000m = 27,405m^2

It is clear, therefore that the area affected by trenching would be much larger than other installation methods. However, any disturbance would be temporary, as the trenches would be filled for the future recolonisation of organisms. If added protection was used, such as rock dumping, the area would remain a different habitat to the existing seabed.

Historically, the seabed has been and is still used for industrial, sewage or ammunition disposal, or has acted as a natural sink for oil and chemical contamination and therefore there is the potential for redistributed or disturbed sediments to release accumulated contaminants into the water column or be redistributed themselves during the construction and operational phases of tidal current energy development, including possible particle re-distribution from localised vortex effects around the turbines, which may have a significance in relation to contaminants having a higher burden on smaller particle sizes. In relation to the Pentland Firth area, there appears to be no ammunition disposal areas, however, with the Dounreay site in close proximity the potential for contaminated sediments in the area is relatively high. Other activities, such as dredging and sewage sludge disposal poses minimum contaminant risk. Sediment redistribution would initially follow the sediment pathways of the area, especially during the construction phase. To minimise or mitigate against any potential risk to the environment, it is advisable that sediment analyses should be conducted prior to the construction phase, accompanied by appropriate chemical risk assessments. This is especially important in areas where contaminated material may be deposited on beaches or environmentally sensitive areas, of which the Pentland Firth has many.

Sediment redistribution at the decommissioning phase of a tidal current energy development is dependent on the extent and methods used for removal, which in turn is dependent on the structural support methods used for the device as a whole. There is some possibility of localised plume creation during the physical removal of the support structures. However, this should be much lower than for the construction phase.

The effects associated with monopile installation on the seabed, is discussed in **Section 5.2.4**.

5.2.2 Tidal Currents and Wave Climate

The introduction of offshore structures also has the potential to induce changes to the current flow patterns and wave climate of an area; these may be on a localised scale or depending on the nature and size of a development the potential to cause far-field effects is also a possibility.

Both current and wave changes can induce indirect impacts on sediment transport and potentially the overall sediment budgets within an area. Localised effects (within the development area) may include scour and sediment mobility, whereas, far-field effects (area surrounding development site and adjacent coastlines) may include the alteration of sediment pathways and sediment transport mechanisms with far reaching impacts to the coastline.

Tidal Currents

The transport of sediment is a natural phenomenon associated with tidal currents, which is potentially an additional problem for offshore structures and their effect on the environment.

When considering tidal turbines, hydraulic resistance is two-fold with respect to tidal currents. The forces transmitted through the turbine support structures by currents may have the effect of removing some energy from the marine environment. In addition, the turbines themselves are also designed to extract energy from the tidal currents.

Research and development into tidal current and sedimentation modelling has been important in terms of many marine applications, including coastal management, marine pollution control and navigation. However, the modelling of tidal energy extraction is still in its infancy, but crucial in determining the overall environmental effects of tidal current energy for a particular location.

Results from modelling studies initiated for the offshore wind farm industry (ETSU, 2002) give some indication as to how monopole type support structures may affect the tidal current regime of an area. Modelling using typical case scenarios concluded that the presence of monopole structures would have a minimal effect on tidal characteristics, such as direction. However, for site-specific scenarios, such conclusions require further validation against local baseline data and project design considerations.

There is ongoing research at the Robert Gordon University (Prof. Ian Bryden, *pers comm.*) to investigate energy extraction from tidal current flows and the thresholds needed to sustain the pre-deployment characteristics of the tidal flows, to ensure the natural variability of such tidal flows are not disrupted. For example, tidal flow (velocity and direction) in a given area is not constant and fluctuates seasonally and diurnally. If energy is extracted from the area beyond these natural changes, then it is possible that this may influence entrainment and deposition rates out-with the area's natural boundaries. Therefore, such research providing threshold levels will enable the natural sediment entrainment and deposition rates to be maintained, thereby mitigating against potential sediment and coastline changes caused by the extraction of tidal energy flux. Details of such research have been discussed in **Section 2.1.1**.

From research and initial modelling already conducted the extraction of energy from a channel has obvious negative influences on current speeds (Bryden, *et al.*, 2005). Initial results indicate that the hydraulic discrepancy increases as the proportion of the local flux extracted is increased. This implies the proportion of the overall head between the up- and downstream boundaries, which is available to drive the flow through the tidal current turbine technology, increases as the flow speed decreases. Overall, it was found that by extracting 10% of the flux in the natural channel, the tidal speed would reduce by approximately 3%. Again, this was a simplified example and generally the hydraulic domain of natural channels is much complicated (Bryden, *et al.*, 2005).

Consideration of Effects

With respect to the Pentland Firth area and despite the significant strength and scouring effects of the tidal currents that predominate this region, a number of shed lines exist where current speeds naturally decrease. These include a line between Swona and Stroma, where deposits in the lee of the Pentland Skerries (Sandy Riddle) and in the vicinity of the "Men of Mey" and Triton Bank near the south approaches of the Scapa Flow. Such deposition and accretion indicates a complex sediment transport regime. Any obstructions in these areas have a high probability with respect to modifying the existing tidal flow patterns and overall, tidal velocity of the area. Sediment particle sizes have different threshold velocities in which they are able to be picked up and carried in the water column or near-seabed currents. When the current velocity is reduced, entrained particles are deposited.

Tidal current energy devices, irrespective of the type of support structure used have the potential to impact upon sediment transport regimes, especially local deposition and entrainment rates. With particular attention to the Pentland Firth area, the entrainment threshold is high, but it is unclear how and to what extent such devices will affect tidal current speeds and subsequently the entrainment threshold of the sediments in the water column. It is assumed, however, that some extraction of tidal current energy will be inevitable. In areas of very high tidal velocities, such as the Pentland Firth, the lack of bottom sediment, due to the high scouring effect of the currents, selective erosion and scour are not thought to not pose much of a negative impact, unless the extraction of energy from the tidal development is sufficient enough or an area of lower tidal velocities is characterised by areas of sediment on the seabed. However, it seems the greater concern is if extraction of energy is sufficient enough to lower entrainment thresholds, increased deposition of sediments will occur.

Wave Climate

Wave climate is an important factor to consider. Like the tidal currents, any obstruction in the coastal zone can deflect, reflect and influence the wave climate of the local area and have a significant impact on the area, both by the waves themselves and in conjunction with tidal currents.

Unlike tides however, waves originate from meteorological forces and are therefore episodic in occurrence and there are often seasonal variations. The wave climate in any location is a combination of locally generated seas and deep-water waves propagating into the area (e.g. long period swell). Where an area is open to long fetches associated with prevailing wind directions, there will be high wave activity. When a surface piercing structure is placed on the seabed in the path of propagating waves, diffraction of waves around the structure and reflection of waves off the structure will inevitably occur.

Wave Diffraction

When waves pass around or through a rigid, impermeable barrier/structure there is a modification to the wave pattern and height as the result of the dissipation or transfer of energy into the structure (Gaythwaite, 1981).

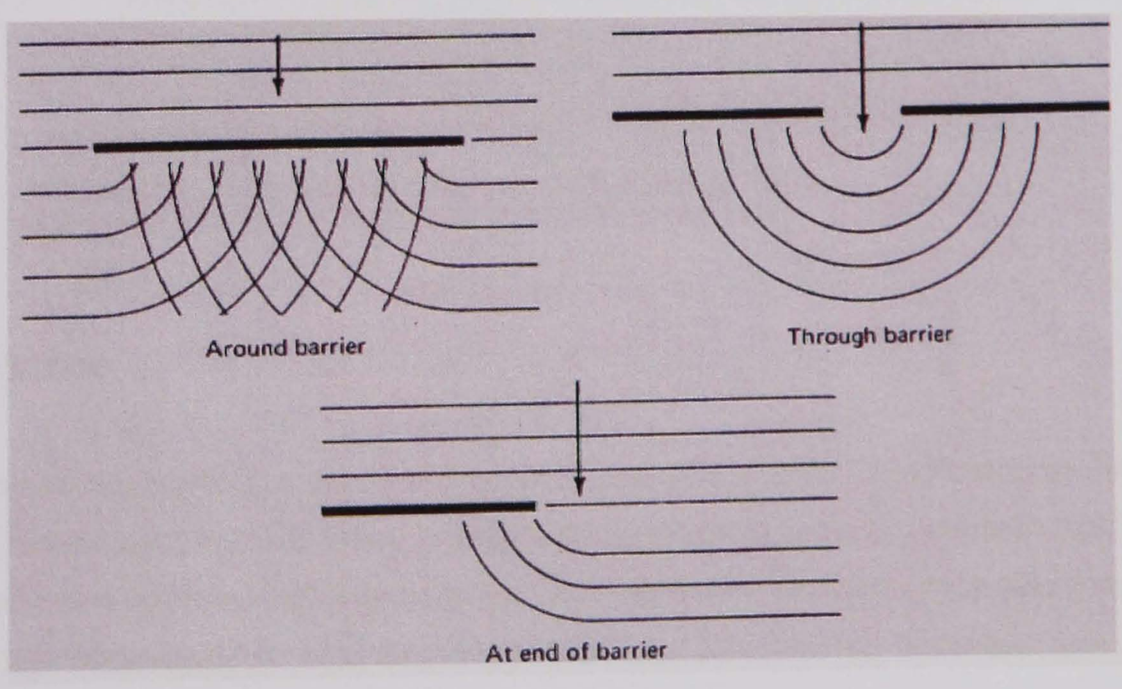


Figure 45: Wave Diffraction Patterns (Gaythwaite, 1981)

The relative wave height at any point is given by the diffraction coefficient,

(10) $K_D = H / H_0$

Where, H = wave height

H_0 = initial or deep water wave height

Figure 46 is a definition sketch for the diffraction of waves behind the end of an infinite barrier. The diffraction coefficient is a function of the 'angle of incidence' (θ), the angle between the barrier and a line connecting the end of the barrier with the location (β), and the ratio *r /L*, where *r* is the radius vector and *L*, the incident wavelength (Gaythwaite, 1981).

The problem of waves propagating around a barrier becomes complicated, due to the complex interference pattern that is established. Problems of combined refraction (the bending of waves because of varying water depths due to part of a wave in shallow water moving slower than the part of a wave in deeper water, causing a bend in the wave) and diffraction effects are much more complex and are a common problem. However, techniques for predicting them are few.

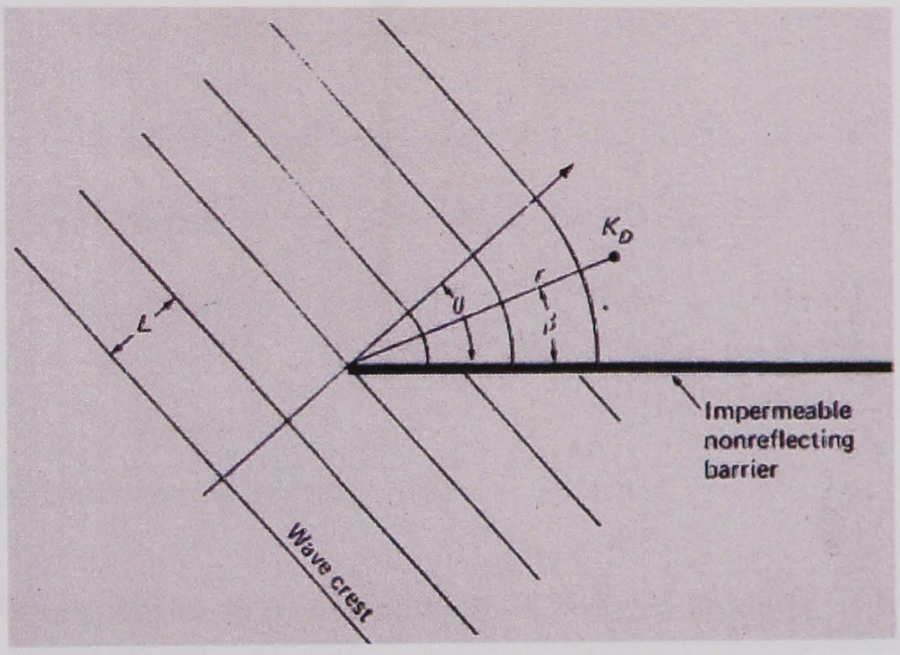


Figure 46: Wave Diffraction Behind a Barrier (Gaythwaite, 1981)

Wave Reflection

When a wave encounters a boundary of any kind and a tidal current energy device is no exception, some portion of the wave energy will be reflected back. It is known that the amount of wave reflection experienced is dependent on the external features of the structure itself. For example, the more vertical, rigid and frictionless the structure is, the more pronounced the reflection.

If the wave strikes a boundary at an oblique angle (**Figure 47**), the wave front is subsequently reflected at approximately the same angle. Therefore, the angle of incidence equals the angle of reflection. A reflection coefficient can be established for a given boundary by,

(11) $$C_R = H_R/H_0$$

Over 70% of a deep water wave's ($d/L \geq 0.5$) kinetic energy is concentrated in the upper 20% of the water column (Gaythwaite, 1981). For example, therefore, a wave's kinetic energy in an area with a water depth of 40m will be in the first 8m. In theory this provides a basic rationale for floating structures.

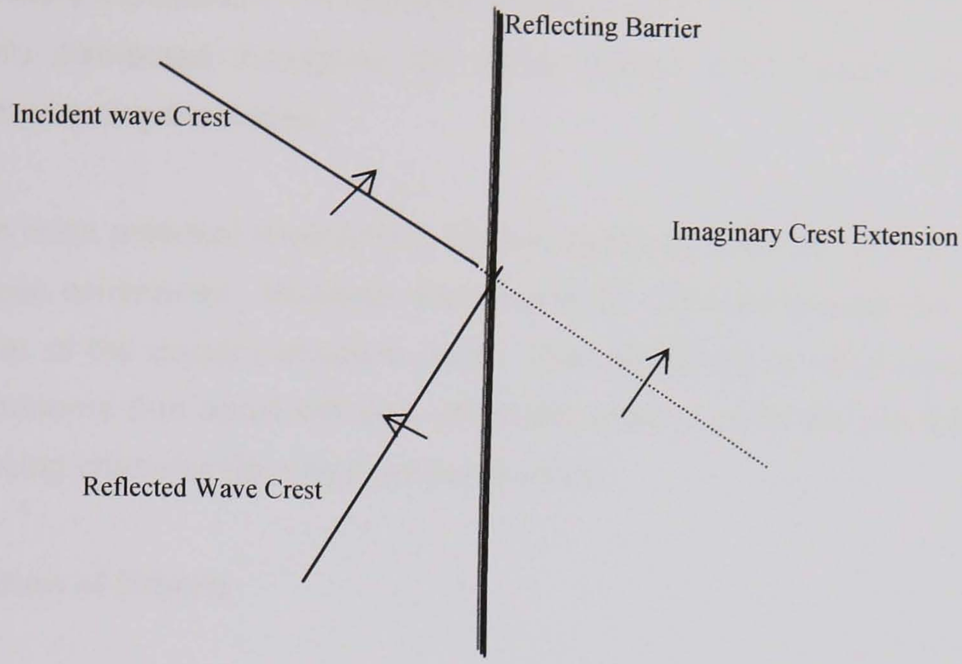


Figure 47: Wave Reflection (Gaythwaite, 1981)

By referring to **Figure 48** for a moored structure, both a reflection (C_R) and transmission coefficient (C_T) can be defined, where $C_R = H_R/H_O$ and $C_T = H_T/H_O$. Therefore, if energy dissipation is neglected, the coefficients can be related by:

(12) $$C_T = \frac{H_T C_R}{H_R}$$

C_T can therefore be estimated when C_R has been determined. In general, as the incident wave increases, C_R decreases, while C_T increases.

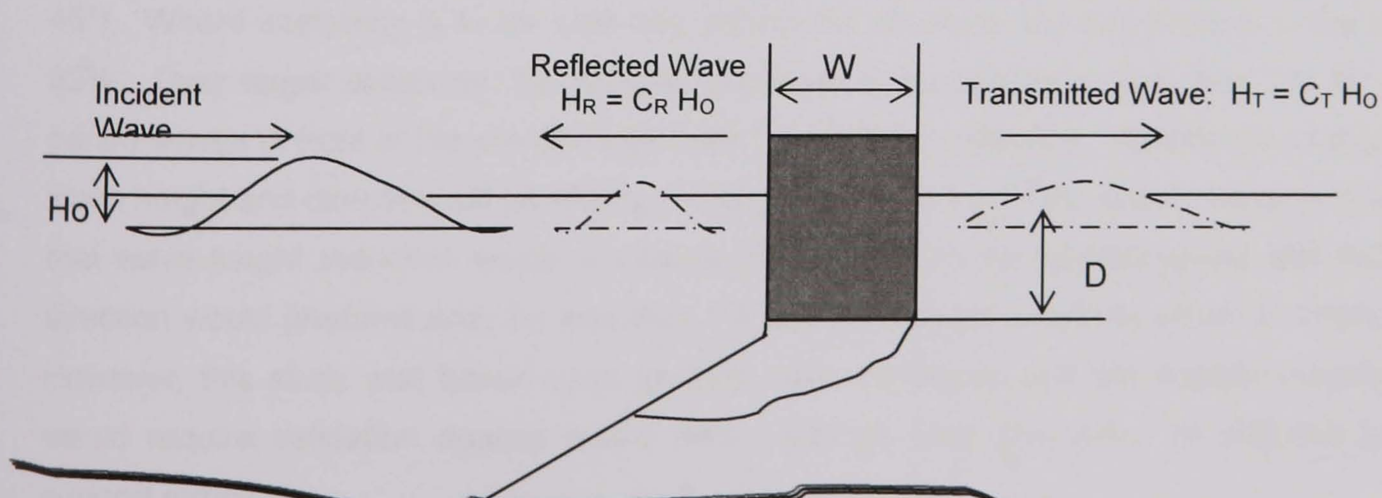


Figure 48: Wave Reflection and Transmission at a Moored Structure

The extent to which the structure aligns perpendicular to the wave direction is another important consideration. For example when the wavelength exceeds the structure's length by approximately 10 times, the structure becomes ineffective in reflecting wave energy, thus, becoming 'wave transparent'. In relatively shallow waters ($d/L \leq 0.5$) the waves kinetic energy is more evenly distributed throughout the water column, thus floating structures become less effective at reflecting the waves.

With this in mind potential implications can be highlighted with respect to the support structure that has been considered. However, the magnitude of these implications will be dependent on the diameter of the support structure itself. The complexity of wave refraction, diffraction and reflection patterns that result will also ultimately depend upon the number of devices and the type of spacing characteristics that are put in place.

Consideration of Effects

For an array of support towers, that would be associated with a design such as the MCT Ltd. concept, the waves, as a whole will be scattered locally and it is probable that the reflected wave components for each support structure will interact. Subsequently, reflected wave heights immediately adjacent to the support structures may increase, which would be more pronounced than for one isolated support structure. The extent of interaction will be dependent on the spacing configuration of each device and the wave period in the area.

Modelling has been conducted for offshore wind energy arrays with monopole type support structures, like those used in the MCT Ltd. concept (ETSU, 2002) and it was concluded that mono-piles exert a minor influence upon waves of period greater than 5s and that the disturbance to the local wave climate is generally small, except close to the support structure and pile itself. It is at this point, the relative amplitude of the wave is in the order of 60%, and the angle of the back reflection is scattered by 180°, but other scatter directions are less (e.g. 45°). Where scattering is to the side and behind the structure, the amplitude is in the order of 32%. Over larger distances, the relative amplitude is far smaller at less than 5% for shorter period waves in front of the pile and less than 1% for a 45° reflection. Results also suggest that wave height and direction will be affected. The outcome of the ETSU (2002) analysis concluded that wave height reduction would equate to less than 0.5% for far-field waves and that wave direction would predominantly be less than 1% and the largest variations would be at low water. However, this study was based upon general wave conditions and site specific investigations would require validation against actual data. Results may also differ for different types of support structure.

Wave modelling work by Halcrow as part of the ES for Scroby Sands (PowerGen, 2001), indicated that wave diffraction effects could result in constructive/destructive interference of up to 5% in the region immediately inshore of the wind farm development. However, the impact of these local effects at the coastline was not investigated, although it was suggested that at "far-field" distances effects would be neglible and too small to be measurable. Different wave models run by ABP Marine Environmental Research Ltd (ABP MER) and HR Wallingford, applied to the Gunfleet Offshore Windfarm and Scarweather Sands Offshore Windfarm, have indicated smaller local changes to the wave regime (<5%), and concluded similar negligible effects in the far-field region. Although each of these models will have been calibrated and validated against baseline field data, there are at present no (post-construction) field data with which to validate the models and therefore such results are reliant solely on the accuracy of the individual wave models used.

A recent report (DTI, 2006) has attempted to quantify the significance of changes to coastal processes, and interpret the subsequent environmental impact associated with the coastal regime using data collated from the Scroby Sands Offshore Windfarm before, during and after construction in order to validate previous environmental impact results with respect to far-field effects. Results again suggested that effects of wave climate were generally neglible.

Overall, it can be assumed that if a structure is surface piercing, there will be an increased spatial variability of wave height within the tidal current development. Due to the interference of incident and scattered waves, with different propagation directions, the vicinity of the development area will also experience an increase in surface 'choppiness'. It is also assumed that there will be an increase of wave/current interaction effects in the immediate vicinity of the support structures, which has the potential to augment sediment re-suspension processes.

In addition, it can also assumed that, no effects of scattering will be present at the coastline as scattered waves decrease as distance increases from the point of scattering. However, in the area of the tidal development and the vicinity of each tidal device, wave scattering and other interaction effects could potentially result in a decrease of wave energy.

5.2.3 Sediment Transport and Seabed Morphology

The transport of sediment is a natural phenomenon associated with currents, which can be an added problem for offshore structures and their effect on the environment. Construction and cable laying can potentially cause the alteration of sediment transport and in turn the seabed morphology of an area either by the direct impact of scouring (**Section 5.2.4**) or by the interference on sediment transport pathways and on local wave climate (**Section 5.2.2**) The construction of a tidal current energy development could potentially reduce the supply of sediment to adjacent areas or cause early deposition of sediment in others. Cumulative sediment movements or deposition could also cause wider alterations to the adjacent coastline.

Despite the significant strength and scouring of tidal currents in the Pentland Firth area, a number of shed lines do exist where current velocities decrease. These include a line between Swona and Stroma, deposits in the lee of the Pentland Skerries (Sandy Riddle) and in the vicinity of the Men of Mey and Triton Bank near the south approaches of the Scapa Flow. Such deposition and accretion indicates a complex sediment transport regime. Therefore, any obstructions have a high probability with respect to tidal pattern and velocity modifications. Particle sizes have different threshold velocities in which they are picked up and carried by the current. When the current velocity is reduced, entrained particles are deposited on the seabed (**Figure 49**).

Tidal current energy devices have potential environmental impacts associated with sediment transport with regard to deposition. It has been established that the firth has a potentially high entrainment threshold, but it is unclear how or to what extent such devices will affect the velocities of the currents. It is assumed, however, some extraction of energy and possible early deposition and change in tidal patterns is inevitable. Initial research suggests that the extraction of energy from a tidal environment should not exceed 10%, minimising the risk of significant hydrodynamic changes (**Section 5.2.2**). Entrapment and selective erosion of sediment is almost always associated with the presence of structures on the seabed. With the lack of bottom sediment the firth seems to exhibit, an assumption can be made that this will not be a problem, unless energy extraction is sufficient enough to cause early deposition in the area.

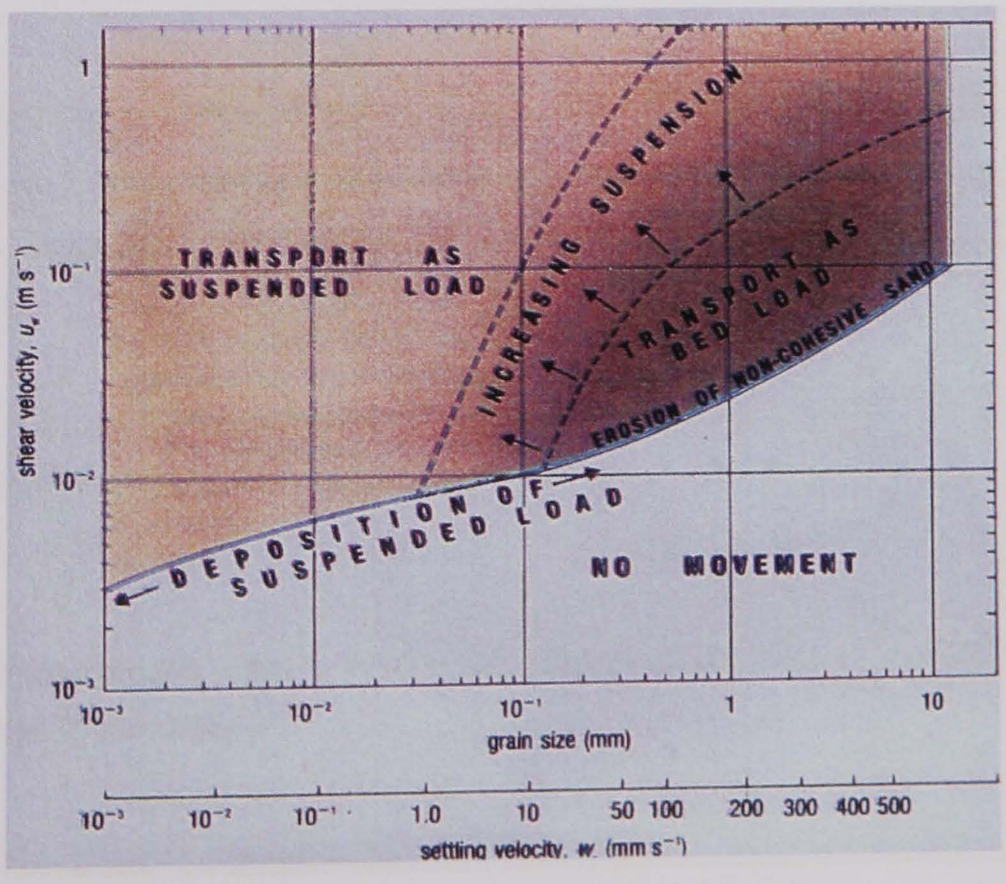


Figure 49: Threshold Velocities for Different Size Particles (OU, 1989)

In areas of significant shed lines of soft sediment, the construction of a tidal current energy development will in the short term increase the sediment stability of the area. However, in the long term there will be a tendency for those shed systems to move.

It has been found that in general the change in tidal energy (flow resistance) and the distance between shed lines is proportional. By simplifying, what is in effect a very complex situation, an estimation of the magnitude of movement can be determined. For example:

Length of shed line (L) = 10km
Width of shed line (B) = 2km

If it is assumed that the bottom friction factor (f) for the Pentland Firth locally controls the tidal flow, a total flow shear force (S) of the bottom of the Pentland Firth can be determined:

(13) $$S = \frac{f}{2}\rho U_{tide}^2 B \cdot L\left\{1 + \frac{2}{3}\frac{d_{\min}}{d}\right\}$$

Where ρ is the density of water, U_{tide} is the tidal velocity at the seabed, $d_{\min}$ the minimum depth at the shed lines mean sea level and d is the average depth (of the shed line and channel together). To account for the increase in friction over the shed line, the total current force, on 60 tidal devices is given by:

(14) $$F = 10 \cdot \frac{1}{2}\rho C_D\left(U_{tide}\sqrt{\frac{d_{\min}}{d}}\right)^2 d_{\min} \cdot D$$

Where, C_D is the drag coefficient, the ratio $\sqrt{d_{\min}/d}$ is the flow velocity reduction at the top of the shed line and D is the diameter of one tidal current energy device support structure. F is the additional flow resistance to the tidal flow caused by the tidal device (not accounting for turbine blade influence).

Therefore, if it is assumed that d = 14m, $d_{\min}$ = 5m, D = 5m, C_D = 0.7 and F = 0.005 the following ratio can be determined:

(15) $$\frac{F}{S} - 2 \cdot 10^{-3}$$

Since the distance from the coast to the middle of the Pentland Firth is say 4000m, the shed line may be displaced in the order of:

(16) $$-2 \cdot 10^{-3} \cdot 4000m \cong 8m$$

Hence, the order of magnitude will be approximately 1cm.

It must be stated that this is a very rough calculation. However, an indication of sediment shed line movement due to 60 tidal devices may be somewhere between 1 and 30m. Relative to the extent of the shed line itself, this is a small movement and may be considerably smaller compared with the natural variations that may occur in a dynamic area like the Pentland Firth.

The increase of flow resistance of a tidal flow may result in lower velocities between each device and thus, the transport capacity of the flow. This in turn may increase the amount of accretion between the devices, until a new equilibrium has been reached. However, there are also other effects to consider.

Impact on seabed morphology from tidal turbines is a complex issue and little or no research has been done to enable an understanding of this issue. From the knowledge and understanding that already exists an idea of the impact can be gained. The Pentland Firth is a tidal dominated flow region and is also exposed to wind waves. The height of the shed lines are generally a balance between secondary flow induced by flow curvature and increased outward sediment transport capacity because of the traverse shape of the shed line.

When tidal devices are installed the following will happen:

i. Increased deflection
ii. A reduction in flow between devices and a similar increase further away due to continuity.
iii.

Increased deflection causes stronger secondary flow, resulting in an increase of sediment to the centre of the shed line. A reduction in flow could potentially cause a decrease in secondary flow and thus, a decrease of sediment to the area. Further away, the flow will become stronger, causing increased sediment supply. Both factors together could potentially result in an increase of the shed line centre that is less than proportional to the increase in flow resistance due to the implementation of the tidal devices. It is estimated that the impact will be approximately half that predicted by proportionality.

For example, if the distance between the lowest point of the shed line and the centre is in the order of 17-20m, the change in amplitude will be of the order of magnitude of 1cm (17).

(17) $$\frac{1}{2}\cdot 20\cdot\frac{1}{2}\cdot 2\cdot 10^{3}\cong 0.01m$$

In addition, waves propagating through a tidal development will be partially reflected from the individual mono-pile foundations. As a whole there is the potential for the devices to give rise to a shielding effect, by 'protecting' areas downstream. Thus, sediment accretion will dominate in this situation.

The hydrodynamics and sediment transport of any marine environment is a complex one and any changes in these can cause problems with respect to the sediment budgets of an area in the long term, having an overall indirect effect on the coastal morphology and navigational channels. There is concern with respect to the number of shed lines already apparent in the Pentland Firth and the importance they have on the sediment and tidal regime. The increase or reduction of such shed lines depends upon the rates of accretion and deposition, which are directly influenced by fluctuations in tidal velocity. Due to the dynamic nature and high tidal velocities in the area, it is unlikely that significant shifts in seabed morphology would occur beyond that which already exists, however uncertainty lies in determining what constitutes 'significant shifts' and at what point in the context of fluctuations in tidal velocity would this occur, if at all. This would be dependant on the extent of the proposed project, such as the number of turbines and the proposed areas, and it is advisable that preliminary studies be conducted to aid the arrangement configurations in such a way as not to restrict or extract energy that may be detrimental to the dynamics of the area as discussed in **Sections 2.1.1 and 5.2.2**.

If significant changes in accretion and deposition occur, it would indirectly affect ecological communities. Creation of new shed lines may also occur depending on the magnitude of the change. However, this is not without its benefits, because the creation of new shed lines can result in the creation of new habitat and the colonisation of benthic communities (**Section 5.3.1**).

5.2.4 Scouring of Sediments

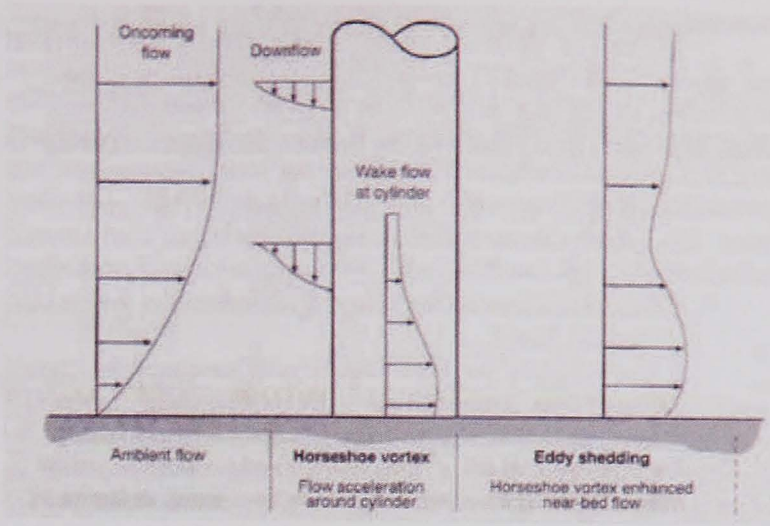
Knowledge of scouring has been the topic of coastal research for many years, but the true complexity and its importance to offshore engineering problems and the local environment has only been acknowledged in recent years. A three year research programme (1997-2000), Scour Around Coastal Structures (SCARCOST) was undertaken by a consortium within the Marine Science and Technology (MAST) programme of the European Union (EU). A summary and review of past research and research conducted in the program can be viewed in Sumer *et al.* (2001). In addition, research within the offshore renewables sector has also been undertaken, not only in the context of engineering (van der Tempel et al., 2004) but also from an environmental impact stance, especially in relation to offshore wind farms (DTI, 2006; Margheritini *et al.*, 2006; ETSU, 2002). Research and development by the *Offshore Center Danmark* into offshore wind turbines in areas of strong currents is probably the most applicable at present to tidal current energy projects.

When a structure is placed in the marine environment, the presence of the structure will change the flow pattern in its immediate vicinity, resulting in one or more of the following impacts: the contraction of flow; the formation of a horseshoe vortex in front of the structure; the formation of lee-wake vortices behind the structure; the generation of turbulence; reflection and diffraction of waves; the occurrence of wave breaking; and the differentials in the soil that may produce liquefaction allowing material to be carried off by currents (Sumer *et al.*,2001) All these changes cause an increase in local sediment transport and subsequently the impact of scour. Scour is not only a threat to the stability of the structure itself, but the process also has indirect impacts on the physical and ecological environment.

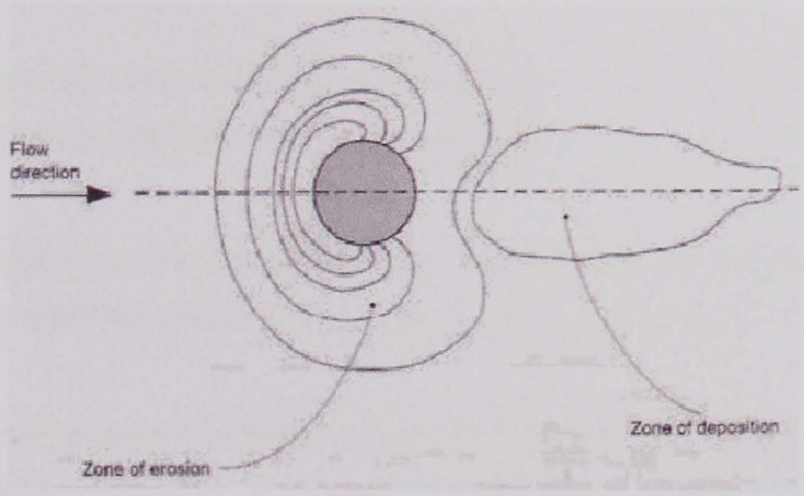
Using a vertical cylindrical structure as an example, which are commonly used as support structures in the offshore renewables sector, it can be seen that the oncoming flow is forced around the structure creating a down flow in front of the structure and a horseshoe vortex near the seabed. Behind the structure the flow is still turbulent. The horseshoe vortex is the main driver of the scour. The turbulent flow behind the structure has a lower velocity, which causes the floating sediment to settle again, creating a zone of deposition higher than the unscoured seabed (**Figure 50**).

With respect to tidal current energy devices, local scour effects would most certainly occur around the base of the support structure and with multiple structures, cumulative effects would certainly have further repercussions on wave climate and sediment transport, predominantly by creating wake vortices associated with existing currents. Even where currents are below the threshold for moving sediment, the localised wake vortices amplify the shear stress on the sediments adjacent to the structure causing scouring (Breusers, 1972; Breusers, 1991). This would be particularly likely where tidal devices were placed in areas of high energy and sediment mobility, which subsequently can result in extensive scour and the power to alter downstream areas of seabed.

There have been many small-scale models of monopile support structures and much existing information is based on this research. Such studies have determined a direct relationship between support structure diameter and the extent of scouring (ETSU, 2002). At present, the extent of scour has been estimated to be in the order of 6-10 times the support structure diameter, e.g. if the support structure diameter is 5m, scour will equate to 30-50m. The extent of scour is however dependent on sediment characteristics and current flow. Scour impacts can be reduced with the addition of scour protection material with a radius of at least 25m, but this in itself causes appreciable local ecological impact. In the high current energy areas of a tidal energy environment, the potential of such protection to disperse is also an added concern.



(a)



(b)

Figure 50: Flow-structure interaction for a vertical cylinder (a) and characteristic scour hole and deposition pattern (b). [Source: Whitehouse, 1998].

Ideally, numerical modelling would be used to establish the potential impact of scour, which would generally provide a scenario as illustrated in Figure 50(b), along with an estimation of the impact area. For the purposes of this section, in order to put the potential impact of scour into perspective, a simplified calculation of impact area can be established. Assuming the area of impact is a circular formation and a worse case scenario of a 50m radius, the following can be determined:

(18) Total Area Impacted (without scour protection)

$$= \pi \times r^2 = 3.14 \times 50^2 = \mathbf{7{,}850m^2}$$

(19) Area of scour protection impact

$$= \pi \times r^2 = 3.14 \times 25^2 = \mathbf{1{,}965m^2}$$

Based on the case study of the Pentland Firth described in **Section 4** and the general device spacing rule of each turbine being spaced 2 rotor diameters apart (40m), with a 20 rotor diameter spacing downstream (400m), the total area associated with each device can be calculated as follows:

(20) Area associated with each turbine

= (40x400) = **16,000m²**

(21) Percentage of area scoured (without scour protection)

= (7,850/16,000) x 100 = **49%**

(22) Percentage of scour protection area

= (1,965/16,000) x 100 = **12.28%**

(23) Percentage of area scoured with scour protection

= ((7,850-1,965)/16,000) x 100 = **36.78%**

Consequently, the footprint on the seabed for each turbine is in the order of 36.78 to 49% of the total area occupied by each turbine and hence of a tidal current farm.

In addition to local scour around individual mono-pile support structures, there is the potential of scour developing between the group of devices (**Figure 51**). The general scour occurs because the limited cross-section due to presence of devices accelerates the flow pattern in between the devices and because there is increased transport due to vortex formations. At present, little is known about scour caused by a large group structures, such as piles. However, there is continued research in this area especially as results from post-construction monitoring of offshore wind farms is becoming known. **Figure 52** shows scour development in between a group of turbines. In general scour occurs because the limited cross-section due to the presence of turbines accelerates the flow pattern in between the turbines and because there is an increased transport due to vortex formations. Research conducted by Sumer *et al.*, 2005 illustrates further the global and local effects of scour at groups of offshore structures. Results show that global scour can be quite substantial.

In areas of high tidal velocity, where the seabed has characteristic coarse material and bedrock outcrops, scour is unlikely to be a problem throughout the development area due to the fact there would be little or no sediment that could be entrained or scoured. However, pockets of finer sediments may exist within areas of natural deposition or within areas closer to the coastline, which may pose a scour problem. This is especially true with respect to cabling. Cables laid on the surface of the seabed can also cause scour. The impacts of scour, which are certain to occur will be localised. Associated impacts of scouring on the ecological environment are discussed in **Section 5.3.1**.

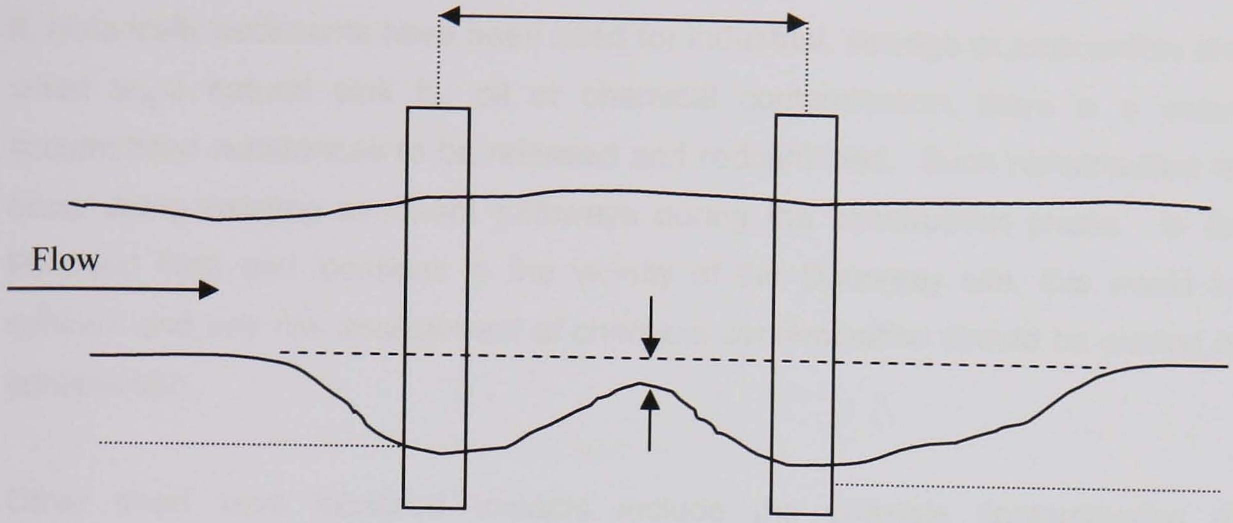


Figure 51: Group Effect of Scour (adapted from LIC Engineering A/S, 1999)

Figure 52: Artists impression of group effect scour
[Source: http://www.isva.dtu.dk/research/scarcost/scarcost.html]

5.2.5 Water Quality and Turbidity

The installation phases are probably the most important aspect of the project concerning the impacts associated with water quality. The extent to which changes occur will depend upon the methods employed to install the devices and to the lay the cables. For example, effects would be minimal if directional drilling was used to lay cables.

Any surface installation and cabling methods will increase the suspension of sediments and solids into the water column culminating into localised increased turbidity and the possible risk of sediment plumes. However, with the strength of the currents (dependent on location), dispersion should be rapid and thus any impacts should be minimal and short term.

If, historically sediments have been used for industrial, sewage or ammunition disposal, or have acted as a natural sink for oil or chemical contamination, there is a potential for these accumulated substances to be released and redistributed. Such redistribution would generally occur along existing sediment pathways during the construction phase. In the case of the Pentland Firth and locations in the vicinity of the Dounreay site, this would be of particular concern and any risk assessment of chemical contamination should be carried out prior to any construction.

Other short term localised impacts include the possible contamination of the marine environment through minor oil and fuel leaks from vessels in times of installation, maintenance and decommissioning. There is also a minimum risk of leakages from the gear-box itself. Prevention and response plans should be implemented to mitigate towards any potential risk.

5.2.6 Underwater Sound

Consideration will now be given to the extent of underwater sound that is thought to constitute the ambient noise in the area and the potential noise emissions generated from the construction and operations of a tidal energy development. Impacts of noise in relation to marine mammals and fish are discussed in **Sections 5.3.2** and **5.3.3** respectively.

General Principles of Underwater Sound

An understanding of the principles of underwater sound is required to fully assess its potential environmental impact. The publications (Richardson *et al.*, 1995; DTI, 2001; WDCS, 2004; Nedwell and Howell, 2004) discuss these principles in detail.

In water sound propagates with velocities of around 1500m/s but this is dependent on the density structure of the water column which can vary with temperature, pressure and salinity changes.

Attenuation (reduction in strength) is primarily caused by geometric spreading (sound energy radiating outwards from the source). As the area in which the sound energy passes through increases, the sound intensity decreases. If sound has no boundaries, spherical divergence of the energy occurs, and sound levels will decrease in proportion to the square of the distance from the sound source. This is equivalent to a 6dB decrease for a doubling of distance.

With respect to shallow waters, underwater sound energy radiating from a specific source may be channelled by the seabed and water surface, providing an upper and lower boundary effect. The sound energy will then only propagate in two dimensions i.e. cylindrical divergence, and sound levels will decrease in proportion to the distance from the source. This is the equivalent to a 3dB decrease for each doubling of distance from the sound source. Very low frequency (long wavelength) sound waves are not sustainable in shallow water columns and therefore attenuate more rapidly.

In addition to geometric spreading, sound energy is also lost due to absorption, scattering, reflection and rarefractrion (WDCS, 2004).

Ambient Marine Noise Sources

Ambient noise is sound that is always present and cannot be attributed to an identifiable localised source (Nedwell & Howell, 2004). Ambient noise consists of a number of 'natural' and 'background' noise sources, including waves (breaking waves and wave interaction), wind, rainfall, seafloor disturbances, noise emitted by marine life, molecular motion of the water (thermal noise), distant shipping traffic and oil and gas activities (i.e. drilling, production and seismic survey) (Nedwell & Howell, 2004). Sounds from onshore activities can also propagate into nearshore waters. **Table 24** and **Figure 53** detail the sources and frequencies of some marine ambient noise sources.

Table 24: Sources and Frequency Range of Ambient Noise [Source: Richardson *et al.*, 1995; Nedwell and Howell, 2004; WDCS, 2004].

Ambient Noise Source	Frequency Range (Hz)	General Comments
Wind and waves	1->30,000	Most common and interrelated source of ambient noise. Levels tend to increase with increasing wind speed and wave height.
Surf noise	100-700	Form of wave noise localised near the land-sea interface.
Seismic noise	2-500	Originates from underwater volcanic/tectonic activity.
Precipitation	100-500	Occurs due to rain or hail falling on sea surface.
Biological noise	1->100,000	Marine mammals are major contributors, but certain fish and shrimp can also be significant.
Thermal noise	>10,000	Results from molecular agitation of water molecules.
Distant shipping	20-300	Generally not seen as background noise, unless originating from over 10km away.
Distant fishing boats	1-<300	Usually occurs in coastal locations.

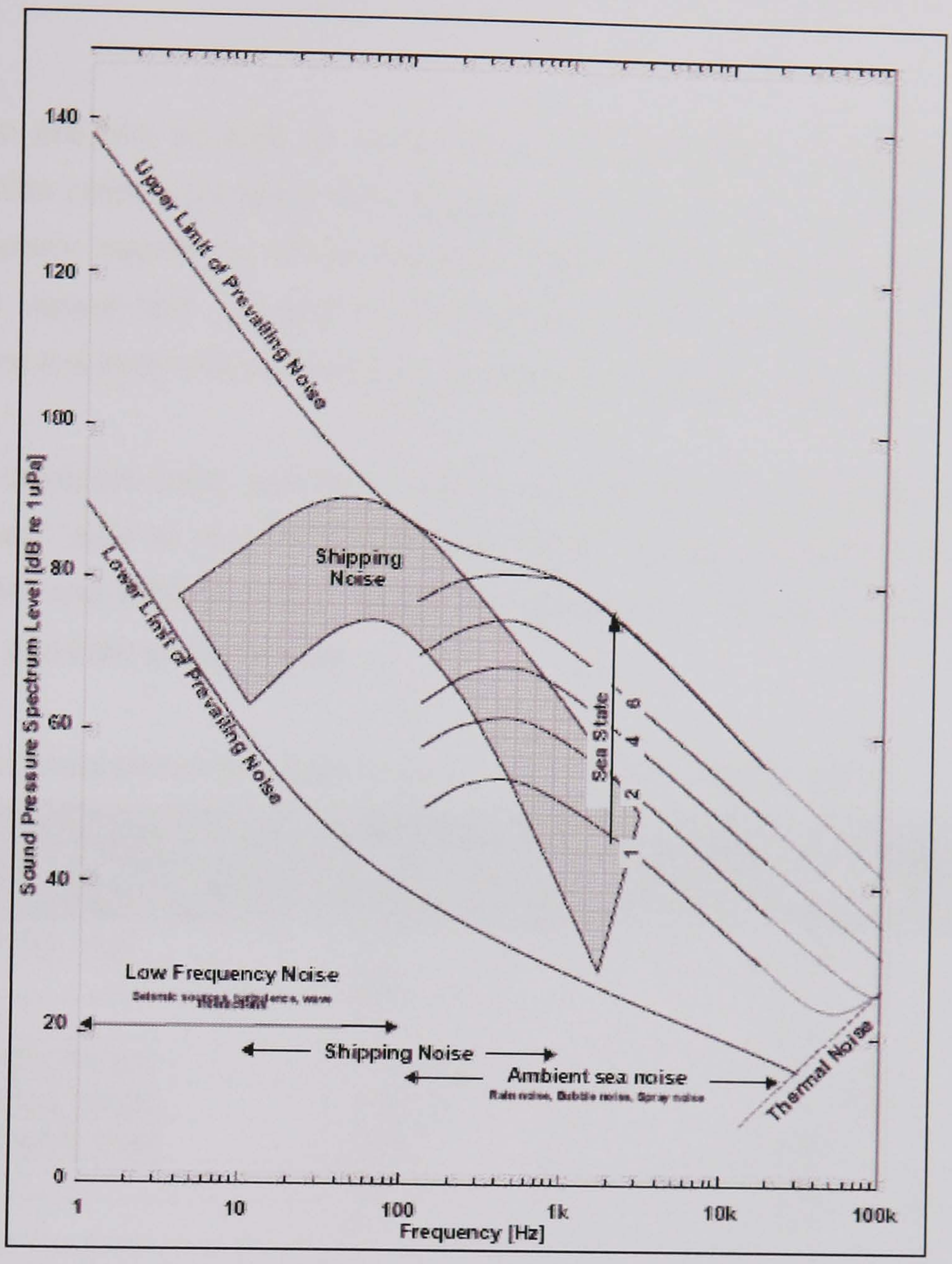


Figure 54: Ambient Noise Frequencies [Source: Nedwell and Howell, 2004].

Sources of Underwater Noise from Tidal Current Energy Generation

There are five main sources of noise impact that may occur from the construction and operation of a tidal current energy development:

Presence and Use of Vessels for Installation

Throughout the life cycle of a tidal current energy development there will be an increase in vessel traffic. This will include vessel support during construction which will continue throughout the operational phase in order for maintenance to be conducted.

Vessel noise is a combination of tonal sounds at specific frequencies and broadband noise. It can be considered a continuous (rather than transient) noise source. Vessel noise depends upon the size of the boat or the ship, but larger ships tend to have stronger, lower-frequency sounds.

Generally, there are two sources of sound generated by vessels. The primary source, is propeller cavitation noise originating from directly under the vessel. The secondary source is due to the propulsion machinery, which originates from inside the vessel and reaches the water column via the vessel hull. During the construction phase both sources of noise will be generated, where it is likely that hull radiated noise from stationary vessels will predominate.

Measurements of vessel noise have been widely documented. The most definitive collation of this measurement data is that by Richardson *et al.* (1995), Heathershaw *et al.* (2002), Hildebrand (2004) and WDCS (2004). **Table 25**, summarises the sound frequencies produced by vessel traffic and their source levels.

Table 25: Sound Frequencies and Source Levels Produced by Vessel Traffic.

Vessel Type	Frequency (kHz)	Source Level (dB re 1μPa)
7m outboard motor boat	0.63	156
Fishing Boat	0.25-1.0	151
Fishing Trawler	0.1	158
Tug (pulling empty barge)	5.0-0.037	166-145
Tug (pulling loaded barge)	1.0-5.0	161-170
34m twin diesel work boat	0.63	159
5m Zodiac	6.3	132
Supply Ship	0.1	164

Piling of the Support Structure

Piling operations create underwater noises of a frequency and level that are audible to seals, toothed and baleen whales, and fish (Richardson *et al.,* 1995; Nedwell & Howell, 2004; Nedwell *et al.,* 2004a). Noise from piling can enter the marine environment by four pathways, but the most significant one is thought to be by transmission of vibration through the pile itself directly into the water column. The noise produced during piling is dependent on the several factors including the type of equipment used, the water depth, and the characteristics of the seabed and has been measured in several studies (Nedwell, *et al.*, 2003; Betke *et al.*, 2004, Blackwell *et al.*, 2004 and Rodkin & Reyff, 2004).

Piling work has been recorded to generate intermittent high intensity sound that is detectable up to 20km away, with a sound power output of 225dB at 315Hz at the source (ERM, 2002). Nedwell and Howell (2004) reviewed data from offshore piling operations, including two recent wind farm sites – North Hoyle off the north coast of Wales and Scroby Sands off the coast of

Norfolk. At North Hoyle the water depth was 6-7m, the substratum below the surface seabed layers required some drilling, and the pile was 4m in diameter. At Scroby Sands the water depth was 1-5m, and although the topography was much more complex than at North Hoyle, the seabed was sandy and no drilling was required. The piles installed were 2m in diameter. Field measurements from North Hoyle showed that the sound Source Levels were 260db re 1μPa @ 1m at a depth of 5m in the water column and 262db re 1μPa @ 1m at a depth of 10m. Most of the energy was in the frequency range 40Hz to 1kHz. At Scroby Sands the Source Level was estimated to be 297db re 1μPa @ 1m, but this was thought to be unrealistically high, possibly as a result of the very shallow water and local topography. At the Horns Rev site in Denmark, piling in water 4-6m deep produced peak Source Levels of at least 215db re 1μPa @ 1m (Tougaard *et al.,* 2003; Nedwell and Howell, 2004). Finally, piling in a water depth of 180m at the Magnus platform in the northern North Sea was found to produce an effective Source Level of 246db re 1μPa @ 1m (Nedwell *et al.*, 2001).

Trenching Operations and Subsea Work

The noises produced by subsea trenching operations depend on the equipment used and, in particular, the nature of the seabed sediments. Cable laying and trenching are estimated to have a much lower sound emission threshold than piling operations, but with short periods of continuous noise, also detectable up to 20km away (ERM, 2002). A trenching noise spectrum, as reported in Richardson *et al.* (1995), has peak levels of 178dB (1μPa @ 160Hz), with an overall source level 185dB (1μPa-m), which coincides with data reported by Nedwell *et al.*, 2004.

Operational Noise from Turbines

It is probably fair to say that the tidal current energy devices themselves will emit underwater sound at some level from turbine operations. However, the significance of the noise emissions generated is difficult to estimate as the level of acoustic emissions from tidal energy technology is at present largely unknown. However, studies were carried out on the MCT Ltd. tidal current generator near Lynmouth in the Bristol Channel (Scottish Executive, 2007). It can be assumed, however, that of all the tidal energy development related noise sources, the marine environment experience the greatest exposure from operational noise created by the turbines. Added sound sources may also be generated through the physical presence of devices due to the interception of waves and water-structure friction, which will be increased in rough conditions.

In contrast to construction-related noise sources, operational noise will occur throughout the operational lifetime of the development. Received level of sound from tidal energy turbines into the underwater marine environment is generally dependent on the sound propagation profile, water column depth, sea surface roughness and seabed geology (Nedwell and Howell, 2004).

From studies conducted on the MCT Ltd. concept located in the Bristol Channel, indications are that source levels are 157.2 dB re 1μPa at a frequency of 15,849 Hz for a 1 MW turbine. Assessments revealed that if a marine mammal were to spend 30 minutes within a distance of 16 metres, it may suffer permanent hearing damage. This relates to a frequency of 19,953 Hz and a source level of 157.6 dB re 1μPa. This is estimated to be the maximum distance over which irreversible physiological damage could occur. However, evidence suggests that it is unlikely that an animal would choose to stay in such close proximity for the stated length of time (Tougaard *et al.*, 2003). In comparison, it is estimated that temporary or partial hearing loss could occur over almost the full range of frequencies and sound source levels produced by an operational tidal turbine.

In comparison, from experience with offshore wind farm turbine structures and associated noise emissions, the main source of underwater noise will be from the working of the gears in the nacelle at the top of the tower (Nedwell and Howell, 2004). This noise/vibration is transmitted into the sea by the structure itself, and is manifested as low frequency noise. Other transmission pathways are via the support structure and the seabed, or through the air and air/water interface, but these are unlikely to be as important as the pathway directly through the tower (Nedwell and Howell, 2004).

For offshore wind turbines, noise levels in the nacelle are estimated to be in the region of 115-120 dB re 1μPa (Vella *et al.,* 2001). Data from the Svante wind farm in Sweden indicate operational noise levels peaking at 120 dB at 16Hz, about 20 dB above background levels (Westerberg 1999). However, later estimations for the surface sound power output of a single turbine is a sound power output 90-100dB and a sound pressure level of 50-60dB(A). The modelling carried out for the Kentish Flats Wind Farm EIA (EMU, 2002) predicted that the 'in field' above the surface sound would be 50dB(A) dropping to 35dB(A) at 2.5km with a frequency estimated at between 20-150kHz.

Published data on the source noise levels from operating wind farms (reviewed by Nedwell and Howell, 2004), indicate that noise generated may have a peak frequency in the range 16 to 25Hz, and that the sound level may be up to 153 dB re μPa @ 1m (Nedwell and Howell, 2004). It should be noted, however, that these data are all for monopole or gravity structures located in relatively shallow water. The character and level of noise generated by operating turbines is dependent not only on the characteristics of the turbine itself, but also on the nature of the support structure and the way in which this may efficiently transmit noise and vibration into the water column.

The subsurface sound has not been measured for any of the current wind farm EIA's and there is concern that the vibration potentially caused by the mechanical operation of turbines could cause infrasound vibration in the water. However, work cited in OSPAR (2003) suggests that underwater noise in the frequency range above approximately 1kHz is not higher than ambient, though noise below this frequency is greater than ambient.

For the purposes of discussing underwater noise associated with tidal current energy generation, it will be assumed that a turbine would create a source level of 157.2 dB re µPa @ 1m and that the noise spectrum would be similar to those reported in literature (i.e.16Hz) (Nedwell and Howell, 2004). Though this value is for one turbine, the combined source noise level for 60 tidal current turbines, is unlikely to exceed 167.2 dB re µPa @ 1m using additive noise source calculations derived from Richardson *et al.* (1995). **Table 26** summarises the received level of sound at distances from the noise source level. Calculations were derived from Richardson *et al.* (1995) and do not include absorption characteristics.

Table 26: Received Level of Sound at Distances from the Noise Source Level of a Tidal Current Energy Development of 60 Turbines.

Lr = Ls – 15.log(range km) - 5.log(depth m) - 60 (dB re 1mPa)									
Water Depth:	40								
Source Level:	229.1								
Range km	1	2	5	10	20	50	100	150	200
Received Level	161.1	156.6	150.6	146.1	141.6	135.6	131.1	128.4	126.6

5.3 Assessment of the Ecological Environment

The ecological environment constitutes the biological components, such as the fauna, flora and their habitats that are influenced by the physical environment.

5.3.1 Benthic Environment

Due to the Pentland Firth's strong tidal current regime, the area is known to provide specialised benthic communities, but relatively little is known about the extent of those communities. Detailed descriptions of seabed fauna and flora have been given in **Section 4, Table 14**.

As stated before, the level of impact is dependent on the type of structure, cables and installation methods used. However, it is inevitable that these processes will result in the impact of the fauna and flora found on the seabed. Benthic fauna and flora are considered susceptible to impact in the following ways:

Effects of Sediment Disturbance

It is anticipated that any sediment disturbance will be localised and of short duration. The extent of this disturbance will be influenced by the characteristics of the sediment in the area of development. For example, the finer the sediment and the greater the current velocities in the area, the wider disturbed sediment will be dispersed.

Benthic communities would be impacted both through mortality and direct displacement of species located in the immediate vicinity of the installation operations and indirectly through re-distribution of any sediment present into the water column and possibly subsequent smothering as a result of the resettlement of that sediment. Different species are variably tolerant to such disturbance, but as the disturbance is localised and short duration, such an impact can be regarded as low. In addition, where mortality occurs, recruitment from adjacent un-impacted areas is likely in a relatively short time period, though this is dependent on the type of benthic community in question and the external environmental characteristics that are present. Sediments that result from drilling operations tend to be coarser than the ambient sediment, however, coarser materials associated with drilling operations are screened out shipboard on the drilling barge. In strong currents, such as in the firth, accumulation of cuttings should be very low due to rapid dispersion. Where there is decreased current activity within the inshore areas, these considerations need to be considered more carefully with cuttings dispersion modelling studies. Once any cables have been buried, there would minimal impact during the operations phase, except for limited repair and maintenance.

Effects of Scouring and Modified Sedimentation Processes

Selective erosion around each device structure will also have an added localised effect on the benthos. Benthic organisms are adapted to the natural processes of sediment movement, erosion and deposition. Natural sedimentation processes have characteristic length and timescales relating to their forcing functions, principally via wind, waves and tides (Komar, 1998). Major sedimentation events as a result of human intervention, and the scale and magnitude of such modifications can greatly exceed that of natural occurrences.

For most benthic infauna, horizontal sediment movement is largely irrelevant and it is the up and down movement of the bed, erosion and deposition that is critical (Miller and Sternberg, 1988). A majority of benthic organisms live in the top 10cm of the seabed and must maintain some connection to the sediment-water interface for ventilation and feeding. Excessive deposition can lead to burial, smothering or even crushing of benthic organisms, thus defaunating erosive sites in a process termed 'washout' by Hall (1994) and Thistle *et al.* (1995).

At present there is little quantitative data that predicts how structural placement, sediment deposition and erosion affects ecology and we are largely ignorant of the magnitudes of erosion and deposition that are detrimental. Miller *et al.* (2002), discuss this further and conclude that by quantifying natural sedimentation rates and the susceptibility of fauna is one key towards understanding environmental impact with respect to the placement of material and structures into the environment. Miller *et al.* (2002), argue that if materials and structure placement is or can be made analogous to natural processes, then benthic community responses will follow natural trends and exhibit minimal anthropogenic impacts. However, if sedimentation exceeds natural thresholds, then impacts will likely occur, such as total loss of the benthic community, and the subsequent recolonisation by other species driven by the 'new' ecological processes introduced. This situation may lead to an extensively altered benthic community. These effects, however, will be long term and relatively slow in developing. The extent of these sedimentary effects is unclear, but it could be argued that the formation of different habitat characteristics could also be beneficial to existing communities. Scour pits appear to be attractive to some mobile seabed species, crabs and lobsters. Where fine sediments have been removed, leaving large shells and coarse sediment, fast growing species such as tube worms and barnacles are often present. In the case of the offshore wind farm development, Lune Deep off Morecambe, scour pits have allowed mussel beds to develop on the turbine structures. Subsequently, detached mussels would attract scavengers such as starfish, flat fish and flounder (Hiscock *et al.*, 2002). There have been studies undertaken to assess recolonisation rates of seabed types after marine aggregate extraction (De Groot, 1986 & Kenny *et al.*, 1994). Though direct comparison cannot be made, they do provide a preliminary indication of such rates, which could be in the region of two to three years.

Presence of Structures

Whilst there is likely to be localised modification to the character of the sediments, the turbine structures and any scour protection may also act as an 'artificial reef' and potentially create the largest changes to the marine communities and species in the area. Much work has been undertaken to survey and describe fouling growths on offshore structures and this is summarised in Hiscock *et al.* (2002). A review of 'artificial reef' knowledge has also been prepared in response to offshore wind energy structure impacts (University of Southampton, 2000). Colonisation will depend on the type of support structure used for a tidal energy development and in addition, species that colonise the structures will depend mainly on depth to the seabed, degree of scour and geographical location.

Disturbance of Chemical Contaminants

Generally, muddier sediments bear the greatest contaminate load, especially those closest to the source of contamination. In the Pentland Firth, radioactive contamination from the Dounray site poses some risk. However, potential impacts on benthic communities associated with the resuspension of contaminated sediments would generally only pose a potential risk in estuaries and muds and thus the intertidal zone of the Pentland Firth and the possibility of disturbing significant contaminated sediments would most likely be a consequence of cable routing.

5.3.2 Marine Mammals and Noise

Sound propagates efficiently underwater, and it has been suggested that the importance of sound propagation can be seen with the development of broader hearing frequencies of marine mammals, such as cetaceans and pinnipeds (Hildebrand, 2005).

Marine Mammal Audiograms and Application of the dB_{ht}(*species*) Concept

There are two main groups of cetaceans: *odontocete* or toothed whales, and *mysticete* or baleen whales. Audiograms have been produced for 10 species of odontocete and 11 species of pinnipeds, out of a total of approximately 119 marine mammal species (Richardson *et al.*, 1995; Hammond *et al.*, 2004). Audiograms show the response of a species to sounds of different frequency and indicate (a) the range of frequencies that a species can detect and (b) the frequency range over which the species' hearing is most acute.

Audiograms can be grouped in three overlapping bands (Heathershaw *et al.*, 2002; Richardson *et al.*, 1995):

i) low frequencies (10Hz to 300Hz, where fish are most sensitive)
ii) mid-frequences (300Hz to 1500Hz, where humans are most sensitive)
iii) higher frequencies (1500Hz to 100KHz, where odontocete species are most sensitive).

Most odontocete have functional hearing from 200Hz to 100kHz, and some species may hear frequencies as high as 200kHz. Odontocete hearing has peak sensitivity between 20 and 80kHz, along with moderate sensitivity in the 1-20kHz range. Ambient noise decreases at high frequencies and therefore, odontocetes may have an advantage in having their hearing and echolocation at high frequency to filter out as much as the low frequency noise as possible (Heathershaw *et al.*, 2002; Richardson *et al.*, 1995).

There have been no measured audiograms of mysticete species, but modelling indicates they have a hearing range between 20Hz and 20-30kHz (Heathershaw *et al.*, 2002; Richardson *et al.*, 1995).

Two pinniped species are found in the UK; the harbour seal and the grey seal and these are both members of the phocinid or 'true seals'. Phocinid seals characteristically have "flat" underwater audiograms that range from 1kHz to ~50kHz with threshold sensitivity of 60 to 82dB (Richardson *et al.*, 1995). However, sensitivity tends to decrease rapidly at higher frequencies (Hammond *et al.*, 2004). The optimum hearing range for phocinid seals is between 1 and 10kHz (Heathershaw *et al.*, 2002; Richardson *et al.*, 1995)

Table 27 shows the audible frequency ranges for some marine mammals, and indicates the threshold value at the peak frequency (i.e. the frequency at which their hearing is "keenest"). It also shows the frequency range and Source Levels from recorded offshore piling and the operation of a turbine.

As discussed, each species' sensitivity to a noise depends on its frequency, and the minimum noise level they are able to hear (the threshold) varies with the frequency of the noise. Nedwell and Howell (2004) have therefore proposed the use of a weighted measure dB_{ht}(*species*) which models the noise level that a species would experience. The dB_{ht}(*species*) value for each species is a function of its sensitivity to noise, as derived from its audiogram; ht refers to the "hearing threshold" of the species which reflects a particular species' ability to detect sounds at different frequencies. It is argued that the application of this measure permits proper examination of the true likely effect of external noises on marine mammals and fish.

The noise level that may be perceived by a particular species can be calculated by applying the dB_{ht} "filter" – a correction factor – to the source noise level at different frequencies. The correction factors can be derived from the species' audiogram. Nedwell and Howell (2004) suggest that a behavioural response in a a marine mammal would be elicited if the dB_{ht}(*species*) noise level exceeded 90dB. At this level marine mammals have shown an avoidance reaction, typically by swimming away from the noise source, however some species may react beyond this range. Ketten (1998) concluded that a noise level of 140dB is necessary to produce a significant temporary change in hearing ability.

Table 27: Hearing ranges, most sensitive frequency and minimum thresholds for some species of marine mammal likely to be present at development site, and comparison with sounds produced by wind farm activities. (Data from Nedwell *et al.*, 2004b; Nedwell and Howell, 2004.)

Species	**Hearing range (Hz)**	**Approximate peak frequency (Hz)**	**Threshold at peak** db re 1µPa @ 1m
Bottlenose dolphin	100 – 300,000	50,000 – 80,000	40 - 50
Harbour porpoise	200 – 200,000	100,000 – 200,000	30 - 60
Grey seal	200 – 200,000	20,000 – 30,000	61 - 70
Harbour seal	100 – 200,000	7,000 – 30,000	63 - 67
Killer whale	500 – 200,000	10,000 – 30,000	30 - 45
Risso's dolphin	2,000 – 110,000	8,000 – 30,000	63.7 – 66.5
	Source frequency range	Source peak frequency	Source level db re 1µPa @ 1m
Piling operations	1 – 10,000	100 – 1,000	215
Operation of turbines	10 – 10,000	16	153

Importance of Sound to Marine Mammals

Marine mammals create sounds to communicate about the presence of danger, food, other animals, positioning, identity, territorial and reproductive status (Richardson *et al.*, 1995). Cetaceans are also known to use echolocation as a means by which to detect and characterise underwater objects. It is these sounds and the potential detrimental affect of possible tidal turbine sound on these activities that have raised considerable concern throughout this study.

Odoncete cetaceans can produce a large repertoire of complicated sounds and can be characterised as narrow-band whistles and tones or broader-band clicks and pulsed sounds which are used for echolocation.

Harbour porpoise and bottlenose dolphin vocalisation has been extensively studied. Bottlenose dolphin echolocation clicks range from a few kHz to >150kHz with dominant frequencies of 110-

130kHz. Bottlenose dolphins also produce whistles between 800hz and 24kHz with source levels of 125-173dB (Au *et al.*, 1997; DTI, 2001).

Harbour porpoises produce narrow-band clicks with a frequency range of 110-150kHz and low frequency sounds at approximately 2khz. It has been noted that the harbour porpoise seems to use a variety of sounds ranging from infrasonic frequencies as low as 47Hz to ultrasonic echolocating sounds (Hoffman *et al.*, 2000; Dolman *et al.*, 1998).

Cetaceans rely on sound as their primary sense for communication and spatial awareness. With extensive research and monitoring a number of important uses of sound have become apparent and are summarised in **Table 28**.

Table 28: Summary of Cetacean Sound Use [Source: WDCS, 2004].

Use of Sound	Summary
Echolocation	Ability by which cetaceans produce mid- or high frequency sounds and detect the echoes of these sounds that bounce off objects to determine the physical features of their surroundings. Echolocation provides accurate and detailed information about the cetacean's surroundings. Echolocation sounds tend to be produced at high frequencies and are vital to odoncetes for 'seeing' the environment around them.
Navigation	Mysticete cetaceans are known to produce low frequency calls of high source level and it is thought that mysticete whales use these sounds to orientate and navigate in a similar way to echolocation but at greater distances using the seabed, or distant oceanographic features such as a continental shelf edge, submarine mountain range or island chain. Such a form of navigation is essential for whales navigating long migration routes.
Communication	Communication is the production of a stimulus or signal that is received by another organism eliciting response. Cetaceans communicate within and between species using sound in a variety of ways.
Intrasexual selection	Incorporates a variety of behaviours that maintains social orders within sexes, such as hierarchies of dominance or maintenance of territories.
Intersexual selection	It has been suggested that female cetaceans choose males for mating in terms of their call patterns and call strengths.
Mother/Calf cohesion	The mother and calf bond is the most important social bond in cetaceans. Calves may stay with their mother for up to 10 years learning life skills such as foraging and social behaviour. Dolphins are known to keep this bond by using unique whistles.
Group cohesion	Cetaceans frequently form groups to forage. Co-ordinated herding of prey allows cetaceans to catch larger and greater quantities of prey. Groups possess specific calls and are also believed to be important in group cohesion.
Individual recognition	It is believed that dolphins produce whistles unique to individual animals, allowing the identification of relatives, form alliances and aid in co-ordinated behaviours.
Danger avoidance	Cetaceans are vulnerable to predation by several marine species. Though there is limited data recording specific 'alarm calls' by cetaceans encountering predators, several studies have documented increases in odontocete calls in response to boat traffic, which have been interpreted as 'alarm calls'.
Prey stunning	Cetaceans may be able to use sound to debilitate and stun prey, however information on this is limited.

Vocalisations in harbour and grey seals have been extensively studied (Goodson, 1996; McConnell *et al.*, 1999; McCulloch *et al.*, 2000; Hammond *et al.*, 2004) and a variety of sounds both on land and at sea have been identified and these are thought to be associated with complex social information regarding dominancy and territory. Pinniped vocalisation is also thought to be important in mother-pup relationships. Vocal characterisations have been summarised in **Table 29**.

Table 29: Summary of Underwater Vocalisation for Marine Mammals and Fish.

	Frequency range	Dominant frequency	Source levels (dB)
Harbour porpoise			
Echolocation	110-150kHz	-	135-177
Clicks	2kHz	-	100
Bottlenose dolphins			
Echolocation	2 - >150kHz	110-130kHz	Up to 218-228
Whistles	0.8-24kHz	-	125-173
Low frequency narrow bands	<2kHz	0.3-0.9kHz	-
Harbour seal			
Social sounds	0.5-3.5Hz	-	-
Clicks	8-150kHz	12kHz-40kHz	-
Roar	0.4-4kHz	0.4-0.8kHz	-
Bubbly growl	<1kHz-4kHz	<100Hz-250Hz	-
Grey seal			
Clicks, hiss	0-30, 0-40kHz	0.1-3kHz	-
6 call types	0.1-5kHz	Up to 10kHz	-
Knocks	Up to 16kHz	-	-
Fish			
Stridulatory	100Hz-5kHz	-	<140
Swimbladder	50Hz-3kHz	-	<140
Choruses	<4kHz	-	Up to 120 in highest 1/3 octave

Potential Effects of Noise on Marine Mammals

From **Table 30** it is clear that the use of sound for marine mammals is important in many aspects of their life and any disruption to sound production or the hearing sensitivity of an animal could result in a number of short and long term impacts (**Table 30**). There is therefore, the potential for marine mammals, such as cetaceans and pinnipeds, to be affected by noise from tidal turbines in all stages of its development.

The extent of cetacean occurrence has already been discussed in **Section 4**. Though the area isn't used extensively for cetacean migration or breeding, it is an area of comparatively high sightings of marine mammals, especially Minke Whales.

Research on the effects of noise transmitted through water on receptors, has been relatively limited in the UK and has generally concentrated on seismic propagated sound and marine mammal receptors (Myrberg, 1988; Myrberg, 1996; Gisiner, 1998; Ward *et al.*, 1998; Heathershaw, 2002; Harwood and Wilson, 2002; Würsig *et al.*, 2002; Hildebrand, 2004; WDCS, 2004). Specific research is also on-going as a consequence of offshore wind farm development through work funded by the DTI, COWRIE and other institutions Europe-wide (Dolman, *et al.*,; ETSU, 2000; DTI, 2001; Nedwell *et al.*, 2003; Booij, 2004; Nedwell and Howell, 2004). In addition a number of studies conducted in response to offshore wind farm development have also investigated potential noise impacts in detail. These include North Hoyle, Burbo , Gunfleet and London Array offshore wind farms in the UK and Utgrunden (Sweden) and Horns Reef (Denmark) to name but a few.

Table 30: Potential Impacts of Noise on Marine Mammals

Type of Response	Potential Impact
Physical ***Non Auditory***	 Damage to body tissue Induction of the "bends".
Auditory	Gross damage to ears Permanent hearing threshold shift Temporary hearing threshold shift
Perceptual	Masking of communication with conspecifics Masking of other biologically important noises Interference with ability to acoustically interpret environment Adaptive shifting of vocalisations
Behavioural	Gross interruption of normal behaviour (acute change over long period of time) Modification of behaviour (becomes less effective/efficient) Short/Long term displacement from area
Chronic/Stress	Decreased viability of individual Increased vulnerability to disease Increased potential for impacts from negative cumulative effects Sensitisation to noise – exacerbating other effects Habituation to noise – causing animals to remain close to damaging noise sources
Indirect Effects	Reduced availability of prey Increased vulnerability to predation or other hazards

The main sources of noise impacts from tidal current energy development were discussed in **Section 5.2.6**. In relation to these, a discussion of the potential impacts of such noise sources will follow.

Presence and Use of Vessels for Installation

Odontcetes, such as bottlenose dolphins and harbour porpoises are most likely to perceive the high-frequency sounds produced by relatively small vessels and most frequencies are emitted at intensities loud enough to be perceived by odontocetes and pinnipeds. Being able to hear vessels, however, does not necessarily mean being disturbed by it. Published literature on the response of marine mammals to vessel noise has been reviewed by Richardson *et al.*, (1995) and DTI, (2001) and it appears that many marine mammals are tolerant of vessel noise and are regularly observed in areas where there is continuous heavy traffic (Simmonds *et al.*, 2003). However, at times, a species that used to show tolerance may show avoidance. A phenomenon which often appears to be related to dolphin activity: resting dolphins tend to avoid boats, feeding dolphins ignore them, and socializing dolphins may approach boats (Richardson *et al.*, 1995). It is not clear if such observations are related to production of noise or disturbance caused by the presence of boats.

It is known that Harbour and Grey Seals, which are commonly found within the area of the Pentland Firth do tend to habituate in places with many boats and distractions. The Pentland Firth colonies do permit close approach by tour boats that repeatedly visit haul out sites and it has been suggested that the Seals do in fact habituate to sounds from regular and specific vessels. With this in mind it can be assumed that regular maintenance activities would not generally affect seal populations in the vicinity. However, short- term installation and cabling works may cause some discomfort and stress, especially in breeding times. Avoidance of these activities in such critical periods of the year should be adhered to in order to avoid the risk of interrupted pup bonding and disruptive nesting behaviour that could potentially occur.

Piling of Support Structures

One of the main sources of noise associated with a tidal current energy development is that produced during piling operations in the construction phase. Sound levels from piling activities exceed ambient levels and are inevitably detectable by marine mammals and could be potentially physically damaging to marine mammals if they are in close proximity to the source. In terms of displacement and behavioural response the effects are likely to be temporary and localised. However, few studies have looked at the effects of pile driving or other high level, low frequency impulsive sounds on marine mammals (Madsen *et al.*, 2006). With the frequencies and intensities produced from piling, evidence suggests that marine mammals would be able to hear the noise over a large area (Laidre *et al.*, 2001). However, monitoring studies conducted for the Horns Reef offshore wind farm found that harbour porpoises returned to an area quickly after cessation of the noise source (Tougaard *et al.*, 2003). This temporary displacement of marine mammals however may have been exacerbated by the displacement of their food source either by avoidance behaviour or mortality. Monitoring of seal activity for the Horns Reef project demonstrated that more seals hauled out during piling activity than without. One possibility for this was the fact that seals may have taken advantage of localised fish mortality brought about by piling activities. A Danish summary paper (Gastrup *et al.*, 2000) on the first four offshore wind farms in Denmark, speculates that the effects of noise on marine life is short term avoidance, with no long-term effect directly linked to the construction phase. However, when assessing such effects it is important to investigate not only the behavioural impact, but also the impact on marine mammals in terms of their 'fitness' (Madsen *et al.*, 2006). For example, if a given activity produces a complete, but temporary displacement from an area and all the animals return to the area shortly afterwards with no hearing impairment, the actual impact on the population may be small. Whether a displacement can be defined as a minor impact depends very much on animal and site specifics, such as biology of the animal and seasonal food source (Madsen *et al.*, 2006).

Trenching Operations and Subsea Work

There is no published information about the effects of trenching operations or subsea work on marine mammals. Noises from the burial operations are likely to be similar to those that very frequently arise offshore as a result of the use of vessels and equipment on the vessels or deployed by them.

Operational Noise from Turbines

For comparison, the operational phase of offshore wind farms have been reported to produce broadband low frequency noise above ambient levels and at the lower end of the threshold frequency spectra of odontocetes (Richardson *et al.*, 1995). The zone of audibility and potential zone of exclusion around operational offshore wind farms has not been clearly defined. Different studies have reached different conclusions, perhaps affected by local conditions. By comparing auditory sensitivities of marine mammal species for different frequencies with wind turbine sound characteristics it was predicted by Henriksen *et al.*, (2001) that the maximum detection distance for harbour porpoises is likely to be 50m. Detection distances in relation to Vindeby (Denmark) and Gotland (Sweden) were predicted to be in the region of 20m (Bach *et al.*, 2000), however, studies at the Vindeby site were not able to demonstrate any noticeable change in behaviour or numbers of animals present during its operation. Koschinski *et al.*, (2003) reported on the behavioural reactions of harbour porpoises and seals to the noise of a simulated 2MW wind turbine. Results indicated that porpoises and seals were able to detect the low-frequency sound generated and that they showed distinct reactions to the noise. In addition, the number of time intervals during which porpoise echolocation clicks were detected increased by a factor of 2 when the sound source was active (Booij, 2004).

The potential impacts of tidal current energy developments, in the low or infrasound frequencies, are dependent on the equipment used for the turbines and propagation of vibrations into the water and sediments. These infrasounds could potentially increase over the turbines lifecycle due to wearing of the gear mechanism or minor increase up to the 6 monthly services.

The extent to which noise will impact colonies of pinnipeds is also a concern. Usually male pinnipeds use airborne calls to compete for females and territory. However, females and their pups vocalise in air and water to maintain contact. Underwater calls are also usually used to co-ordinate mating. There is concern with regard to the possible noise emissions from the operating turbine, but there has been evidence to suggest that seals readily habituate to low level background noise and sounds that become familiar to them. However, the extent to which noise interference impacts on seal colonies is unknown and to minimise any impact, construction works should be kept out-with breeding times.

5.3.3 Marine Mammals and Collision Risk

The key impact for marine mammals is the operational noise, and the attraction/repulsion affects of the noise versus the potential attraction of fish aggregation.

With respect to collision risk, the probability is small. Avoidance and detection techniques have been witnessed through controlled experiments, whereby cetaceans have clearly avoided oil spills and slicks. However, this has been dependent on the area and the avenues of escape (Boesch & Rabalais, 1987). There has been concern about the extent of noise emissions from the operational turbine, but such emissions may act as a deterrent from the immediate vicinity of the turbines.

There has been concern that pinnipeds in the area will be subject to collision risk with the rotor blades of the devices installed. Pinnipeds are known to be naturally inquisitive, which implies that a risk is probable. However, detection and avoidance behaviour has been evident in marine mammals, such as the Harbour and Grey Seal and over time they will most likely learn to coexist with such activities and obstacles. The fluid dynamics of the tidal device may also aid in the protection of straying seals. The physical forces involved are expected to push any objects through or over the blades clear of any collision.

5.3.4 Fish

Fish are most likely drawn into the area through the strong tidal currents, bringing food in suspension and the strength of the currents themselves. There are a number of direct and indirect potential sources of impact associated with a tidal current energy development on fish, which include the following:

Noise Disturbance

For offshore developments, such as tidal current energy, seismic activity would be within the pre-construction phase and related to the use of airguns during seismic surveys. Potential impacts on fish are generally associated with mortality of planktonic eggs, larvae and pelagic fish species. Research suggests that such impacts are highly localised, within a few metres or less and therefore the overall potential impact is considered minimal (La Bella *et al.*, 1996; Turnpenny and Nedwell, 1994). Studies of the effects of noise on fish at the small wind farm site at Vindeby, Denmark, and oil and gas platforms in the UK sector have concluded that they appear undisturbed by the background noise climate. Further, as noted elsewhere, fish may actually accumulate in the area of the turbines and foundations as occurs at other offshore structures. (Vella *et al.*, 2001).

Disturbance of Sediments and Seabed Scouring

Disturbance and re-distribution of sediment during the installation phase may have the potential to affect fish species with respect to:

- reduced egg hatching and increased egg and larval mortality;
- mortality or displacement of benthic fauna providing food;
- impact of re-suspended sediment on juvenile and adult fish due to clogging of the gills and abrasion of body surface;
- reduced feeding due to a decrease of visibility in the water column;
- stress primarily due to construction work; and
- displacement of fish species from the proposed development.

A primary short term effect which is very likely to occur during the installation period, is the disturbance and temporary displacement of fish species from the area due to increased turbidity of the water through the disturbance and re-suspension of sediment, changes in underwater water movements and other sea bottom activities. Experience suggests, however that once installation activities have been completed, the fish species affected will return quickly.

The main impacts likely to arise are those associated with seabed disturbance, especially concerning spawning and nursery grounds during installation phases. Most fish species that are found in the Pentland Firth area spawn outside the region, with one exception, the Herring. Herring are particularly sensitive, because their eggs are laid on the seabed. There are a number of spawning grounds that cover a wide area, where spawning takes place between August and October. To minimise any detrimental affect, installation should be limited to times outside these months.

Indirectly, beneficial impacts may also occur due to the re-suspension of sediment through installation and cable laying and also through possible rotor disturbance. These impacts could possibly cause an increase in food source, especially for pelagic species. The 'artificial reef' scenario could also be beneficial for the same reason. It has been well documented over time that structures attract motile animals such as fish (Boesch & Rabalais, 1987). The probability of direct collision with the support structure and rotor blades is extremely low.

Physical Presence of Turbine Structures

For juvenile and adult fish, the presence of turbines is not thought to represent a significant impact on their viability. As discussed previously, the capacity for fouling growth on the support structures to attract fish has the potential to be quite significant. Observations of the turbine structures at Blyth, indicate that they appear to have attracted fish (Hiscock *et al.*,. 2002).

5.3.5 Seabirds

The Pentland Firth is an area internationally important for its seabird colonies, especially those associated with cliff- and island nesting birds. There is little or no literature on the potential and actual effects that tidal current energy developments may have on birds. However, the construction and operation of a commercial scale tidal current development may produce a variety of effects including:

- the displacement of birds from the area;
- detrimental effect or loss of feeding grounds or food sources; and
- presenting a collision risk to birds.

With respect to the proposed project there are activities that may be deemed as sources of disturbance. These include the close approach of vessels and the approach of people near to a colony. Though such activities seem relatively harmless, they can in effect cause detrimental impact on bird populations. Though most disruption will occur in the installation phase, intrusion is bound to occur when maintenance checks are carried out. There is evidence to suggest that constant, systematic intrusion can lower bird productivity and in the severest of cases result in total desertion.

In theory, most forms of disturbance can be eliminated by prohibiting disruptive activities near colonies. However with respect to the Pentland Firth (and possibly other areas suitable for tidal energy development) a majority of sites follow the 40 metre depth contour, which will be in the vicinity of cliffs and near-shore areas.

Birds will be sensitive to all activities and phases associated with the construction and operation of a tidal current energy development. Birds tend to depart from an area of disturbance and will generally avoid the area for the duration of the disturbance. The risk of a potentially significant impact from displacement is dependent on a number of factors, including the availability of other sites and feeding areas, the scale of disturbance, the frequency and duration of disturbance and the potential to which a species may habituate to the disturbance. The area itself, however, experiences a number of potentially disturbing activities, such as tours of the Pentland Firth, where ribs are frequently taken to within metres of the cliffs. Bearing this in mind, it is plausible to suggest that the bird colonies in the area are used to human presence.

Terns are especially vulnerable to disturbance. This is due to the fact they are ground nesting birds and therefore any cabling or construction base activities within the vicinity of such breeding ground would have a detrimental affect. They are also an internationally important species, listed in Annex 1 of the EU Birds Directive, so careful consideration of breeding sites is advisable. To minimise any cumulative or direct impact it is common practice to avoid sensitive breeding times throughout the year.

Habitat loss may occur mainly through displacement of birds from an area around the tidal turbines and may include reduced access to feeding areas and other important locations for specific activities, such as moulting. Physical changes to the local environment, as described in **Section 5.2** primarily include the loss of the area of seabed covered by the turbine support structure. For example, 60 turbines with a rotor diameter of 20m and support structure diameter of 5m would have an estimated overall seabed area of 134.4km^2. Direct seabed contact area would be approximately 1.17km^2. Existing studies (ETSU, 2002) on the effects on bird populations of the loss of feeding habitat through the physical loss of seabed habitat indicate that changes to sediment character and physical processes are localised and restricted to the development area. In addition, though there is very little data on the diving depths of seabirds, most have diving depths of less than 20m, though there some, such as Cormorants, Gannets and Auks that dive as deep as 40m or more (Wilson *et al.*, 2007). It is important that any proposed site should avoid important areas of suitable feeding habitat for particular species of interest.

Concern was also raised by the RSPB about the possible collision risk that may occur with diving birds, but this is thought to be an extremely low impact potential due to the low rotation speed of the rotors.

In addition to the physical loss of habitat and potential collision risk, there is also a potential 'zone of avoidance' around turbines and tidal energy developments where foraging birds are displaced. The probability of this effect occurring is unknown and it is possible some species may be more sensitive to this issue than others, where some species would be likely to forage around turbines. The consequence of exclusion on bird populations in the area would be dependent on the extent of the exclusion and the availability of an alternative habitat (DTI, 2003).

Contrarily, seabirds may be attracted to tidal turbine structures following colonisation by shellfish and other marine organisms (DTI, 2003). Increased abundance of fish species around the structures may potentially attract divers, auks, terns and gulls (DTI, 2003).

5.4 Assessment of the Socio-Economic Environment

5.4.1 Fisheries Activity

Potential Interactions

The dominant fisheries activity in the Pentland Firth area was identified as static gears (creels) for shellfish, undertaken by around a dozen boats from each side of the Firth. Fishermen tend to favour working out of the main tidal areas, however creels are occasionally laid in the central Firth areas, where strong tides make the timing of deployment and retrieval vital. There is believed to be no dredging activity occurring in the areas of potential development.

With single tidal turbine developments, the likely reaction of fishermen would be to regard the structure as a skerry and thus avoid laying creels in the immediate area. It is certainly possible that creeling may pose a threat to the type of generator proposed. Impacts on the tidal turbines themselves could be an issue where there may be the possibility of creel lines becoming entangled with the blades. For example storms could shift the creels and cause entanglement, or indeed fishermen could seek to exploit any enhanced reef affect caused by the development, and lay creels within designated exclusion zones.

Interactions should be minimised by the establishment of development exclusion zones, and because both ends of a creel line have a marker buoy attached, aiding deployment and retrieval along a known route. With larger development scenarios and the setting up of larger exclusion zones, there may be a case presented for a loss of access (see below) implying a level of compensation were productive fishing grounds to be impacted.

Another possible interaction could take place between towed dredges and the development, where damage to cables could result. Again this risk is deemed minimal with no reports of dredging taking place in Firth areas and particularly in tidal areas.

Loss of Access

The installation of tide devices, whether individually or as a large multi-device development will undoubtedly result in the imposition of safety zones around structures, the area affected relating to the size and distribution of the structures. The imposition of such zones will effectively, through licence, preclude fishermen from fishing in these areas, providing a clear indication that it is unsafe to do so. A similar prospect has faced fishermen with respect to offshore development and abandonment in the North Sea. In this instance, problems in relation to loss of access have historically centred upon broken promises by the UK Government to completely remove all structures, leaving fishermen little choice but to pursue adequate compensation for loss of access to fishing grounds in perpetuity. Offshore operators and Government, however, do not consider this "loss of access" to be proven.

If there is a loss of access to fishing grounds in the Pentland Firth, one that is licensed by Government, particularly in perpetuity, fishermen are likely to look for a case by case assurance that the safety zone is necessary to reduce risks to fishermen. Where deemed reasonable, organisations such as the Scottish Fishermen's Federation (SFF), may pursue a claim on behalf of present and future generations of fishermen for adequate compensation for the loss of access to fishing grounds in perpetuity.

Such reactive situations in the Pentland Firth can be avoided through early and proactive discussions with fishermen. Issues that may need to be clarified include:

- proximity to historical fishing grounds;
- number of fishermen affected and area lost to fishing;
- disruption to fishing routes and effects on e.g. fuel usage;
- the length of time structures will be in place, whether temporary or in perpetuity, including plans for their future removal. Fishermen have a strong sense that equity should be maintained between present and future generations of fishermen when seeking compensation (if applicable); and
- projected loss of earnings as a result of tidal developments (if applicable).

5.4.2 Recreation and Tourism

Positive Impacts

The main significance of the Pentland Firth area for recreation and tourism is derived from the unspoilt coastal and marine environment and seascapes. There are few water sports in the area and impacts with such activities would be minimal. A recent addition to the tourist attractions to the Pentland Firth area has been the setting up of mini wildlife cruises by 2 companies based at John O' Groats, and centred on the island of Stroma and Duncansby Head.

It is likely that a tidal current power generation project would, for many visitors, add to the interest in the local environment where powerful tidal regimes are well documented. With a growing interest in sustainable energy solutions, the placement of tidal turbines would add to the attractions for boat trips into the Firth, providing additional visitors to the area. John O'

Groats has a growing number of tourism developments and would also provide an ideal location for any interpretation and information centre for tidal power developments.

Local acceptance of such developments significantly increase where there are direct social and economic benefits from projects, and this aspect should be uppermost in general development planning.

Visual Impacts

Generally the greatest impact of tidal power generation developments of the type proposed would be visual impact. Similar surface piercing structures in the marine environment include lighthouses, navigation lights and offshore wind turbines. Unlike wind turbines, however the above surface structure will be much reduced (around 15-20 metres) and there would be no moving parts in view. The tower and top platform with access / maintenance housing and navigational equipment would form the visible structure.

The extent of impact would be ultimately dependent on the scale of developments – single devices, tidal 'crofts' or larger tidal 'farms'. Single and individual tidal croft developments would involve limited visual impact, whereas a number of such developments scattered throughout the area would be visible over several kilometres from both sides of the Firth. From most land perspectives the developments would be viewed against a coastal back-drop which would reduce their prominence, however due to navigational marking requirements the towers would be made as conspicuous as possible (see section 6.4.1 'Charting and Marking of Structures'). This would involve day markings and navigation warning lights. The tower structures would have a close resemblance to features already in the marine environment and it is hoped this would ensure that they appeared reasonably in place within their surroundings.

5.4.3 Potential Seabed Interactions

Marine Archaeology and Wrecks

The majority of wrecks within the Firth lie in close proximity to coasts and skerries having become grounded due to navigational error. Concentrations of wreck sites are found particularly at Duncansby Head, but also at Stroma and Pentland Skerries.

These should not impact on tidal developments (or vice-versa) which would be developed further offshore, however once development areas have been finalised the wider area, cable routes and landfall areas should be fully surveyed. A Code of Practice (JNAPC, 1998) has been produced by the Joint Nautical Archeology Policy Committee, setting out recommended procedures for consultation and co-operation between seabed developers and archaeologists.

Other Users of the Coastal Zone

Crown Estates – Seabed Lease Implications

Crown Estates would require to issue a lease or consent for the use of the foreshore and seabed, providing: -

i) a right to occupy the area involved; and,

ii) security of tenure, subject to the terms of the agreement.

The Crown Estates Commissioners (Edinburgh) were consulted on the general principles of establishing tidal energy devices within the Pentland Firth area. The device concept would be regarded as a more permanent feature than say a wave device due to the nature of fixing to the seabed and similar to offshore wind turbine placement. CEC are generally keen to encourage such developments within the area, which provides them with additional income. Most of Scotland's coastline will not be favourable to offshore wind projects due to water depths and therefore wave and tidal options would tend to be encouraged.

For an untried technology a guarantee of the means and funding in place for the removal of the device (in the case of failure or longer-term routine removal) would be required. This could be through the guarantee of financial backing in place by the developer or the setting up of a bond with CEC. The bond approach would allow CEC to hire a contractor to remove the turbine and pile - cutting off the pile structure at the seabed.

The actual seabed area involved would not be a factor in the lease costs – the Crown Estate preferring to license a footprint or square. Experimental turbines, where not grid-connected and earning income, would be charged a rent based on experimental rates. When generating to the grid, the rent charged would be royalty based – on the amount of energy generated and price received. The licence would cover all aspects of the development, including cables. The footprint approach means that no other developments would be permitted in the areas between individual turbine installations.

Industry

There are few industrial developments along the coastal zone of the Pentland Firth. The main site is Dounreay where any exclusion zone which may be in force (associated with plant discharges) should not impact on developments, unless a cable landfall is chosen to take advantage of the 275kV electricity connection.

There are no Crown Estate licences for marine aggregate dredging in any areas of the Pentland Firth. There are a number of solid waste disposal sites in the area mainly for dredged harbour spoil. The area impacted from such activities is small and localised.

Electrical Grid Constraints

General – Offshore Projects

The size of any offshore generating project will dictate the appropriate connection voltage to the onshore grid. Smaller projects, (e.g. <20MW) will find connection at distribution medium voltages (MV) up to about 35kV. Larger projects (e.g. 50MW+) will, in general, require higher voltages (HV), such as 110kV. The largest projects, those in excess of several hundred MW, will require connection to transmission system grids, such as the UK 275/400kV system. The available grid power transport capacity will dictate the level of connectable generation, since all grids have limits to the amount of new power they can accommodate. Nationally there are significant areas, where the available grid capacity is very low, and this will restrict development in these areas unless the grid is reinforced (See **Section 7.1.2**).

Grid connection and site electricals for a typical offshore project may be taken as about 30% of the overall costs (Scott, 2001) and are therefore a very significant issue. The electrical works may be broken down into the onshore grid connection, the connection from the offshore site to shore, and the offshore site infrastructure. The difficulties of the offshore marine environment require careful design of the electrical system so as to minimise costs and maximise generation availability. The key elements in transporting the generated power from site to shore are the transmission cables and associated works.

These elements are not discussed further in this present study, however the availability and capacity of the onshore grid infrastructure must be considered as it forms an essential component of any future generation within the Pentland Firth area (See **Section 7.1.2**).

Caithness Connections

It is likely that any tidal energy developments within the Pentland Firth would be connected to the National Grid on the Caithness side of the Firth, the Orkney grid being a lower voltage (33kV) and weaker system.

The north coast of Caithness has a 275 kV connection point, located at Dounreay, some 21 km west (by road and therefore by overhead transmission cable route) of Dunnet Head. This point may well be important in the future if large generation plant is installed. However, the presence of this connection point does not mean that significant amounts of power can be accepted into the national grid system at this point in time, without large-scale investment further south.

Discussions were held with Scottish and Southern Energy (SSE) to gauge the potential for connections to be made in the north of Scotland, both at present and in the future. At present a major constraint on any additional generation capacity being accepted into the grid in the North of Scotland, is a 'bottleneck' on the 275 kV line between Aberdeen and Dundee. This constraint limits any and all new generation development in the north of Scotland as it restricts the electricity which can be exported to the highly populated areas in southern Scotland. The mechanism by which this restricts the generation of power in the north is as described in the following paragraphs.

At present a percentage of power flows from Peterhead and hydro-electric schemes northwards to feed Northern Scotland. If additional generation is introduced in North Scotland, the northward flow from Peterhead is reduced, and power from Peterhead would require to flow south through the bottleneck. Scottish and Southern Energy have a limitation in that they must be able to meet demand in the south with a scenario of two from four 275kV circuits 'down' (e.g. one out for maintenance and one out for fault). Consequently, to prevent worsening of the situation, they have a virtual 'capping' of new generation in the north. In reality this capping would only be applied to connections over 2MW. Therefore, If a developer in the north wished to connect more than around 2MW, he would (in theory) be liable for the costs of re-inforcement. An unofficial, though widely available estimate for the costs of upgrading the Scottish grid system to overcome this difficulty is in the region of £82M.

This problem has not gone unnoticed in the Scottish Executive, as it has placed a barrier in front of renewable developments in the north. A number of developers have approached SSE to see if a connection can be agreed on the basis of supplying electricity for the best case scenario, i.e. when all 4x275 kV circuits are operational, and the bottleneck is removed. The approach adopted in such a scenario could be for selective shedding of generation in the event of faults/maintenance. At present, there is no mechanism to select which generation to shed, and there could be contractual difficulties in doing so. The Electricity Regulator is expected to make an announcement on this shortly, in an effort to improve the viability of new connections, and put an end to considering the worst case (bottleneck) scenario each time.

At the present time the grid along potential Pentland Firth landfall points is 11kV - a relatively weak system, prone to local problems. An upgrade of the system would be required to allow more power to be accepted to the grid. The connection of a generation capacity of 5 - 10 MW would require an upgrade to a 33kV system, entailing installation of new 33kV lines to the closest connection point (e.g. Thurso) and the installation of sub-stations/switchgear[1]. Connection of a larger project (50MW+) would require upgrade to a higher voltage, such as 132kV.

An initial enquiry for a sizeable (> 2MW) power generation connection would involve a feasibility study being carried out by the utility. The result would be a quote for local connection being made but also (in theory) a quote for overcoming the larger constraint of the bottleneck in the wider system. Such a case could well be referred to the Electricity Regulator, who could recommend changes to the electricity supply infrastructure. A connection report would also be issued which would consider voltage step conditions in the area to ensure that the new generation would not compromise the local area supply.

Economic Benefits

The Pentland Firth borders both Orkney and Caithness and both areas could benefit economically from the development of tidal energy within the area. The successful development of tidal energy conversion systems would lead to a new and apparently inexhaustible venture for the area, with opportunities for local business in all development stages.

A previous tidal development study for Orkney and Shetland waters (ICIT, 1994) suggested local companies could benefit from up to 25% in terms of value of any construction contracts for the generation systems, and that there would also be opportunities for maintenance and servicing of the various systems.

Established technological expertise in Caithness includes a major offshore fabrication facility, a skills base including the UKAEA facility at Dounreay, power engineering expertise, energy consultancy and a marine surveying capability. These suggest opportunity for a high level of local involvement in any developments within the Firth. With landfall and grid-integration for tidal developments likely to be along the Caithness coastline, it is inevitable that Caithness firms will have opportunities in certain key areas (electrical maintenance, coastal civil works, etc.).

There would also be opportunities for Orkney involvement. In terms of installation works the sheltered support base offered by Scapa Flow, together with it's towage capacities could provide an ideal base for jack-up rigs during installation of tidal systems, and for longer term support. In addition there are several local firms in a position to offer engineering, fabrication and subsea inspection service.

[1] Approximate costs for onshore 11kV line installation are £30,000/km; for 33kV line installation £40,000/km while sub-station / switchgear costs could be in the region of £100,000 (Scottish and Southern Energy).

5.5 Cumulative and Transboundary Impacts

5.5.1 Cumulative Impacts

There is no doubt that the impact assessment process focuses on the specific project and the direct impacts on the environment that may occur. However, there is increasing concern about the cumulative impacts of human activity on the environment. Geographical and temporal boundaries and the consideration of all other projects in the area, whether they are in the past, present or in the reasonably foreseeable future are becoming more important. In other words cumulative impacts are those that influence the environment outside the local scale, the immediate future and ultimately add to existing impacts.

Area of Influence

- The scope of the project is limited to specific locations and routes within the area of the study with respect to its physical and biological characteristics and location

- It is anticipated that all the adverse impacts that may occur will be within these specific areas and routes with the exception of the potential influence of the project on tidal flow and sedimentation. The possibility of sound propagation may also have an influence that's not limited to specific locations and routes.

- Economic benefits out with the area may include the creation of employment and tourism

Time Scale

- Within the scope of the project it is thought that most direct impacts will occur once or twice for a relatively short period of time with respect to construction and decommissioning phases, with recovery expected to occur with 2 to 5 years.

- Exceptions may arise with the more unpredictable impacts that may occur, such as, the influence of such energy devices on the tidal flows and ultimately sedimentation processes, which may occur over longer timescales, such as the lifetime of the project and perhaps beyond (**Section 5.2**). In addition, marine mammal population shifts may also be a long term consequence with respect to large scale developments.

Existing Activities and Impacts

- Overall it is difficult to assess the interactions of the project with existing activities and impacts due to the different and sometimes contrasting, synergistic or neutralising affect of the various impacts that may occur.

5.5.2 Transboundary Impact

In 1991 the UK became a signatory to the ESPOO Convention. Under this convention parties are required to identify and jointly take appropriate measures to prevent, reduce and control significant adverse transboundary environmental impacts from proposed projects. Overall there are number of potential transboundary impacts that may occur within the scope of the project.

Ecological

- Potential change in environmental quality within the localised area with respect to localised habitat creation;

- Possibility that project will have beneficial effect on the concentrations of gases associated with global warming – there will be no harmful emissions.

Socio-economic

- Diversification of the oil and gas industries;

- Potential for foreign companies to provide services, equipment and resources to the project;

- Potential for project technology etc. to be exported and applied to other operating sectors i.e. opportunities to develop a new UK supply industry and establish a lead in a global market context;

- Provides positive example in the future development of renewable energy throughout Europe and the rest of world.

5.6 Assessment and Evaluation of the Technical and Environmental Constraints

5.6.1 Physical Environment

From what has been established about the geological, sediment and tidal characteristics of the Pentland Firth area, the following main technical constraints have been highlighted.

Water Depth

Many parts of the Pentland Firth have depths beyond 50 metres and in some places extend beyond 100 metres. With regard to current technology this poses some constraint on the positioning of devices. Supporting structures at present are unable to withstand the environmental forces imposed in such depths and it is encouraged to restrict installation to depths below 50 metres. It is envisaged however, that placement of the devices will follow the 40 or 50 metre contour lines.

Lack of Sediment

There is a lack of offshore sediment throughout the area of the firth and the direct local coastline in the area also affords few places where cable can be buried in the surf zone - this causes problems with respect to cable protection. Where there is perceived adequate sediment towards the west of the firth careful consideration would be required during the planning of cable burial. Depths of sediment are unknown and although shallow water burial methods may suffice for the coastline, such as trenching and jetting, problems may occur in establishing an adequate burial depth, which in depths of less than 61 metres requires cabling to be laid approximately 0.9 m deep.

Outcrops of Bedrock

The extensive bedrock outcrops that make up the seabed of the firth cause problems that go hand-in-hand with the constraints of the previous point. It is feasible to trench the cables, but this would inevitably cause greater disturbance to the seabed. This method also relies on the waves and currents to aid in the eventual burial with sediment. However, with very little or no sediment this would not be the case. Without adequate restraint and surface support, laying of cables can cause numerous implications with regard to bending and flexing and thus overall power transmission. Directional drilling would be a good option, due to the fact cables are protected by rock and any visual impact is in effect removed.

Currents

Parts of the Pentland Firth are renowned for their turbulent and extremely strong tidal currents, which places constraints on the locations in which devices can be installed with respect to the environmental forces placed upon the devices. A detailed description of the Pentland Firth current regime can be found in Dacre and Bullen (2001). It is advised that installation should be kept to areas where current velocities are below 5 $m.s^{-1}$. Problems associated with current turbulence and strength have been highlighted in **Section 5.6.2** with regard to potential ship collision.

Currents act as a transport medium, which to some extent causes problems with offshore structures, especially those of a sensitive nature. For example, currents carrying floating debris may have the potential for causing damage and mechanical difficulties, as well as initiating debris 'build-up' on the sea surface. With respect to the type of device being deployed this would be unlikely due to the fact blades are sub-sea situated rather than at the surface.

Corrosion and Biofouling

Corrosion

All marine structures are subject to deteriorating agents and usually the harsher the conditions the more prominent the degree of deterioration. The marine atmosphere contains salt, which increases the rate of corrosion quite considerably. With respect to the tidal current energy devices, the rate and type of corrosion will depend upon the type of construction material. Bearing in the mind the relatively extreme conditions of the firth the use of robust materials will be inevitable. The effects of corrosion on the marine environment are not highly publicised, though Thick (2006), discusses the historical perspective of offshore corrosion control in some detail. In the light of the offshore industry it is fair to say, however, that such technology is well defined and tested. The main methods of corrosion prevention are corrosion resistant materials, two-pack epoxy coatings and cathodic protection. With the emergence of pre-qualification testing, the implementation of ISO 203040:2003 and proven offshore credentials methods of corrosion prevention should have a minimum acceptance criteria in terms of control specification and environmental impact, as well as providing a robust platform for developers to utilise best practice techniques. Research into non-corrosive materials and protection methods is sustained and on-going, with numerous companies providing extensive research and development within the offshore sectors (Thick, 2006). Regular maintenance plays an important role in establishing these safeguards. In the view of the devices in mind, a modular or jack-up system, whereby the rotor can be 'lifted' and inspected will provide accessibility and a means to establish a continuous program.

Biofouling

Fouling refers in general to the accumulation of plant and animal growth on immersed and partially immersed surfaces. The effects of fouling on a marine structure are severe, but for systems such as tidal current energy devices a number of implications can occur. These include: increased drag and lower blade efficiency; increased inertial and gravity loads due to increased surface roughness, area and mass; increased corrosion rates and the possible abrasion of cables and mooring lines.

Fouling prevention is a difficult problem and has undergone much debate over the years. Some metals and materials exhibit a natural resistance to fouling, but they are unusual, expensive and generally not feasible for this sort of application. With the well documented adverse affects and and the ban on TBT based coatings, alternative approaches to antifouling need to be considered that will be suited in maintaining the performance, 'clean' reputation and costings of the tidal current devices in question.

Overall, the Pentland Firth presents a unique challenge to the engineer in terms of suitable selection of materials, structure type and function over a range of conditions that are present from the relatively calm to the harsh environment of the area.

Designated Areas and Protected Sites

There are a number of designated sites and protected sites within the area, which may have implications when considering the development of the proposed project (Section 4.2.3).

International Designations

Special Protection Areas (SPA's) have an important presence within the Pentland Firth area and span a relatively large proportion of the coastline, including all three islands of Swona, Stroma and Switha. Unless construction works do not avoid these areas it is highly unlikely that any impact on these sites will occur. Accordingly within these areas, renewable energy developments are allowed to proceed under exceptional circumstances. This includes instances only where it is known that the development will not adversely affect the habitat or species concerned or there is a national interest in allowing such a development to take place and there is no foreseeable alternative.

National Designations

There are a number of sites established under national statute, which include Sites of Special Scientific Interest (SSSI's) and National Nature Reserves (NNR's). Within these areas Government policy seeks to protect the environmental assets represented by these designations.

Renewable energy developments are not actually prohibited, but care must be taken to establish reconciliation with conservation interests. It has been recommended that renewable energy projects should only be permitted where it can be demonstrated that the designated area will remain largely unaffected by such developments or any adverse effects are significantly outweighed by the national benefits that could accrue from the development.

Other Designations

There are extensive Preferred Conservation Zones (PCZ's) along the coastlines adjacent to the Pentland Firth. They are designations not actually protected by statute, but are nonetheless important in terms of scenic, environmental and ecological aspects and any proposed development will be taken very seriously.

A Regional Landscape Designation (RLD) is situated near Duncansby Head. Such designations are recognised for their scenic resource, especially in terms of an unexploited tourism resource. Tidal current turbines are not without their visual impact in terms of their surface piercing support structures. However, with respect to visual impact, effects will be minimal and may even enhance the already established tourism resource.

5.6.2 Socio-economic Environment

Navigational and Shipping Constraints

Due to the environmental conditions needed for a tidal current development, navigational and shipping issues are of paramount importance in the siting of devices. Though the following discussion is directly concerning the Pentland Firth area, it can be assumed that similar problems and constraints may arise in most sites suitable for tidal current development.

Existing Traffic Patterns and Problem Areas

An analysis of vessel traffic through the Firth by radar was contracted by the Maritime and Coastguard Agency (Safe Marine Ltd., 1999). The results of the radar tracking exercise highlighted the presence of a number of well-defined encounter points in the Firth, contained within relatively narrow confines. These include crossing points and 'melee' areas where traffic can be encountered from more than one direction.

A Melee Area was identified in the Firth to the east of Swona and Stroma where several frequently used traffic routes converge. Such areas pose more collision problems for mariners than straight forward crossing situations, particularly when aspect may not be a reliable indication of the relative course another vessel is making, as frequently might be the case in the Firth's strong and in places confused tidal streams. A high incidence of unfavourable weather adds to the potential difficulties.

The Firth is unlike many other areas with high traffic densities in that the options available to control this traffic are limited (MCA, 2000). Routeing schemes (such as adopted by the International Maritime Organisation (IMO)) in which two opposing traffic lanes are separated by a separation zone, are not be feasible in the Firth since there is insufficient space to provide these in the deep draft channel between Stroma and Swona. In addition, although the Pentland Firth is entirely within the territorial waters of the UK, ships of all States enjoy the right of Innocent Passage through its waters. Thus, although some degree of control can be exerted, it would be difficult to exercise any prevention of vessels using the Firth.

Consultations on Tidal Developments, Navigational Issues and Concerns

It is against the existing navigational difficulties, traffic levels and challenging environment that any potential developments in the Firth must be assessed. Discussions on navigational issues and the development of tidal energy in the Pentland Firth were held with a number of key organisations[2] with both local and national jurisdiction. The main concern raised in all cases was a potential reduction in the already limited main navigation channel (Outer Sound), particularly in the central routes, and where strong tides make keeping course and speed difficult. In such conditions vessels require as much space as possible.

Particular concern would be raised by developments in the main navigation channels of the Outer Sound to the east of the Firth - between Duncansby Head and Muckle Skerry; north of Pentland Skerries; and, north of Stroma. Such concerns were of an advisory nature at this preliminary stage and various mitigating actions were discussed. For example, developments located in the 'shadow' (coastal fringes) of land masses (i.e. not projecting into main 'through' or 'cross-traffic' channels) would be broadly more acceptable to authorities.

A development located well out into navigation channels would be "intimidating to navigation" due to the reduction of the available channel. The addition of an exclusion zone around the tower of a turbine, (as for offshore installations) would reduce the available navigation channel where the zone established extended beyond the (approximate) 0.5 mile clearance which a vessel's master would routinely allow for a coastline or hazard. In such a case a balance would have to be reached between providing an exclusion zone and leaving a reasonable navigation channel (*pers. comm.* Orkney Harbours).

Generally reducing the potential development footprints and concentrating on the regions adjoining land-masses would be viewed more favourably. Outwith such areas (i.e. where development areas encroached on navigation channels), objections to development on the grounds of reduced navigation and increased collision risk would inevitably be made.

The Inner Sound channel was also regarded as an important navigation channel, being used for coasters, sizeable fishing vessels in transit through the Firth and Ferries. Similar issues outlined above would also apply.

Inevitably the contents of vessels must also be considered in any risk assessment – there are already concerns regarding the expanding traffic through the Firth, and in particular the large vessels carrying oil in bulk and other hazardous cargoes.

The above scenarios and feedback from consulted authorities suggested that it may be necessary to negotiate for the exclusive use of an area for tidal energy extraction, if safe, long-term operation is to be achieved.

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[2] OIC Harbours Dept.; Scrabster Harbour Office; MRSC Pentland; HM Coastguard Wick; Northern Lighthouse Board, Edinburgh.

Charting and Marking of Structures

For the purposes of navigational charts a single surface piercing structure with moving machinery (rotor) would be classed as an 'isolated danger' where all around was classified as safe waters.

This would require navigational markings and lights for identification and warnings to traffic (*pers. comm.* Northern Lighthouse Board). Routine navigation markings would be required on tower structures (red/black vertical bands, a beacon (emitting white light all round) and 2 black spheres on top (day mark)).

Where more than one device were being considered in an area it was suggested that a channel formed by a line of devices, and with a lateral marking could be an option – too many lights would be confusing to mariners.

Potential Anchoring Impacts and Constraints

Anchoring in the Pentland Firth is unlikely to be considered in anything but an emergency situation due to the inability of anchors to hold in the prevailing tidal and seabed conditions. If a vessel was to drift with no power and the tide was not bringing it clear, then anchors may be employed to slow the vessels movement. Such an incident leading to a collision with a tidal turbine structure would obviously cause concern for the safety of the vessel and to the integrity of power cables and structures associated with any development. There are no measures which can be taken to prevent such an occurrence, however the quick reporting of such incidents (e.g. loss of power) by vessels should be emphasised (including appropriate warnings on charts, etc.), allowing a rapid response to be organised. There is, for example, a Coastguard tug stationed in northern waters and also tugs in Scapa Flow which would respond. From the design of tidal turbine structures there are obviously design implications which will minimise third party damage and reduce the severity of impacts.

CHAPTER 6

Assessment of EIA Methodology

6. ASSESSMENT OF EIA METHODOLOGY

6.1 Introduction

Environmental Impact Assessment (EIA) is recognised as an effective tool to support environmentally conscious decision-making world-wide. However, as new development and technology moves forward and in turn becomes increasingly complex, the effectiveness of EIA has, in some cases been diminished. Eventually, present EIA methodology may be incapable of providing the necessary level of environmental protection that is needed.

Generally, energy projects pose a number of significant challenges to the EIA process, despite the wealth of experience that has been generated over the years, especially in the offshore oil and gas sectors. Conducting EIA on marine energy projects has become very complicated and a majority of this complication has arisen due to increased knowledge, not only of the energy industry itself, but also of the marine environment. EIA consultants are able to draw upon almost 30 years of experience conducting EIA's within the marine environment. However, though this may seem advantageous, it is also causing problems with the fact that by solely drawing upon this past experience, the methodology used for EIA is not necessarily keeping up with increasingly advancing energy developments. However, there is no perfect EIA for an energy project, so it is not the aim of this chapter to criticise EIA practice. However, through assessing current marine environmental assessment practice, the aim is to capture key governing principles to be used in the development of an EIA framework that is transparent, effective and not overly complex for tidal current energy development in **Chapter 9**.

6.2 Evaluation of EIA Methodology and Criteria

6.2.1 Selection of Existing Environmental Statements

In order to evaluate current marine environmental assessment a review of existing standards of both past and relatively recent Environmental Statements (ES) was conducted. A total of 12 projects were reviewed in order to provide a representative example of the range of offshore EIA work undertaken, covering a range of projects from large to small demonstrator projects. All of the ES's evaluated are marine-energy related projects, a majority of which are offshore wind energy projects, which have some generic environmental issues with respect to tidal current energy systems. Three of the projects evaluated are tidal current energy projects. The evaluation of these projects is important mainly in the fact that they are early examples of environmental impact assessment for such projects, despite the fact they consist of small-scale demonstration projects. In response to the extensive experience of the oil and gas sector, some oil and gas projects were also evaluated, where like, offshore wind energy projects, some generic environmental issues are also evident. Environmental Statements evaluated are summarised in **Table 31**. The date corresponds to the date of the Environmental Statement.

Table 31: Summary of ES's Evaluated

Project Name	Date	Developer/Researcher	Type of Project	Distance Offshore
Blue Mull Sound	1994	ICIT	Tidal Current	<5km
Scroby Sands	1999	E.ON UK Renewables	Offshore Wind	2.3km
Horns Rev	2000	I/S Elsam	Offshore wind	14-20km
Burbo Offshore	2002	Seascape Energy Ltd.	Offshore wind	6.4km
Gunfleet Sands	2002	GE Wind Energy	Offshore wind	7km
SEAFLOW	2002	MCT Ltd.	Tidal Current	c. 3km
North Hoyle	2002	npower	Offshore Wind	7.5km
Barrow	2002	Centrica/DONG	Offshore Wind	7km
Stingray	2003	The Engineering Business Ltd.	Tidal Current	c. 2km
Pict Field	2004	Petro-Canada	Oil and Gas	152km
London Array	2005	London Array	Offshore wind	20km
Golden Eagle	2006	Apache	Oil and Gas	c. 12km

6.2.2 Environmental Statement Review

The Institute of Environmental Assessment recommends that two evaluators are used to review environmental statements to ensure a lack of bias and an adequate range of experience (Coles *et al.*, 1992). In this instance, an evaluation is provided by the author only. Most methodology used to assess the ES's use specific criteria to evaluate the components in the EIA process in a structured, scientific way. Though these methods are inherently subjective, they provide adequate transparency in their approach, minimising any bias, whilst maximising replication of conclusions.

Key objectives of an EIA review are:

- to assess the quality of information contained in the EIA;
- to determine how stakeholder concerns have been addressed;
- to determine if the information is adequate for decision-making; and
- identify gaps and deficiencies.

ES review systems have already been developed for many types of EIA's (Brookes, 1993; Coles *et al.*, 1992; Lee and Colley, 1990; Thompson, 1990; EIA Centre, 1995; Sadler, 1996; Thompson *et al.*, 1997; Brookes, 1999; Russo, 1999; Wood, 1999; Sippe, 1999; IAIA, 1999; EU, 2001; DEAT, 2004 and Surrey County Council, 2005). The latter list of references is not exhaustive, but presently holds some of the most definitive sources of EIA review methodology. A majority of reviews rely on a structured approach using the EIA process as a whole, reviewing and assessing each section of the ES in turn and assessing its quality and relevance against specific criteria, whilst establishing an overall appraisal of the ES under review against points of reference established at the project proposal stage.

Review of the selected ES's (**Table 31**) draws upon the final key objective stated above, namely the deficiencies and gaps of the ES's under review, as well as the governing strengths that have been established to provide a comprehensive EIA. Though ES's were assessed on an individual basis, the overall conclusion of the following review does not express opinion on any individual ES.

6.3 Observations of ES Review

On reviewing the selected ES's a number of observations were made where gaps or improvements needed addressing.

6.3.1 EIA Integration

The purpose of an EIA is to improve decision making, ensuring that project options under consideration are environmentally sound, providing a balance between development needs and protecting the environment. The EIA process should have an integrated approach, where EIA is appropriately related to the decision-making process. However, a number of observations were made that were not entirely conducive to this:

- EIA is generally applied after broad project options are analysed. Often, however, project options are developed with little consideration of environmental issues, so the EIA process is applied at a late stage in project development and thus the decision making process.
- EIA is generally poorly adapted to project planning and design. This is evident in the fact that most EIA's are not carried out until project developers are sure that a project will be accepted, thus removing the iterative process of technological and site selection, failing to evaluate the '*best practicable environmental option*'. There is evidence to suggest that developers use of EIA is merely a 'means to an end' in order to meet planning approval, rather than

using it as a decision-making tool to improve the environmental integrity of a development.

- Most EIA processes reviewed followed a similar pattern. However, as stated above, the process should be iterative as opposed to a linear one and therefore though the EIA process will be similar, it should be also evident that each project was assessed on an individual basis, using site specific information.

6.3.2 Project Description

An important element of the EIA process is the detailed description of the proposed project and the objectives of the ES. A majority of the ES's reviewed maintained a good standard. Though some provided an adequate textual description they failed to use any graphical measures to enhance the description visually.

6.3.3 Project Alternatives

Section 6.3.1 describes issues that are related to project alternatives. Generally, the descriptions and justifications of project alternatives lacked detail in terms of the way differing alternatives were quantified and assessed. A majority lacked even a simple matrix detailing the potential effects of each alternative.

6.3.4 Environmental Description and Baseline Conditions

It is impossible to assess the effects of any new development unless an adequate model of the existing environment is considered, identifying key environmental features, constraints or limiting factors. The interrelationship of such environmental factors is unique to each site and all of the projects reviewed adequately described the existing environment, its natural trends and component interrelationships.

Incorporation of baseline data into the environmental description was conducive to most of the ES's reviewed. However, ES's consistently seemed to lack 'up-to-date' information, favouring past surveys etc. and considering the environment is dynamic, baseline data should reflect this, even to the point of detailing environmental changes over time to be able to fully assess any future short and long term changes as a consequence of a new development.

In relation to **Section 6.3.1**, there is also unsatisfactory consideration in detailing impacts and failure to integrate such impacts at the planning stage to enable environmental issues to be incorporated into the design and planning of the development through discussion of technological and site alternatives.

6.3.5 Environmental Impact

A majority of the ES's reviewed identified the key environmental issues that needed to be addressed through comprehensive scoping studies. However the standard of detailed analysis of effects and their predictions were varied throughout the selection of ES's. In general, the analysis of effects was predominantly subjective and in some cases where quantitative techniques could be used, such techniques were omitted in favour of subjective assessment. In addition, there has also been a failure to consider the time frames indicative to when impacts are likely to occur and where possible for how long. In many cases, interactions between environmental components and processes were not expressed, thus environmental components were treated as individual entities and consideration of 'indirect' impacts was not considered. In this respect, it is difficult to make an overall analysis of the total impact or cumulative impact of a project.

In an earlier ES, failure to account for all phases of a project within its impact analysis is a serious omission. It is important that all phases of a project are considered and evaluated. Further changes could result in a further ES having to be submitted or the inclusion of a substantial amendment with a probable public consultation period being initiated for a second time.

6.3.6 Mitigation and Post-project Monitoring

Mitigation and monitoring is a key component of any development ES, so that mitigative measures can be monitored and that post-development problems can be identified and further mitigated or rectified.

Generally, mitigation measures and their effectiveness were related to negative potential effects, however, justification of methods was handled in an entirely subjective manner and no quantification of 'environmental improvement' was quantifiably assessed, thus predicting the likely success of mitigation.

Apart from the most recent projects, specification of a monitoring program was not detailed and even then the need for monitoring was only mentioned without detailing how and on what timescale this would be done. With respect to offshore renewables, discussion is ongoing with regard to how such monitoring can be 'policed' to ensure commitments are being adhered to. At present, monitoring conditions are attached to the FEPA consent, which can be generic, device or site specific requirements and have usually been developed by Dft, DEFRA, Crown Estates and the DTI in conjunction with the developer.

6.4 Applicability to Tidal Current Energy EIA

Apart from the demonstration and prototype projects, most marine energy projects are long-term assets and the EIA process devoted to such projects should take this factor into account, along with the following weaknesses and gaps discussed in the previous sections. A summary of these can be found in **Table 32**.

Table 32: Summary of the Key EIA Weaknesses and Gaps.

1.	Lack of detail concerning project alternatives.
2.	EIA process poorly adapted to project planning and design.
3.	EIA process rarely adapted to suit project needs or uses iterative process.
4.	Lack of adequate base-line data.
5.	Failure to consider interrelationships of environmental components and processes and thus there is a failure to provide an EIA using a *holistic* approach.
6.	Failure to detail monitoring programmes.
7.	Lack of comparability/transparency between projects of a similar nature.

The Pentland Firth study (Dacre & Bullen, 2001) highlighted that tidal current energy technology has its unique, but diverse environmental problems and considerations, despite also having some generic ones that compare with other marine or offshore renewable energies, such as the oil and gas and offshore wind energy sectors. It also became apparent working through the EIA process used that in terms of tidal current energy a standardised EIA framework and methodology for assessing potential environmental impact would be beneficial, especially with respect to future potential development. These sentiments have also been iterated since then in terms of the future development of marine energy systems (Dacre *et al.*, 2002; Lowther, 2002; Harper, 2002; Wilson & Downie, 2003 and Band, 2003). Crown Estates recently shared similar concerns (Heeps, 2006) explaining that detailed guidance on EIA was needed. In addition, it was also suggested that it was paramount that more devices should be deployed in order to build up data sets, which would subsequently help to build upon pre-commercial consenting issues. In respect of this, data management and the need to use robust science to make decisions would be crucial. For the purposes of an EIA, it was stressed that baseline conditions or site-specific data were also paramount to determine any changes during the operational and post construction phase, in order to validate any environmental modelling.

By reviewing existing EIA's, as well as taking into account the methodology and processes used for the Pentland Firth study it is hoped that a majority of the gaps and weaknesses can be addressed to standardise the EIA process used to evaluate future tidal current development in order to maintain and encourage an 'environmental integrity' that should be conducive to renewable energy systems. This is a complex issue and there is no definitive answer to mitigate the weaknesses at hand or develop standardised criteria for tidal current energy EIA. However, an attempt has been made to do so and this is detailed within **Chapter 9**.

CHAPTER 7

Barriers to Development

7 BARRIERS TO DEVELOPMENT

With respect to the study (Dacre, 2003) in order to properly evaluate the market potential of tidal current energy in Scotland it was important to consider the problems and hindrances with regard to such a new and up-and-coming industry. Other reports, such as that produced by the DTI (2001; 2004), SWREA (2003), Metoc (2004), the Climate Change Capital (2004) and BWEA (2006) have also highlighted important issues. With such issues highlighted and actions considered, it was easier to determine the needs of the industry in terms of growth and economic potential with respect to a developmental 'route-map', which follows in **Chapter 8**.

At the beginning of the renewable energy drive, land-based and more recently offshore wind was deemed to have less of a technological risk compared to other sources of energy. More and more interest was cultivated and through this 'critical mass' at the time, the wind industry was able to take-off, unlike many other sources of new and renewable energy.

Despite the obvious encouragement of renewable energy, including that of tidal current energy development, progress is slow, especially with respect to the offshore renewable sector. Barriers are no longer associated with poor technology, though continued research in this area is paramount to increase the economic and environmental viability of technology. Tidal current energy technology is relatively well developed. At present, most barriers seem to be predominantly institutional, rather than for any other reason. There have been a number of reports that have touched on the issue of developmental barriers (PIU, 2002; HC, 2002a and 2002b; SEn, 2001; SE, 2001). However, most have merely concentrated on planning and the problems with the grid infrastructure. Though they are highly important considerations, it is necessary to broaden the context to appreciate all the problems involved in developing a productive and sustainable tidal current energy industry within Scotland, the UK and even worldwide.

Through the consultation process that accompanied the market potential study (Dacre, 2003), a number of developmental barriers were highlighted. Generally, these barriers can be divided into those of an institutional context and those that encompass other issues. The barriers to tidal current energy are complex issues and some are very much related to each other. Most barriers identified are generic with respect to other renewable energy sectors. **Table 33** summarises these.

Table 33: Summary of Key Developmental Barriers

Institutional
Project Consents and Environmental Policy
Electrical Transmission/Grid Infrastructure
Funding/Finance
Energy Industry Re-structuring
Export Support
Governmental Awareness/Attitude

Other
Environmental
Public Awareness and Perception
Technological
Industrial Capability

7.1 Institutional Barriers

7.1.1 Project Consents and Marine Environmental Policy

It is widely accepted that with respect to offshore renewable energy development, obtaining planning permission and indeed the planning process in general is a key barrier to development and offshore tidal current energy no exception. The problem has not been helped by the fact that past NFFO planning statistics have been played down quite considerably with respect wind farm development (Hartnell, 2001).

Project Consents

The consents process is a complex issue, resulting from a number of requirements and Acts through numerous statutory bodies. A summary of such requirements can be found in **Appendix 10** (adapted from Dacre & Bullen, 2001) and from a recent paper presented at MAREC 2003 (Trinick, 2002). A brief discussion of requirements and Acts can be found in **Chapter 4**.

Both the UK Government and The Scottish Executive is well aware of the need to amend the offshore consents process and the Scottish Executive conducted a consultation process on such issues in early 2001. The Draft Regulatory Impact Assessment was also initiated to view such amendments and lay out the options intended. The overall aim was to streamline the consents process for offshore electricity generation systems. The introduction of the DTI's Offshore Renewables Consents Unit (ORCU) provides a single application point for developers. It is hoped that such changes will make it easier for developers to proceed. Already guidelines have been set out regarding offshore wind development, but such guidelines are also required for the tidal current energy industry and indeed for other offshore renewable energy development. It is not adequate to follow the history of the offshore wind energy sector in this endeavour, in the fact that such consents procedures were still being reviewed after the offshore wind energy industry took off and developments were granted. Problems duly arose because of the lack of guidance initiated throughout the whole process. One such problem has been the lack of consultation with stakeholders in order to address environmental impact issues, not only on the developers part, but lack of consultation with stakeholders from regulatory authorities is also a significant issue. This has caused alarm for many stakeholders, such as the chamber of shipping and the RSPB. In addition, evidence suggests that potential environmental, safety risks and cumulative impacts were overlooked in the EIA process for some offshore wind developments, which has caused much scepticism in relation to the integrity of the consents process. Therefore, it is paramount for the tidal current energy industry that such consents and consultation processes are fully in place before any significant growth in the industry occurs to avoid disruption and controversy of any kind.

Despite efforts to amend the consents process, conflict has been identified between Crown Estates that handle consents and the DTI. Both have a significant influence in the development process. Basically, it is the responsibility of the DTI (key policy drivers) to authorise Crown Estates to issue licences for deployment. In other words Crown Estates cannot act on their own initiative, which has caused some frustration, for example, in the fact that this prevents Crown Estates from capitalising upon its assets and generating revenue from potential development. In addition, despite the ORCU, consent procedures are still spread across a number of government departments, leading to an inadequate consideration of the environmental implications of potential offshore developments.

To compound this lack of integration between Government departments in terms of marine planning consents, it seems that all sectors of the marine environment also lack integration and co-operation, making the approach to marine planning very difficult. All sectors of the marine environment (which include aggregates, coastal defence, oil and gas, fish farming, historic wrecks, conservation etc.) have environmental management practices in place to ensure best practice for each sector. However, each regulator that is related to a sector basically works on an individual basis according to its own set of regulations and guidance. It is rare to find each sector conversing with the other on a common development or planning application. In addition, the introduction of the Water Framework Directive and Habitats Directive with its legislative requirements to monitor the status of the environment irrespective of activity or sector compounds the lack of integration even further.

The duplication of environmental management systems is a compelling reason to develop a 'seamless' planning policy to ensure integrity in the planning process within the marine environment.

Marine Environmental Policy

Due to the increasing need to balance environmental concerns with new development the majority of proposed marine renewable energy projects, including that of tidal current energy require Environmental Impact Assessments (EIA) under Directive (97/11/EC) through the Transport and Works Act 1992. The scope of work required for an EIA to meet the EC directive has been under intense discussion, including developers, non-statutory and statutory organisations. In response to this, guidance notes have been drawn up to provide a framework with respect to EIA, but these are generally generic in nature and many are specifically related to the offshore wind industry (CEFAS, 2001; DTI, 2001a; ETSU, 2000). Though there are generic issues pertaining to marine renewables, detailed consideration should be considered for each technology because each varies in size, deployment location, and power extraction mechanism etc. In order to establish such detail a comprehensive EI framework and guidelines are required to be developed for the assessment of tidal current energy sources to ease the overall consents process.

With the introduction of the Habitats Directive (Council Directive 92/43/EEC) and the possibility of a Marine Act in the future, management of the marine environment is an important concern. In relation to the consents process, the management of the marine environment at present is *ad hoc* and there is little transparency behind planning and development decisions. The marine environment ideally needs to be managed with a more integrated and holistic approach. There is concern that there is increased pressure being applied to the marine environment with the introduction of offshore renewables, antagonising an already fragile environmental system. The DTI are already proposing to declare a Renewable Energy Zone (REZ) out to 200 nautical miles but there is already concern that developments are going ahead of conservation and sustainability policy. There is a clear need for a 'marine spatial planning' approach to bring together all aspects of the marine environment, such as existing activity and the physical and biological components to avoid conflicts of interest, loss of vulnerable habitats and species, and achieving the best use of marine resources whilst maintaining sustainable management of marine activities. The lack of designated sites (SACs and SPAs) being identified may also impede not only the environmental assessment process of marine renewables, but also future development. At present, developers cannot know whether a possible development site is likely to be environmentally contentious until they have invested heavily in it. Conflict can lead to project delays, increased costs and in extreme cases the refusal of consent altogether or may be the abortion of a project altogether. In addition, the delay in designating marine protected sites (MPAs) is a principal barrier to full Strategic Environmental Assessment (SEA) analysis of potential impacts.

Strategic Environmental Assessment provides an important tool for integrating environmental considerations into future development plans and programmes, however, they are not without their problems and misgivings. SEA's have been implemented for both the oil and gas sector and offshore wind and plans are underway to implement a SEA for the marine renewables sector. Though the application of SEAs is of relative importance, the effectiveness they have in terms of overall marine environmental protection and management is questionable (**Section 7.2.1**) and therefore, they can only indirectly impede the development of marine renewables with respect to the time it will take to initiate and complete such a task.

7.1.2 Electrical Transmission and Grid Infrastructure

Due to Scotland's massive renewable resource a major concern for the renewable energy sector in general is the impact new development will have on the grid infrastructure of Scotland and the UK. This is under serious scrutiny at present, with respect to developers, distributors and Government bodies. A report prepared by Scottish and Southern and Scottish Power (SE, 2001a) details the impact of renewable energy generation on the grid infrastructure.

General Consideration for Tidal Current Generation Projects

The size of a project generally dictates the appropriate connection voltage to the onshore grid (**Table 34**) and the available grid power transport capacity that dictates the level of connectable generation.

Table 34: Project Size and Connection Voltage Requirements

Project Size	Required Connection Voltage
Small (< 20 MW)	up to 35 kV
Large (> 50 MW)	110 kV
Very Large (hundreds of MW)	275/400 kV

Where available grid capacity is low (**Figure 56**), this will restrict development in those areas unless the grid is reinforced and this is extremely expensive. At present, it is the responsibility of the developer to meet these costs and this accounts for a high percentage of the overall project costs, therefore this is a very significant issue in terms of economic viability for tidal current energy generation and indeed other renewable energy sources. The resource for tidal current power is generally well positioned and exists primarily in the north and west coast of Scotland (**Chapter 2**). However, at present all areas of the grid appropriate for tidal current energy extraction have low availability capacity. These issues do not just involve Scottish and UK supply, but also create barriers in terms of export potential.

The predictability of tidal current energy is advantageous compared to other technologies in the fact that it is easier to calculate the impact of energy surges and this in turn allows transmission authorities to make a more informed decision on the electrical needs of the country.

Grid Constraints

With respect to the Market Potential study (Dacre, 2003), discussions were held with Scottish and Southern Electric in early August 2002 and at that time a cost study was in progress involving the National Grid, Scottish Hydro and Scottish Power. The aim was to determine the cost and location of upgrade.

A constraint on any additional generation capacity in the north of Scotland will result in a 'bottleneck' on the 275 kV line between Aberdeen and Dundee. This inevitably will restrict the electricity that can be exported from the north to the highly populated areas in southern Scotland and the rest of the UK. The Peterhead power station has a capacity of 2000 MW and hydro accounts for approximately 1500 MW and at present a percentage of that power is fed northwards. If additional capacity is introduced into the north of Scotland, the northward flow from Peterhead is reduced and power from there will then be required to move south through the 'bottleneck'.

With these constraints Scottish and Southern have a major limitation in that they must be able to meet demand in the south with 2 out of 4 275 kV circuits. To prevent worsening of the situation there is a virtual 'capping' on new generation schemes in the north which exceed 2 MW.

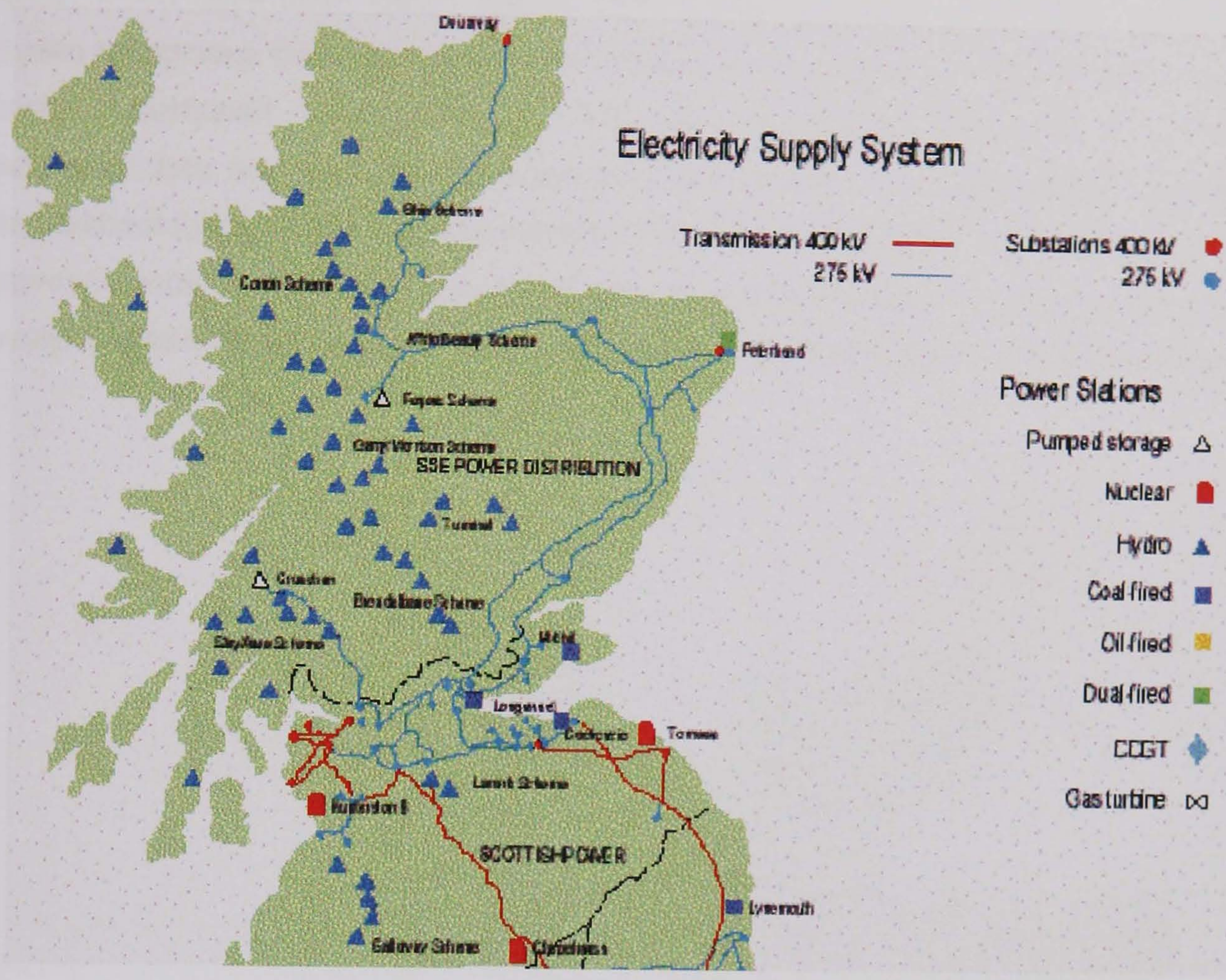

Figure 55: Electricity Supply System [Source: UK Electricity Association (www.electricity.org.uk)]

Mitigation

At the moment solutions to this are under review and can be divided into two main themes. The first are the planning, cost and upgrade issues and the second involves detailed analysis and specification of transmission sizes/capacity needed and where the needs are greatest. In order for the second phase to be comprehensive, detailed resource assessments are required and this in turn will help in the planning and costing issues. Recently, a tool that provides detailed resource mapping (i.e. wind, wave and tidal current data) has been developed. The purpose of the Renewable Energy Atlas is to spatially map coastal and offshore resources within the limits of the UK continental shelf (UKCS). It is the plan of the DTI to use the atlas to assist in the decision making process with respect to future licensing rounds of large scale deployments of marine renewable technologies (BWEA, 2004; Cooper, 2004). A report (DTI, 2004), describes the data resources, methods of analysis and an overview of the resource maps provided. When developing the atlas, the approach was taken to recognise the value of previous resource studies and provide an improved level of understanding and integration of information. In doing so, the system was also developed to provide a basis for continued updates as more information becomes available. At present, the atlas uses best available data to derive resource estimates, which have been tested against technologies available at the time. However, the report also recognises that data sources and technologies will advance and therefore the atlas will require sustained maintenance. This will include the integration of site-specific measurement data and updating of constraints and assumptions with respect to new and updated technologies. There are also plans to add further GIS layers, such as seabed geology and environmental sensitivities. The report also recognised that with respect to the electricity grid system, details of distribution circuits operating at 132kV and below are not presented in the atlas.

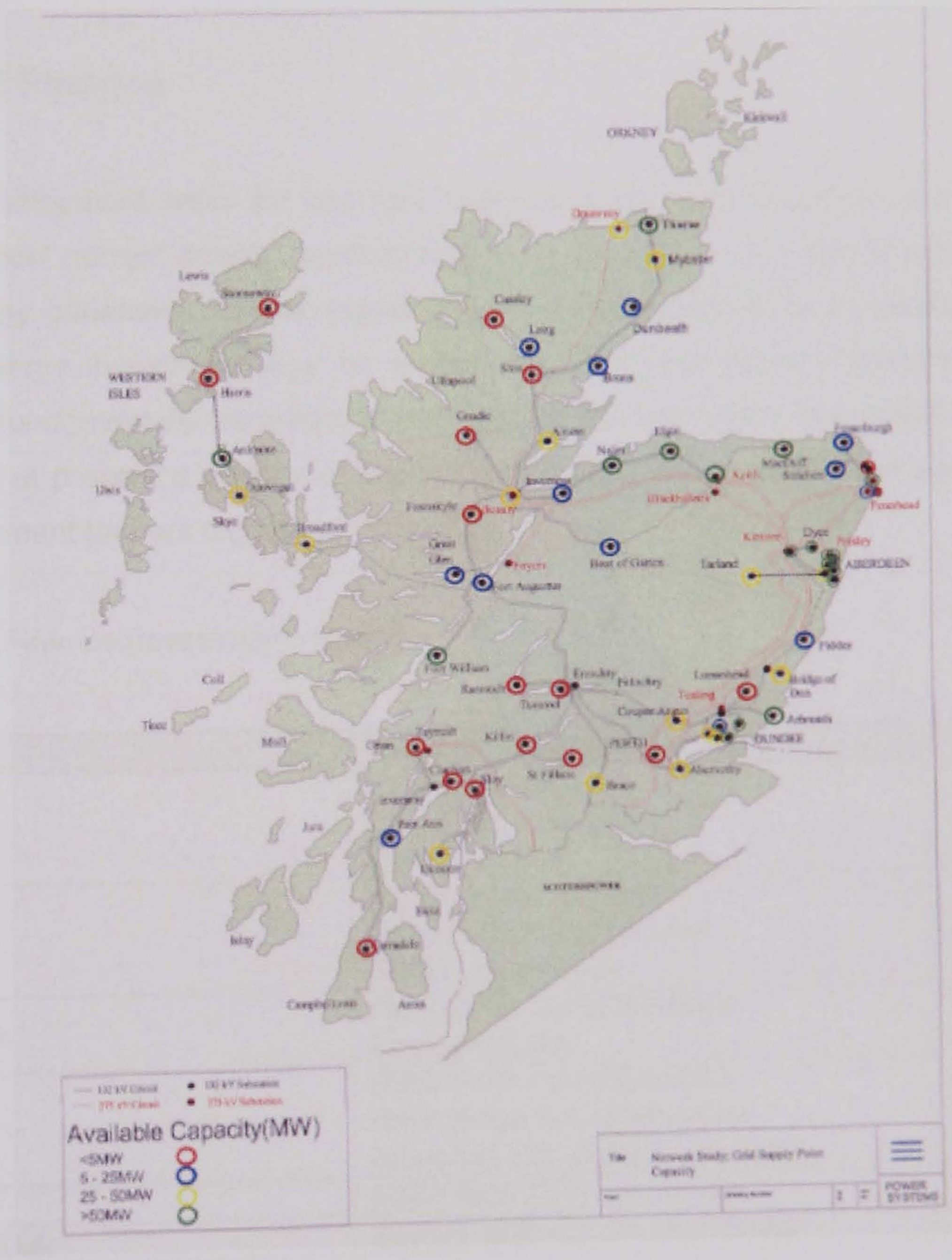

Figure 56: Available Grid Capacity in Scotland [Source: SE, 2001a].

There is no doubt that the renewable energy capacity in Scotland is far greater than that of the rest of the UK. It has been speculated that the key energy distributors (i.e. Scottish & Southern and Scottish Power) will be willing to make the investment to upgrade the grid system (an unofficial cost estimate of £40 million). It was suggested that investment would be eventually recouped by the developer delivering a connection charge amounting to 10% of the project costs that would also be initiated in England and Wales, where renewable energy capacity is much lower. The power transfer from Scotland to England would also necessitate upgrading of the Anglo-Scottish interconnector to accommodate this venture. A recent OFGEM consultation confirmed plans to upgrade the grid by 1000MW over the next few years. The first phase is planned for the Inverness to Stirling line. Beyond this, regulators need proof that renewable energy will be enough to sustain the economics of the upgrade. In the same consultation it was suggested that the consumer would sustain the costs of the upgrade, starting in Scotland, with all of the UK's consumers contributing indirectly by 2005 (Todd, 2004).

7.1.3 Funding and Finance

Initial research and development costs for any new technology are very expensive and the same process for the tidal current energy development is no exception. In order to achieve overall renewable energy generation targets, significant investment needs to be achieved. A potential renewable energy investment may be sustainable and have many environmental benefits, but it is only fundamentally beneficial if there are sound economics associated with development. There is at present a number of finance and funding issues, which can also be related to other development barriers discussed (**Table 35**).

Table 35: Funding and Finance (investment) Issues

Investment Issue	Related Section	
Project Location	*Consents/Policy* *Grid Infrastructure* *Environmental*	7.1.1 7.1.2 7.2.1
Political Risk	*Funding and Finance* *Government Awareness* *Public Awareness*	7.1.3 7.1.5 7.2.2
Resource Strength/Risk	*R&D/Tech Considerations* *Environmental*	7.2.4 7.2.1
Technology Risk	*R&D/Tech Considerations* *Knowledge & Collaboration* *Industrial Capability/Core Skills*	7.2.4 7.2.3 7.2.5
Project Lifetime	*R&D/Tech Considerations*	7.2.4
Power Price Certainty/Risk	*Energy Industry Re-structuring*	7.1.4

The Scottish Executive and the UK Government have set up a number of financial and fiscal options to help reduce the initial start-up costs of renewable energy technologies. The level of support however, does depend on the relative priority given by government or support agencies to specific renewable energy technology and this has presented some financial constraint towards tidal current energy. At present, there does seem to be a major drive with respect to the offshore renewable sector and although there has been positive feedback concerning tidal current energy, wave and offshore wind energy seems to have a higher priority. One influencing factor in this is the fact there are not enough technologies being developed to constitute a 'critical mass', which is crucial in the way the DTI governs its market support. This leaves us with a 'chicken and egg' scenario whereby central government will not promote the development of an industry until it sees more technologies being developed. A number of developers have expressed their frustration at this scenario, especially when it is clear that technological development in both sectors is competent with respect to the technologies under development at this time. If tidal current energy development is to move at a faster rate, increased financial support in all areas of R&D is paramount. Within Scotland, however, Tidal Current Energy has begun to benefit considerably through increased funding and finance for research and development needs. Examples include a Scottish Enterprise £30M Proof of Concept Fund and the Enterprise Fellowship scheme that aims to help the innovation process.

'Scottish Renewables', Scotland's leading renewable energy organisation has also introduced new financing and investment opportunities for renewable energy in Scotland by bringing the financial and renewable energy sectors together. These funding and finance initiatives are an excellent source of encouragement to establish potential companies, but more funding and finance is needed to stimulate the market and encourage companies to diversify their skills into the renewable energy sector.

In March 2004, the Renewable Power Association (RPA), put forward requests to the DTI for enhanced revenue support, but the Government rejected any such amendment to the Energy Bill. One reason for this lack of financial support is the fact that Government seems to have the idea that finance strategies will not be needed for a number of years. This has led to much disappointment, as tidal current energy technologies will not survive such a lengthy development programme. In the recent study (Climate Change Capital, 2004) presented to the various Government bodies, consultees unanimously confirmed the existence of a funding gap between the research and development stage of a project and its full commercialisation. There was a general consensus that mechanisms need to be put in place now which provide the opportunity for growth. To finance the funding gap, it has been suggested by investors that equity should be the key finance tool, rather than a debt-based strategy. For example, there are no debt financed offshore wind developments and therefore it is highly unreasonable to suggest another mechanism for other marine renewables, despite them being at a much earlier stage of development. Many arguments have been put forward for the preference of equity-based finance options. At present, smaller developers or those who have no track record in the energy industry find it difficult to secure debt-based funding, because they are unable to put forward large amounts of equity negotiated by banks in order to secure the loans. Bearing this in mind, equity-based funding would seem the preferred option in acquiring external finance from larger companies or specialised investment funds. However, some developers may find this may also require a change in ownership of the project, though Intellectual Property is usually retained. Finance mechanisms are complex and many factors are considered when proposing the financial elements of a project, such as project size and profitability. Dinica (2003) describes such factors in detail.

Generally, the renewable energy industry does not have the same advantageous terms to borrow in the financial markets, as do other energy and technology sectors. They can be helped through funding as described above, but help also needs to come from the utilities themselves and other investment opportunities from the oil and gas industry or alike. It has been expressed that the industry needs a 'key' investor or supporter from established industry to push the sector forward. Experiences from other renewable sectors have not been particularly successful. In part, for example, where companies have decided to invest alongside government subsidy and then the government pulls out, leaving companies high and dry with regard to that project. Generally, such financing will improve if there is an assurance that there is a long-term market through the mitigation of other barriers to tidal current energy development, such as the grid infrastructure, price structuring and technical competence. It is a complex issue, but financial constraints for tidal current energy need to be at a minimum, for the industry to grow and become sustainable. Despite some financial constraints with respect to Government and agency funding, tidal energy companies have been relatively successful in raising money in the venture capital, industrial and public markets.

If financial strategies are not formulised as soon as possible, consensus between developers suggests that moving overseas could potentially be a viable option. The Portuguese Government is in the process of market testing a support regime for early wave and tidal projects. The object of which is to pay developers 15p/kWh for developments. Many developers and investors agree that this is set at a reasonable level in the short term, and are actively pursuing projects in Portugal. If such projects go ahead and other developers follow suit, this could adversely affect the potential of the industry in Scotland and the UK.

In terms of the diversification of the oil and gas industry towards the tidal current energy industry, an additional barrier relating to financial constraints was highlighted in section 2.5.2. The oil and gas industry is an expensive industry, possibly due to the demand it has created over the years in terms of skills and expertise. The tidal current energy sector, at present cannot cope with that financial capacity within any supplier capability. In order for financially adequate diversification to occur, companies need to change or re-structure their way of thinking and in turn their profit margins for tidal current energy or indeed any related marine energy to succeed in the short and eventually the long term.

7.1.4 Energy Industry Re-structuring

The economics of tidal current energy is primarily a technical constraint issue, where deployment and generation needs to be efficient and cost effective. A theory put forward by one interviewee suggested that the projected cost for tidal current energy had been "accidentally inflated" in a government report in the 1980's, creating a perception that has been difficult to supersede. With reference to **Section 2.3.3**, it is evident that developers have not quite reached a competitive edge with respect to cost per unit due to a number of technical problems. However, other factors influencing cost are also involved.

Increased competition through the liberalisation of the energy market should have in theory driven down costs and prices to obtain a competitive advantage. It was also assumed that such initiatives would help the renewable energy market. It has been found however, that liberalisation has adversely affected the commercialisation of the renewable energy sector. Due to liberalisation and increased competition, conventional energy sources have also readily decreased their energy prices, making it even harder for renewable energy options to compete.

The participation of the utilities is crucial in solving this barrier. Through the SRO and other initiatives the utilities have made commitments to increase their share of renewable energy generation, which in the long-term signals commitment.

Therefore, in the long-term it should enable policy makers and regulators to create a more balanced approach and improve competition overall and in turn provide greater competition between renewable energy options, this will in turn create competitive prices throughout the whole energy sector. Despite the endeavours to keep prices low and competitive, in terms of 'clean' energy it could be that the notions of cheap energy may have to diminish altogether to provide the low carbon, 'green' energy alternatives that are imperative to global needs. For example, in Denmark the introduction of their large wind energy industry has resulted in increased energy bills for consumers overall.

7.1.5 Government Awareness and Attitude

For tidal current energy at this time it is not necessarily technological development that is important, because that is in place, but the most crucial factor is government policy and action, which relates heavily to **Section 7.1.3**.

This issue is probably the cornerstone of all the developmental barriers, as it is the government that has an influence on all the other concerns addressed and therefore plays a key role in the promotion and ultimate development of any renewable energy industry.

There is a strong feeling throughout Government that renewable energy is a crucial practice to adhere to and much of Government's agenda has focused on these issues. However, there seems to be a clear dichotomy that while renewable energy is a good thing in principle, action is not being initiated quickly enough. There is a general consensus that there are firm believers in renewable energy and those that have placed their faith in the more conventional fuel base. It is the latter that seem to have the stronger hold on the energy situation as a whole promoting other fuel bases, such as gas and nuclear as the seemingly cheaper option and not really looking to a safer, more environmentally benign and sustainable future. There has been great concern that financial support has been given to the renewable energy competitors such as nuclear, but it is until recently that this has begun to change. It is understood that there will have to be a transition stage to meet a renewable energy future, but complacency is still apparent throughout Parliament and this needs to change if promotion of renewable energy is to be sustained and successful.

Attitudes are changing, however, with the introduction of new initiatives that seriously promote the renewable energy sector. The fact that the Government has seen fit to establish a new DTI unit, 'Renewables UK' in Aberdeen is a powerful signal that they are considering renewable technologies as serious contenders in the energy market, and that Scotland is at the 'hub' of that market.

The Scottish Enterprise Energy Team has recently launched a 'diversification toolkit' which aims to encourage companies to exploit their potential in key industry areas, one of which being renewable energy and even more specifically tidal current energy generation (DTI, 2001b). Again this is another clear indication that key Government bodies are seeing renewable energy as a serious market contender to those willing and able to diversify.

However, criticism has been widespread with respect to the publication of the UK Government's *Renewables Innovation Review* (DTI, 2004a). The review was conducted jointly by the DTI and the Carbon Trust with the aim to aid the Government in prioritising support for renewable energy technologies. A major drawback of the review is its focus on achieving targets. The key target date is 2010 followed by 2020, where 20% of electricity is hoped to come from renewables. After this the next date is 2050. With respect to the review, if a particular technology cannot meet the 2010 target its priority slips down. In the review, tidal current energy has been recognised as important but concludes by suggesting that it could develop into a significant global market by 2050. Effectively, the Government are recognising tidal current energy benefits, but postponing their achievements until 2020 and beyond. Such procrastination has additional repercussions to the developing tidal current industry as a whole (**Section, 7.1.3**).

Though the Government has historically been biased towards onshore wind energy development, MSP's have recently called for major investment in renewable energy, stating that the focus should shift from wind to tidal and wave power. There has been cross-party concern that the focus on wind power has detrimentally affected other technological advances (BBC News, 2004). The Scottish Executive currently gives onshore wind companies subsidies for development, however, if the current energy policy changes reflecting MSP's concerns, tidal current energy could benefit from the same subsidies as wind power, thus providing a beneficial mechanism for commercial development.

7.2 Other Barriers

7.2.1 Environmental

The issues detailed in **Section 7.1.1** under marine environmental policy and consents have a direct relation to other environmentally related barriers. With respect to tidal current energy it is paramount that the right interface between tidal current development and the marine environment is achieved.

Tidal current energy is publicly supported by environmental authorities and groups, such as Greenpeace and Friends of the Earth, World Wildlife Fund and Scottish Natural Heritage (SNH), and is seen as the renewable energy with the least environmental impact, however in the study conducted by Dacre and Bullen (2001) the potential environmental impacts of tidal current energy were clearly highlighted. SNH commissioned a report (Wilson & Downie, 2003) also highlighting potential environmental impacts and has subsequently issued a policy statement on such issues (SNH, 2004). It has been recommended by the Dacre & Bullen (2001) and SNH reports that further studies should be conducted with respect to a number of key potential environmental impacts (including impacts on cetaceans and sedimentation issues). There is a need for EIA, but at present all impacts highlighted in such assessments are speculative and qualitative, thus it is unclear to what extent tidal current energy generation will impact on the environment. With this mind and in addition to the consultative process of the Pentland Firth study (Dacre & Bullen, 2001) there is shared reluctance among stakeholders, environmental groups and consents officials to proceed with such projects when there is little understanding in this area. Indeed, the DTI have responded to this need and a study was conducted to scope for a programme of work in this area (DTI, 2002). The establishment of an EI framework and methodology to accommodate marine renewables and specifically tidal current energy is of paramount importance if such constraints are to be minimised. The 'chicken and egg' scenario still remains however. In order to conduct a full programme of research into EI, baseline studies need to be conducted and operational monitoring is essential to establish environmental change. In order to do this, monitoring initiatives need to be facilitated with respect to demonstration and prototype devices (**Section 6**). This problem may be solved in time with the deployment of technology, such as 'Stingray' (The Engineering Business) and the Seaflow and Seagen concepts (MCT Ltd.), but as yet such initiatives have not been undertaken, though it is understood that funding has been placed for a substantial environmental monitoring programme, including comprehensive monitoring of many environmental impacts, such as underwater acoustics and tidal stream effects with respect to the MCT Ltd. project located in the Strangford Lough, Northern Ireland.

In addition, Government apathy can also be related to environmental barrier issues. With respect to the offshore wind industry, it has taken the Government three years to respond to the need for more environmental impact research to be initiated (HC, 2003). It is clear that the same apathy has emerged with tidal current energy with a scoping study initiated in 2002 (DTI, 2002) and no response beyond that.

Concerns have also emerged concerning the approach to EIA methodology, in terms of both individual assessments and the recently established Strategic Environmental Assessments. Though such concerns have been highlighted through offshore wind development, they are nonetheless important with respect to tidal current energy development and the barriers they create. For many offshore wind developments, it appears that the initial consultation process is a closed loop between the DTI, Crown Estates, developers and the consultants appointed. Where stakeholder consultation is an important process of the EIA, such a strategy undermines the effectiveness of EIA in the fact there is little opportunity to make changes to developments which may have an adverse impact on the marine environment. Through offshore wind development, it has also become apparent that through the lack of early consultation with EIA and SEA, fundamental environmental implications have been overlooked bringing the environmental integrity of a development into question and consequently much contention has resulted. The SEA process has also come under criticism with respect to the size of each strategic area. With such large areas to contend with and without prior knowledge of where potential developments may be situated it is extremely difficult to make any 'sound' analysis of the environmental implications that may occur. Further criticism alluding to the extent to which the DTI and other Government sectors influence the overall outcomes has also been acknowledged.

With tidal current energy being in relative developmental infancy it is fundamental that such problems need to be minimised. The industry needs an integrated environmental impact assessment approach, with a robust and transparent methodology to ensure the right interface or balance is achieved between tidal current energy developments and all aspects of the marine environment.

7.2.2 Public Awareness and Perception

Generally public attitude towards renewable energy is positive, perceiving that renewables are clean, safe and good for the environment and beneficial in terms of long-term energy security, employment, economic well being and overall quality of life. However, public acceptability is increasingly seen as a barrier to development. To a large extent this is due to public opposition to local development with respect to local environmental concern, despite the socio-economic and long-term environmental benefits. One of the main reasons for public opposition in the siting of renewable energy generation is the lack of trust towards the developer and even national government policy makers and industry. It is evident that more and more of the public's belief and trust lay in the environmental stakeholders and pressure groups. In reality such groups need to balance their conscience with their intellect. A majority are in favour and promote renewable energy development, but on the other hand projects are rejected due to local environmental concern from some stakeholders and NGO's, ignoring the global and long-term scenario. In many cases, a balance can be found with a development and the environment, but lack of information of these issues leads to opposition. There is an on-going need to promote the benefits and cost of renewable energy, but there are different levels of information available. To date, developers concentrate on the technical and economic issues. Given that most local opposition involves environmental, socio-economic and even policy issues a greater balance needs to be found for the information made available. An increased public awareness of all issues involved in the development of a scheme needs to be established in an unbiased manner using accurate information.

Public awareness is an important consideration when dealing with the market development of tidal current energy. Most associate tidal energy with large barrage schemes and these views need to be changed and more awareness about potential development needs to be a priority. Greater understanding of the issues involved with respect to environmental concerns (section 7.2.1) and the future benefits incurred compared to other energy generation is a crucial element in successfully infiltrating the renewable energy market with tidal current technology. Further research is needed to gather a clearer and more sensitive understanding of the public's perception and attitude and how they were formed.

Recently, the importance of public perception with respect to renewables is emerging. A new campaign "Its Only Natural", initiated by the UK Government to raise awareness of the renewable energy sector has been launched. The objective is not only to inform planners and investors of the potential benefits of renewable energy, but also to inform the wider public (DTI, 2004b).

7.2.3 Knowledge and Collaboration

Another setback for the future of renewable energy industry in general and a view shared by many in the tidal current energy sector is the lack of willingness to impart knowledge and collaborate with like-minded initiatives, and research and development, whether within the public or private sector.

To encourage those involved in the renewable energy to work more closely together and create solidarity in the field can only enhance the growth and commercial viability of tidal current energy and renewable energy as a whole.

Overall, there needs to be collaboration, rather than competition between researchers, developers and key stakeholders. The 'All-energy' conference hosted in Aberdeen has been a pro-active example of this. It was founded to stimulate diversification of the oil and gas industry into the renewable energy sector, promoting positive networking of sector expertise. Other conferences that have helped in this endeavour include the Marine Renewable Energy Conference (MAREC) organised by the Institute of Marine Engineers, Scientists and Technologists (IMARest) and also the newly established annual Renewable Realities conference in Orkney.

Over recent years there have also been groups and associations set up throughout the UK both in the public and private sectors concentrating on all aspects of renewable energy, including tidal current energy technology and development. These have included the Aberdeen Renewable Energy Group (AREG), the Renewable Power Association (RPA), Seapower and the Forum for Renewable Energy Development in Scotland (FREDS). In addition, DTI stakeholder forums have also been set up, including OREEF, NOREL and RAG. In order for growth to be maintained and become successful, a core task force for tidal current energy needs to be established. This would encompass expertise not only in the field of tidal current energy development, but also others with an interest in renewable energy from research and development to public relations. The main objective would be to establish a broad group of people with renewable energy and tidal current energy expertise to impart knowledge and experience. In this, the aim is to successfully bring the tidal current resource of Scotland and even the UK to commercialisation.

Through the consultative process there has also been concern within the manufacturing industries with respect to the lack of communication between developers, stakeholders and the manufacturing and other related industries. There are a significant number of companies with a strong interest in diversifying, but many do not have the 'know-how' to pursue this interest or have had their seriousness about diversifying questioned. **Section 7.2.5** highlights such concerns in more detail.

7.2.4 R & D and Technological Considerations

With at least two key market contenders in the tidal current energy sector it is accepted that tidal current energy concepts have a technological edge over most other marine renewables and such issues are deemed not necessarily a developmental barrier. However, the general consensus is that such technology is still not quite ready for commercialisation. With demonstration projects underway it is only a matter of time before commercially viable devices will be available. As with all new market initiatives, as well as within the established technologies, research and development needs to be a continuous process in order to achieve better reliability, efficiency and overall an economically attractive commodity. The introduction of the Energy Test Centre in Orkney and NAREC at Blythe, Newcastle-Upon-Tyne should help in this endeavour if such ventures will acknowledge tidal current energy technologies as serious contenders. It is an opinion of some that aspects and concepts for tidal current energy generation are perhaps beyond this stage, and this has been witnessed through the widely publicised demonstration projects of 'Stingray' and 'Seaflow'. Further phases are also in the planning stage to take such technologies to prototype deployment and the early commercialisation stage.

With relation to **Section 7.2.3** there has been concern demonstrated by a number of manufacturers that developers are not negotiating adequately at this early stage of development. With respect to manufacturing, design of devices should lend themselves to be of a repetitive nature to reduce costs and allow automation. It has been recommended within an industrial context, that early negotiation and collaboration should exist if problems regarding design are to be reduced and mitigated. Overall, this would be beneficial to the tidal current energy industry in terms of reduced costs and ease of development constraints towards full commercialisation. However, developers have usually invested much time and money in the design of their technology and are unwilling to share 'sensitive' information regarding this, especially if there is a high commercial element. With early collaboration specifications for manufacture could be identified and cost levels to meet renewable energy expectations can be found. At present, the current costs reflect the oil and gas industry and these are deemed to be too expensive in terms of the renewable energy sector. Despite this, manufacturers feel if requirements and specifications need to be similar, the costs themselves should need to reflect this.

7.2.5 Industrial and Manufacturing Capability and Sustainability of Core Skills

With respect to the research illustrated in **Chapter 2**, it has been suggested that though there is probably sufficient skill and expertise within the marine and offshore industry to establish a tidal current energy industry, there may be insufficient capability to reach such an objective. With the oil, gas and marine industry and markets changing, core skills need to be sustained and new skills need to be established in these areas to withstand the diversification towards tidal current energy and marine renewables in general. Capabilities also need to be extended to meet the needs of the tidal current energy industry if it is to become a successful market contender in terms of the energy industry.

There needs to be a renewed drive to 'energise' companies and established industries, as well as drawing new companies into the marine renewables sector. Chapter 2 touched on these actions, but more research and planning needs to be achieved in order to actively involve companies to the extent which is needed to establish the 'critical mass' that is required to create a tidal current energy industry. Experience needs to be drawn from the already established offshore wind industry; the oil and gas operators and the electricity supply companies to move the industry forward. One such example is the multinational oil and gas company, Talisman Energy. In recent months, there has been a growing interest with their research and development initiative to use existing oil and gas infrastructure to build offshore wind projects. One such project, the Beatrice Wind farm is under development in the Moray Firth, North east Scotland.

Further identification of companies and businesses committed to and motivated to develop renewable energy and specifically offshore concepts is needed. Further identification of the associated transferable skills and the capabilities is also needed. The Scottish Enterprise Energy Team's 'diversification toolkit' is a significant step in achieving this. There also needs to be encouragement and help for business willing to identify with the 'new industry' and other companies and businesses in the sector. Section 7.2.3 touches on this, however, in light of continued research it was found that a number databases have been formed with respect to businesses interested in renewable energy. It is clear that this lack of consolidation could inhibit knowledge in this area and a core database needs to be created.

By accomplishing the above, it is hoped that companies and businesses will be able to identify and encourage other individuals to become aware of the skills and capabilities available within Scotland and diversify into the offshore renewables sector and the potential tidal current energy sector. It is hoped that development of an industry will in turn encourage the export of these skills, capabilities and technologies to other countries, thus building upon an already strong marine renewables reputation.

CHAPTER 8

Research Development

8. RESEARCH DEVELOPMENT

8.1 Introduction

A number of generic studies and reports concerning research development of marine renewables and tidal current energy have been commissioned, including the most recent Boud (2002), BWEA (2004), EUREC (2005) and BWEA (2006). However, there have been many research programmes and reports prioritising environmental impact research with respect to the offshore wind energy sector, including OWEN, (1999; 2003), ETSU (2000), DTI (2001; 2002), EWEA (2005), and COWRIE (2006). With respect to tidal current energy alone, there has only been one detailed report (DTI, 2002) commissioned to formulate research priorities for tidal current energy generation.

The Department of Trade and Industry's (DTI) renewable energy programme appointed RGU in December 2001 to conduct a study to define a programme of work to enable the assessment of the key potential environmental impacts of tidal current energy (DTI, 2002). Using methodology employed in the Pentland Firth study conducted by Dacre and Bullen (2001), it does not attempt to quantify the environmental impacts of tidal current energy, but merely identifies them with a view to prioritising further research. The DTI study only focuses on the research development of the physical and biological implications of tidal current energy with respect to environmental impact. However, the Pentland Firth study and the market potential study (Dacre, 2002) also identified socio-economic implications and these also have further research needs, which will also be explored. All considerations have been amalgamated to form an overall picture of the research and development priorities that need to be accomplished in order to ease the environmental and in turn the developmental barriers of the growing tidal current energy industry.

8.2 Considerations

The methodology used was that employed in the Pentland Firth Feasibility Study conducted by Dacre and Bullen (2001), detailed in **Chapter 4** and that of the market research study. However, development of that methodology is apparent within the context of the DTI study and consequently this chapter, in order to provide a comprehensive examination of research requirements.

The methodology employed was formulated to give a systematic appraisal of potential impacts using data and knowledge that was currently available and therefore, enabling gaps within that existing knowledge to be found and further research in this area to be considered.

All potential impacts were identified in a generic context and are generally not site specific, though the Pentland Firth study did contribute to the overall context of impact identification. It must be noted that some impacts for any given development are dependent upon site-specific details as a whole and can be unique to that area. The marine environment is an environmental system with a range of complex physical, biological and human interactions and processes, which govern the potential perturbations that may be caused by tidal current development.

There have been several mechanisms proposed for enhancing tidal currents for the generation of electricity. There is a wide combination of support structure and rotor type configurations and the selection of technology depends directly upon specific site characteristics and environmental conditions. For the purpose of this chapter environmental impacts identified are of a generic nature common to most tidal current energy systems.

8.3 Identification of Environmental Impacts

The interactions between the deployment activities (external variables) and the environment (environmental variables) were initially identified in list form then summarised using a matrix system (**Chapter 4**). This provided a simple representation of a tidal current energy project and the associated environmental interactions, establishing a basis for determining possible implications of deployment impacts and influence on the various environmental components. This formed the basis for the conceptual models and input for a research programme. The matrix itself, however, is unable to take account of the fact that environmental components may be affected through more than one environmental pathway and by more than one aspect of the development. In reality, potential impacts are a complex web of interactions. Hence, it fails to draw upon the additive, synergistic or neutralising effect some interactions may have. A simplified conceptual diagram was also constructed (**Figure 39**, **pp.125**) to illustrate the complexity of potential impacts within the marine 'natural' environment (Dacre & Bullen, 2001).

Having provided an initial identification of the deployment activities and the physical, ecological and socio-economic components such a project may affect, it was also necessary to prioritise each mode of interaction and thus provide a process to establish principal research areas. This was established by applying an overall significance, using the following criteria and definitions which related to:

- Likelihood of activity leading to environmental impact and Magnitude of predicted potential impact;
- Level of legislation and policy requirements associated with each potential impact;
- Level of importance expressed by consultative bodies.

The above criteria and definitions are discussed in **Chapter 4** and results of this process are also illustrated in **Chapter 4** (**Figures 41-43** and **Tables 17-20**).

8.3.1 Key Environmental Impacts

Physical and Biological Environment

With respect to the identification process, the key environmental interactions that have been recognised as being of particular interest are summarised in **Table 36**.

In terms of potential environmental impact there were a variety of physical and ecological issues identified that need to be addressed with regard to further research. Such physical and ecological issues will be briefly discussed, concentrating on their generic importance in terms of the environment and the possible implications of tidal current energy system development. Detail discussion has already been established in **Chapter 5**. These issues can be divided into four main categories of impact source, which are:

- Kinetic Energy Removal
- Rotor and Support Structure Interference
- Ambient Noise Levels/Vibration/Visual
- Installation/Decomissioning Disturbance

These sources of impact, whether directly or indirectly have a potential effect on the following physical and ecological components of the marine environment:

- Tidal Current Velocity
- Tidal Current Dynamics
- Wave Climate
- Sedimentation and Seabed Disturbance
- Turbidity and Water Quality
- Resident or Migratory Cetaceans
- Marine Ecology

Table 36: Sources of Impact and Related Biological and Physical Environmental Components Likely to be Affected.

Impact Source	Affected Components
Kinetic Energy Removal	Tidal Current Velocity Wave Climate Sedimentation/Turbidity Marine Ecology
Rotor/Structure Interference	Wave Climate Tidal Current Dynamics Seabed Disturbance Sedimentation/Turbidity Marine Ecology
Ambient Noise/Vibration	Resident or Migratory Cetaceans Marine Ecology
Installation / Decommissioning	Seabed Disturbance Turbidity Marine Ecology Resident or Migratory Cetaceans

Socio-Economic Environment

With respect to the identification process, the key environmental interactions that have been recognised as being of particular interest are summarised in **Table 37**.

In terms of potential environmental impact there were a variety of socio-economic issues identified that need to be addressed with regard to further research. Such issues will be briefly discussed, concentrating on their generic importance in terms of the environment and the possible implications of tidal current energy system development. Detailed discussion has already been established in preceeding chapters, which include **Chapters 2**, **5** and **7**. There is a complex overlap of issues with respect to biological and physical interactions and those associated with the socio-economic environment. An example of such interactions is demonstrated in **Figure 40 (pp.127)**. These issues can be divided into four core categories associated with the socio-economic environment that may be impacted, these are:

- Offshore environment
- Energy and Environmental Policy
- Industry and Employment
- Public Awareness and Education

These sources of impact, whether directly or indirectly have a potential effect on the following socio-economic components of the marine and local environment:

- Commercial Fisheries
- Navigation and Shipping
- Tourism and Recreation
- Electricity Generation
- Seabed/Marine Industry
- Energy Policy
- Planning Policy
- Import and Export

Table 37: Sources of Impact and Related Socio-economic Components Likely to be Affected.

Core Categories	Affected Components
Offshore Environment	Commercial Fisheries Navigation and Shipping Seabed and Marine Industry Tourism and Recreation Local Economics
Energy and Environmental Policy	Planning/Environmental Policy Energy Policy
Industry and Employment	Technological Capability Industrial/Technological Experience/Skills Employment/Training Energy Industry Energy Imports and Exports Local/National Economics
Public Awareness and Education	Renewable Education and Awareness

8.4 Modelling Criteria and Quantification

Drawing upon the issues set out in **Section 8.3.1**, it is the aim of this section to develop them further in order to establish measurables and fieldwork requirements. This will potentially enable quantifiable results and further understanding of the impacts that may be associated with tidal current energy development. This can be initially established by developing consequence models.

8.4.1 Research and Modelling Development

The development of the research and modelling requirements involves a preliminary understanding of the environmental system in question as a whole. It also requires understanding in terms of the detailed behaviour and characteristics of the individual environmental components and processes that govern that environmental system. The methodology conducted has been summarised in **Figure 57**. It is the objective of this chapter to conduct stages 1 and 2, in order to determine stages 3 and 4. All modelling requirements are an iterative process and should be continued throughout all stages.

8.4.2 Consequence Model Development

Purpose

For the purposes of this chapter, consequence models are basically used as a structured description of the processes, interactions and factors involved with respect to the environmental system and the external factors in question. For example, the marine environment is an environmental system and a tidal current energy device is the external factor influencing the system in which it is installed. Such models can be used to define the requirements for mathematical modelling, which result in the use of equations to represent each process or interaction. They also form the basis of physical modelling and monitoring requirements. For the purposes of this chapter, the consequence models developed will form the basis and help determine the measurables or observables for further research that is needed.

Development

For the biological and physical environmental impacts a base scenario was established which describes and represents the environmental system and the external factors involved.

With reference to the environmental interactions matrix (**Table 38**, **pp.124**), the likelihood and

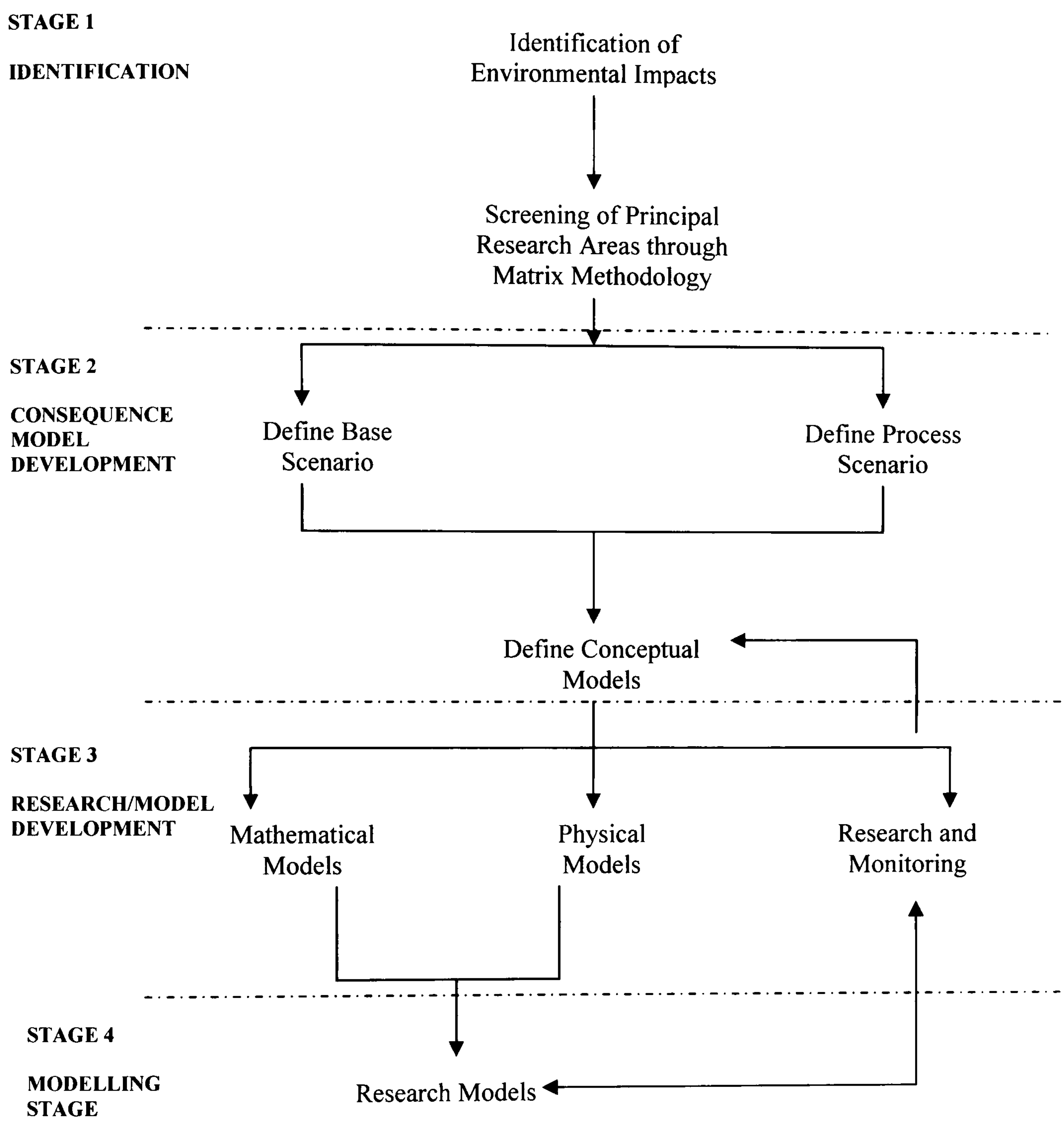

Figure 57: Research and Model Development for Environmental Impact

magnitude significance matrix (**Figure 41**, **pp.128**) and the conceptual diagrams (**Figures 39 and 40**, **pp.125 and 127**), a further table was developed incorporating all the key environmental interactions, processes and potential impacts (**Table 23 pp.135**). This constitutes the basis for the process scenarios, which describe the relationships and processes between the environmental and external factors and the environmental consequences. This helped to gain a comprehensive definition of the modelling requirements and information to formulate the consequence models for the biological and physical environment.

Consequence models (CM) were then developed for all key impact sources outlined in section **Table 38**, using the process scenarios formulated. All models are a complex set of interactions and processes and some overlap with other consequence models. Processes and interactions may also have neutralising, synergistic or additive affects on each other. Each CM does not have the capacity to reflect these complexities. However, in time such models may be integrated.

With respect to the socio-economic environment, the method employed for the development of consequence models was not as systematic compared to that developed for the biological and physical environmental scenarios. The sequence of processes and consequences involved in determining the potential impacts within a socio-economic context seem in the first instance comparatively straight forward with each process leading towards the next in a uniform fashion. However, in real terms the socio-economic factors are even less predictable than their biological and physical counterparts. This is generally because the unpredictability of human action is at play. Despite trying to conceptualise the socio-economic interactions and potential impacts of tidal current energy development it is important to stress that such an 'environmental system' it is highly complex and many external factors can contribute to and change the process pathways. Such change can affect the overall outcome of the potential impacts that were originally forecast.

Table 38: Key Environmental Interactions and Process Scenarios

Matrix Ref	Environmental Interaction		Potential Impacts/Environmental Interrelationships		
Process scenario	**Influencing External Variable (Project Activity)**	**Affected Environmental Components**	**Environmental Processes Involved**	**Environmental Impacts/Consequences (Level 1)**	**Environmental Impacts/Consequences (Level 2)**
a1	Manu/Installation	Atmosphere	Dispersion of gas conc.	Local atmospheric pollution	
Phases b-l p-r	Installation/Decomm Phases	Tidal currents	Blockage/Obstruction	Tidal dynamics disruption	
		Wave climate	Blockage/Obstruction	Wave dynamics disruption	
		Ambient noise	Sound Propagation	>ambient noise	Disturbance of marine ecolgy
		Seabed	Direct seabed disturbance from piling, disposal of spoil, installation of foundation; cables etc.	Benthic ecology impacts i.e. smothering, crushing etc. Increased sed. entrainment	Mortality/re-distribution/<pop Increased turbidity
		Water column	Sediment entrainment	>turbidity	Ecological Implications
		Water quality	Chemical diffusion of leaked substances	>local pollution	Ecological implications
		Coastal Environment	Cabling processes/disturbance	Habitat distruction	Ecological Implications
		Benthos	Disturbance/smothering/crushing/ vibration/sound propagation	Re-distribution/Mortality	<population/recolonisation
		Pelagic Org.	Sed entrainment/ Sound propagation	>turbidity/ambientnoise	Avoidance/<population
		Demersal Org.	Disturbance/smothering/crushing sediment deposition	>turbidity/deposition	<population
		Seabirds	Visual/Physical Intrusion	Increased activity/disturbance	Temporary avoidance
		Pinnipeds	Visual/Phy Intrusion Sound Propagation	Increased ambient noise/disturbance	Temporary avoidance
		Cetaceans	Sound propagation	Increased ambient noise	Avoidance/Chg in migration routes etc.

Matrix Ref	Environmental Interaction		Potential Impacts/Environmental Interrelationships		
Process scenario	**Influencing External Variable (Project Activity)**	**Affected Environmental Components**	**Environmental Processes Involved**	**Environmental Impacts/Consequences (Level 1)**	**Environmental Impacts/Consequences (Level 2)**
j2		Tidal currents	Blockage/Obstruction/Funnelling	Tidal dynamics disruption	Chg in coastal dynamics
j3		Wave climate	Blockage/Obstruction	Diffraction/reflection	Chg in coastal dynamics
j5		Temperature	Heat Transfer	Localised sea temp rise	
j6	Structure Presence	Ambient Noise	Sound propagation	>ambient noise	Disturbance of marine ecology
j7		Sedimentation	Entrainment/Deposition	Scouring/Deposition	Chg in Sediment/coastal Dynamics
j8		Seabed	Direct disturbance/vibration	Seabed movement	Sedimentation Implications
j11		Coastal Env	Coastal dynamics/Sedimentation	Chgs to Intertidal area	Ecological Implications
j12		Benthos	Direct disturbance/Sound Propagation	Redistribution Avoidance/Recolonisation	< / > population
j13		Pelagic Org.	Direct disturbance/Sound Propagation	Avoidance/Recolonisation	< / > population
j14		Demersal Org.	Direct disturbance/Sound Propagation	Avoidance/Recolonisation	< / > population
j17		Seabirds	Visual disturbance	Avoidance/Habituation	
j18		Pinnipeds	Visual/Sound Propagation	Increased disturbance/ambient noise	avoidance/habituation
j19		Cetaceans	Visual/Sound Propagation	Increased disturbance/ambient noise	avoidance/habituation
k2	Rotor Effects	Tidal currents	Vorticity effects	water column disturbance flow distortion	sedimentation implications
k3		Wave climate	Wake effects	water column/current disturbance	wave/tide dynamics
k6		Ambient Noise	Sound Propagation	> ambient noise	Disturbance of marine ecology
k7		Sedimentation	Entrainment/disturbance	scouring/sed disturbance	benthic ecology implications
k9		Water Column	wake effects; vorticity effects	disturbance	
k10		Water quality	Sediment Entrainment	> turbidity	Ecological Implications
k12		Benthos	Ref. k2,3,6,7,10	Mortality/Re-distribution/avoidance	< / > population
k13		Pelagic Org.	Ref. k2,3,10/collision risk	Mortality/Re-distribution/avoidance	< / > population
k14		Demersal Org.	Ref. k2,3,6,7,10	Mortality/Re-distribution/avoidance	< / > population

k17		Seabirds	Collision (diving)	Mortality/Injury	Avoidance/Habituation
k18		Pinnipeds	Collision	Mortality/Injury	Avoidance/Habituation
k19		Cetaceans	Collision	Mortality/Injury	Avoidance/Habituation
l2		Tidal currents	< tidal flow	tidal/sedimentation implications	Chgs in Coastal env
l7		Sedimentation	>deposition	Chgs in sedimentation/seabed	chgs in coastal env/ecological implications
l9		Water Column	< turbulence	Sedimentation Implications	
l10	Extraction of Energy	Water quality	>deposition	< turbidity	Improved visibility
l11		Coastal Env.	Sediment/coastal dynamics	Chgs in Intertidal area	Ecological Implications
ll2		Benthos	>deposition	Smothering/Chg in benthic env	Re-distribution
l13		Pelagic Org.	>deposition/< entrainment	< in dissolved nutrients/org. matter	Avoidance/ <population
l14		Demersal Org.	>deposition	smothering/chg in env	< / > population

8.5 Consequence Models

8.5.1 Biological and Physical Environment

Each consequence model (CM) reflects the broad research areas highlighted in **Sections 8.3.1** with respect to the key sources of impact and related physical and ecological implications. Environmental processes established in **Table 39**, are also incorporated into each model, and these are represented as follows:

Table 39: Key to Environmental Processes Represented in the CM's.

Environmental Process	CM Reference
Chemical Absorption	CA
Chemical Diffusion	CD
Collision Risk	C
Direct Seabed Disturbance	DSD
Encrustation (artificial reef)	E
Heat Transfer	HT
Liquefaction	Lq
Organism Re-distribution	OR
Recolonisation (recovery)	R
Sediment Deposition	SD
Sediment Entrainment	SE
Sediment Movement (scouring/erosion)	SM
Sediment Threshold	STh
Sound Propagation	SP
Surface Distortion	Sdist
Tidal Energy Decrease	TED
Tidal Flow Distortion/Modification	TFM
Turbidity	Tb
Turbulence	T
Vortex Formation	VF
Vorticity Effects	VE
Wake Effects	WA
Wave Diffraction/Reflection	WDR
Wave Modifications	WM

Kinetic Energy Removal

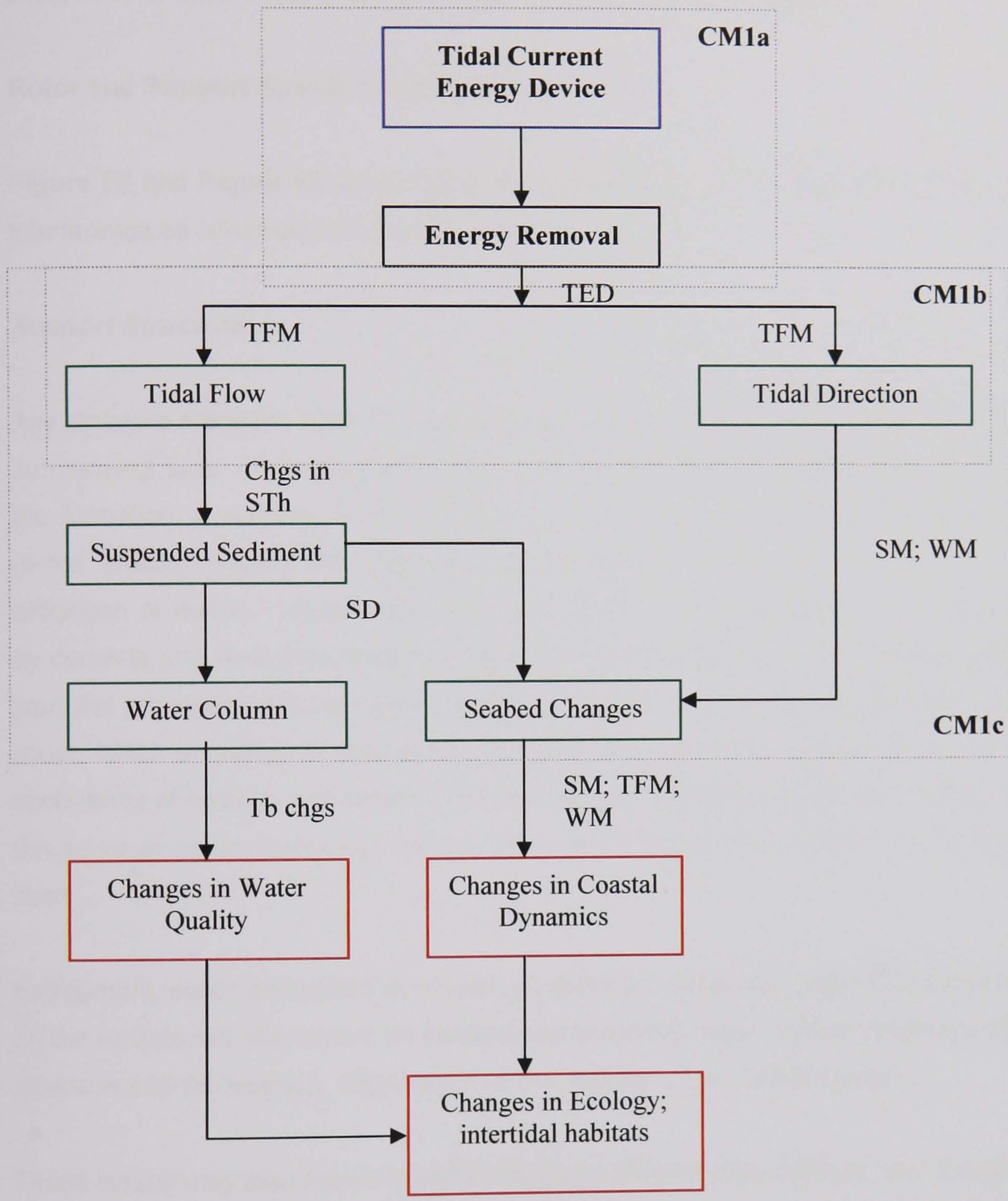

Figure 58: Impact of Kinetic Energy Removal (CM1)

All marine environments, especially those with high tidal energy have complex tidal and sediment transport dynamics. Tidal current energy devices have the potential of modifiying such dynamics by the removal of tidal energy. Potentially, such energy extraction or modification could result in changes with respect to tidal flow and direction. If significant enough, changes in the coastal dynamics and intertidal areas, as well as already defined navigation channels may occur. All consequence pathways could cause potential impacts with regard to marine ecology, whether positively or detrimentally. For example, early deposition may create new habitat areas and may result in the colonisation by benthic communities. **Figure 58** summarises the potential impacts due to energy extraction as consequence model 1 (CM1). Discussion of such impacts and processes are detailed in **Section 5.2**.

Rotor and Support Structure Interference

Figure 59 and **Figure 60** summarises the potential impacts of the support and rotor structure interference as consequence model 2(i) and 2(ii).

Support Structure

Any structure placed in a marine environment has the potential to change the flow patterns in its surrounding area. Resulting implications include the reduction of current flow (section **5.2.2**); the formation of vortices in front of the structure (section **5.2.2**); the formation of a lee-wake (wake effects) behind the structure; the generation of turbulence and the reflection and diffraction of waves. Liquefaction may also occur, allowing sediment material to be carried off by currents and thus may lead to increased turbidity and changes in water quality. All these potential processes will inevitably cause changes in local sediment transport and thus lead to scour, which is related to changes in sediment re-suspension (section **5.2.5**) and the potential occurrence of hollows and selective erosion around the structure (section **5.2.4**). Not only does this serve as an environmental impact, but is also a threat to the stability of the support structure itself.

Entrapment, scour and selective erosion of sediment associated with the presence of structures on the seabed are dependent on seabed characteristics and sediment type and also the type of structure and the spacing, alignment and the number of structures imposed.

These issues may also have an added localised affect on the benthos, and though such effects are assumed to be long term and relatively fast in developing the extent of these physical effects on the biological environment is unclear, but could be beneficial to existing communities with the formation and development of new seabed habitats. Changes may also encourage the colonisation of other benthic communities. **Section 5.3** discusses these implications further.

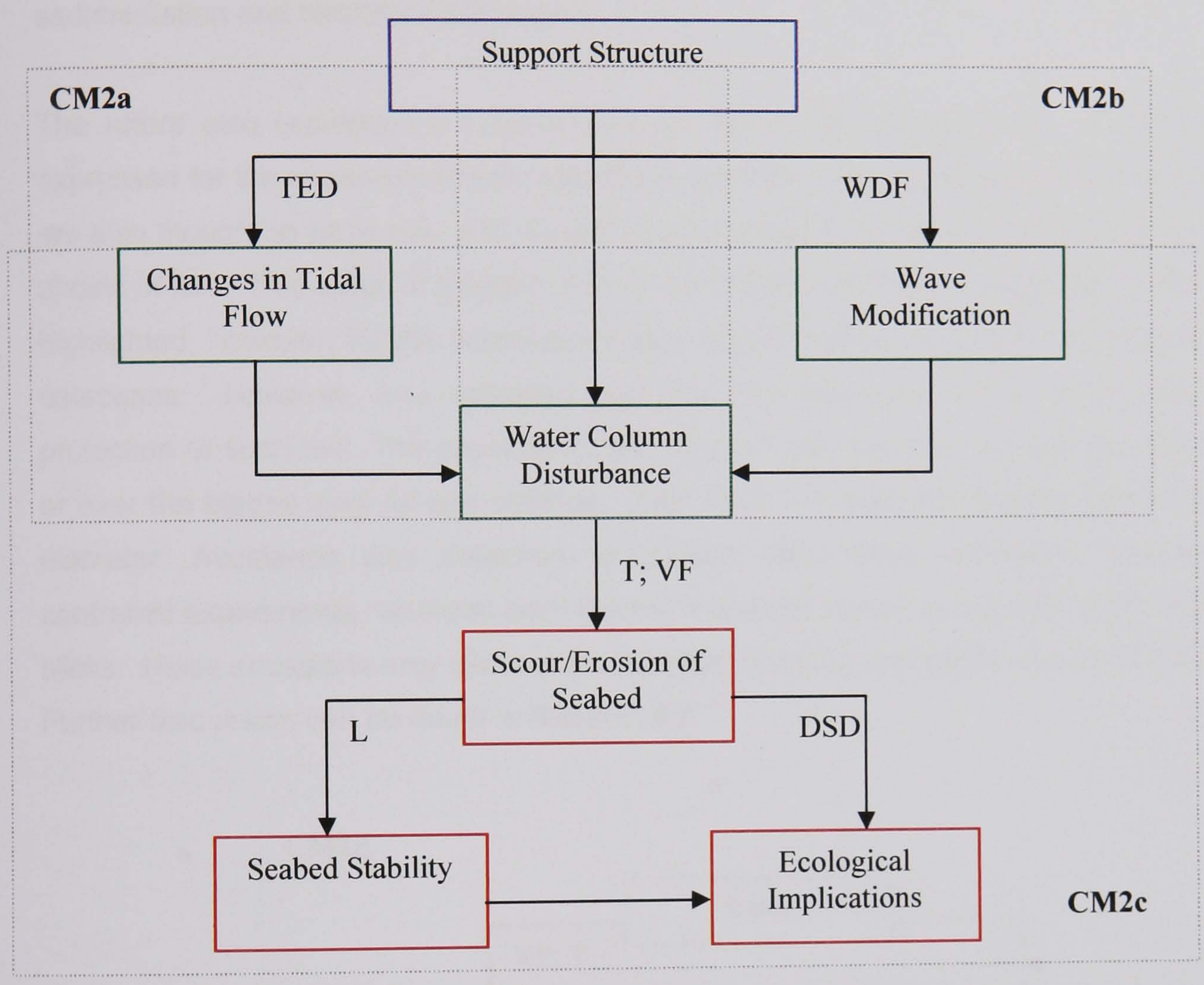

Figure 59: Support Structure Impacts (CM2(i))

Rotor

The rotors themselves are potentially an added complexity. The rotors will inevitably cause added vorticity shedding throughout the water column, complicating the issues that are already highlighted, including the generation of turbulence in the water column and subsequent sedimentation and turbidity iimplications.

The rotors also represent a collision risk for some marine organisms. Concern has been expressed for the possible collision risk of fish, but this is thought to be extremely low. Seabirds are also thought to be at risk, with regard to underwater shadowing and the mistaken identity as shoals of fish. This again is thought to be a low impact potential. Substantial concern has been highlighted, however, for the potential collision risk of marine mammals, such as pinnipeds and cetaceans. However, it is assumed that the fluid dynamics of the rotors may aid in the protection of such risk. The physical forces involved are expected to push any objects through or over the blades clear of any collision. This does not apply for species larger than the rotor diameter. Avoidance and detection techniques have been witnessed, however, through controlled experiments, whereby such marine mammals have the capacity to avoid oil spills and slicks. Noise emissions may also act as deterrent from the immediate vicinity of the turbines. Further discussion can be found in **Section 5.3**.

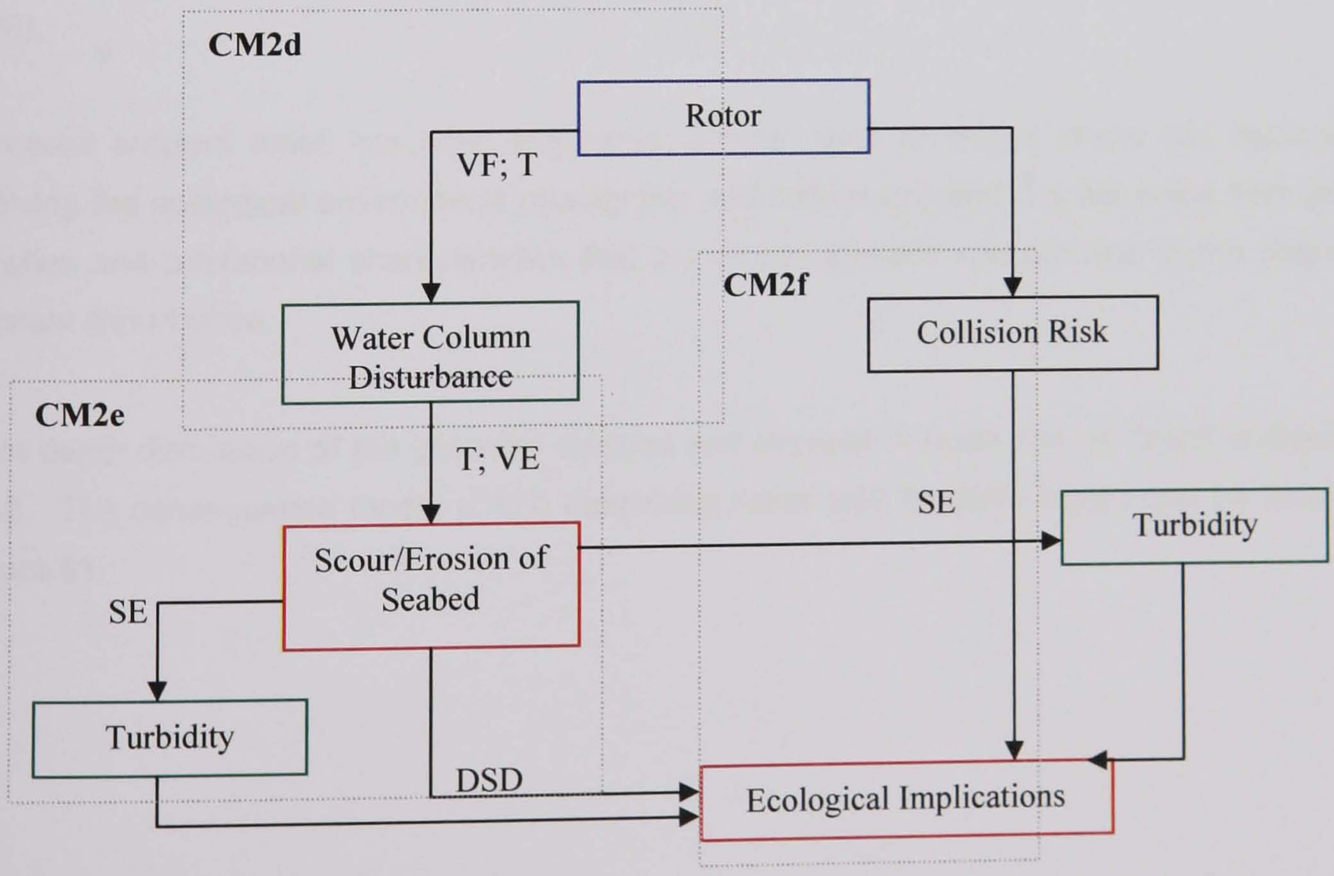

Figure 60: Impacts of Rotor Interference (CM2(ii))

Ambient Noise and Vibration Levels

There are two main sources of noise and vibration within the context of tidal current turbine development. The first is the installation phase, which may include the propagation of noise from cable construction and the presence of boats and other equipment (for example, vessel engine noise; propeller and thruster cavitation; vessel ancillary equipment, both continuous [machinery] and impulse [hammering]; and piling to secure the structure) and from the piling of foundations. Sound from on-shore activities may also propagate into near-shore waters. The second concerns the possible noise emissions from the operational characteristics of the device itself.

In terms of impact there are two main sources of consequence. The vibration of the seabed, and secondly, the influence noise may have on the ecological environment in terms of its biological components.

Excessive vibration may cause direct effects to the seabed, including liquefaction, increasing turbidity and disturbing benthic communities. However, this is dependent on the type of seabed and sediment characteristics and it is more significant in areas of soft, sand sediments. However, unless physical vibration of the support structure changes the physical composition of the seabed through liquefaction, little or no effect on benthic communities is expected (ETSU, 2000).

Increased ambient noise has other less direct effects, such as added stress and discomfort involving the ecological environment (mainly fish and cetaceans) and it is the noise from piling activities and operational characteristics that are of the greatest concern due to the potential constant disturbance.

An in depth discussion of the potential sources and impacts of noise can be found in **Section 5.3.2**. The consequence model (CM3) describing noise and vibration impact can be found in **Figure 61**.

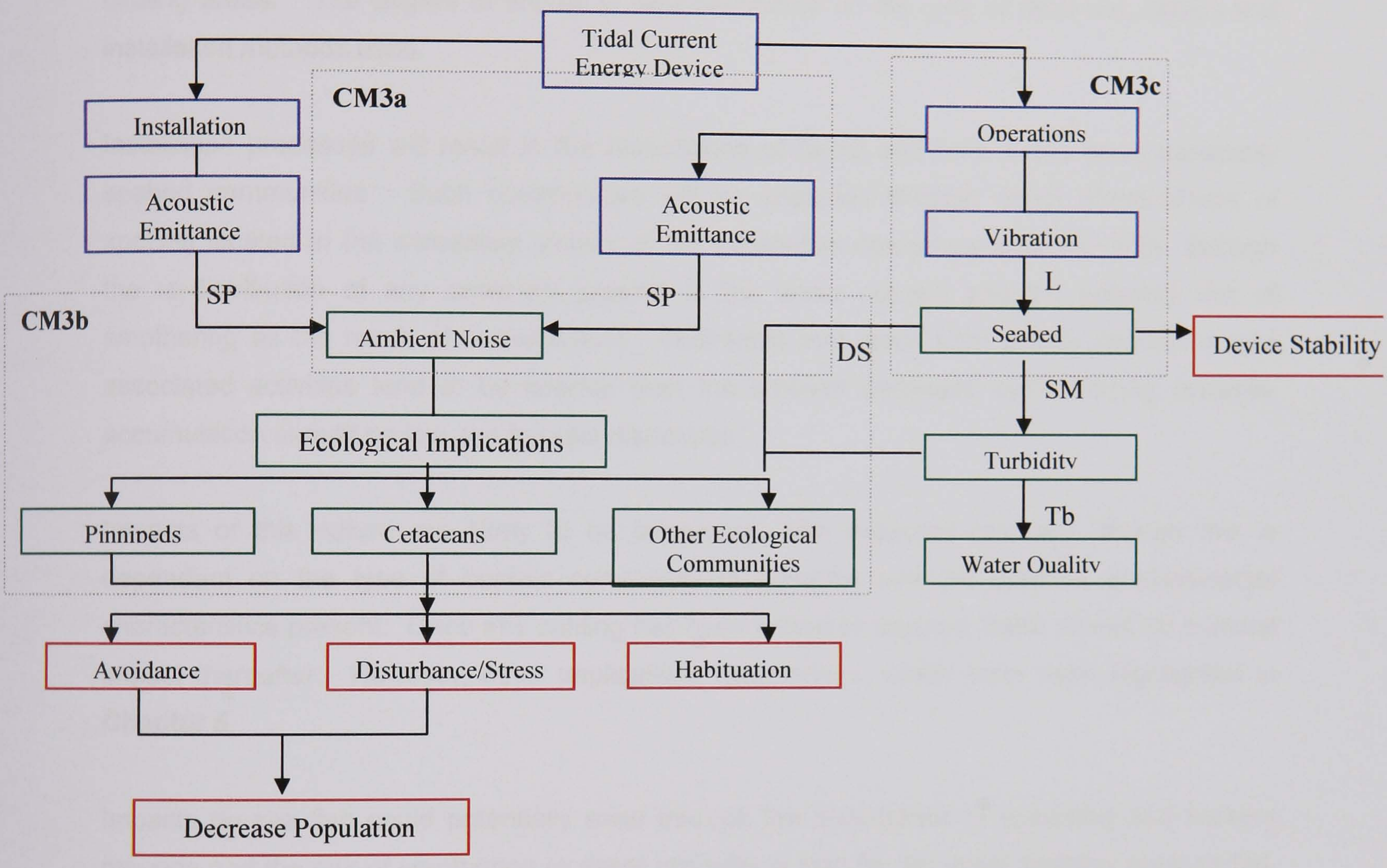

Figure 61: Acoustic and Vibration Impacts (CM3)

Installation/Decommissioning Disturbance

With any offshore or coastal development, installation and the cabling involved will inevitably affect the seabed. The installation and decommissioning phases are assumed to create the most direct adverse impact with respect to seabed disturbance. Impacts of this nature, however, are predicted to be short-term and very local, concentrating around the structure and cabling areas. The degree of impact is very dependent on the type of structure, cables and installation methods used.

Installation processes will result in the disturbance of fauna and flora in the area, especially seabed communities. Such communities will be impacted through direct displacement of species located in the immediate vicinity of the installation operations and, indirectly, through the re-distribution of any sediment present in the water column and the possible risk of smothering as the result of re-settlement. Sediments that result from drilling operations and associated activities tend to be coarser than the ambient sediment, but in strong currents, accumulation should be low due to rapid dispersion.

Impacts of this nature are likely to be temporary, with expected recovery, though this is dependent on the type of benthic community in question and the external environmental characteristics present. Once any cabling has been buried or secured, there should be minimal impact thereafter. However, other implications have arisen, which have been highlighted in **Chapter 5**.

Impacts on sea fish could potentially arise through the disturbance of spawning and nursery grounds and the risk of smothering or direct mortality is high for demersal species, such as flat-fish. Indirectly, re-suspension of sediment may possibly increase any food source, especially for pelagic species.

Installation and decommissioning may also have an effect on seabird colonies. Close approach of vessels and the approach of people are effective sources of disturbance. Though such activities seem relatively harmless, they can in effect cause detrimental impact on bird populations and there is evidence to suggest that constant or systematic intrusion can lower bird productivity and, in the severest of cases, cause desertion.

Awareness must also be made of the short-term localised impact of contamination. Through the installation and decommissioning phases, contamination may occur through minor oil and fuel leaks from vessels. There is also a minimum risk of the gear-box leaking. Anti-corrosion and anti-fouling agents may also have an influence on the chemical composition of the local seawater environment. This is likely to be negligible due to the fact that many present agents are less damaging to the environment with regard to their chemical composition and the amount of time it takes for such agents to be released into the environment, if at all. **Figure 62** summarises installation and decommissioning impacts.

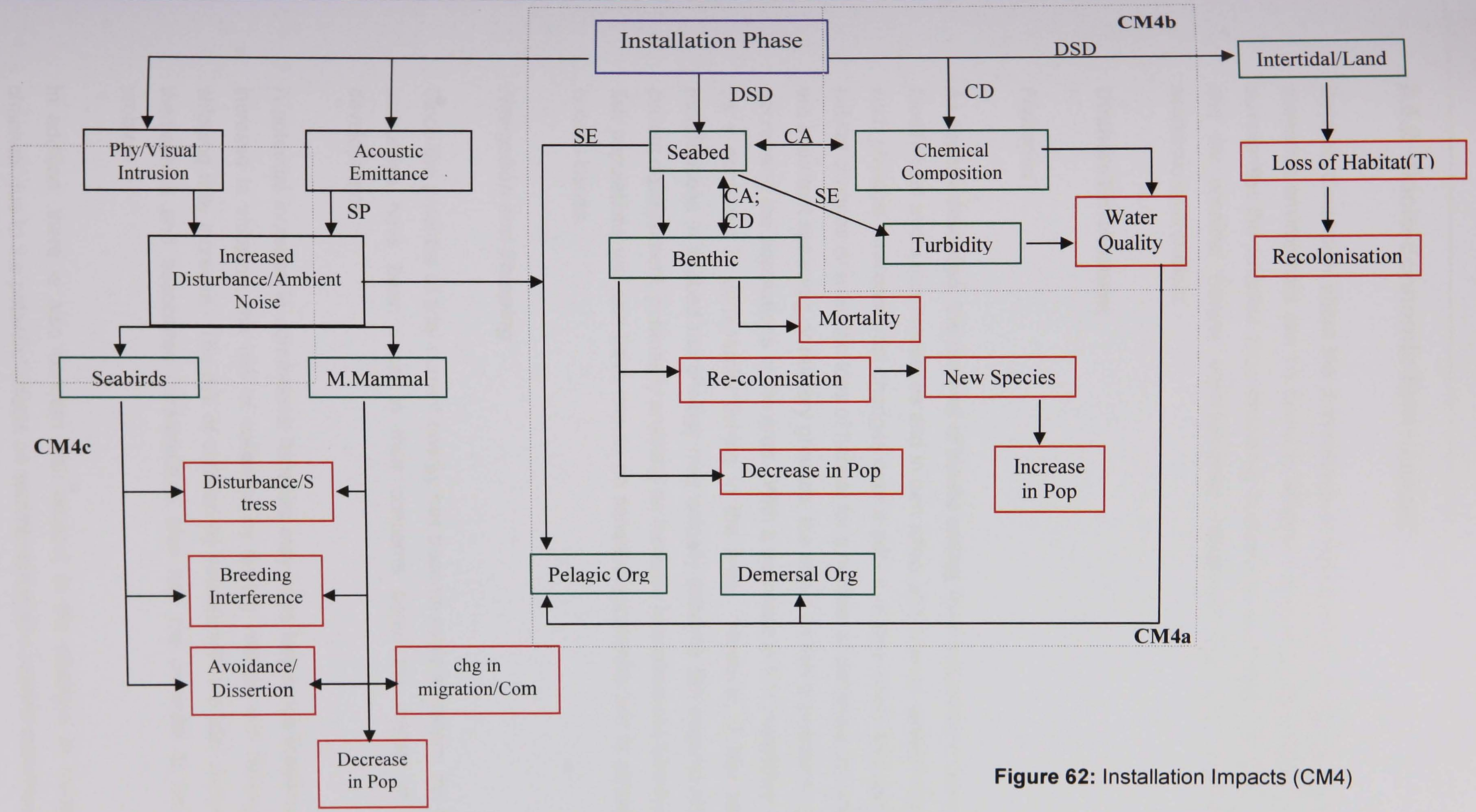

Figure 62: Installation Impacts (CM4)

8.5.2 Socio-Economic Environment

Detailed discussion about the implications of tidal current energy development on the socio-economic environment can be found in **Chapters 5 and 7.** **Figure 62**, a conceptual diagram summarises the potential socio-economic implications associated with tidal current development and the possible 'natural' environmental interactions that may indirectly affect the socio-economic environment.

Offshore Environment

Fisheries

As already described, the removal of kinetic energy from a channel or area has the potential to modify tidal and wave processes and in turn affect and change seabed morphology. Likewise, such physical environmental changes over a period of time could also potentially contribute to habitat changes or even the loss of habitat for a number of demersal fish species. Where there are important spawning or nursery grounds, the effect on fish populations could be detrimental, decreasing the populations in the area. With a decrease in fish population, there will inevitably be a decrease in commercial fishing in the area. However, it has been suggested that modifications in seabed morphology may actually enhance fish populations in an area of tidal current development, potentially enabling an increase in commercial fisheries. Such changes in fish populations will also have impact on fisheries economics and is closely related to loss of access issues.

Navigation and Shipping

Since the potential of tidal current energy has become more a realism, the fishing and shipping authorities have been vocal in their concerns about the impact of increased offshore development.

A potential increase in commercial fisheries may have further implications however. With an increase in shipping, the risk of collisions by fishing vessels with fishing vessels and other shipping may increase. The risk of collision by vessels with the tidal current energy structures themselves and associated infrastructure also has the potential to become an increased problem.

In addition, there is also concern with respect to the changes in navigation and shipping channels due to the potential affects on sedimentation and seabed morphology.

Recreation and Tourism

It is unlikely that a tidal current energy development will have a significant detrimental impact on recreation and tourism, however this is very much dependent on the site-specific characteristics of a development area. With regard to areas that are popular places for water sports etc. the issue of 'over-crowding' is similar to the issues related above. In contrast, there is evidence to suggest that tidal energy development would be beneficial to an area with the ever-increasing interest in sustainable energy solutions and attract visitors to the area. Local acceptance of any potential large development usually depends upon the direct or indirect social and economic benefits that can be highlighted and as such are an important consideration in the planning of a development.

For certain configurations of tidal energy technology visual impact is an additional concern and may have an impact on the scenic views within an area, but to what extent is still unclear.

Other Coastal Zone Users

Other coastal zone users may include industries such as, aggregate dredging and waste disposal, as well as the indirect implications of marine archaeology and in exceptional circumstances, as in the case of the Pentland Firth, sea burial sites. Again, it can be seen that 'over-crowding' issues play a large role within this context, as well as the effects sediment and morphological changes would have on any marine aggregate industry within an area. Though these issues seem relatively unimportant in comparison to other potential implications discussed, they are nonetheless another added component to the complex array of environmental considerations.

Energy and Environmental Policy

Planning Policy

It is widely acknowledged that the planning and consents procedures relating to offshore renewable energy development is a fragmented and complex issue (**Section 7.1.1** discusses this in detail). The problems associated with planning and consents have been particularly highlighted since the increased interest in offshore renewable energy through the difficulties that have already been faced by developers in the offshore wind energy sector. A wider and better understanding of the issues faced by developers is crucial if the development of tidal current energy is to succeed. A balanced solution between developers' needs and the needs of the environment is a crucial element in any planning and consent procedures.

Energy Policy and Electricity Generation

There is no doubt that the emerging offshore renewable energy industry will have an impact on energy policy and the structure of electricity generation. Since the emergence of renewable energy and the drivers that have initiated such development in general, there has been a significant change in the energy policy with respect to issues such as sustainability, energy efficiency and new electricity generating technology. Over recent years, government has taken a back step in promoting tidal current energy development, but as the emerging industry grows and more research and development has been initiated, such attitudes have changed considerably in favour of a tidal energy industry within the sector of offshore renewables. Taking into account these changes it is safe to presume that further policy will engage tidal energy even more and in turn help to strengthen the growth of the sector. How and to what extent energy policy will change is still questionable but such impacts will have more far reaching effects, such as changing public attitude and the re-structuring of the energy industry as a whole.

The problems with the electrical grid infrastructure have been of paramount concern, especially over recent years. It is evident, that the most suitable areas of tidal energy generation lie in areas remote from main grid connection and therefore, require major connection work. Additionally, the grid infrastructure at present is also unlikely to withstand added capacity. It is not difficult to see the pressures of tidal energy development places on the current infrastructure and as with any emerging industry such infrastructure needs to be able to grow to enable sustainable growth to match the energy and environmental needs of the UK.

Industry and Employment

Of all the renewable technologies, land-based wind power is the nearest to being able to generate electricity at competitive costs and has resulted in a significant number of turbines operating throughout the UK. However, Danish companies dominate equipment manufacturing and there is minimal indigenous UK capacity.

During the 1960's and 1970's marine energy established a strong position in the UK, however, with little prospect of competing commercially at that stage, UK funding decreased considerably. In contrast, other countries continued to invest significantly. Over the last decade, marine energy, including tidal current energy has re-established its stronghold within the renewable energy sector. Continued research and development has clearly proven that the technology has a potential to be efficient and competitive.

With this in mind, an emerging tidal current energy industry offers a huge opportunity to enhance the UK's manufacturing and offshore services capacity, strengthen existing offshore related jobs and provide new employment. However, as discussed in section 7.2.5, though oil and gas and other marine-based skills could, in part be transferable, there isn't a clear indigenous capacity in manufacturing the higher value generating and power transmission equipment. In theory, much of the construction and installation skills of the existing marine industries are relevant to the tidal current energy industry, but with the costly culture of marine industries in general, the transfer of these skills do not transfer to tidal current energy generation in the cost-efficient manner that is necessary.

Public Awareness and Education

With understating comes acceptance. As tidal current energy becomes more main-stream in the understanding of the general public, the impact on public attitude towards development will change, but there is still uncertainty to what extent changes would occur and if such changes would in fact make a difference to the emerging tidal current energy industry. As the industry emerges, it is inevitable that educational needs will change to suit the needs of the industry. In terms of education and training it would be beneficial to understand how changes can be implemented and what impact this would have on the current understanding of energy generation and the existing offshore industry.

8.6 Identification and Formulation of Research Projects

8.6.1 Identification and Prioritisation of Research Projects

By assessing the importance of the overall impact significance, as summarised in **Table 22** (pp.133), and using the consequence models formulated in **Section 8.5.1** and **8.5.2**, a number of research projects were identified with respect to the biological and physical environment. Some other projects were also identified, though not directly related to the consequence models (**Tables 40 and 41**).

With respect to the biological and physical environmental components, all projects were identified with respect to impact source and divided into sub-projects or stages. Each project was then given a project reference code. It is evident some projects are significantly related to others, in the fact that sub-projects are likely to be precedents to other sub-projects. For example, project CM1b cannot be achieved without the results from CM1a.

To address the research needs of the socio-economic environment, a less systematic approach was formulated by using the conceptual model (**Figure 40**, **pp.127**) illustrating the potential socio-economic interactions and impacts. The original model was divided into the core categories described in **Section 8.3.1** and research projects were identified within these. Like the biological and physical environmental projects identified, some of the socio-economic projects are related and many overlap.

The further research ideas are certainly not exhaustive in this chapter, but those that have been identified demonstrate the need for a co-ordinated approach to the research and development of tidal current energy as a new industry.

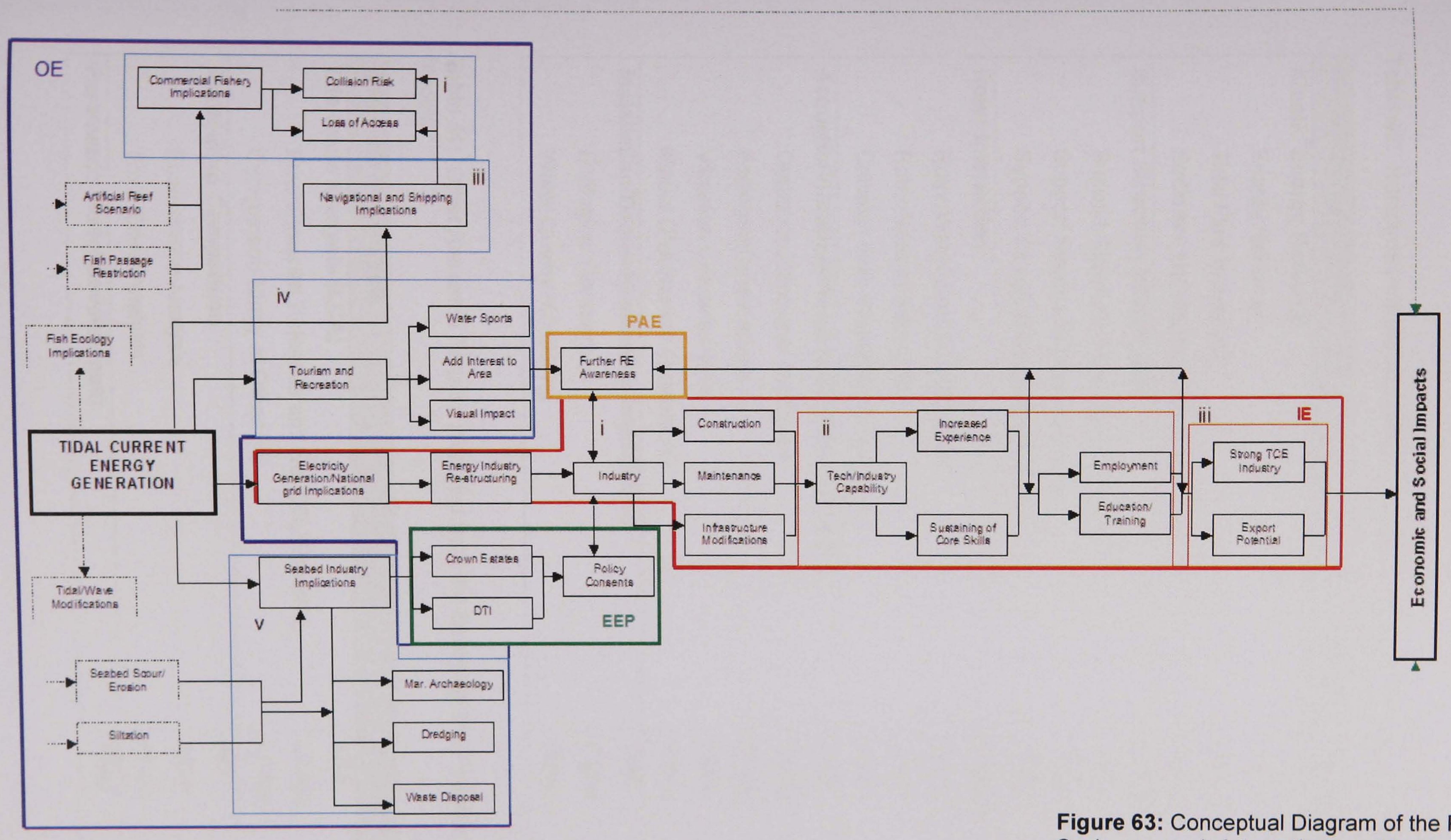

Figure 63: Conceptual Diagram of the Potential Socio-economic Interactions and Impacts and Identified Research Areas

The tables below summarise the research projects identified.

Table 40: Research Projects Identified from the Biological and Physical Conceptual Models

Research Project Title	CM Reference
Kinetic Energy Removal	**CM1**
Energy Removal	CM1a
Tidal Flow Interaction	CM1b
Sediment and Seabed Interaction	CM1c
Support Structure Interference	**CM2(i)**
Support Structure/Tidal Flow Interaction	CM2a
Support Structure/Wave Interaction	CM2b
Support Structure/Seabed Interaction	CM2c
Rotor Interaction	**CM2(ii)**
Rotor/Water Column Interaction	CM2d
Rotor/Seabed Interaction	CM2e
Collision Risk Probability (Ecological)	CM2f
Acoustic/Vibration/Visual (AVV) Characteristics	**CM3**
Operations Acoustic Emittance	CM3a
Ecological Implications	CM3b
Vibration Characteristics	CM3c
Visual Disturbance Assessment	CM4c
Installation/Decommissioning Implications	**CM4**
Ecological Comparison	CM4a
Water Quality Monitoring	CM4b

Table 41: Other Research Projects Identified from the Biological and Physical Conceptual Models

Research Project Title	Reference
Life Cycle Analysis (LCA)	**LCA**
Environmental Releases and Net CO_2 Emission	LCA(i)
Comparison Study of Other RE	LCA(ii)
Antifouling Comparison	**AC**
Encrustation Analysis	AC(i)
Toxic Effect Analysis	AC(ii)
Parametric Model Development	**PMD**

Table 42: Research Projects Identified from the Socio-Economic Conceptual Model

Research Project Title	Reference
Offshore Environment	**OE**
Commercial Fisheries Impact Analysis	OE(i)
Collision Risk Analysis	OE(ii)
Loss of Access Analysis	OE(iii)
Navigation and Shipping Impact Analysis	OE(iv)
Seabed Industry Impact	OE(v)
Energy and Environmental Policy	**EEP**
Energy Policy Impact	EEP(i)
Offshore Planning and Consents Impact	EEP(ii)
Energy Industry/Grid Impact	EEP(iii)
Industry and Employment	**IE**
Industry Capability Analysis	IE(i)
Employment Impact	IE(ii)
Export/Import Analysis	IE(iii)
Public Awareness and Education	**PAE**
Educational Impact	PAE(i)
Public Awareness/Attitude Analysis	PAE(ii)

Projects were also prioritised in terms of their potential overall impact; current consultative concern and present state of knowledge with respect to the area involved (**Tables 41, 42 and 43**). In order to establish this priority, the following criterion was used:

Overall Significance

Overall significance was established using the criteria already formulated in **Chapter 4** and summarised in **Table 21** (**pp.133**).

Consultative Concern

This was assessed in order to establish whether consultative concern has been or could potentially be voiced, through stakeholder organisation, through scientific approach or public scrutiny.

Knowledge Status

Level of knowledge is an important issue to review. Where there is a complete lack of knowledge in a particular area, a one (1) was given. Where there was deemed to be a good theoretical knowledge of the area, but where little is known about the application of this knowledge to tidal current energy, a medium level was given (2). In projects where knowledge has been established in all areas and could be readily applied, three (3) was given.

Research Priority

Research priority was established using a cross-reference system with respect to overall significance and knowledge status. For example, where there is a complete lack of knowledge in a particular area and where the potential impact is deemed particularly significant, research was given high priority (3). Where potential impacts are deemed significant and research areas have a medium (2) knowledge status, a high research priority was also given. Conversely, where there is a low significance level and a high knowledge status, a low priority was given. **Table 43** summarises this.

Table 43: Research Priority Matrix

Overall Significance	**H**	3	3	2
	M	3	2	2
	L	1	1	1
		1	**2**	**3**
	Knowledge Status			

From the research prioritisation (**Table 44**), a number of projects were found to be of a high to moderate research level. This indicates that there are not only many knowledge gaps that need to be closed, but the research issues identified have associated impacts that are deemed to be significant with respect to tidal current energy and the environmental implications involved. With this in mind, it is evident that a comprehensive programme of research needs to be established in order to accommodate all research areas. Research projects identified have also been ranked in order of priority (**Tables 45 and 46**), which reflects not only the importance of such research towards the development of tidal current energy, but also the overall research need and availability of current knowledge. Some projects are ranked in pairs, which emphasises the fact that some projects are highly dependent upon the results of the relevant preceding project. Prioritisation was given to those projects deemed to have a potential significant environmental impact, where there was little understanding of the potential significance and that attracted high consultative concern. However, the priority ranking overall was a subjective exercise and merely expresses the opinion of the author and as research progresses and more knowledge is gained, so will the prioritisation of projects. However, a strategy developed by the Wave and Tidal Stream Energy Research Advisory Group (formerly part of the DTI) have proposed that energy removal, tidal flow interaction, operational acoustics and collision risk should have research priority (RAG, 2006).

Table 44: Research Project Prioritisation

Research Project	CM Ref	Overall Sig.	Cons.Con	Know. Status	Comments	Researc Priority
Kinetic Energy Removal	**CM1**		Yes		Little is known about the quantity of energy extracted from the marine environment through a tidal energy device. There is concern about the amount of energy extracted and the relationship or effects this will have on the tidal and wave dynamics of an area and consequently the sediment/seabed interactions of these components.	
Energy Removal	CM1a	H		1		**3**
Tidal Flow Interaction	CM1b	H		1		**3**
Sed/Seabed Interaction	CM1c	H		1		**3**
Support Structure	**CM2(i)**		Yes		Over the last few years there has been a growing interest of the effects offshore structures have on the surrounding marine environment. Though some experimental and computational work has been completed, more research into specific structures and their affects needs to be done. Research of this kind in the area of TCE will help in the understanding of these effects and in the long-term mitigating measures may be found. Such research may also help in understanding the affects of similar offshore scenarios, such as for the wind energy and wave sector.	
SS/Tidal Flow Inter'	CM2a	H		2		**3**
SS/Wave Interaction	CM2b	M		2		**2**
SS/Seabed Interaction	CM2c	H		2		**3**
Rotor Interaction	**CM2(ii)**		Yes		Offshore structures are known to affect the marine environment, through increased turbulence etc., and the support structure for tidal devices is no exception. However, concern lies with the impacts associated with the rotor interaction i.e. the behaviour and propagation of the tip vortices associated with the rotor and their effects on the water	
R/WC Interaction	CM2d	H		1		**3**
R/Seabed Interaction	CM3e	H		1		**3**

Collision Risk	CM4f	H		1	column and subsequently the seabed. Though collision is thought to be a low risk impact, much concern has been shown through particular consultative groups, such as the RSPB and the Seal Rescue Associations, as well as other marine mammal organisations. With this in mind it is crucial to conduct research in this area to prevent misunderstanding in this area, and find suitable mitigation/prevention measures.	**3**
Research Project	**CM Ref**	**Overall Sig.**	**Cons.Con Source**	**Know. Status**	**Comments**	**Researc Priority**
AVV Characteristics	**CM3**					
Acoustic Emittance	CM3a	H		1	The effects of anthropogenic noise in the marine environment has been under investigation for a number of years now, but there is still much research needed in this area with respect to specific noise sources in order to be able to make comparisons with species sensitivity. Consultative concern in this area has been high with regard to the impacts of noise emission on the marine ecology and marine mammals in particular. As yet no such knowledge is known with respect to tidal current energy. Vibration characteristics are also unknown and it is important to establish such data in order to assess the potential impact on erosion and scour and ultimately the overall stability of the structure itself.	**3**
Ecological Implications	CM3b	M		2		**2**
Vibration Characteristics	CM3c	M	Yes	1		**3**
Visual Assessment	CM4c	M		2	Visual impact is an important factor to assess, not only from an ecological point of view, but also with respect to human consideration and can be associated with noise impact. All in all it will be a useful exercise to assess the visual amenity of tidal current energy. Though studies have been conducted with respect to one-off deployments, assessing 'tide-farm' scenario's would be beneficial.	**2**
Install/Decomm	**CM4**	H	Yes		Impacts can be compared to the oil/gas industries and other offshore projects, but there	

Ecological Comparison	CM4a			2	is little documentation, especially concerning recovery rates. Monitoring is an essential process in these areas to ensure minimal impact and to quantify species abundance and density impacts. Once fully understood, mitigation procedures may be established.	3
Water Monitoring	CM4b			2		3
LCA	**LCA**		Yes		Though tidal current energy is a renewable resource, harmful releases will inevitably occur during the manufacturing, installation and decommissioning phases of a project. In order to quantify such releases a Life Cycle Assessment needs to be done. This will also enable the net CO2 release to be quantified in order to establish the benefit of a tidal current energy device in this area. Comparison of results to other renewables will also be very useful.	
Env Releases/CO_2 Study	LCA(i)	n/a		1		**2**
RE Comparison	LCA(ii)	n/a		1/2		**2**
Antifouling Comparison	**AC**		Yes		A major concern is what effect antifouling and corrosion prevention will have on the local marine environment. Much research has gone into establishing the effects of antifoulants, with new products on the market. Environmentally, toxicity comparisons of different products should be assessed, along with an assessment of the effectiveness of each product on encrustation - an important factor associated with the efficiency of tidal current energy.	
Antifoul Analysis	AC(i)	M		3		**2**
Toxicity Comparison	AC(ii)	M		3		**2**
Parametric Model	**PMD**	n/a		n/a	Parametric modelling development is an important stage to consider with respect to the further development of tidal current energy. Such modelling will allow tidal energy systems to be equated with potential sites and their environmental conditions.	**n/a**

Research Project	**CM Ref**	**Overall Sig.**	**Cons.Con Source**	**Know. Status**	**Comments**	**Research Priority**
Offshore Environment	**OE**				Little is known about how tidal current energy projects will affect the offshore environment with respect to fishing, navigation, loss of access and other issues relating to seabed industries. Experience and expertise from other offshore industries can be used to develop research in these areas, which have been highlighted as important potential impacts and constraints of tidal current development. Strategic shipping, navigation and fisheries research to identify specific conflicts of interest and further research into loss of access issues and collision risk would also be beneficial.	
Commercial Fisheries Impact Analysis	OE(i)	H	Yes	2		**3**
Collision Risk Analysis	OE(ii)	M	Yes	2		**2**
Loss of Access Analysis	OE(iii)	M	Yes	2		**2**

Research Project	CM Ref	Overall Sig.	Cons.Con Source	Know. Status	Comments	Researc Priority
Navigation and Shipping Impact Analysis	OE(iv)	H	Yes	2	Research into the effects on other sea users would also be beneficial, especially in terms of the marine aggregate industry, waste management and also recreational users.	**3**
Other Sea User Impact	OE(v)	M	Yes	2		**2**
Energy and Environmental Policy	**EEP**				There has been consideration of how renewable energy in general may affect energy policy and the energy in the UK, but further research and development into the implementation of renewable energy (including that of tidal current energy and other marine renewables) is crucial if a balance of competition between conventional fuels and renewable energy is to be found and how conventional fuels could be potentially phased out in the long term. The streamlining of the consents and planning process for marine renewables is at present being addressed and a more streamlined approach has been formulated, but there is still further scope for improvement to bring marine energy development in line with the current oil and gas planning and consents process or even developing a spatial planning system to integrate all sectors of the marine environment. A review of costing, upgrade and capacity issues are also under review with regard to grid infrastructure impacts, but further analysis is recommended with respect to the matching of potential resource, optimum tidal energy sites and the UK's energy requirements.	
Energy Policy Impact	EEP(i)	H	Yes	3		**2**
Offshore Planning and Consents Impact	EEP(ii)	H	Yes	3		**2**
Energy Industry/Grid Impact	EEP(iii)	H	Yes	3		**2**
Industry and Employment	**IE**				Understanding of the industrial implications and constraints concerning tidal energy development has increased. Further assessments, however, need to be made, including infrastructure capabilities, as well as gap analyses of skills, industry needs etc. It would also be beneficial to the emerging tidal current energy industry to gain a further	
Industry Capability Analysis	IE(i)	M	Yes	2		**2**

Employment Impact	IE(ii)	L	Yes	2	insight into the impact of employment and how in the long term this will affect local economies with respect to job creation and even job loss through the potential impacts on other marine industries.	1
Export/Import Analysis	IE(iii)	L	n/a	1	An analysis of key export areas would be beneficial at this stage to fully understand the international implications of such a new industry.	1
Research Project	**CM Ref**	**Overall Sig.**	**Cons.Con Source**	**Know. Status**	**Comments**	**Researc Priority**
Public Awareness and Education	**PAE**				The development of programmes to promote the understanding of renewable energy at all levels should be considered in conjunction with full understanding of the public's attitude towards renewable energy and its benefits/disadvantages. Such studies have been initiated in the past, but specific studies on tidal current energy/marine renewables would be beneficial in terms of identifying knowledge gaps.	
Educational Impact	PAE(i)	L		1		1
Public Awareness/Attitude Analysis	PAE(ii)	L		1		1

Table 45: Research Project Priority for Biological and Physical Environmental Impacts

Project Priority	Project Title	Preceding Project	CM Reference
1	Kinetic Energy Reduction Tidal Flow Interaction	 CM1a	CM1a CM1b
2	Acoustic Emittance Ecological Implications	 CM3a	CM3a CM3b
3	Rotor/Water column Interaction		CM2d
4	Ecological Collision Risk		CM2f
5	Support Structure/ Tidal Flow Interaction Support Structure/ Wave Interaction		CM2a CM2b
6	Support Structure/Seabed Interaction Rotor/Seabed Interaction	CM2a CM2d	CM2c CM2e
7	Ecological Comparison Water Quality Monitoring		CM4a CM4b
8	Parametric Model		PMD
9	Vibration Characteristics Visual Assessment		CM3c CM4c
10	Life Cycle Analysis		LCA (i) LCA (ii)

Table 46: Research Project Priority for Socio-Economic Environmental Impacts

Project Priority	Project Title	Preceding Project	CM Reference
1	Commercial Fisheries		OE(i)
2	Navigation and Shipping	CM2c CM2e	OE(iv)
3	Collision Risk	OE(i) OE(iv)	OE(ii)
4	Loss of Access	OE(iv)	OE(iii)
5	Other Sea Users		OE(v)
6	Energy Policy		EEP(i)
7	Offshore Planning and Consents		EEP(ii)
8	Energy Industry/Grid		EEP(iii)
9	Industry Capability		IE(i)
10	Employment		IE(ii)
11	Export/Import	IE(i)	IE(iii)
12	Education Public Awareness/Attitude		PAE(i) PAE(ii)

8.6.2 Research Project Measurables and Observables

It is apparent that the research projects identified are not only individual systems, but they are also a series of inter-related scenarios that can be additive, synergistic and neutralising in nature. Bearing this in mind, it is also evident that such projects have similar project measurables and will be aggregated as one, but could also be used for a number of different ends and means. **Section 8.7** discusses this further. **Table 47** summarises research measurables.

Kinetic Energy Removal

In order to quantify the scale of likely effects associated with the extraction of energy a computational study will need to be formulated. Initially, it would be practically realistic to deploy ADCP's to measure current characteristics around a given development to assess tidal current interactions with the technology used. However, further computational measurables associated with the total amount of energy extracted by one turbine in a hypothetical channel using computational modelling techniques. From these results, tidal and wave influences can then be established through further modelling techniques. Sediment interactions, such as deposition can then be established using a theoretical or modelling approach. In time, it would be helpful to extend this research to different numbers of turbines, configurations and channel scenarios.

Support Structure Interference

Using known theoretical and computational approaches, support structure influences on flow can be quantified by establishing flow profiles and dynamic activities of the tides and waves. This involves using techniques such as wave diffraction modelling and other hydrodynamic modelling techniques.

The influence of these latter effects and the structures themselves, on local sedimentation can be quantified through the flow/sediment processes that are involved, though such modelling techniques are in their infancy, especially with respect to groups of structures. Quantification in the area of sedimentation interactions may include, bed shear stress and the near bed oscillatory flow velocity. Turbulence associated with the structures can also be modelled and the effects on sediment transport, bed-shear stress, bed load transport and suspended load assessed. This can be done using computational and numerical methods, as well as experimental work and real time measurement.

Rotor Interaction.

Rotor interactions can be assessed physically and numerically. Quantification includes the behaviour and propagation of the tip vortices and eddies associated with the turbine rotors. Such results will help in the seabed interaction studies.

Hydrodynamics of the flow and the associated ecological collision risk may also be established by physical and numerical simulation and although behavioural responses from cetaceans, fish and birds are not able to be quantified at present, this should be considered. In fact, a very recent study (Wilson et al., 2007) attempts to predict encounter probabilities, to further understand the implications of collision risk for marine renewable energy technologies.

Acoustic, Vibration and Visual Characteristics

Research into the acoustic emissions of devices is required to establish whether such emissions are significantly higher than the ambient noise levels and the potential impact this may have on marine life.

This should include quantifying the characteristics regarding the nature of the noise source, such as frequency and sound power level and should determine such levels generated by a single turbine and eventually a number of turbines so that cumulative affects can be measured. Attenuation of noise also needs to be assessed, which could combine measurement with modelling techniques and should investigate a variety of weather and hydrographic conditions at various distances. This will give an idea of the propagation path and the potential distance observable emissions are liable to travel.

Determination of the ambient noise characteristics can be established using a theoretical or physical measurement approach. Data should include, noise generated by wind and waves at a variety of depths and on a variety of seabed substrates. This will enable an assessment to be made of the contribution tidal energy devices make to ambient noise conditions.

To assess the ecological implications of acoustic emissions, comparisons need to be made with animal sensitivities and will only be achieved through consultation with noise, fish and marine mammal specialists. Ongoing monitoring and field investigations of marine mammals around the UK would also be paramount in determining construction and operational effects on marine mammal species. Monitoring of this nature should be a continuous process.

Vibration characteristics should also be assessed, along with the visual amenity and ecological and human response to this.

Installation and Decommissioning

Seabed and ecological community (benthos, fish etc.) studies should be included to determine any change in species abundance and composition. Monitoring should be compared to baseline data collected prior to installation and operation and, possibly, with the use of a control site near the area to assess adaptation responses. Recovery response should also be monitored after the decommissioning phase.

Water and sediment quality impact should also be assessed throughout the project lifetime. This may include chemical composition characteristics of seawater and sediment and the turbidity of the immediate area.

Life Cycle Analysis

An LCA involves making detailed measurements during the manufacture of the product, from the raw material stage through its production, use and decommissioning. It allows a quantification of how much energy and raw materials are used and how much solid, liquid and gaseous waste is generated at each stage of the products life. Such an analysis will establish a system's 'industrial ecology' and overall carbon dioxide burden or release for comparison with other renewable technologies and energies. Such an analysis can be used as a decision making tool to identify key areas where process changes could reduce the overall impact, encompassing and enhancing the role of renewable energy as a 'clean energy'.

Antifouling Comparison

Encrustation is an important issue with respect to tidal energy devices - the effects can be severe, which include increased drag and lower blade efficiency; increased inertial and gravity loads due to increased surface roughness, area and mass and increased corrosion rates and the possible abrasion of cables. A comparison of treated and non-treated devices would be advantageous with respect to increased knowledge in growth rates and the effects on efficiency. Toxicity comparisons with antifouling treatments should also be taken into consideration to ensure the minimum of impact possible. A desk study encompassing toxicity, diffusion rates etc. would probably suffice.

Commercial Fisheries, Navigation and Shipping

Strategic fisheries and shipping studies with the aim of identifying the effects of tidal current energy devices would be highly beneficial. Identifying the effects of different tidal current energy systems on the various types of shipping and fishing techniques and activities with regard to different device layouts and support structure designs, would enable a comprehensive interpretation of site-specific studies and identify the degree in which different methods and scenarios would cause potential conflict.

In addition, further impact research is needed to identify the cumulative impact of tidal current energy including:

- The assessment of the potential impacts of tidal energy devices interfering with navigation, radar and communication systems, including vessel traffic systems and navigational aids;
- Assessment of the impacts on the operation and function of maritime emergency services;
- Studies to investigate the potential of fishing gear interaction;
- Assessments of the potential impacts of scouring and sedimentation changes will have on navigational channels and known fish spawning and nursery grounds.

Collision Risk

Collision risk implications are particularly related to navigation and shipping. It is evident that given the potential for ships and fishing vessels to collide with tidal devices and the possibility of ship-to-ship collisions in the event of vessels becoming 'crowded' by developments or vessels having to deviate from optimum routes, it is essential that a comprehensive risk analysis be conducted. This in essence, is likely to be site-specific.

Loss of Access

The installation of tidal energy devices will undoubtedly result in the imposition of safety zones around structures, the area affected relating to the size and distribution of the structures. The imposition of such zones will effectively, through licence, preclude fishermen from fishing in these areas, providing a clear indication that it is unsafe to do so. Issues that may need to be clarified within the context of tidal current energy development, especially on a site-specific basis, include:

- the proximity of tidal current developments to historical fishing grounds;
- number of fishermen affected and area lost to fishing;
- disruption to fishing routes and effects on e.g. fuel usage;
- the length of time structures will be in place, whether temporary or in perpetuity, including plans for their future removal. Fishermen have a strong sense that equity should be maintained between present and future generations of fishermen when seeking compensation (if applicable);
- projected loss of earnings as a result of tidal developments (if applicable); and

- the effect exclusion from fishing will have on the fauna and flora of a site. It is assumed that the support structures will act as a refuge for fish and other animals, creating new spawning habitat.

Other Sea Users and Spatial Planning

The marine environment, though vast, can be a very busy area. In addition to shipping, and fisheries, there are many other users of the sea, including the oil and gas industry, the marine aggregate industry and recreational users etc. With this in mind, there is a strong argument for the implementation of a spatial planning exercise to highlight those offshore areas that are particularly widely used and in turn identify optimum areas for the siting of tidal energy development. Within a spatial planning exercise other users of the marine environment would inevitably include those associated with the fishing and shipping industries and also include and help the understanding of loss of access issues.

Spatial planning is a complex issue and has been comprehensively discussed within the context of the Government's *Safeguarding our seas* (Defra, 2002) initiative, where commitment was made to explore the role of spatial planning in the marine environment. Through spatial planning the interrelationships that exist among coastal and ocean uses and the environment the potentially effect must be acknowledged. It should be a continuous and dynamic process by which decisions are made with regard to sustainable use, development and protection of the marine environment, as well as the overall integration of all these components together. With the use of spatial planning an understanding of current knowledge in terms of the environment (natural and socio-economic) can be ascertained in order to provide a comprehensive tool in decision-making and planning for specific areas. Through such a tool, shared values in terms of the environment and culture can be identified and gaps in that knowledge can also be more easily established. Knowledge of a specific development area can also be integrated to provide a more robust resource management criterion and in turn be adapted to suit specific scenarios and conditions and enable a development to be integrated within its environment with minimum impact. **Section 7.1.1** and **7.2.1** describes the institutional problems associated with the lack of integration that currently exists in the planning and development process.

Energy Policy

There is a whole interrelated realm of issues that are associated with energy policy and the barriers to tidal current energy they reflect. It is in the interest of tidal current energy development and indeed renewable energy development in general that such policies are comprehensively reviewed and the impacts of any potential changes related to energy policy are highlighted.

Offshore Planning and Consents

There are a number of issues that reflect the need for further research and development within the offshore planning and consents processes. One paramount issue has already been discussed encompassing the potential physical and some socio-economic environmental impacts of tidal current energy development. A continued understanding on the level of environmental impact is crucial in developing a planning and consents system that actually provides guidance and evaluation to help planners assess schemes. Clear, transparent and consistent criteria needs to be developed to inform planning and industry on the potential impacts of any given potential development. A Strategic Environmental Assessment is underway for the UK, where survey work and analysis are due to begin in spring 2005. However, the level of detail for such assessments is not adequate enough and will merely provide identification of the resources available and identify some potential environmental impacts and constraints for specific sectors of the UK. A higher level of generic assessment is needed to provide a "bench-mark" for site-specific studies to enable comparisons to be made. In addition, it is inevitable that full EIA's will need to be conducted for any potential tidal current energy development, and 'bench-marks' to assess and compare impacts would be beneficial and though a SEA would give some indication with respect to 'regional' impacts and constraints, it would not necessarily provide the detail that is actually needed.

Further consultation and research needs to be conducted with respect to developers, planners and stakeholders to assess the needs of each in terms of tidal current energy development. All inevitably have their concerns with respect to development and gaining a better understanding of these will enable the adequate implementation of environmental guidelines (or "bench-marks") for tidal current development. By encompassing the key concerns of all parties involved, and finding a balance between development and the marine environment the industry will benefit not only from its standing as a 'renewable energy', but also as an energy and industry that does not compromise its overall environmental integrity.

Grid Infrastructure and Energy Industry

Since the emergence of the consultation document, *Transmission Investment for Renewable Generation* (OFGEM, 2004), a funding mechanism to make new money available to strengthen electricity transmission networks in Scotland and North of England has been announced (OFGEM, 2004). The mechanism allows an increase in investment of more than 50% from the previous figure of £360 million to £560 million. With this increased investment, the development of renewable energy generation with respect to grid constraints will not be delayed unnecessarily and renewable energy generators and developers will be able to enter the electricity market in a more cost effective way. Though there has been the go-ahead for increased funding in this area and it has been anticipated that tidal current energy generation will be contributing to the national grid within 3 years, there are a number of issues that need to be addressed in conjunction with the planning of such transmission and grid upgrades.

It would be highly beneficial for a developing tidal current energy industry to have the first developments in areas where the electricity network could best accommodate such a development. Therefore, mapping of electricity network for weak and strong points is imperative and it must be ensured that information is freely available to developers to aid in site selection. In the long term it is necessary to strengthen the electricity network so that renewable energy and embedded generation can be accommodated. With this in mind, additional comprehensive investigations needed to find best practice and best practical options in terms of feeding electricity into the grid, whilst ensuring minimum environmental and electricity network impact.

Despite the evidence that ROCs are operating as planned and the investment just provided to strengthen the grid, the future of renewables deployment in general will continue to be hindered by other financial constraints and uncertainties. As the current electricity market stands, the New Electricity Trading Arrangements (NETA), were introduced in 2001 to encourage a more competitive market and reduce overall prices. Though NETA on the whole achieved these goals (with additional unforeseen problems discussed in **Section 7.1.4**), the market also created negative outcomes for some renewable energy generators. NETA was designed to operate like other commodity markets and therefore favours predictable sources of generation. With this in mind, relatively unpredictable sources, such as wind and some marine renewables have the potential to face significant costs for being out of balance with their expected levels of generation. Tidal current on the other hand is seen to be predictable. However, it is too early to speculate how the current NETA mechanism will affect tidal current energy generation. A number of modifications to NETA have already been made and implemented (OFGEM, 2002; Cornwall, 2003; Xueguang *et al.*, 2004) however the fundamental structure of NETA still has the potential to pose significant difficulties with regard to renewable energy generation. A comprehensive review of the structure and workings of NETA and the implementation of further modifications are paramount to ensure fair access to the electricity network for embedded renewable energy generation overall. In addition, the promotion to increase network operator's familiarity with renewable energy systems will also benefit the overall process of ensuring renewable energy, including that of tidal current energy, will have a future within the UK electricity transmission system.

Industry Capability

There is a great opportunity to develop a renowned sector within the UK and this can only have a significant positive impact on existing related industries and the overall economy. There is, however, much research that needs to be done in order to foresee potential impacts in quantifiable terms and identify ways in which to achieve them, including effects of energy import and export strategies, the identification of potential markets for goods and services, and the identification of market opportunities and company exposure to name but a few. The DTI have already commissioned a gap analysis in the renewable energy supply chain (DTI, 2004), and the potential for renewable offshore power generation has also been touched upon (Scottish Enterprise, 2002), but more energy specific studies need to be considered to grasp a more detailed overview of what the gaps are.

Employment

The issue of employment is very much related to industrial capability and educational factors. The reports (Scottish Enterprise, 2002 and DTI, 2004) have discussed employment implications concerning renewable energy. However, they concentrate mainly on the generation of employment opportunities. It would also be beneficial to the emerging tidal current energy industry to gain not only a further insight into potential employment opportunities, but it would also be of invaluable interest to determine the overall impact of the industry on employment and how in the long term this will affect local economies with respect to job creation and potential job loss through the potential impacts on other marine industries.

Export and Import

An analysis of key export areas would be beneficial at this stage to fully understand the international implications of such a new industry.

Education, Public Awareness and Attitude

These are important factors to consider in the development of any renewable energy and tidal current energy is no exception. Generally, while many people have concerns about renewable energy schemes before they are developed, local support usually concedes to the beneficial aspects once such developments are commissioned. In relation to the planning and consents issues and research needs, a more community or public based approach is needed at the scoping and planning stage of development. This will provide an opportunity to gain support earlier to counter the minority who often dominate decisions at the planning stage.

In addition, the Identification and profiling the existing skills and experience associated with tidal current and marine energy would be a beneficial key step in establishing an analysis of educational gaps within the sector. An evaluation of potential industry vocational qualifications and further development of 'continued professional development' (CPD) opportunities to those that are at the beginning of their careers or already have established careers would also enhance the industry. The development of a database providing contact details, methodologies and experience would not only aid developers, academics and interested professionals, but it would also enhance the knowledge of educational providers across all sectors of education and facilitate awareness throughout all public sectors.

Table 47: Summary of Research Measurables

Research Project	Type of Study	Required Measurables		Summary of Research Objectives
		Monitoring Programme	***Computationa/Analysis Programme***	
Kinetic Energy Removal	Cp Nm	Tide/Wave M'ment Sediment characteristics	Energy extracted Tidal/Wave distortion Sed. Interaction	To quantify the scale of likely effects associated with the extraction of energy by tidal current energy generation, including potential changes in tidal regime and sedimentation processes.
Support Structure	DS Cp Nm	Tidal velocity Wave m'ment Suspended load Sediment characteristics Bed formation	Bed shear stress Oscillatory flow Sediment transport Bed load transport	To quantify the support structure influences on tidal flow and wave characteristics and associated sediment and turbulence impacts.
Rotor Interaction	Cp Nm	Tidal velocity/flow Sediment characteristics Seawater characteristics	Tip-vorticity propagation/behaviour Seabed Interaction Hydrodynamics of flow	To quantify the behaviour and propagation of the tip vortices and eddies associated with the rotor blades and assess these effects on the seabed, flow and sediment processes.
Acoustic, Vibration and Visual Characteristics	M Nm Cp DS	Seawater characteristics Frequency Sound power level Attenuation Seabed characteristics Ecological abundance/composition	Propagation path/distance Ecological sensitivities	To quantify the noise emissions and propagation levels of tidal current energy generation and assess the implications on marine life of such.
Install/Decomm	M DS	Seawater composition Sediment composition (chem/phys) Turbidity Ecological abundance/composition	Statistical analysis Pre/post comparison	To determine the pre-construction composition and density of ecological communities and assess adaptation responses within the operational and post-decommissioning phases.
LCA	DS Cp	Manufacturing processes Materials analysis Waste monitoring	CO_2 release Overall LCA	Comprehensive analysis of the overall 'environmental integrity' of the system in terms of carbon dioxide burden/release and material/process overview.

Research Project	Type of Study	Required Measurables		Summary of Research Objectives
		Monitoring Programme	***Computational/Analysis Programme***	
Antifouling Comparison	DS M	Encrustation	Toxicity analysis	Comparison of antifouling agents to compare overall environmental risk to the marine environment.
Commercial Fisheries, Navigation and Shipping	M A Cp Nm	Fishing Activity Maritime Emergency Services Fishing Gear Interaction Navigational Channels and fish spawning grounds (re sedimentation process)	Fishing Techniques/Activities Fishing gear interaction Sedimentation	Comprehensive investigation into the impacts of tidal current energy devices on fishing, navigation and shipping and sedimentation issues in relation to navigational channels and fish spawning sites.
Collision risk	M A	Shipping	Collision risk	Analysis of the probability of collision risk with respect to shipping and fishing vessels.
Loss of Access	DS A	N/A	Fishing ground proximity Livelihoods affected Equity Projected loss of earnings	Detailed analysis on the impacts of the imposition of safety zones/loss of access due to tidal current energy devices.
Other Sea Users and Spatial Planning	DS A Cp	Spatial/Resource Management	Optimisation of tidal current energy sites.	Extensive marine resource management analysis and mapping exercise.
Energy Policy	DS	N/A	Review of energy policy	Comprehensive review of energy policy in terms of how policy not only affect the development of tidal current energy, but how in turn a tidal current energy industry may affect policy, using case studies/country scenarios for comparison.
Offshore Planning and Consents	DS A	N/A	EIA methodology development 'Bench mark' criteria Further consultation to assess environmental concerns	A high level generic impact and spatial assessment and methodology development to provide 'bench mark' for site specific development studies to enable comparisons and standards to adhere by.
Grid Infrastructure and Energy Industry	M DS A Cp	As industry grows close monitoring of the situation is imperative to establish industry and grid needs.	Analysis of grid connection options Impact on/from NETA	Comprehensive study to determine best practice and best practical options with respect to connecting tidal energy generation to the grid. Detailed review on the structure and workings of NETA and the impact of tidal energy generation.
Industrial Capability	DS A Cp	As industry grows close monitoring of the situation is imperative to establish industry needs.	GAP analysis with respect to tidal current energy	Quantify and further identify potential impacts on industry and ways to achieve a positive impact.

Research Project	Type of Study	Required Measurables		Summary of Research Objectives
		Monitoring Programme	*Computational/Analysis Programme*	
Employment	DS A Cp	As industry grows close monitoring of the situation is imperative to establish the overall impact.	This closely relates to loss of access issues but in a broader context, including all marine and associated industries and the long term affect on local economies.	Comprehensive review maybe on a regional basis to establish net impacts on employment through the growth of tidal current energy.
Export and Import	DS A	As industry grows close monitoring of the situation is imperative to import and export needs/opportunities.	International implications. Energy import/export strategies. Market opportunities	Detailed analysis of export/import potential of tidal current energy in terms of energy produced, manufacturing and experience etc.
Education, Public Awareness and Attitude	DS A	N/A	GAP analysis Development of database for teaching and knowledge purposes Facilitate full awareness	GAP analysis of the skills and experience required for a tidal current energy industry, including school curriculum gaps, qualifications and career training. Detailed study on the awareness and attitude towards tidal current energy generation.

Type of Study	Abbrev.
Monitoring	**M**
Desk Study/Theoretical	**DS**
Analysis	**A**
Computational	**Cp**
Numerical	**Nm**

8.7 PROGRAMME OF WORK

8.7.1 Physical and Ecological Environmental Impact Research

To achieve the physical and ecological research projects outlined, the programme of work can be divided into two areas, which can run simultaneously. The first is a field monitoring programme and, the second a programme purely for computational and analysis purposes. Both can be developed to complement each other in terms of real-time monitoring and validation. Such a programme could run for a maximum length of 40 months and a minimum of 28 months, but the time period is ultimately dependent on the resources involved. The latter period of time is set at such a minimum in order to maintain an adequate time for baseline surveys and continued monitoring. A longer period would inevitably be beneficial in order to maintain valid and unbiased data. For example, the Danish Demonstration Programme (Environmental Monitoring) for offshore windfarms, performed a 2 year baseline study before construction and a further 2 year operational study (Bruns *et al.*, 2004). In Denmark, however, there are very few, if not non-existent generic research programmes in offshore renewable energy which are not project related and as such are not liable for specific licensing conditions. For example, in the UK when a development has been granted consent, it is usual for conditions to be made as part of that consent which usually encompass monitoring requirements. Any generic research projects carried out in relation to tidal current energy will in effect be separate from those requirements on developers to undertake site investigations in relation to feasibility studies, environmental impact assessments or any site monitoring requirements initiated as a requirement upon construction. At present, in the UK, construction licences for offshore renewable energy projects often require the implementation of environmental baseline and monitoring studies. This is an expensive requirement to place on a developer and a more structured approach needs to be initiated by the state using applicable demonstration projects to assist in environmental impact research. MCT Ltd. have successfully secured funding from Northern Irelands newly launched 'Environment and Renewable Energy Fund', where a comprehensive monitoring programme has been drawn up in collaboration with Northern Irelands Environmental and Heritage Service, Ulster Wildlife Trust and other marine specialists.

8.7.2 Socio-Economic Impacts

Unlike the physical and ecological impact research, to achieve the socio-economic research projects outlined, it is difficult to define the programme of work into two distinct areas, which can run simultaneously. In effect, a less structured approach is inevitable due to the nature of the research associated with some of the studies needed. However, like the physical and ecological impact research some studies do go hand-in-hand. Generally, the focus of these proposed research studies is to facilitate continued tidal current energy development, supporting projects and trying to resolve issues that are a potential barrier to development and ultimately optimising the growing industry in general.

Research concerning commercial fisheries, navigation, collision risk and losses of access are issues concerning spatial planning and should be a priority before deployment of any tidal current energy development. It is these issues that have been and will be highlighted in response to EIA consultation and to have quantitative response to such concerns would be highly beneficial at this stage, even if such research was hypothetical and therefore generic or a specific area was studied as a worst case scenario. Issues concerning grid infrastructure are also paramount in the overall development strategy for tidal current energy development and such research should take precedence in order to resolve the issues in question. Planning and consents' research relates significantly to potential physical and ecological impacts and again this is something that inevitably needs to be addressed before any large-scale development is commissioned. Likewise, concerns relating to industrial capability and employment may also full into the prospect of pre-deployment research initiatives, however, such issues may also benefit from a simultaneous approach within the overall development of tidal current energy generation, addressing needs as they come to light.

8.8 ROUTE- MAP TO DEVELOPMENT

To develop a route-map to market for tidal current energy needs the aim is to improve confidence in all aspects of research, development and industry status and therefore calls to establish the priorities for each aspect.

As part of the DTI's Sustainable Energy Programmes technological route maps were developed up until the year 2020. The main aim of the maps was to determine research and development needs and priorities for funding and further work. With reference to the Tidal Stream Status Report (DTI, 2001a) and the discussions placed in this report, a route-map to market will be discussed, taking into account the following:

- Themes and requirements that need to be achieved to reach competitiveness and market infiltration; and
- Prioritisation of those requirements and formulation of a route-map to achieve them.

8.8.1 Route-map Development

Ideally each tidal current energy device concept should have its individual route-map, as developmental needs of each concept are potentially different in terms of technical, environmental and industrial capability. However, the options discussed below will be of a generic basis, relating to all concepts in all stages of development.

8.8.2 Identification and Formulation of Development Requirements

All development requirements were identified under 4 major themes, technical, environmental institutional and industrial (**Table 48**) and have been formulated with relation to the previous section. In terms of development areas, overlap may occur within some development themes and related research and in some cases development areas may be significantly related and therefore influence one another.

A number of sub-areas or stages were also identified within a majority of main development areas. Each area in many respects constitutes a number of individual research or development projects. It is also evident that some areas or projects are significantly related to others and there are a number of areas and sub-areas that are predecessors to each other. Other areas can be conducted in parallel or have no relationship with others. Some actions are already in progress or are in the planning stages.

Table 49 details the development needs and priority actions potentially required for the development of a tidal current energy industry within Scotland. **Figure 64** summarises this in a simplified conceptual diagram or route-map.

Table 48: Summary of Development Areas

Theme	Development Area
Technical	▫ Resource Assessment ▫ Long-term Reliability ▫ Efficiency and Economics ▫ Installation and Support Methods ▫ Device Spacing and Optimisation ▫ Electrical Connection
Environmental	▫ Environmental Impact ▫ EIA Framework and Methodology ▫ LCA ▫ Public Awareness/PR Issues
Institutional	▫ Consents/Environmental Policy ▫ Grid Infrastructure Planning/Upgrade Analysis ▫ Funding/Finance
Industrial	▫ Access to market ▫ Gap Analysis ▫ Industry and Skills Development ▫ Diversification ▫ Business Support/Infrastructure ▫ Export Potential

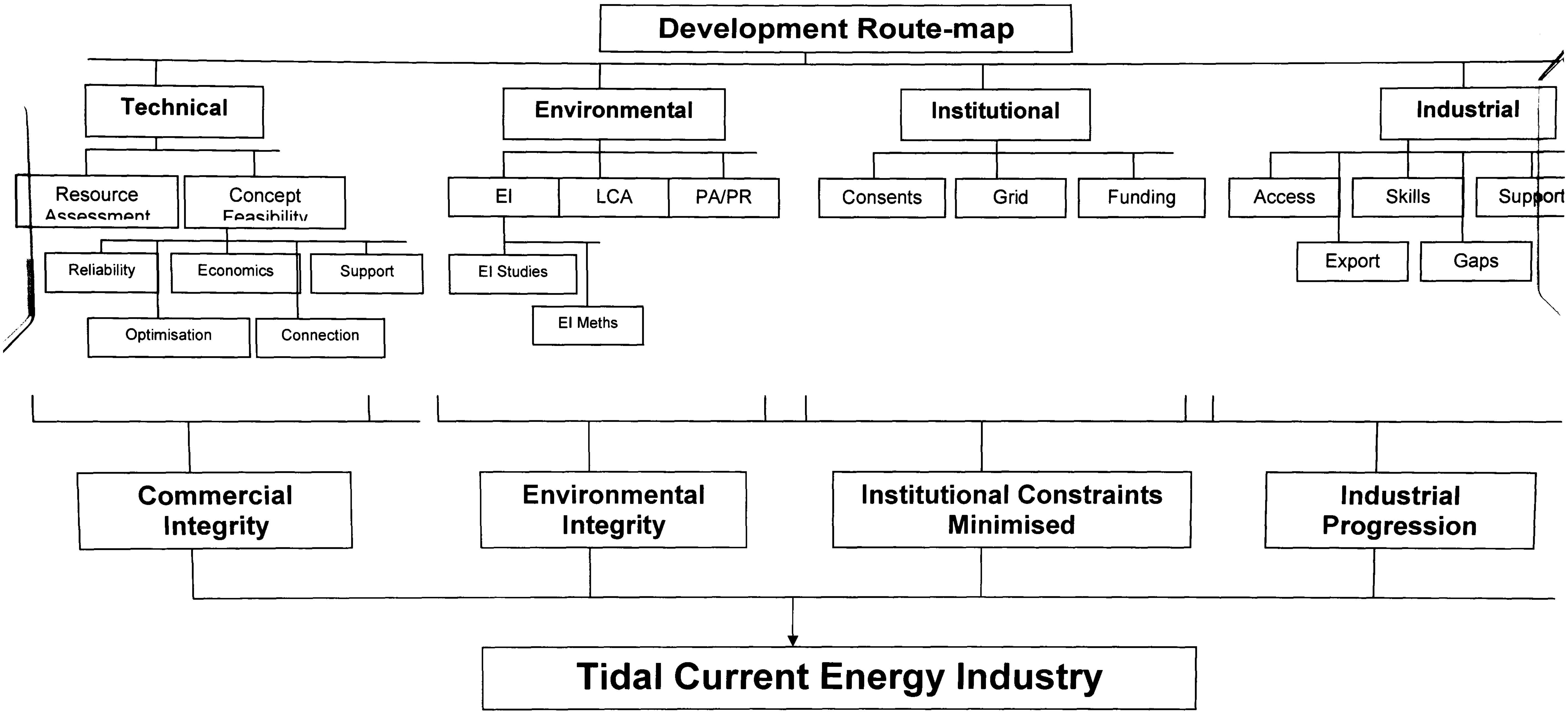

Figure 64: Developmental Route-map to Tidal Current Energy Development

Table 49: Formulation of Development Requirements

Scale	
National	N
Regional	R
Local	L

Priority	
High	H
Medium	M
Low	L

Development Area		Needs/Emphasis	Priority Action(s)/Sub-area(s)		Predecessor(s)	Scale	Priority
Technical							
1	Resource Assessment	Detailed worldwide tidal velocity resource assessment, energy output and electricity cost estimates for key regions.	1a 1b 1c	ID of potential resources using existing maps and charts, as well as more sophisticated tools such as remote sensing techniques. Detailed assessment of total energy output for key areas Electricity cost estimates	n/a	N	M/H
2	Long-term Reliability	Such requirements go hand-in-hand and if efficiency/economics are to be achieved within stated targets related R&D areas need to be addressed. These needs are very concept specific and demonstration/prototype devices are paramount for the industry to go forward.	2a	For new concepts initial design and feasibility studies need to be conducted, encompassing all the study outputs addressed and further identify development issues and uncertainty. Small models should be produced, with further design/costing studies with the aim to produce model prototypes in a 'real' environment.	n/a	N	M
3	Efficiency/Economics		2b	For existing concepts demonstration projects should paramount with the view to encompassing L/T performance, cost and environmental evaluation using electrical connection.		N	H
4	Installation/Support Methods		2c	Progressive discussions with key manufacturing base to aid design and cost assessments and to build upon standard specifications.		N	H
5	Spacing/Optimisation						
6	Electrical Connection						

Development Area		Needs/Emphasis	Priority Action(s)/Sub-area(s)		Predecessor(s)	Scale	Priority
Environmental							
7	Environmental Impact	For development to take place questions regarding the environmental integrity of devices need to be explored. This will aid the planning and consents process, whilst also easing concerns of stakeholders and the public with respect to the potential impacts of such developments. A detailed scoping study of these issues and a related programme of work have already been formulated[1] involving monitoring, theoretical, analytical, computational and numerical studies.	7a	Initialise programme of work for environmental impact studies to address environmental uncertainty.		N	M
			7b	For each potential development it is necessary for an EIA to be conducted to scope and assess potential environmental impact and to form mitigation procedures.	8a		H
			7c	Formulate programme to monitor environmental risk/disturbance.	(7a)		H
8	EIA Framework/Methodology	To aid planning/consents and the EIA process a detailed strategic EIA framework needs to be formulated.	8a	Develop framework to set down specific environmental standards to aid EIA process.	(9a)	N	H
			8b	Develop EI 'decision tool' to aid the process of EIA and planning procedures	8a		M
9	LCA	To gain a holistic approach to the developmental life of a tidal current energy development a Life Cycle Analysis is critical in establishing net CO_2 emissions etc.	9a	LCA's need to be conducted and specific manufacturing standards need to be formulated.	n/a	n/a	M
10	Public Awareness/PR/ Communications	Promotion and awareness of the needs and benefits of RE in general, as well as tidal current energy specifically needs to be addressed at all levels of society.	10a	Promote collaboration rather than competition between researchers, developers and companies etc.	n/a	N	H
			10b	Develop programmes to promote the understanding and need for RE at all levels with the aim to change attitudes towards energy sources - educational establishments - families - Government - Manufacturers/Companies etc.		N	H
			10c	Continue to establish Scotland's profile in RE and specifically tidal current energy through the media and other public outlets		N	H

[1] Department of Trade and Industry, UK (2002) "*Scoping Study for the Environmental Impacts of Tidal Stream Energy*". Report No. ETSU T/04/00213/00/REP. Prepared by The Robert Gordon University, Centre for Environmental Engineering and Sustainable Development, Aberdeen

Development Area		Needs/Emphasis	Priority Action(s)/Sub-area(s)		Predecessor(s)	Scale	Priority
Institutional							
11	Consents/Environmental. Policy	Amendment of offshore consents process is needed. EIA standards need to be addressed.	11a 11b	Streamlining of process in progress through Government bodies. EI framework development to ease development and consents process	(8a)	N	H
12	Grid Infrastructure	Grid Infrastructure up-grade to accommodate further RE development, especially concerning remote areas.	12a	Solutions to this problem are under review. This involves detailed cost, size, and capacity and location analysis.	n/a	N	H
13	Funding/Finance	Funding/Finance issues need to be simplified	13a 13b 13c	Increased and promotable funding opportunities need to be instigated Other industry needs to be encouraged to invest in the tidal current energy sector and diversify their skills and profit. Energy costing issues need to be addressed	10a 12a; 2	N R L	H
Industrial							
14	Access to Market/Diversification	Need to make market more accessible	14a 14b 14c 14d	Launch initiatives to encourage Scottish companies into the RE sector and promote opportunities and belief in the industry Develop ways to promote industry within industrial Scotland and formulate strategies and help for willing companies to diversify. To help them become aware of the new industry and depth and range of industry within Scotland. Create resources for business advice, support, enterprise, project/business planning etc. specifically suited to the RE industry Creation of a detailed web-based, cd-rom or hardcopy database of companies within Scotland that have an interest in RE diversification to aid 14a/b	13 10	N R L	H

Development Area		Needs/Emphasis	Priority Action(s)/Sub-area(s)		Predecessor(s)	Scale	Priority
15	Industry Skills/Development	Access to employment is an essential need for a new industry and provision id needed to adjust to these needs	15a 15b	Identify gaps in skills base and develop a structured approach to meet these gaps Provision of adequate training and career development within the RE sector for interested parties to fill those gaps	14d	N R L	M
16	Business Support/Infrastructure	Need to build upon existing strengths and opportunities to match new industry.	16a 16b	Assessment of infrastructure capabilities (transport, commercial premises/land, communication networks etc.) and determination of further needs. Provision of encouragement and opportunity for new businesses to settle in Scotland to meet support/infrastructure needs	10c	N R L	M
17	Export Potential	Need to fulfil target of promoting Scotland as skills/technology base and market leader in tidal current energy	17a 17b	Identify key areas that the industry could export both technology and skill throughout the EU and worldwide Provision of info and advice on international trading and the promotion of business opportunities and creation of market entries and exports	14	N R L	M
18	Gap Analysis	Explore gaps within industry to aid understanding.	18a 18b	Continue to identify key businesses committed to diversifying and identify their specific capabilities and skills - see 14c Formulate continuous programme to assess and audit the tidal current energy market in terms of development, potential development, research and industrial capability and skill.	All	N R L	L

CHAPTER 9

EIA Framework Development

9. EIA FRAMEWORK DEVELOPMENT

9.1 Introduction

Overall, the thesis has drawn upon a number of interrelated issues concerning the development of tidal current energy. Firstly, it discusses the resource and development potential, putting the importance of tidal current energy in context with conventional energy sources in terms of global environmental impact, and energy diversification, security and demand. Secondly, the thesis discusses tidal current energy within the context of potential environmental impacts and attempts to evaluate current EIA methodology and the way in which developers and EIA practitioners use this process for marine development. Focusing on the latter themes, the thesis evolves to discuss the barriers that are hindering the development of tidal current energy and attempts to formulate a comprehensive list of research and development needs that would remedy or mitigate present barriers to development.

One key measure is the formulation of an EIA framework to ensure all key potential environmental impacts and issues are identified and assessed for proposed tidal current energy developments and to provide thematic and technical minimum requirements on these issues. At present uncertainty regarding the potential and significance of impacts of tidal current energy development is an important consideration to many stakeholders. However, uncertainty can be safeguarded if there is a proper framework for the management of environmental issues whether they are negative or beneficial. It is crucial that more comprehensive criteria are applied in order to protect the environment as a whole. A number of benefits that can be attributed to the standardisation of an EIA framework with respect to tidal current energy development and these can be summarised as follows:

- A standardised EIA framework would provide developers and EIA consultants with terms of reference for assessing potential environmental impacts and constraints;
- Stakeholders, developers and EIA practitioners alike will be encouraged to make more quantitative predictions of the effects expected both spatially and temporally and perform properly designed monitoring programmes which have adequate means to detect the changes expected. The scientific understanding is in hand, however, the application of this science with appropriate funding is needed to ensure the best possible protection for the marine environment in addition to ensuring the best possible energy solution to ensure a future for sustainable energy;

- By taking into account the individual needs of such developments a rational, defensible and problem-relevant EIA process can be applied to ensure all issues are accounted for;
- Developing such a framework would also create an effective decision tool to aid the consents and deployment process and alleviate the environmental uncertainty that surrounds such developments; and
- If an EIA framework is standardised, individual projects, technologies and sites become comparable to one another providing a knowledge-base of environmental impacts, which is paramount in fully understanding and mitigating the potential environmental issues that may be key in the continued development of tidal current energy generation. This may also help to build upon present environmental impact knowledge to ensure future developments have increased 'environmental integrity' and facilitate the need to have a comparative record of assessments in terms of specific technological issues or types of location.

9.2 Methodological Approach in the Development of an EIA Framework

9.2.1 General Overview

Theoretically, in any comprehensive EIA, all potential impacts should be studied (Abbasi and Ayra, 2004; Ayra and Abbasi, 2000; Biswas, 1999). However, to do so may not only be daunting, but also costly and time-consuming. In addition, such an exercise may not be necessary because not all potential impacts would have a significant or even a detectable impact. In formulating an EIA framework and methodology the intention is to develop an approach where an assessment of the relative importance of each impacting component is made and where possible formulate a hierarchal relationship between them. In doing so, it may be possible to establish which of the impacts components are 'stand alone' and which ones generate indirect or higher order impacts. To successfully implement such a framework, understanding of the marine processes that govern potential impacts is important. **Chapters 4** and **5** identify and attempt to assess the potential impacts of tidal current energy generation. Drawing significantly upon these chapters, **Chapter 8** details many of the environmental impact interactions associated with a tidal current energy development and its research needs. The development of the framework will thus draw upon this section of the thesis and apply the conceptual analogies and research priorities in order to formulate an EIA framework. In addition, the EIA framework will also draw upon the observations recorded in **Chapter 6**.

A number of reports and guidelines for marine energy EIA have been published (BSH, 2001; EA, 2002; MCEU, 2004; EMEC, 2005; DEFRA, 2005) in addition to some papers outlining procedures for EIA for different types of development (Hickie and Wade, 1998; Hoepner, 1999; Walker and Johnston, 1999; Salter and Ford, 2001 and Polychronidou *et al.*, 2002) and reports identifying potential impacts for marine renewables (ETSU, 2000; Ball, 2002; DTI, 2002; UCS, 2002; Wilson and Downie, 2003). This list of references is not exhaustive and with continued research focusing on EIA approach and methodology to suit specific developments continues to expand. For the most part, these references concentrate on marine developments other than that of tidal current energy, where a majority focus on offshore wind energy. The approach taken for most of the guideline and identification reports are merely that; guidelines without any points of reference or comparability of what constitutes a significant impact. It is well understood that EIA's are development, technological and site specific, but generally there are generic issues that occur throughout the myriad of ES's that have been undertaken with respect to the marine environment. The oil and gas industry have drawn upon their experiences to develop specific criteria or environmental boundaries with which to adhere to, defining what constitutes an acceptable level of impact. Though marine renewable energy development is relatively recent, it is surprising that similar criteria are not forthcoming. Drawing upon the range of offshore wind energy studies and the Pentland Firth study an attempt will be made to define some environmental boundaries where possible, and include them in the EIA Framework. However, in the long term this is an iterative process and as such will require adjustment in order to account for further environmental knowledge, based on experience and data gained.

9.2.2 EIA Framework Approach

It is evident from the reviews described in **Chapter 6** that environmental impact assessments with respect to the marine environment there is a lack of baseline data available and therefore assessments made are primarily based on assumptions and best judgement. Ideally, prognosis of environmental impact should be based on measurable indicators, though it is recognised that in the marine environment availability of quantifiable measurables is historically limited. For Tidal Current Energy development this is especially the case being a very new marine activity, where proven effects are clearly unknown and subject to experience. As tidal current energy developments are deployed, there will be the opportunity to improve knowledge in relation to specific effects. Bearing this in mind, the development of an EIA framework for the evaluation of impacts is very much in its infancy and therefore a precautionary principle will be used to ensure that the framework is weighted in favour of protecting the marine environment. By taking this approach, the framework will support comprehensive monitoring throughout the construction and operating stages of the project lifetime. From a tidal current energy development stance, validation of impact evaluation will also require continued research effort and in reality this can only be possible through the deployment of projects, careful monitoring of such projects and through broader research of the marine environment as a whole through other marine activities and academic research.

Drawing upon the research prioritisation and research measurables identified in **Chapter 8** a framework can be implemented to evaluate the environmental impact of the construction and operation of Tidal Current Energy development. It is evident that the structure of the EIA framework can be divided into 5 key stages (**Table 50**) and encompass the environmental components summarised in **Tables 36** and **37 (pp. 230** and **232)** and the summary of research measurables described in **Table 47** (**pp.274**), in addition to drawing on **Section 8.7.1**.

Table 50: Key Stages in EIA Framework

Key Stage	Description
Project development and study area planning	The EIA process should be started as soon as possible to aid project planning and therefore a literature study to characterise the development area should be undertaken, including alternative sites. This may be formulised as a feasibility study or scoping document and may include an initial proposal for the subsequent assessment programme.
Baseline surveys - preliminary	This includes characterisation of the development and reference areas if applicable.
Baseline survey status assessment and precautionary criteria	Determination of the nature of the environment and the definition of environmental boundaries/terms of reference to be integrated within the project planning process. Assessment of the potential impacts in terms of likelihood and significance.
Construction phase EIA monitoring	Assessment of impacts within the construction phase on the marine environment.
Operational phase EIA monitoring	Assessment of impacts within the operational phase on the marine environment.

9.3 EIA Framework for Tidal Current Energy Development

9.3.1 Project Development and Study Area Planning

The study area generally comprises the development area and, where appropriate, the reference area of a project. It is widely accepted that individual environmental features that may be impacted by the proposed development require different study areas in terms of size and in some cases location. **Table 51** illustrates 'study areas' for the development area with respect to the key environmental components and **Tables 52** to **59** describe the framework for the preliminary baseline surveys and further survey work recommended for the EIA process with respect to a tidal current energy development. However, it must be stated that such techniques will need to be carefully designed and fit for purpose with respect to individual proposed sites and will depend on the status of knowledge and environmental sensitivity of the proposed development area.

Table 51: Area of Study with Respect to Key Environmental Components.

Environmental Component	Area of Study
Benthos and fish	The size of the study area should ideally correspond to that of the development area, encompassing all infrastructure associated with the development, including pipelines, rock dumping etc.
Birds	Drawing upon studies associated with offshore wind farm developments, each side of the study area should be at least 25% greater than the development area. Due to the fact turbines are below the sea surface and the diving depth of some bird species is less than the rotor-tip depth it may be satisfactory to reduce the overall study area. However, to initially establish the importance of the proposed area to birds' ecology the study area would ideally need to be 25% greater than the proposed development area.
Marine mammals	The investigation area must cover an area extending at least 10km beyond the development area boundary and/or correspond to the minimum noise propagation during construction, as this is expected to be the phase generating the maximum sound levels.
Sedimentary processes and hydrodynamics	The size of the study area will need to encompass both near-field (area within the vicinity of the development) and far-field (coastline, sites of scientific and conservation value) spatial scales.
Marine users	Ideally, the study area should cover a 10nm radius from the development boundaries.

9.3.2 Baseline Surveys

Characterisation of the baseline development area is crucial in assessing environmental impact and verifying predicted changes. Baseline surveys need to have technical integrity in order to provide meaningful data that can endure scientific and stakeholder scrutiny. In order to do this well, defined survey targets and scope need to be addressed, including investigation and evaluation techniques.

In terms of ecological monitoring, baseline studies will concentrate on density and abundance of benthic and pelagic species. Such studies should, ideally, be conducted over a twelve-month period, in order to obtain data that reflects all seasons and conditions. However, a shorter period could be initiated. It is recommended that the duration be no shorter than three months. The spring and summer months are the most critical and such studies should be conducted within that time-scale. The duration of the study is not so critical, as long as samples and data are collected at the same time of year and then seasonality differences can be ruled out. However, defining and monitoring a similar control site near by (reference area), concurrently through the operations phase, may be equally beneficial and consistent as a conventional baseline study. A short baseline and concurrent monitoring in a similar area may be a further option, not only for the ecological studies, but also for the physical parameter monitoring also.

There are a number of physical parameters that need to be established. These include the local tidal velocities, wave height and speed. The sedimentation parameters, such as, sediment characteristics, suspended load, turbidity and local seabed morphology are important baseline parameters.

The chemical composition of the seawater, as well as salinity and temperature profiles will also need to be established. Ambient noise levels are also important in terms of comparison with acoustic emission results.

With respect to baseline study length, duration is less important for the physical parameters than that of the ecological ones. However, a minimum period of one month is recommended in order to gain a full tidal cycle. Concurrent monitoring in other sites for more generic parameters such as acoustics is reasonable, but not ideal.

9.3.3 Status Assessment and Precautionary Criteria

This again is a crucial element in the environmental impact assessment process. In conjunction with the preliminary baseline assessment, further investigations prior to the start of construction may need to be conducted in order to determine an in depth knowledge of the nature of the environment and assess how it may react to the changes placed upon it due to the proposed development. In addition to further survey work, such investigations should also draw upon other quantitative and/or predictive impact assessment outlined in **Tables 45 and 46 (pp.264)**. It is from these investigations that any environmental boundaries or terms of reference can be established and integrated within the project planning process in order to mitigate potential significant impacts. Drawing upon the environmental impact assessment work in **Section 5** and related sources, a few examples of environmental boundaries or terms of reference have been established (**Table 59**).

9.3.4 Construction Phase EIA Monitoring

Monitoring and environmental should ideally be conducted throughout the construction phase of development to assess the impacts on the marine environment associated with the activities associated with constructing and deploying a tidal current energy development. This should include monitoring of sediment structure and dynamics and benthic surveys, as well as monitoring of birds and marine mammals where appropriate. In addition, monitoring of structure fouling should also ideally be undertaken, taking into account both the support structure and the foundations.

9.3.5 Operational Phase EIA Monitoring

Operational monitoring should be conducted throughout the project life-time, but it is recommended that a twelve month period be considered, mainly for the reasons discussed within an ecological context. Any extended amount of time (no shorter than 6 months) is advisable. Data sets for all parameters should be collected at suitable periods throughout that time, preferably monthly, to gain a comprehensive idea of the changes and influences that may occur. Continuous recording of some parameters would be highly beneficial.

9.3.6 Post-project Monitoring

Post-monitoring allows the rate of recovery to be examined after decommissioning and should again encompass an extended duration, as well as just a one-off post-survey. Such a survey will only allow changes or impacts to be noted between the operation and decommissioning phase. Post monitoring also aids in the verification process with respect to environmental prediction and modelling. Data sets for all parameters should be collected.

It must be understood that with all monitoring projects, there will be impacts that are probalistic in nature, i.e. they may not exist or occur within the timescale set. So an element of uncertainty in these areas will still exist, unless spot surveys are conducted in future years.

9.3.7 Computational and Analysis Programme

The computational and analysis programme could run parallel to the monitoring programmes.

With respect to each project, sub-projects rely on the preceding project to gain results, so any programme of work will need to reflect this. However, most projects will run concurrently and results will not only reflect the computational and numerical aspects of the programme, but also an analysis (of the fieldwork) and desk study areas of the overall programme. A detailed approach to this is outlined in **Chapter 8**.

Table 52: Framework for Monitoring Benthic Communities

Benthos	Target	Scope	Timing	Technique
Preliminary	Basic description of benthos in tidal current development area. Suitable reference area may also be determined.	Both beam trawl surveys[1] and video footage is recommended. At least 10 stations should be used in small areas. A random approach should be undertaken to account for habitat patterns. Grab sampling[1] should also be used for identification of infauna and as a ground truthing tool.	One preliminary survey is sufficient and can be used for status/criteria assessment. If possible, spring is a good time for benthos survey work.	High resolution camera is recommended with 30min transects. Beam trawl[1]. A grid of 1nm spacing should not be exceeded. In areas where there is potential sensitive species a smaller grid structure is recommended. Results should include video footage and/or photos; total number of individuals per an area, total biomass, number of species, dominance ratios, diversity, and cluster analysis.
Status/Criteria Assessment	Small to medium scale survey of status quo ante as a basis for evaluating potential impacts, including seasonal dynamics.	At least 10 epifauna beam trawl[1] stations are recommended with 2 surveys per year (spring and autumn) Two grab samplings[1] in spring and autumn for infauna.	Two years prior to construction commencing.	As above
Construction Phase Monitoring	Small to medium scale survey of impacts in construction/post-construction phase, including seasonal dynamics.	As above, but 3 surveys/samplings per year.	During the construction phase.	As above
Operational Phase Monitoring	Small to medium scale survey of impacts in the operational/post-operational phase, including seasonal dynamics.	As above, conducting 3 surveys/samplings in the first year, but 2 surveys/samplings per year thereafter.	Two-five years after commissioning.	As above

[1] Survey and seabed sampling methods will be dependent on the proposed location. In areas of high tidal velocities, beam trawling and grab sampling may not be possible. Other methods, such as acoustic methods (Side scan sonar), ROVs and underwater video may be more suitable.

Table 53: Framework for Monitoring Sediment and Sediment Dynamics

Seabed and Sediment Dynamics				
	Target	**Scope**	**Timing**	**Technique**
Preliminary	Seabed characteristics, includimg topography, sediment type, seabed features and chemical analysis.	Side Scan Sonar (SSS) survey with a transect spacing of at least 500m. Verification/ground truthing by video and/or grab sampling[1] is also essential.	Once	SSS and the production of topographical/ substratum maps
Status/Criteria Assessment	If control study is required, same as above.	SSS survey of pilot development area	Once a year	Same as above
Construction Phase Monitoring	Same as above	Survey single turbines to aid subsequent biological studies and determine overall impact area, including turbines and any other infrastructure.	As long as required.	Same as above
Operational Phase Monitoring	Same as above	Survey single turbines to aid subsequent biological studies and monitor overall impact area.	As long as required.	Same as above

[1] Survey and seabed sampling methods will be dependent on the proposed location. In areas of high tidal velocities, beam trawling and grab sampling may not be possible. Other methods, such as acoustic methods (Side scan sonar), ROVs and underwater video may be more suitable.

Table 54: Framework for Monitoring Structural Fouling

<table>
<tr><th colspan="5">Structural Fouling</th></tr>
<tr><td rowspan="2">Preliminary</td><td>Target</td><td>Scope</td><td>Timing</td><td>Technique</td></tr>
<tr><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Status/Criteria Assessment</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Construction Phase Monitoring</td><td rowspan="2">Investigation of fouling on support structures and foundations</td><td rowspan="2">Ideally at least two units should be checked at 3 different water depths each (near surface, middle and near the bottom)</td><td>Directly after erection of support structure and laying of foundations</td><td rowspan="2">Sampling by divers, photo, video documentation.

Determination of the number of species, individuals per species and estimation of biomass.</td></tr>
<tr><td>Operational Phase Monitoring</td><td>Every 3 to 5 years after commissioning of development</td></tr>
</table>

Table 55: Framework for Monitoring Fish Populations

Fish Populations				
	Target	**Scope**	**Timing**	**Technique**
Preliminary	Desk study to determine the fish species in the vicinity of the development area, including spawning and nursery grounds.	-	-	Use of Coull *et al.* (1998), CEFAS and FRS statistics and information sources.
Status/Criteria Assessment	Detailed characterisation and identification of fish fauna in the development area.	For development areas >100km^2 the minimum number of hauls should be 30 if using a random distribution of stations. For development areas < 100km^2 the minimum number of hauls should be 20 if using a random distribution of stations. Alternatively, if fixed stations are used at least 10 hauls per year would be adequate providing they are taken periodically throughout the whole year	Ideally February/March and August/September and preferably at least 2 years before the start of construction.	Ideally a 6-8 metre beam trawl[1] or otter trawl with a minimum mouth width of 15m in combination with a 3 metre beam trawl. Data to be recorded would include casting and recovery co-ordinates, towing time and area covered. For species, weight, number and length distribution. In addition a description of invertebrate by-catch should also be recorded.
Construction Phase Monitoring	Assessment of the impacts of construction activities and comparison with reference area and/or baseline data.	Same as above (once a year), but ideally monitoring of a selection of turbines (2 minimum) approximately 6 days/ 1 year later respectively.	During construction phase.	
Operational Phase Monitoring	Assessment of the impacts of tidal current energy development operation and comparison with reference area and/or baseline data.		3 to 5 years after commissioning.	

[1] Survey and seabed sampling methods will be dependent on the proposed location. In areas of high tidal velocities, beam trawling and grab sampling may not be possible. Other methods, such as acoustic methods (Side scan sonar), ROVs and underwater video may be more suitable

Table 56: Framework for Monitoring Birds

Bird Populations

Investigations and monitoring of birds may comprise studies of abundance and distribution, habitat use as well as studies on impacts of noise, physical disturbance, collision risk and adaptive behaviour.

	Target	Scope	Timing	Technique
Preliminary	Desk study to determine the bird species in the vicinity of the development area, including resting, feeding, moulting and migratory areas.	-	-	Use of bird sensitivity data and statistics from appropriate bodies such as JNCC, RSPB, NE and SNH.
Status/Criteria Assessment	Bird surveys to assess the areas importance to birds, especially diver species and those that rely on fish as a source of food.	2-3 surveys per month.	At least 2 years before construction phase.	Bird survey methodology has been evolving with respect to offshore wind farm research and no doubt specific techniques with regard to tidal current energy development will also evolve over time. As a guideline, boat-based transect counts are paramount with a recommended transect spacing of between 1.5 and 3km. Air transect surveys may also be used.
Construction Phase Monitoring	Observations of impact and adaptation behaviour during construction phase.	2-3 surveys per month.	During construction phase.	
Operational Phase Monitoring	Observations of impact and adaptation behaviour during operational phase.		Optimally 5 years after commissioning.	

Table 57: Framework for Monitoring Marine Mammals

Marine Mammals

Investigations and monitoring of marine mammals may comprise studies of abundance and distribution, habitat use as well as studies on impacts of noise, physical disturbance, collision risk and adaptive behaviour.

Abundance and Distribution

	Target	Scope	Timing	Technique
Preliminary	Desk studies/baseline surveys to determine the marine mammal species in the vicinity of the development area, to enable an assessment of the ecological importance of marine mammals in the area.	Surveys should ideally be undertaken at least 6 times per year in February, May, August and November and during June/July to account for calving.	At least 2 years prior to the construction phase.	Use of existing data.
Status/Criteria Assessment				The type, duration and extent of survey data needed, will depend on the ecological importance of marine mammals within the vicinity of the development area. Ship and aircraft surveys maybe required if the area is highly important to the area and there is the potential that impacts will be significant with respect to abundance and habitat use. If marine mammals are significant in the area, as a precautionary approach Marine Mammal Observers should be used throughout the construction phase and periodically throughout the operational phase if abundance in the area is significant.
Construction Phase Monitoring	Monitoring of the impacts of construction activities on the abundance and adaptation behaviour of marine mammals.		During the construction phase	
Operational Phase Monitoring	Monitoring of the impacts of operation on the abundance and adaptation behaviour of marine mammals, taking into account different modes of operation.		Minimum of 3 years after commissioning.	

Habitat Use

	Target	Scope	Timing	Technique
Preliminary	Observation of habitat use (frequency and duration) of important species in the vicinity of the development area	Long-term continuous deployment	At least two years prior to construction phase.	Deployment of click detectors or other means of underwater sound monitoring. If marine mammals are significant in the area, as a precautionary approach Marine Mammal Observers
Status/Criteria Assessment				

Construction Phase Monitoring	Occurrence and habitat use during construction phase.		During operational phase.	should be used throughout the construction phase and periodically throughout the operational phase if abundance in the area is significant.
Operational Phase Monitoring	Occurrence and habitat use (including single animals near turbines) taking into account different operating modes.		Minimum of 3 years after commissioning.	

Noise Disturbance

During the construction and operation of a tidal current energy project a broad range of noise frequencies will be transmitted into the water column. The measurement of on-site noise immission and noise source emissions should be paramount during the construction and operational phases of a development.

	Target	Scope	Timing	Technique
Preliminary	Prediction of noise propagation during the construction and operation phases and comparison with background noise scenarios.	Measurements should be undertaken at different ambient conditions (wind conditions, sea states, salinity and temperature).	Forecasts should be predicted prior to construction in order to improve design improvements and/or define area of propagation levels for mitigation purposes.	Noise measurements should ideally be taken in the frequency range of 0.3Hz – 200KHz Detailed calculation of noise propagation and impact zones from the sound sources is paramount. There should be a comparison between predicted and measured emissions and propagation. Noise sources should ideally be individually assessed and assessed cumulatively. Correlation of noise disturbance and changes in abundance and/or species composition should also be reported.
Status/Criteria Assessment				
Construction Phase Monitoring	Measurement of frequency range and noise level.		During the construction phase.	
Operational Phase Monitoring	Measurement of frequency range and noise level.		Minimum of 3 years after commissioning.	

Table 58: Framework for Other Marine Users

Other Marine Users It is crucial in the early stages of any proposed development, local fishing industry representatives, the MOD and the MCA are contacted. In addition, local port and harbour authorities, the Trinity Lighthouse Service should also be contacted.				
Preliminary	**Target**	**Scope**	**Timing**	**Technique**
Status/Criteria Assessment	Desk studies/baseline surveys to determine the scale and seasonality of fishing, MOD and navigational implications in the vicinity of the proposed development	Detailed description of the commercial fisheries in the area, including fishing effort, landings and assessment of potential commercial loss. Identify navigational issues and incorporate into EIA process.	At least 2 years prior to the construction phase.	Use of existing fisheries statistics and local information. Navigational and collision risk studies.
Construction Phase Monitoring	Continued liaison with appropriate authorities.	Long-term monitoring.	-	
Operational Phase Monitoring				

Table 59: Examples of Environmental Boundaries or Terms of Reference

	Environmental Component/Impact Source
	Tidal Currents
Environmental Boundary/Terms of Reference	By extracting 10% of the flux in the natural channel, the tidal speed would reduce by approximately 3%.
Information Source	Bryden *et al*., (2005). Detailed site-specific data and modelling.
Project Implications/Mitigation	This is dependent on the scale of the development and the tidal characteristics and natural boundary conditions of the proposed development area. Assessments may predict lower or higher reductions and based on these an assessment can be made to determine how this would affect the sediment dynamics in the area overall. If significant effects are predicted, development design may need to be altered in order to reduce the significance of the predicted impacts.
	Operational Noise Disturbance
Environmental Boundary/Terms of Reference	Operational noise has been predicted to be 102.8 (dB re 1mPa) at 1km from the sound source and 63.3 (dB re 1mPa) at 200km from the sound source.
Information Source	Section 5.2.6 and 5.3.2. Detailed site-specific data and modelling.
Project Implications/Mitigation	Dependent on cetacean activity, pre-project revisions or mitigation procedures would need to be put in place. For example, if it is likely that cetaceans would be detrimentally affected and/or the area was a protected site under the Habitats Directive, a revision of development layout/development size may be necessary.
	Benthic Communities
Environmental Boundary/Terms of Reference	*Reefs* as defined in Annex 1 of the Habitats Directive have been located in an area within the development boundary.
Information Source	Site and pipeline route surveys.
Project Implications/Mitigation	A measure of the extent of the reef structure. The most significant project implication would be the re-routing and/or re-defining the pipelines and turbines that could potentially affect the reefs present.

9.4 Development of Tidal Current Energy EIA Methodology

9.4.1 Context of Methodology

At present it seems that a majority of EIA's are in fact a two-stage process incorporating environmental characterisation (i.e. identification of potential impacts) and some sort of environmental assessment using both subjective and quantitative approaches (i.e. prediction and analysis techniques). However, what they fail to incorporate is a comparative environmental assessment mechanism in which other projects can be compared to each other, or a tool in which different technologies or project sites can be compared in terms of environmental impact significance. It can be argued that EIA systems and methodologies in place are comparative with respect to the fact most use the same methodological criteria, however there is no data capture or overall environmental impact reference to determine the extent to which projects, sites or technologies differ in impact significance, if at all.

9.4.2 Development of Semi-quantitative EIA Tool

Basis of Assessment Tool

The basis of the EIA Comparative Assessment Tool (EIA CAT) is that used in environmental impact identification in the form of a matrix. For a majority of matrix and EIA methodologies there is the use of questionable numerical values regarding magnitude and significance, creating quite subjective and arbitrary criteria and as a consequence subjective conclusions. The EIA CAT uses 'real data' and determines significance impact accordingly. The approach is however semi-quantitative in the fact that in some instances a non-quantitative assessment is used, where 'real data' cannot be used or determined from the baseline and status assessments. The overall aim of the CAT is to have a set of resultant impact references that describe the overall impact significance of a particular action and consequence and the project or development overall. **Figure 65** shows an annotated diagram of an example EIA CAT matrix.

EIA CAT Criteria

It is proposed that the EIA CAT criteria will mirror, in some circumstances, the matrices developed in **Chapter 4**, incorporating a quantitative approach with respect to the significance of physical consequences on each individual environmental component. **Table 60** outlines some hypothetical examples of integrating a quantitative approach. The examples given however are not necessarily based on validated quantitative data and are merely to give an idea of the approach that would be taken. By integrating this individual component approach within a matrix system enables a more structured and unambiguous approach with respect to assessing the environmental impact of a given project or project scenario. In other words it enables impact significance to be assessed with respect to not only direct impacts, but also those that are indirect in nature. For example, matrices have an inability to take adequate account of the fact environmental components may be affected through more than one pathway and more than one aspect of a project. By incorporating an additive and synergistic approach potentially significant impacts may be recognised that may not have been identified using a conventional matrix approach.

Table 60: Hypothetical Examples of Integrating a Quantitative Approach

Activity	Physical Consequence	Environmental Component	Criteria	EIA CAT Code
Piling Foundations	Increased underwater noise	Ambient noise	If difference is under 10% of ambient noise levels	Negligible (1)
			If difference is between 10% and 25% of ambient noise levels	Moderate (2)
			If difference is over 25% of ambient noise levels	High (3)
Piling Foundations	Direct Seabed Disturbance	Seabed	If disturbance is under 2% of the project area	Negligible (1)
			If disturbance area is between 2.1% and 3%	Moderate (2)
			If disturbance area is over 3%	High (3)
Operation of turbine	Tidal current modification	Tidal currents	If modification is under 5% of baseline tidal velocity	Negligible (1)
			If modification is under 5% and 7% of baseline tidal velocity	Moderate (2)
			If modification is over 7% of baseline tidal velocity	High (3)

Overall Impact Reference

One key problem with some forms of EIA methodology is the fact by and large the total impact of a project or development is not necessarily considered. However, by generating an overall impact reference, not only are individual interactions assessed, but the project as whole will be assessed, providing a transparent and permanent record of the potential impacts of a given project or project scenario and a more definitive comparison between projects and project scenarios. The overall impact reference is designed to incorporate a weighted average of each project interaction or impact pathway, as well as a weighted average of each component impact total whereby a more realistic overall assessment can be made. For instance, with respect to piling operations, a higher weighting allocation will be given to the noise/cetacean pathway to determine overall component impact significance. However, in terms of the overall project, piling operations may be deemed to have low significance due to the short duration of the activity, so the total component impact will have a lower weighting. Overall the method allows project options to be reappraised with ease and better accuracy.

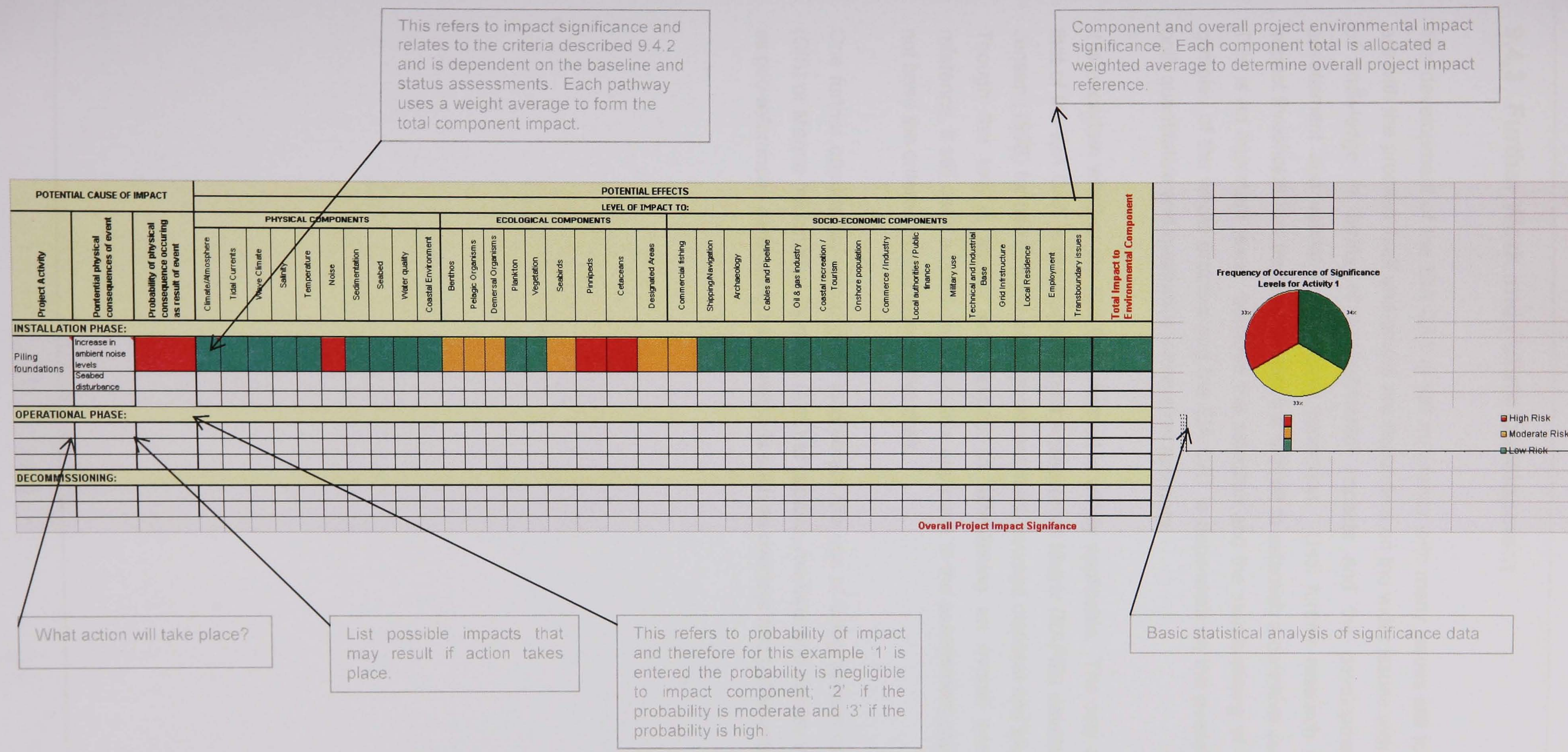

Figure 65: Annotated diagram of EIA Comparative Assessment Tool

9.4.3 Further Work and Future Development

The development of the EIA CAT is still its infancy with many issues still to overcome. Some are with the process itself and others are dependent on the wider issues with respect to the lack of knowledge in terms of environmental impacts and the development of quantitative assessment and validation of impact prediction. Until further research into environmental impact thresholds has been achieved, it is difficult to establish a definitive assessment criterion. This is an important issue, because the selection and the standardising of criteria is the most complex of the whole process and the EIA CAT is dependent on the availability and quality of both quantitative and qualitative information and data.

It is uncertain whether the EIA CAT method is widely applicable. The only other tool similar to that of the EIA CAT is the Rapid Impact Assessment Matrix (RAPID) developed by Pastakia & Jensen (1998) for use in flood damage assessment, sewage disposal and tourism development. Though the tool is similar with respect to establishing an overall environmental impact reference, it still uses a relatively subjective approach to the assessment criteria used and does not base the criteria on real quantitative data.

One further opportunity would be to incorporate the use of Geographical Information Systems (GIS) or Marine Information Systems (MIS) to capture, manage and display the EIA CAT results as geo-referenced data using basic methods such as overlays and buffer analysis.

CHAPTER 10

Discussion and Conclusions

10. DISCUSSION AND CONCLUSIONS

10. 1 Summary of Research

The aims of the research were as follows:

- To determine the environmental impacts and constraints of tidal current energy and assess the methodology that governs the identification of such impacts.

- To ascertain the developmental barriers associated with tidal current energy and develop further research needs to accommodate and mitigate such barriers.

During the research process a number of themes emerged, each contributing towards meeting the aims of the research.

- Tidal current energy and its relationship to the environment;
- EIA methodology employed to identify environmental impacts with respect to potential development, especially within the marine environment;
- The development potential for tidal current energy and the barriers that hinder such development;
- Research and development that focuses on the mitigation and assessment of environmental impact with respect to tidal current energy development; and
- Environmental impact framework/guidelines and EIA methodology specifically related to tidal current energy and other marine related developments.

In addition, throughout the research process and thesis development a number of direct and indirect contributions to tidal current energy development and EIA research were achieved.

Four direct beneficial contributions can be highlighted, not only concerning the development of tidal current energy, but also with respect to EIA methodology:

- A greater understanding of the potential environmental implications of tidal current energy and a general assessment of the environmental integrity of tidal current energy systems.

- A further understanding of the development potential of tidal current energy and the developmental barriers faced, concerning such a new energy industry.

- The scoping and establishment of research and developmental needs to sustain tidal current energy interest and market potential.

- An understanding of the EIA process in terms of offshore projects and the development of a standardised EI framework and methodology for the assessment of potential site-specific tidal current developments.

From the contributions outlined above, a number of indirect outcomes have also been achieved:

- A reduction in uncertainty with regard to the environmental integrity of tidal current energy, allowing barriers to development in this area being reduced or removed;

- The research provides an adequate mechanism to ensure mitigation through technological design and environmental management and prediction;

- With developmental barriers being removed through the reduction in uncertainty and the process of mitigation the commercialisation of tidal current energy can potentially become more of a reality, in turn creating a significant contribution to the renewable energy resource and producing further beneficial social and economic impacts;

- Though there are unique environmental implications associated with tidal current energy, there are commonalties with other offshore and coastal industries, such as other marine renewables and therefore it is anticipated that research will provide and enhance knowledge and understanding of environmental issues that may be common to all;

- A standardised environmental impact framework and methodology will enable a transparent and consistent assessment of potential impacts for comparing different sites using the same tidal current system or comparing different systems with respect to the same site, creating an effective decision tool to aid the consents and deployment process and;

- With the development of such a framework and methodology in time it has the potential to be adapted for other offshore and coastal projects creating the same consistency when assessing a specific project or a number of options

10.2 Discussion and Evaluation of Research

In order to discuss and evaluate the research that has been drawn together in this thesis, the following section will be structured in terms of themes that have emerged throughout the thesis development. Each section will consider the implications of the results, the limitations of research, and finally, provide conclusions with respect to that theme. Future work and any issues needing further clarification and recommendations are discussed in **Chapter 11**.

10.2.1 Tidal Current Energy and its Relationship with the Environment

Environmental Impact Assessment is an important process in the development of Tidal Current Energy due to the intimate association of the technology and the potential effects it may have on the 'natural' and 'human' energy flows already described by Clarke (1993; 1994) and the potential subsequent ecological, physical and socio-economic implications that may arise (Wilson and Downie, 2003; Ball, 2002; Pelc *et al.*, 2002; DTI, 2002; Dacre, 2002; Dacre *et al.*, 2002; Dacre and Bullen, 2001). **Chapter 3, 4** and **5** describes the relationship between tidal current energy and the environment and draws upon the identification and assessment of such implications.

The importance of comprehensively identifying potential environmental impacts associated with tidal current energy are summarised below:

- Tidal current energy is obtained through the natural energy flows of the marine and/or coastal environment. These flows contribute significantly to the maintenance and functioning of such environments and abstracting energy may in some instances modify them;
- Tidal Current Energy technologies often harness diffuse energy flow and therefore require a large number of devices, which may in turn contribute to significant environmental impacts;
- Tidal Current Energy technology is site specific and therefore the potential environmental impacts will also be specific to those sites or types of location that optimise the tidal current energy generation;
- Tidal Current Energy sources will be limited by the capacity of the environment to accommodate potential impacts, as well as by the amount of extractable energy;
- There is more than one type of tidal current energy device, each potentially having unique environmental impacts. There is thus, a need to compare the technologies available for the purposes of strategic decision-making with respect to assessing potential development projects or specific locations.

In terms of environmental impacts, the thesis identified a number of diverse issues that are of key importance to tidal current energy development. Some are generic and well understood which can be applied to other offshore and coastal problems; others are unique to this type of development.

A number of direct and indirect environmental impacts, concerning the physical, ecological and socio-economic environment have also been highlighted. These include:

- A direct disturbance of the seabed and benthic ecology with regard to installation of tidal energy devices and overall operation;

- Potential disturbance of seabirds, pinnipeds and cetaceans during the installation phase relating to equipment activity, both visual and auditory;

- Potential changes in the tidal and wave dynamics in the vicinity of the device and on a local level due to the structure itself, the rotor vortices and the extraction or blockage of tidal energy;

- The potential seabed disturbance and change in sediment dynamics due to the potential changes of tide and wave dynamics;

- The potential changes in water quality and turbidity due to associated seabed disturbance and chemical leakages from the device and installation equipment;

- The possibility that acoustic emissions from the operating devices will be sufficient to disturb migrating or resident cetaceans, pinnipeds and other marine animals; and

- The potential collision risk associated with diving birds and marine mammals.

In addition, a number of impacts associated with the socio-economic environment have been highlighted as follows:

- There are potential problems with regard to the existing traffic patterns, such as the frequency of traffic, navigational difficulties and the carrying of hazardous material;

- Problems have also been associated with the reduction of the already limited navigational channels, particularly in the central routes, with respect to the risk of collision, not only with the devices themselves, but also with other traffic;

- With regard to larger tidal current turbine scenarios, the loss of access for creel fisherman is another concern.

Throughout the research it has became apparent that some of the potential impacts could be deemed to be highly to moderately significant in terms of their potential likelihood and magnitude. However, the assessment conducted in **Chapter 5,** though 'fit for purpose' and adequate in terms of offshore development EIA, does not provide the modelling and quantitative methods that are required to fully understand the potential impacts and it is clear that further work is necessary to enable this. From this point of view, those impacts deemed to have a high to moderate significance may in fact have a minimal one and within the boundaries of the 'natural change'.

Overall, the research has highlighted that it is a common misconception that renewable energies are without environmental detriments and that adequate research is required to eradicate uncertainties with respect to the magnitude and likelihood of such impacts

10.2.2 EIA Methodology

In terms of tidal current energy, it is crucial that the environmental impact assessment process is effective and capable of providing the required information for the project decision making process and to eliminate as much uncertainty regarding the potential detrimental impact on the environment as possible. The objective of **Chapter 6** was to highlight some of the inadequacies of the EIA process by reviewing and evaluating not only the methodology but also past environmental statements (ES). There is no 'fool-proof' way in reviewing and evaluating documents and much of the process is relatively subjective and based on experience. Though a systematic approach was taken, it is not to say another person's opinion would different.

With respect to the ES's evaluated, there was generally a lack of detail concerning project alternatives within the EIA process; the process was poorly adapted to suit the needs of the proposed development and generally failed to use adequate baseline data. In addition, there was also a failure to consider the inter-relationships between environmental components and there was a lack of transparency and comparability.

By reviewing existing EIA's, as well as taking into account the methodology and processes used for the Pentland Firth study key gaps and weaknesses were identified. By addressing these issues and incorporating some or all of them into the EIA process used to evaluate future tidal current development an 'environmental integrity' conducive to renewable energy systems could be maintained. However, this is a complex issue and there is no definitive answer to mitigate the weaknesses at hand or develop standardised criteria for tidal current energy EIA.

10.2.3 Development potential and Barriers to Development

Scotland's resource alone holds a significant contribution. The Pentland Firth could generate anything up to approximately 80 TWh/yr, with other Scottish locations estimated to produce approximately a further 35 TWh/yr. These figures are far greater than other resource estimates and this is due to a number of technical constraints, such as navigational and shipping implications, and constraints associated with depth and tidal velocity. Basically, no boundaries were included and therefore, this is a maximum resource estimate. Overall, it is clear that tidal current generation has the potential to meet a significant proportion of UK requirements. It is estimated that at least 34% of the UK's electricity demand could be generated, which on a European level would be a contribution of nearly 5%.

With respect to industry status, there are a number of promising and innovative concepts for enhancing tidal current energy and therefore the drive for such technology cannot be ignored. Most use proven engineering experience, but there is no 'best option' identified. It is thought that as time progresses and more concepts are developed technology may become site specific taking into account environmental characteristics and design criteria.

Despite efforts to enhance commercial competitiveness throughout the renewable energy market, tidal current energy generation fails to meet such targets as yet. However, there is no reason why such technologies cannot become competitive over a short period of time. The skills base for the development of tidal current energy industry in Scotland is already apparent and the industrial capability for tidal current energy development needs to be extended to meet the needs of the potential industry in terms of mass production facility and reduced manufacturing costs compared to the oil and gas industry.

Despite some capability limitations companies in general have a significant willingness to diversify into the industry and understand the needs and drivers to do so. Many recognise they have the experience, skill and capability to diversify.

However, notwithstanding the clear development potential of tidal current energy through the research conducted a number of developmental constraints were identified:

- *Project Consents and Environmental Policy*

  The process is complex and needs to be simplified and streamlined to meet offshore development needs. The requirement for an EIA framework also needs to be addressed to aid the overall consents and development process.

- *Electrical Transmission and Grid Infrastructure*

  The grid infrastructure at present generally could not accommodate the volume necessary to meet 2010 renewable energy targets. A review of costing, upgrade and capacity issues is high on the agenda for many stakeholders.

- *Funding and Finance*

  Despite the increased funding and finance initiatives this is still seen as a major barrier towards new development/technology, such as the tidal current energy industry, where it is clear that it does not have some of the advantageous borrowing/funding terms as other industries in the RE sector. Increased financial support and investment is paramount and new drives need to be initiated and encouraged.

- *Energy Industry Re-structuring*

  Increased electricity generation competition in theory was meant to drive costs down to meet renewable energy means and obtain a competitive advantage, but instead such measures have adversely affected the commercialisation of RE. It has become increasingly harder for RE options to compete with more conventional energy sources as prices sink even lower. A more balanced approach is crucial.

- *Government Awareness and Attitude*

  Government policy, action and attitude play a vital role in the development of tidal current energy development and is probably the cornerstone for a majority of other barriers to development. Though it is understood that there will have to be a transition stage with conventional energies to meet a renewable energy future it is still apparent that some government bodies and individuals are complacent and not forward thinking enough.

- *Environmental*

  Environmental uncertainty is a significant barrier in relation to tidal current energy development. Key government bodies, stakeholders and environmental groups have issues relating to the environmental integrity of development and research is crucial in this field to enable fears to be mitigated and ease the difficulties associated with development consents.

- *Public Awareness and Perception*
  Public acceptability is increasingly seen as a barrier to development, due to public opposition towards development with regard to environmental concern, despite the socio-economic and long-term benefits.

- *Knowledge and Collaboration*
  A lack of willingness to impart knowledge and collaborate with like-minded researchers, developers and manufacturers etc. is another possible set back in the future for a tidal current energy industry.

- *R & D and the Technological Considerations*
  Though it has been accepted that tidal current energy technology has an edge over other marine renewable concepts, there is a need for further research into design and other technical areas of development, which have significant bearing on the economics of an industry and the overall cost of electricity.

- *Industrial and Manufacturing Capability and Sustainability of Core Skills*
  There is sufficient skill within the UK to accommodate a tidal current energy industry, however, the manufacturing capability needs adjusting to suit industry requirements and skills need to be enhanced and maintained.

10.2.4 Development of Environmental Impact Research

Through identifying and assessing the key environmental impacts associated with tidal current energy development, it was concluded that further knowledge of the environmental issues surrounding tidal current development is recommended. In addition, through Chapter 7, many barriers to development were highlighted. The identification of research and development needs and priorities was an iterative process, focusing on the inter-relationships between project activities and the individual environmental components it may impact on, as well and the inter-relationships of individual environmental components. Through this process, an enhanced knowledge and understanding of the complexity of the physical, ecological and social environmental and developmental issues involved was obtained.

The process itself was a complex one, mirroring the complexity of the issues involved. The approach taken was a reasoned and systematic one, but also one that was based purely on the authors views and interpretation, albeit in the early stages of the research process consultation from industry was sought and such opinion was also considered an important contribution within the process of defining what research and development needs were priority. Again, the conclusions of this, are not a definitive one, but there merely to guide and help create awareness of the issues involved in developing what in so many terms is a new industry.

10.2.5 Environmental Impact Framework and Methodology

Overall, the thesis has drawn upon a number of interrelated issues concerning the development of tidal current energy. Firstly, it discusses the resource and development potential, putting the importance of tidal current energy in context with conventional energy sources in terms of global environmental impact, and energy diversification, security and demand. Secondly, the thesis discusses tidal current energy within the context of potential environmental impacts and attempts to evaluate current EIA methodology and the way in which developers and EIA practitioners use this process for marine development. Focusing on the latter themes, the thesis evolves to discuss the barriers that are hindering the development of tidal current energy and attempts to formulate a comprehensive list of research and development needs that would remedy or mitigate present barriers to development.

One key measure is the formulation of an EIA framework to ensure all key potential environmental impacts and issues are identified and assessed for proposed tidal current energy developments and to provide thematic and technical minimum requirements on these issues. At present uncertainty regarding the potential and significance of impacts of tidal current energy development is an important consideration to many stakeholders. However, uncertainty can be safeguarded if there is a proper framework for the management of environmental issues whether they are negative or beneficial. It is crucial that more comprehensive criteria are applied in order to protect the environment as a whole.

The framework that was formulated has two main aims: the first was to highlight the complexity of the project impact issues in terms of physical and ecological environmental impacts. Secondly, it was an attempt to describe the pre- and post monitoring efforts to enable environmental impacts to be assessed. Though the framework in itself is relatively complex, it is also very dependent on site specific characteristics and will need to be developed to fit individual project requirements. Therefore, it is merely a guide to developers and consultants to aid in the assessment process as a whole and will no doubt be subject to time and financial constraints.

The development of the EIA Comparative Assessment Tool is still in its infancy, but it was indeed necessary to include it in the scope of the thesis to provide an awareness of how EIA methodology can be developed as a 'fit for purpose' tool to not only aid decision making, but to also provide a means of standardising the process for comparative purposes. On the whole, however, it has the potential to be a very useful tool and deserves greater development effort to become accepted as such and become widely applicable to other types of scenarios requiring EIA.

10.3 Overall Conclusions

The research described in this thesis and the development of the thesis itself has been a long and at times arduous process. However, it has also been iterative and evolutionary one. Initially the aim of the research was to identify and assess the environmental impacts of tidal current energy with the objective of focusing on the physical and ecological aspects of environmental impact in the marine environment. It was soon discovered however, that despite there being no previous work in the area of tidal current energy impacts, the potential impacts and the assessment of them were if not many PhD thesis rolled into one, a monumental task. Irrespective to and in addition to this, the whole scope of environmental impact changed. It was soon realised that in reality it should be managed from a focused approach to a holistic approach, incorporating many social issues. From this approach many physical, ecological and social impacts and constraints were realised and needed to be seen and pursued as a whole entity and it is hoped that the thesis clearly demonstrates how they inter-relate and depend on each other.

The emphasis of the research also changed from aiming to *just* identify and assess the potential environmental impacts of tidal current energy development to examining the EIA process as a whole and finding ways to improve the process to meet the needs of the tidal current energy industry. In addition, it looked at the information, data gaps and processes that were missing in order to bring tidal current energy to a reality.

CHAPTER 11

Recommendations

11. RECOMMENDATIONS

Throughout the thesis recommendations for further work and research have been discussed, in fact **Chapter 8** discusses these in depth. However, the following sections briefly summarises the key recommendations for further work. Each section is defined in terms of key themes of the thesis.

11.1 Tidal Current Energy and its Relationship with the Environment

- The impact of extracting energy through tidal current devices and the effects on tidal flow patterns, sedimentation processes and seabed morphology;

- The effects of the support structures on the wave and tidal dynamics in the area and the possible implications of this on local sedimentation and seabed movement;

- The effects of the rotor interactions with the water column and the subsequent effects on seabed morphology;

- The collision risk probability for marine mammals and fish;

- The acoustic emissions of the tidal energy device and the potential implications involved with respect to marine mammals and elsewhere in the marine ecology, such as fish;

- The vibration and visual characteristics of tidal current energy technology;

- The overall ecological impact of the installation and operation of a tidal energy device, including an assessment of recovery time after decommissioning;

- A comprehensive Life Cycle Analysis (LCA) concentrating on CO_2 emissions and a subsequent comparison with other renewable energies;

- An assessment into the need for antifoul prevention and a toxic comparison of each alternative;

- It is considered that the industry would possibly benefit from a strategic shipping and fisheries study aimed at identifying the affects of offshore structures on the types of shipping and fishing techniques and activities with regard to various layouts and support structure designs. This would enable interpretation of site-specific studies and identify which methods would cause potential conflict; and

- With regard to larger tidal current turbine scenarios, the loss of access for fisherman is another concern and further research into such impacts is an important consideration.

11.2 Development potential and Barriers to Development

A number of recommendations and initiatives were outlined to assist in the development of a tidal current energy industry to achieve competitiveness and market infiltration. They can be summarised as follows:

- *Technical*

  It was recommended that a detailed resource assessment should be carried out using remote sensing techniques to establish a detailed energy output and electricity cost estimates for different areas of the world.

  To achieve better efficiency and economics of concepts the areas of reliability, installation/support, spacing and electrical connection also need to be addressed with the aid of demonstration projects etc.

  Encouragement of further development needs to be addressed. New technologies need to be investigated and encouraged to form the 'critical mass' that is needed to drive significant funding and support from the DTI.

- *Environmental*

  A detailed scoping study was carried out on behalf of the DTI and a related programme of work was formulated. Such a programme of work should be initiated as soon as possible.

  The development of an EIA framework to aid the consents and planning process and the development of an EIA 'decision-tool' to aid the EIA process was also recommended.

  To ease the questions associated with environmental implications a LCA for the development of a tidal current device should be conducted.

  The promotion and awareness of tidal current energy and renewable energy sources needs to be increased at in all sectors of society. Collaboration between researchers, developers, stakeholders and companies would also be beneficial, along with continued promotion of the UK's profile as a high source of RE generation.

- *Institutional*

  Amendment and streamlining of the consents process is paramount for development to go ahead and it is recommended that EIA standards also need to be addressed.

  For any development to be commercially viable the grid infrastructure needs to be strengthened and a continuation of associated reviews to mitigate these problems is paramount.

  It is recommended that increased funding should be negotiated to fulfil development needs. Other industries also need to be encouraged to invest and diversify their skills and knowledge.

- *Industrial*

  There is a need to make the market more accessible by launching and strengthening various initiatives to promote opportunities, provide advice for diversification, to create business resource for advice, support and enterprise etc. It was also recommended that a working database for RE based companies and companies of interest should be compiled and updated regularly.

  Access to employment is also a need for a new industry and it is essential that provision is made to adjust to new needs by identifying gaps in the skills base and providing adequate training and career development for interested parties.

  There is a need to build upon existing strengths and opportunities to match the potential new industry and to promote skills and technology base as a market leader.

  Further it is recommended that a gap analysis should be conducted on a regular basis to assess and audit the tidal current energy market and industry.

11.3 Environmental Impact Framework and Methodology

As recommended above the development of an EIA framework to aid the consents and planning process and the development of an EIA 'decision-tool' to aid the EIA process was also recommended. **Chapter 9** attempts to develop this further. However, further work is needed with respect to the decision tool EIA CAT.

CHAPTER 12

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APPENDIX 1

Electrical Generation Statistics

Electricity Generation*

Terawatt-hours	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	**2001**	Change 2001 over 2000	2001 share of total
USA	3172	3221	3235	3353	3414	3521	3614	3663	3795	3886	3988	**3968**	-0.5%	25.3%
Canada	482	508	521	532	556	560	573	574	562	577	605	**582**	-3.7%	3.7%
Mexico	122	127	130	135	146	153	163	175	182	192	204	**206**	0.7%	1.3%
Total North America	3776	3856	3886	4021	4116	4234	4349	4412	4538	4656	4797	**4756**	-0.9%	30.3%
Argentina	51	54	56	63	66	67	70	72	74	81	89	**90**	1.0%	0.6%
Brazil	223	234	242	252	260	276	291	308	322	332	348	**326**	-6.4%	2.1%
Chile	18	20	22	23	25	27	30	33	35	38	40	**41**	4.3%	0.3%
Colombia	35	37	36	40	43	45	45	46	46	44	42	**43**	2.4%	0.3%
Venezuela	61	65	69	71	74	77	79	83	87	86	89	**95**	5.6%	0.6%
Other S. & Cent. America	121	124	125	132	143	151	156	173	182	190	200	**207**	3.5%	1.3%
Total S. &. Cent. America	509	534	550	582	612	644	671	715	745	771	808	**802**	-0.8%	5.1%
Austria	50	51	51	53	53	57	55	57	57	60	62	**62**	1.1%	0.4%
Belgium & Luxembourg	72	73	73	72	73	76	77	80	81	82	82	**81**	-1.4%	0.5%
Bulgaria	42	39	36	38	38	42	43	43	42	38	41	**44**	7.3%	0.3%
Czech Republic	63	61	59	59	59	61	64	65	65	65	73	**75**	1.6%	0.5%
Denmark	26	36	31	34	41	37	54	44	41	39	36	**38**	4.9%	0.2%
Finland	54	57	57	61	65	63	69	69	70	69	70	**75**	6.8%	0.5%
France	420	455	463	473	477	494	513	504	511	524	541	**550**	1.7%	3.5%
Germany	550	539	537	526	528	535	550	550	553	555	564	**571**	1.1%	3.6%
Greece	35	36	37	38	41	42	43	44	46	50	53	**55**	3.2%	0.4%
Hungary	28	30	32	33	34	34	35	35	37	37	35	**36**	3.0%	0.2%
Iceland	5	4	5	5	5	5	5	6	6	7	8	**8**	4.5%	0.1%
Republic of Ireland	15	15	16	16	17	18	19	20	21	22	24	**25**	5.6%	0.2%
Italy	217	222	226	223	232	241	244	251	260	266	277	**280**	1.1%	1.8%
Netherlands	72	74	77	77	80	81	85	87	91	87	89	**94**	4.8%	0.6%
Norway	122	111	118	120	113	123	105	112	117	123	143	**122**	-14.7%	0.8%
Poland	136	135	133	134	135	139	143	143	143	142	145	**146**	0.3%	0.9%
Portugal	29	30	30	31	31	33	35	34	39	43	44	**47**	7.5%	0.3%
Romania	64	57	54	55	55	59	61	57	53	51	52	**54**	3.3%	0.3%
Slovakia	24	23	22	24	25	26	25	24	25	28	31	**32**	3.2%	0.2%
Spain	152	159	161	161	164	169	177	184	196	209	225	**237**	5.6%	1.5%
Sweden	147	147	146	146	143	148	140	149	154	155	146	**162**	11.4%	1.0%
Switzerland	56	58	59	61	66	63	57	63	63	70	66	**71**	7.1%	0.4%
Turkey	58	60	67	74	78	86	95	102	111	117	125	**123**	-1.5%	0.8%
United Kingdom	320	323	321	323	327	337	351	348	363	368	375	**384**	2.4%	2.4%
Other Europe	90	90	76	73	73	77	82	82	85	88	91	**94**	3.3%	0.6%
Total Europe	2844	2886	2889	2909	2954	3045	3127	3152	3230	3294	3398	**3464**	2.0%	22.1%
Azerbaijan	23	23	20	19	18	17	17	17	18	18	19	**19**	0.5%	0.1%
Belarus	40	39	38	33	31	25	24	26	24	27	26	**25**	-4.2%	0.2%
Kazakhstan	87	86	83	78	67	67	59	52	50	47	52	**55**	7.2%	0.4%
Lithuania	28	29	19	14	10	14	17	15	18	14	11	**15**	29.0%	0.1%
Russian Federation	1082	1068	1008	956	876	862	847	834	826	846	878	**890**	1.4%	5.7%
Turkmenistan	15	15	13	13	10	10	10	9	9	9	10	**10**	-	0.1%
Ukraine	299	279	253	230	203	194	182	176	172	171	169	**172**	1.8%	1.1%
Uzbekistan	56	54	51	49	47	47	45	46	46	45	47	**47**	-	0.3%
Other Former Soviet Union	95	88	76	69	64	59	61	55	55	57	55	**53**	-3.4%	0.3%
Total Former Soviet Union	1726	1681	1560	1460	1327	1295	1262	1230	1217	1234	1267	**1286**	1.5%	8.2%
Iran	58	63	67	75	81	84	89	97	102	110	119	**127**	6.7%	0.8%
Kuwait	18	11	17	20	23	24	25	27	30	32	34	**35**	3.0%	0.2%
Qatar	5	5	5	6	6	6	7	7	8	9	9	**10**	6.4%	0.1%
Saudi Arabia	70	75	80	88	97	100	103	107	113	122	130	**135**	3.8%	0.9%
United Arab Emirates	17	17	19	22	24	25	27	28	33	37	40	**43**	6.3%	0.3%
Other Middle East	78	73	84	89	97	102	111	119	126	132	140	**147**	5.0%	0.9%
Total Middle East	246	243	272	299	327	341	362	386	413	442	472	**496**	5.1%	3.2%

Algeria	16	17	18	19	20	20	21	21	24	25	25	**26**	5.0%	0.2%
Egypt	43	45	47	48	50	53	57	61	65	71	73	**80**	9.9%	0.5%
South Africa	165	168	168	175	182	188	200	210	205	203	211	**210**	-0.3%	1.3%
Other Africa	101	103	105	104	108	112	113	115	118	121	124	**127**	2.4%	0.8%
Total Africa	325	333	338	346	361	373	390	408	412	420	433	**444**	2.5%	2.8%
Australia	155	157	160	164	168	173	178	183	195	202	203	**208**	2.5%	1.3%
Bangladesh	8	9	10	10	11	12	13	13	14	15	16	**16**	3.6%	0.1%
China	621	678	754	812	928	1007	1081	1105	1164	1197	1368	**1478**	8.0%	9.4%
China Hong Kong SAR	29	32	35	36	27	28	28	29	31	29	31	**32**	3.5%	0.2%
India	285	309	327	350	379	413	431	455	489	519	548	**562**	2.4%	3.6%
Indonesia	49	51	55	59	64	68	78	84	90	100	107	**112**	5.2%	0.7%
Japan	843	880	890	900	954	978	1006	1036	1040	1050	1081	**1075**	-0.5%	6.9%
Malaysia	25	28	32	36	40	47	53	59	60	63	67	**72**	8.4%	0.5%
New Zealand	31	33	32	33	34	35	36	36	37	36	38	**39**	1.1%	0.2%
Pakistan	46	50	54	57	58	64	68	62	66	65	65	**75**	16.2%	0.5%
Philippines	26	26	26	27	31	33	37	40	42	41	45	**47**	3.7%	0.3%
Singapore	16	17	18	19	21	22	23	26	28	29	30	**29**	-2.3%	0.2%
South Korea	119	132	148	163	185	205	228	249	241	267	291	**311**	7.0%	2.0%
Taiwan	90	99	106	115	125	133	142	150	163	169	185	**188**	1.9%	1.2%
Thailand	46	52	60	66	74	84	91	98	94	94	96	**101**	5.3%	0.6%
Other Asia Pacific	82	83	68	70	72	73	76	79	80	83	86	**89**	3.5%	0.6%
Total Asia Pacific	2472	2637	2772	2917	3169	3375	3568	3702	3833	3961	4257	**4436**	4.2%	28.3%
TOTAL WORLD	**11899**	**12170**	**12266**	**12533**	**12865**	**13307**	**13729**	**14004**	**14389**	**14776**	**15432**	**15684**	**1.6%**	**100.0%**
Of which: European Union 15	2157	2220	2229	2233	2272	2330	2411	2421	2484	2529	2588	**2661**	2.8%	17.0%
OECD	7573	7758	7838	8024	8244	8492	8737	8885	9101	9327	9625	**9663**	0.4%	61.6%
Former Soviet Union	1726	1681	1560	1460	1327	1295	1262	1230	1217	1234	1267	**1286**	1.5%	8.2%
Other EMEs	2600	2730	2868	3049	3295	3519	3731	3889	4071	4216	4541	**4735**	4.3%	30.2%

*Based on gross output

Appendix 2

Developer and Stakeholder Contact Letter

THE
ROBERT GORDON
UNIVERSITY
ABERDEEN

Sarah Lynn Dacre
Centre for Environmental Engineering and Sustainable Energy
The Robert Gordon University
Schoolhill
Aberdeen
AB10 1FR
Tel:

Monday 9th September 2001

RE: Tidal Current Energy Research

Dear

I am currently conducting a market research study into the potential of tidal current energy funded by Scottish Enterprise. A number of aspects have been under investigation, including:

- Identification of potential market (resource availability, local power demand etc.)
- Size of potential market
- Development, design, manufacture capability in Scotland; and
- Barriers to Development

Part of the study is to gain stakeholder and key organisation opinion on various aspects of the study.

As an organisation that promotes and is an advocate of renewable energy technology and policy I am hoping you would be willing to share your views on such technology. I am especially interested in the barriers to development and why in general it is hard for renewable energy to become market contenders against other energy systems. Do you think there are any specific barriers concerning tidal current energy?

I would appreciate any views, however short or long concerning this matter by the end of the month.

Thank you in advance.

Yours Faithfully,

Sarah Lynn Dacre

Appendix 3

Summary of Energy Computations

Rotor Diameter 20

Site		Velocity (m/s)	Velocity (Knots)	Power Density (MW)	Rated Velocity m/s	Energy Capacity (MW)	Site	Surface Area (m/sq)	No. of Devices	Site Capacity (MW)	Energy Capacity (GW)	TW/h per year
Scotland							**Scotland**					
Pentland Firth (1)		4.5	8.747301	46.70156	3.825	2.70308289	Pentland Firth (1)	4835000	604.375	1633.6757	1.633676	14.311
		6	11.66307	110.7	5.1	6.407307591		4835000	604.375	3872.4165	3.872417	33.92237
		8	15.55076	262.4	6.8	15.18769207		4835000	604.375	9179.0614	9.179061	80.40858
Pentland Firth (2)		4.5	8.747301	46.70156	3.825	2.70308289	Pentland Firth (2)	6380000	797.5	2155.7086	2.155709	18.88401
		6	11.66307	110.7	5.1	6.407307591		6380000	797.5	5109.8278	5.109828	44.76209
		8	15.55076	262.4	6.8	15.18769207		6380000	797.5	12112.184	12.11218	106.1027
Pentland Firth (3)		4.5	8.747301	46.70156	3.825	2.70308289	Pentland Firth (3)	7200000	900	2432.7746	2.432775	21.31111
		6	11.66307	110.7	5.1	6.407307591		7200000	900	5766.5768	5.766577	50.51521
		8	15.55076	262.4	6.8	15.18769207		7200000	900	13668.923	13.66892	119.7398
Pentland Firth (4)		4.5	8.747301	46.70156	3.825	2.70308289	Pentland Firth (4)	21000000	2625	7095.5926	7.095593	62.15739
		6	11.66307	110.7	5.1	6.407307591		21000000	2625	16819.182	16.81918	147.336
		8	15.55076	262.4	6.8	15.18769207		21000000	2625	39867.692	39.86769	349.241
Pentland Firth (5)		4.5	8.747301	46.70156	3.825	2.70308289	Pentland Firth (5)	2100000	262.5	709.55926	0.709559	6.215739
		6	11.66307	110.7	5.1	6.407307591		2100000	262.5	1681.9182	1.681918	14.7336
		8	15.55076	262.4	6.8	15.18769207		2100000	262.5	3986.7692	3.986769	34.9241
Pentland Firth (6)		4.5	8.747301	46.70156	3.825	2.70308289	Pentland Firth (6)	5200000	650	1757.0039	1.757004	15.39135
		6	11.66307	110.7	5.1	3.60411052		5200000	650	2342.6718	2.342672	20.52181
		8	15.55076	262.4	6.8	8.543076787		5200000	650	5552.9999	5.553	48.64428
Pentland Firth (7)		4.5	8.747301	46.70156	3.825	1.520484125	Pentland Firth (7)	2610000	326.25	496.05795	0.496058	4.345468
		6	11.66307	110.7	5.1	3.60411052		2610000	326.25	1175.8411	1.175841	10.30037
		8	15.55076	262.4	6.8	8.543076787		2610000	326.25	2787.1788	2.787179	24.41569
Pentland Firth Total	@	**4.5**	8.747301	**46.70156**	**3.825**	**1.520484125**	**Pentland Firth Total**	**49325000**	6165.625	**9374.7349**	9.374735	82.12268
Pentland Firth (Density)	@	8	15.55076	**262.4**	**6.8**	**8.543076787**	Pentalnd Firth (Densit	1000000	125	**1067.8846**	1.067885	9.354669

Site	Velocity (m/s)	Velocity (Knots)	Power Density (MW)	Rated Velocity m/s	Energy Capacity (MW)	Site	Surface Area (m/sq)	No. of Devices	Site Capacity (MW)	Energy Capacity (GW)	TW/h per year
Hoy Sound	2.57	4.995681	8.699479	2.1845	0.283232913	Hoy Sound	1687500	210.9375	59.744443	0.059744	0.523361
Westray Firth	2.3	4.470843	6.235588	1.955	0.203014874	Westray Firth	22500000	2812.5	570.97933	0.570979	5.001779
Rathlin Island	0.77	1.49676	0.233973	0.6545	0.007617571	Rathlin Island	40500000	5062.5	38.563954	0.038564	0.33782
	3.08	5.987042	14.97428	2.618	0.487524559		40500000	5062.5	2468.0931	2.468093	21.6205

Mull of Kintyre	0.92	1.788337	0.399078	0.782	0.012992952	Mull of Kintyre	16875000	2109.375	27.407008	0.027407	0.240085
	2.05	3.984882	4.415252	1.7425	0.143749364		16875000	2109.375	303.22131	0.303221	2.656219
Yell Sound, Burra Ness	1.28	2.488121	1.07479	1.088	0.034992443	Yell Sound, Burra Nes	360000	45	1.5746599	0.001575	0.013794
Shetland Isles	2.57	4.995681	8.699479	2.1845	0.283232913	Shetland Isles	360000	45	12.745481	0.012745	0.11165
N. Fair Isle, Shetland	0.66	1.282937	0.147342	0.561	0.004797071	N. Fair Isle, Shetland	1000000	125	0.5996339	0.0006	0.005253
	2	3.887689	4.1	1.7	0.133485575		1000000	125	16.685697	0.016686	0.146167
Firth of Lorn	0.77	1.49676	0.233973	0.6545	0.007617571	Firth of Lorn	1000000	125	0.9521964	0.000952	0.008341
	2	3.887689	4.1	1.7	0.133485575		1000000	125	16.685697	0.016686	0.146167
East Lewis	2	3.887689	4.1	1.7	0.133485575	East Lewis	1000000	125	16.685697	0.016686	0.146167
Fall of Warness	1.54	2.993521	1.871785	1.309	0.06094057	Fall of Warness	1000000	125	7.6175712	0.007618	0.06673
	3.34	6.492441	19.0956	2.839	0.621704126		1000000	125	77.713016	0.077713	0.680766

Site	**Velocity (m/s)**	**Velocity (Knots)**	**Power Density (MW)**	**Rated Velocity m/s**	**Energy Capacity (MW)**	**Site**	**Surface Area (m/sq)**	**No. of Devices**	**Site Capacity (MW)**	**Energy Capacity (GW)**	**TW/h per year**
Fairhead to Cushendun bay	1.54	2.993521	1.871785	1.309	0.06094057	Fairhead to Cushendur	1000000	125	7.6175712	0.007618	0.06673
South Rathlin	3.08	5.987042	14.97428	2.618	0.487524559	South Rathlin	1000000	125	60.94057	0.060941	0.533839
Strangford Narrows	3.6	6.997841	23.9112	3.06	0.778487872	Sytrangford Narrows	1000000	125	97.310984	0.097311	0.852444
Mull of Galloway	1.02	1.982722	0.543869	0.867	0.017706995	Mull of Galloway	1000000	125	2.2133744	0.002213	0.019389
	3.08	5.987042	14.97428	2.618	0.487524559		1000000	125	60.94057	0.060941	0.533839
Rhins of Galloway	2.05	3.984882	4.415252	1.7425	0.143749364	Rhines Of Galloway	1000000	125	17.968671	0.017969	0.157406
	2.57	4.995681	8.699479	2.1845	0.283232913		1000000	125	35.404114	0.035404	0.31014
Sound of Islay	2.57	4.995681	8.699479	2.1845	0.283232913	Sound of Islay	1000000	125	35.404114	0.035404	0.31014
Blue Mull Sound, Orkney	2.05	3.984882	4.415252	1.7425	0.143749364	Blue Mull Sound,	1000000	125	17.968671	0.017969	0.157406
	3.08	5.987042	14.97428	2.618	0.487524559	Orkney	1000000	125	60.94057	0.060941	0.533839
General Areas (Scotland)											
Orkney	3.5	6.803456	21.97344	2.975	0.715399252	Orkney	7.32E+09	914500	654232.62	654.2326	5731.078
Shetland	3.5	6.803456	21.97344	2.975	0.715399252	Shetland	5.53E+11	69125000	49451973	49451.97	433199.3

Western Isles	3.5	6.803456	21.97344	2.975	0.715399252	Western Isles	2.70E+11	33750000	24144725	24144.72	211507.8

Site	Velocity (m/s)	Velocity (Knots)	Power Density (MW)	Rated Velocity m/s	Energy Capacity (MW)	Site	Surface Area (m/sq)	No. of Devices	Site Capacity (MW)	Energy Capacity (GW)	TW/h per year
Wales											
NW Holy Island	1.54	2.993521	1.871785	1.309	0.06094057	NW Holy Island	18000000	2250	137.11628	0.137116	1.201139
	3.6	6.997841	23.9112	3.06	0.778487872		1800000	225	175.15977	0.17516	1.5344
NW Carmel Head	1.02	1.982722	0.543869	0.867	0.017706995	NW Carmel Head	4500000	562.5	9.9601847	0.00996	0.087251
	3.08	5.987042	14.97428	2.618	0.487524559		4500000	562.5	274.23256	0.274233	2.402277
England											
Bristol Channel	1.02	1.982722	0.543869	0.867	0.017706995	Bristol Channel	108000000	13500	239.04443	0.239044	2.094029
	1.54	2.993521	1.871785	1.309	0.06094057		108000000	13500	822.69769	0.822698	7.206832
Suffolk Coast	1.54	2.993521	1.871785	1.309	0.06094057	Suffolk Coast	1000000	125	7.6175712	0.007618	0.06673
	2.05	3.984882	4.415252	1.7425	0.143749364		1000000	125	17.968671	0.017969	0.157406
S. Foreland, Dover	1.54	2.993521	1.871785	1.309	0.06094057	S.Foreland, Dover	1000000	125	7.6175712	0.007618	0.06673
	2.57	4.995681	8.699479	2.1845	0.283232913		1000000	125	35.404114	0.035404	0.31014
Isle of Wight	1.54	2.993521	1.871785	1.309	0.06094057	Isle of Wight	1000000	125	7.6175712	0.007618	0.06673
	2.57	4.995681	8.699479	2.1845	0.283232913		1000000	125	35.404114	0.035404	0.31014
Lynmouth, Devon	1.8	3.49892	2.9889	1.53	0.097310984	Lynmouth, Devon	1000000	125	12.163873	0.012164	0.106556
	2.57	4.995681	8.699479	2.1845	0.283232913		1000000	125	35.404114	0.035404	0.31014

Site	Velocity (m/s)	Velocity (Knots)	Power Density (MW)	Rated Velocity m/s	Energy Capacity (MW)	Site	Surface Area (m/sq)	No. of Devices	Site Capacity (MW)	Energy Capacity (GW)	TW/h per year
Europe											
Straits of Messina, Italy	1.5	2.915767	1.729688	1.275	0.056314227	Straits of Messina, Ital	12500000	1562.5	87.990979	0.087991	0.770801
	3	5.831534	13.8375	2.55	0.450513815		1000000	125	56.314227	0.056314	0.493313
Straits of Gibraltar	2.05	3.984882	4.415252	1.7425	0.143749364	Straits of Gibraltar	1000000	125	17.968671	0.017969	0.157406

	3.6	6.997841	23.9112	3.06	0.778487872		1000000	125	97.310984	0.097311	0.852444
Netherlands Coast	1.2	2.332614	0.8856	1.02	0.028832884	Netherlands Coast	1000000	125	3.6041105	0.003604	0.031572
Australia						**Australia**					
Torres Strait	1.54	2.993521	1.871785	1.309	0.06094057	Torres Strait	1000000	125	7.6175712	0.007618	0.06673
	3.6	6.997841	23.9112	3.06	0.778487872		1000000	125	97.310984	0.097311	0.852444
Apsley Strait						Apsley Strait					
Asia						**Asia**					
Singapore Strait	2.57	4.995681	8.699479	2.1845	0.283232913	Singapore Strait	1000000	125	35.404114	0.035404	0.31014
Selat Riau	1.54	2.993521	1.871785	1.309	0.06094057	Selat Riau	1000000	125	7.6175712	0.007618	0.06673
Naruto, Japan	2.05	3.984882	4.415252	1.7425	0.143749364	Naruto, Japan	1000000	125	17.968671	0.017969	0.157406
	4.63	9.000001	50.86708	3.9355	1.656102917		1000000	125	207.01286	0.207013	1.813433
Site	**Velocity (m/s)**	**Velocity (Knots)**	**Power Density (MW)**	**Rated Velocity m/s**	**Energy Capacity (MW)**	**Site**	**Surface Area (m/sq)**	**No. of Devices**	**Site Capacity (MW)**	**Energy Capacity (GW)**	**TW/h per year**
Kurushima Kaikyo, Japan	2.57	4.995681	8.699479	2.1845	0.283232913	Kurushima Kaikyo, Ja	1000000	125	35.404114	0.035404	0.31014
	4.63	9.000001	50.86708	3.9355	1.656102917		1000000	125	207.01286	0.207013	1.813433
Kanman Kaikyo, Japan	2.31	4.490281	6.317275	1.9635	0.205674423	Kanman Kaikyo, Japai	1000000	125	25.709303	0.025709	0.225213
	4.37	8.494601	42.76989	3.7145	1.392479018		1000000	125	174.05988	0.17406	1.524765
Phillippine Island., Basilian Strait	1.54	2.993521	1.871785	1.309	0.06094057	Phillippine Island, Bas	1000000	125	7.6175712	0.007618	0.06673
	3.08	5.987042	14.97428	2.618	0.487524559		1000000	125	60.94057	0.060941	0.533839
Canada						**Canada**					
Seymour Narrows, British Columbia	2.57	4.995681	8.699479	2.1845	0.283232913	Seymour Narrows	1000000	125	35.404114	0.035404	0.31014
	7.2	13.99568	191.2896	6.12	6.227902978		1000000	125	778.48787	0.778488	6.819554
Active Pass, British Columbia	2.05	3.984882	4.415252	1.7425	0.143749364	Active Pass, British C(	1000000	125	17.968671	0.017969	0.157406
	3.08	5.987042	14.97428	2.618	0.487524559		1000000	125	60.94057	0.060941	0.533839
Akution Pass, Aleution Islands	2.05	3.984882	4.415252	1.7425	0.143749364	Akution Pass, Aleutioi	1000000	125	17.968671	0.017969	0.157406

	4.11	7.989202	35.5811	3.4935	1.15843005		1000000	125	144.80376	0.144804	1.268481
USA						USA					
Deception Pass	1.54	2.993521	1.871785	1.309	0.06094057	Deception Pass	1000000	125	7.6175712	0.007618	0.06673
	4.11	7.989202		3.4935	1.15843005		1000000	125	144.80376	0.144804	1.268481
San Franscisco Bay	1.02	1.982722	0.543869	0.867	0.017706995	San Fransisco Bay	1000000	125	2.2133744	0.002213	0.019389
	2.57	4.995681	8.699479	2.1845	0.283232913		1000000	125	35.404114	0.035404	0.31014
Site	**Velocity (m/s)**	**Velocity (Knots)**	**Power Density (MW)**	**Rated Velocity m/s**	**Energy Capacity (MW)**	**Site**	**Surface Area (m/sq)**	**No. of Devices**	**Site Capacity (MW)**	**Energy Capacity (GW)**	**TW/h per year**
The Narrows, Puget Sound North	1.54	2.993521	1.871785	1.309	0.06094057	The Narrows, Puget S(	1000000	125	7.6175712	0.007618	0.06673
	2.57	4.995681	8.699479	2.1845	0.283232913		1000000	125	35.404114	0.035404	0.31014
The Race, Long Island Sound	1.54	2.993521	1.871785	1.309	0.06094057	The Race, Long Island	1000000	125	7.6175712	0.007618	0.06673
	2.57	4.995681	8.699479	2.1845	0.283232913		1000000	125	35.404114	0.035404	0.31014
Hell Gate, East River, New York	1.8	3.49892	2.9889	1.53	0.097310984		1000000	125	12.163873	0.012164	0.106556
	2.57	4.995681	8.699479	2.1845	0.283232913		1000000	125	35.404114	0.035404	0.31014
Tidal Velocities over 1Km^2 (Power Density)	1.5	2.915767	1.729688	1.275	0.056314227	**Tidal Velocities over (Power Density)**	1000000	125	7.0392784	0.007039	0.061664
	2	3.887689	4.1	1.7	0.133485575		1000000	125	16.685697	0.016686	0.146167
	2.5	4.859612	8.007813	2.125	0.260714013		1000000	125	32.589252	0.032589	0.285482
	3	5.831534	13.8375	2.55	0.450513815		1000000	125	56.314227	0.056314	0.493313
	3.5	6.803456	21.97344	2.975	0.715399252		1000000	125	89.424907	0.089425	0.783362
	4	7.775379	32.8	3.4	1.067884598		1000000	125	133.48557	0.133486	1.169334
	4.5	8.747301	46.70156	3.825	1.520484125		1000000	125	190.06052	0.190061	1.66493
	5	9.719223	64.0625	4.25	2.085712106		1000000	125	260.71401	0.260714	2.283855
	5.5	10.69115	85.26719	4.675	2.776082813		1000000	125	347.01035	0.34701	3.039811
		0	0	0	0			0	0	0	0
		0	0	0	0			0	0	0	0
	2.05	3.984882	4.415252	1.7425	0.143749364		135970000	16996.25	2443.2001	2.4432	21.40243
	3.85	7.483802	29.24665	3.2725	0.952196405		135970000	16996.25	16183.768	16.18377	141.7698
		0	0	0	0			0	0	0	0
		0	0	0	0			0	0	0	0

APPENDIX 4

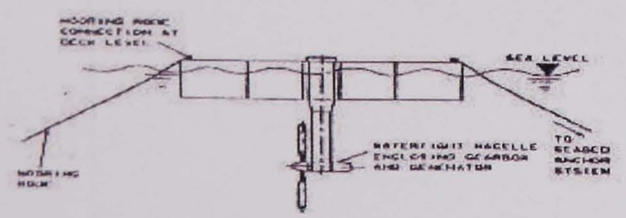
Summary of Support Structures and Rotor Types

Support Structure and Rotor Types

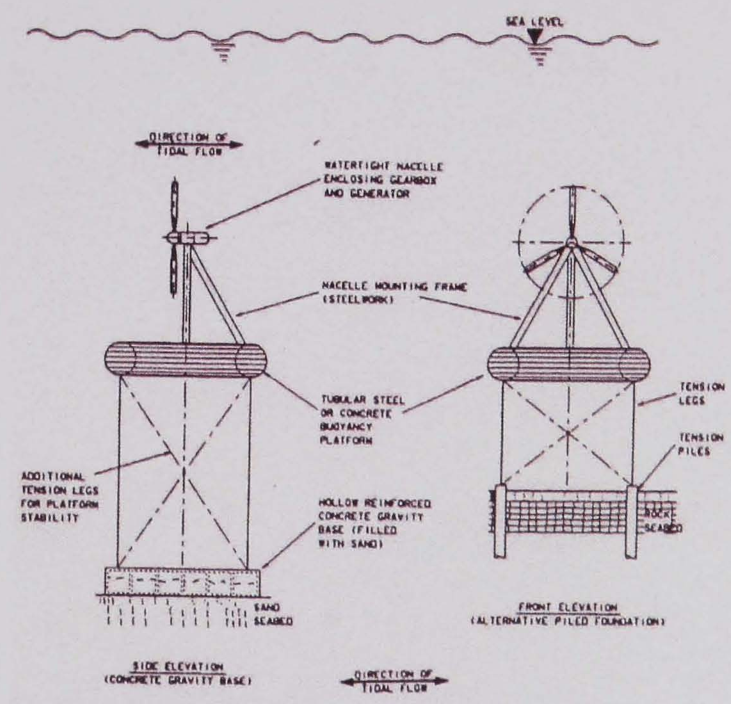
Section	Type	Description
Support Structure	Surface Mounted System	Consist of a floating pontoon with moorings or anchorages, where the turbine would be located below the structure mounted on a frame. Anchor types include piles, gravity bases, drag anchors and ground anchors. Drilled piles are most suitable for rock, whereas, piles and gravity bases are most suited for sand and gravel.
	Buoyant Submersible Structure	Usually located at mid sea depth. The nacelle (generator, gear box and blade support) would be mounted above the buoyancy platform by a steel frame. Platform would be positioned, aligned and levelled by tension-leg moorings. Anchorage would be similar to the surface mounted system.
	Fixed Mounted Seabed System	Elements include nacelle (rotor, gearbox and generator), tower support and a foundation base. Offshore technology is well established and such a support structure could be implemented without extensive research and development. Fixed Mounted structures may include piled structures such as monopiles, gravity based structures or reticular structures.
	Other Fixed Mounted	Support structure designed so that there is no dependancy on fixed pillars or foundations. Uses the downthrusts from reversible lifting surfaces (hydrofoils) to enhance weight of fixed structure.
Rotor/Energy Extraction Mechanism	Axial Flow	Propeller type rotor, which is a horizontal axis device, therefore, its axis of rotation is parallel to the horizontal axis in a cross-current configuration. The predominant force of this type of rotor is lift, allowing the blade sections to move predominantly faster than the current speed.
	Darrieus	These are vertical axis devices and can accept velocity currents from any direction. Axis of rotation is perpendicular to the direction of flow. Usually has straight blades which are mounted on stream lined horizontal cross-arms and can have up to four blades.
	Savonius	Similar to the Darrieus whereby it turns about its axis perpendicular to the current flow.
	Panamones	These also rotate about their axis perpendicular to the flow and rely on drag force by means of blades or cups on opposite sides of the rotor. They have a near linear relationship between rotational frequency and velocity.
	Helical	Variation of the Darrieus rotor. Has a helical arrangement of rotor blades.
	Hydroplanes	The oscillatory movement of the hydroplanes driven by tidal currents is the key factor for converting tidal energy into electricity. Hydroplanes are designed to rise and fall as the angle of each hydroplane is altered at the end of each stroke.
	Open-Centred Turbine	Developed specifically for the dynamics of the Gulf Stream. Encompasses no central shaft and a continuous ring-shaped blade design.

APPENDIX 5

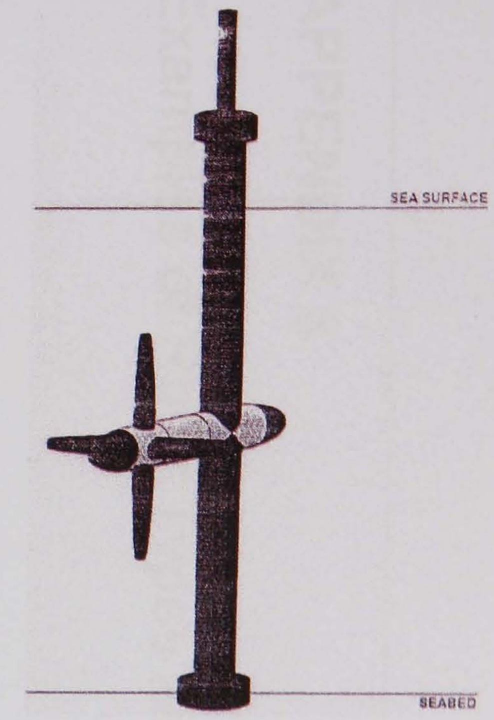
Examples of Support Structure Types



Surface Mounted



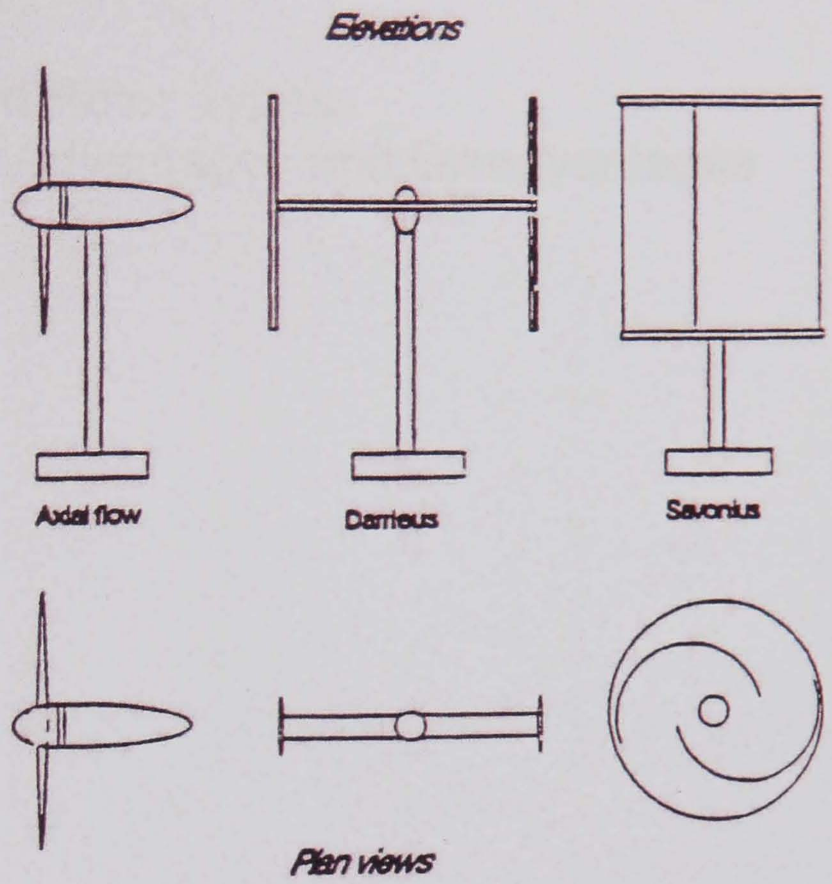
Tension-leg Submersible Platform



Seabed Mounted Monopile

APPENDIX 6

Examples of Rotor Types and Configurations



Helical

(Gorlov & Rogers, 1997)

APPENDIX 7

Structure and Rotor Types: Summary of Advantages and Disadvantages

Support Structure	Advantages	Disadvantages
Surface Mounted	▪ Access comparable less difficult for maintenance and repair ▪ Greater flexibility with respect to water depth	▪ motion and oscillation of pontoon would cause significant power perturbations and in turn present problems in power transmission to shore ▪ movement would also affect power supply cable causing fatigue from constant bending and flexing ▪ May be difficult to maintain sufficient restraint to keep pontoon in position, especially in strong currents and adverse conditions ▪ Require adequate spacing, thus larger turbine spacing ▪ Mooring lines more susceptible from shipping and fishing nets
Buoyant Submersible	▪ Spacing arrangement would be closer, therefore making energy capture more efficient	▪ Problems associated with cable flexing and bending would still occur, but not so severely as the latter support ▪ Movement also expected from subsurface drag forces ▪ Installation more difficult compared to surface option ▪ Access for maintenance and repair more difficult
Fixed Mounted	▪ Flexing and bending of the cables would be eradicated due to the fact it would feed through the tower and base structure ▪ Less exposed to wind and wave forces and inevitably designed to withstand tidal current drag ▪ Comparable economic if right material is used ▪ No movement from structure, thus, perturbations from system would be negligible ▪ Without need for anchorage, turbines can be more closely spaced ▪ Uses proven offshore technology and thus, could be implemented without extensive research and development	▪ Increased installation difficulties, especially in particular strong tidal current areas ▪ Only really suitable for shallower waters
Other Fixed Mounted	▪ All the above ▪ Suitable for all water depths ▪ Minimum seabed damage/disturbance ▪ Uses known hydrodynamic theory ▪ proven to be more economical compared to other principle methods ▪ Readily retrievable ▪ Suitable large and small developments	▪ Still in research and development stage and concept not yet proven.

Rotor Type	Advantages	Disadvantages
Axial	▪ Found with numerous blade combinations (1 to multi-bladed) ▪ Simplest and cheapest option ▪ Low starting torque, even in light current situations ▪ Overall efficiency ▪ Affords flexibility in design (fixed or variable pitch; No. of blades etc.) ▪ Easier starting and stopping ▪ Avoidance of cavitation	▪ Needs to be yawed to meet changing tidal direction ▪ Drivetrain and generator need to be mounted below sea-level at the same depth as the rotor (use of nacelle to house these combats this problem).
Darrieus	▪ Found with numerous blade combinations (1-4 blades) ▪ Comparable efficiency to the Axial	▪ Not self-starting and difficult to stop ▪ Higher torque ▪ Subject to greater marine growth, leading to lower efficiency ▪ Pulsating of blades ▪ Vulnerable to cavitation ▪ Minor surface degradation ▪ Overall less efficient
Savonius	▪ Relatively simple design	▪ Cannot be considered for all power generation scales ▪ Efficiency approximately half of the Darrieus rotor ▪ Turns at lower tip-speed ratio, therefore produces greater torque and consequently higher transmission costs ▪ Low solidity
Panamones	▪ Relatively simple design	▪ Not adequate for power generation ▪ Even less efficiency than the Savonius rotor ▪ Designed solely for unidirectional flow ▪ Low solidity
Helical	▪ One or more blades can be used ▪ unidirectional and uniform flow in all current directions ▪ Uniform turning in slow current - less pulsating than Darrieus ▪ Self-starting ▪ Comparable efficiency even in slow currents ▪ Vertical distribution of helical system can be achieved ▪ Especially useful for buoys, channel markers etc.	▪ Can only be deployed from floating structures - not suitable in high currents or adverse conditions
Hydroplane	▪ Analogous to airfoil and aeroplane wing technology ▪ Able to generate optimum power over wider range of current speeds ▪ Potentially more environmentally benign	▪ Potentially less efficient than more conventional turbine designs ▪ Potentially more susceptible to marine growth and unit maintenance
OpenCentred Turbine	▪ Tensile strength to handle feasible range of turbine size ▪ Design eliminates high expenses of central shaft and bearings (60% less expensive) ▪ Design of the device may mitigate against potential fish and mammal collision	▪ Large units needed to maintain efficiency and power out-put

APPENDIX 8

Summary of Tidal Current Energy Research and Development

Summary of Tidal Current Energy Research and Development [Adapted from Dacre & Bullen, 2001]

Developers/Researchers	Date	Type	Comments
Europe	12th Century	Tidemills and Water wheels	Records indicate that such energy was exploited before AD 1100 along the coasts of the Uk, France and Spain[1].
MacArthur Workshop: US	1973		First major study of tidal current energy, probably as a response to the 'oil shock' of 1973[2]
GEC: UK	1976-79		Also prompted by the oil crisis of 1973, GEC initiated a research programme[3]
Reading University; Fraenkel and Musgrove	1979		General Research in Tidal Current Energy
ITDG (IT Power): UK	1976-84	River/Darrieus Rotor	Tested on the Thames; successful experimental raft-mounted river turbine deployed in the Nile, Sudan - ran for 2 years[4].
UEK Corporation, Canada	1981- present		Developing river, tidal and ocean methods of harnessing energy using hydrokinetic turbines[5] UEK Delaware LP, formed in 2005, plan to develop the 'Bi-Directional Hydroturbine Assembly for Tidal Deployment'.
National Research Council Hydraulics Laboratory: Canada	1983	Darrieus	Tests conducted on 3-bladed vertical-axis rotor in St. Lawrence Seaway, Ontario.
Nihon University: Japan	1983-1996	Darrieus	3 projects leading to the deployment of a 3-bladed 1.8 m turbine in the Kurushima Straits conducted in 1983-1988. Other work has also been conducted since[6]
Joint Stock Co. of Energy and Electrification: Russia	Late 1980's-1990's	Axial flow	Developed a twin axial flow ducted rotors of 1.8 m diameter mounted below a twin-hulled pontoon for use on rivers
Blue Energy: Canada (formerly Nova Energy Ltd.)	1984; 1991-1994	Davis Hydro Turbine	Prototype tested in Canada. 100kW turbine connected to Novia Scotia grid. US Army Corp of Engineers assessed proposals for 2 100 kW turbines and found technology to be technically sound.[7]
NASA	1990's	Various	Conducted 3 year research programme to determine feasibility of producing energy from the Gulf Stream.
ETSU (for DTI): UK	1992-3		Desk study to evaluate the national tidal current resource[8]
Scottish Nuclear, IT Power (Fraenkel), NEL: UK	1993-4	Axial flow	Experimental tidal current system. 3.5 diameter rotor with floating support structure. Generated 15kW in 2.2 m.s current velocity in Loch Linnhe, Scotland - largest turbine so far demonstrated[9].

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Fraenkel, P. (1997a) "Marine Currents - The Most Promising Undeveloped Renewable Energy Source". *Energy World*, June 1997. No. 250, *p.*11
Fraenkel, P. (1997b) *"Marine Current Energy: Present State of Development"*. Briefing Document submiited to the DTI REAC Committee, October 1997.

Developers/Researchers	Date	Type	Comments
Naval Surface Warfare Centre; Harbour Branch Oceanographic Institution, Florida, USA	1994	Axial flow	Turbine Under Gulf Stream (TUGS). Feasibility study into the potential energy source of the Gulf Stream[10].
Northern Territory University and DPIE: Australia	1994-1998	Axial Flow	Small (3kW) rotors using floating support structures deployed for experimental work in the Apsley Straits[11].
EC Joule Programme	1994-6		Technical and resource assessment of tidal current energy in Europe
Gorlov & Rogers and Gulf Stream Energy: USA	1994 -1999	Helical Rotor	Variation of the Darrieus rotor was first developed in 1994/95. Various experiments and tests have been run in Cape Cod Canal and possibly the Gulf Stream[12].
ICIT: UK	1995		Feasibility study on supplying Orkney and Shetland with electricity from tidal current energy[13]
William Herbert	1995	Open-Centred	Construction of small-scale prototype, with 3m diameter blade. Tested n St. Johns River, Florida.
Prof. Salter Edinburgh University: UK	1998	Darrieus	Rotor diameter of 50m[14].
EC Joule Programme (RGU, IT Power, University College Cork [Ireland], Thetis [Italy])	1998-2001		Development of a methodology for optimum technical and economic matching of turbines to local flow conditions "Opt Current".
EC Joule Programme (IT Power): UK, MCT Ltd., UK.	1998-2002	Horizontal axis	"Seaflow". Involves the development of a commercial scale tidal current turbine (300kW) mounted on a monopile support. Demonstration project underway at Lynmouth, Devon, UK.
Blue Energy: Canada	1998- present	Davis turbine	Vertical Axis Darrieus type turbine. Proposed project originally to be installed at the San Bernando Srait between the two Phillipine Islands of Samar and Leyte[15]. Ambitious 2200 MW Proposal now being considered for Dalupiri, Phillipines using tidal fence of 274 turbines (4 km long and 41 m deep)[16].
Sea Power Group	1998-present	Savonius	Over the last 8 years the group have been initiating tidal current energy development in the form of the EXIM tidal stream turbine. Research and development has continued for the Exim device and plans are underway to site a pilot power station in Blue Mull Sound, between the islands of Yell and Unst, Shetland.

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[15] International Water Power & Dam Construction (1998) "Sink or Swim". *International Water Power & Dam Construction*, July 1998, *pp.*49-50

[16] Blue Energy. http://www.bluenergy.com

Developers/Researchers	Date	Type	Comments
Engineering Business: UK	1997 - present	AWCG & "Stingray"	Active Water Column Generator (AWCG) first developed in 1997 and tested at Blyth in 1999. "Stingray" was developed later and was based on the original AWCG and plans are underway for a large-scale demonstration[17]. Successfully demonstrated 150kW system in Yell Sound in 2002.
Universities of Reggio Calabria and Basilicata, Italy	1999 - present	Vertical Axis	Investigation into the performance of a vertical axis variable pitch turbine[18]
ISEP Group, University of Buenos Aires, Argentina.	1999 - 2000	Vertical axis	Development of a vertical axis water-current turbine, using a channelling device integrated into the floatation system to modify flow conditions in the rotor locality. Theoretical modelling and small-scale model stage[19].
The Robert Gordon University (Tidal Current Energy Research Group)	2000- present	Based on axial-flow	PhD research into the environmental impacts of tidal current energy.
Verdant Power, USA	2000-present	Axial-flow	Ducted twin turbine. Prototype was demonstrated at DeCew Falls. 2002-2003 successfully deployed a prptptype system in the East River, New York City. There is continued development, including a partnership with GCK technology to develop a tidal site in Massachusetts.
SEDO, Government of Western Australia	2001- present		Assessment of tidal power alternatives for the supply of electricity to Derby from a tidal power development – part of a proposed tender for such a development[20].
The Robert Gordon University (Tidal Current Energy Research Group)	2001 - present	Axial-flow	Optimisation of Tide Farms – development of computer program to assist with the optimal layout of tidal current turbine arrays.
The Robert Gordon University (Tidal Current Energy Research Group)	2001- present	Axial- flow	Resources Assessment, Associated parametric design and Implementation Plan for the Pentland Firth: 3-Phase feasibility study to determine the potential of economic generation of electricity in the Pentland Firth funded by Scottish Enterprise. Environmental Impact phase was completed in Oct 2001[21].
Alexander Gorlov and GCK Technology Inc., USA.	2001 - 2005	Helical Rotor	Currently generating system for micro applications in remote areas. Demonstration sites in Maine, USA and the Amazon River, Brazil. Estimated to be fully commercialised in 10 years or more[22].
Enermar, Italy	2001 - present	Cross-flow	Developing a 130kW prototype [23] 3-blade turbine mounted on a floating platform. Deployed in the Straits of Messina[24].

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Developers/Researchers	Date	Type	Comments
William Herbert/FHPL Co.	2001-present	Open-Centred	Second prototype was constructed with refined 31m diameter blade and tested in the Atlantic Ocean, where Florida Hydo Power and Light Co. tested and analysed device and concluded device was ready to start the process of commercialisation. US Naval Surface Centre proceeded R&D programme. Tests in the Gulf Stream are imminent. In 2000, the sea trials off Palm Beach, Florida were successful and electricity was generated in 2003.
Korea	2001-present		Ocean Energy Utilisation study initiated including technical development and prediction modelling techniques for tidal currents and site characteristic assessments.
Nanyang Technological University, Singapore	2002		Research into a floating tied platform for the generating of energy through tidal currents using a low-velocity energy converter operated by parachutes[25].
Tidal Hydraulics Ltd., Wales	2002	Axial Flow	Device based on a numerous small axial flow rotors set into a frame mounted on the seabed.[26]
Hammerfest Stroem AS, Norway	2002 - present	Axial Flow	Developing a seabed mounted axial-flow system of about 300kW[27]
Teamwork Technology, Netherlands	2002 - present	Axial Flow	Marketing a small floating axial-flow device rated at 25kW, primarily for use on rivers.[28]
Aquantis (Enron Wind Corp.), USA	2002 - present		Process of designing and developing marine current turbine technology[29]
Tyson Turbine	2002 - present	Axial Flow	Tethered buoy system, which provides the ability to pump water. Commercially available in Australia, but only available up to 3 kW and intended for isolated areas[30].
J A Consult, London (Collaborators: R L Associates and P D Design)	Present	Axial Flow	Developing a semi-submersible, bouyant axial flow concept. A prototype (1.5 diameter rotor) is currently being tested in the River Thames at Chiswick under DTI contract.[31]
Rvco Ltd. Dr. John Hassard, imperial College, london	2002	Venturi	Development of tidal cuurent energy device based on venturi theory. Experimental stage, with deployment/monitoring of device in the Alexander Dock, Grimsby.
Edinburgh University (Prof. Salter)	Present	Cross-flow	Proposal of a large floating cross-flow rotor system at a conceptual stage of development.[32]
SEAPOWER/ MCT Ltd. Peter Fraenkel	Present	Axial	Demonstration project installed, Lynmouth, Devon
The Robert Gordon University (Tidal Current Energy Research Group)	2002	'Stingray'	Hydrodynamic Modelling of Yell Sound, Shetland. Commissioned by the Engineering Business Ltd. To produce accurate digital representation of the flow environment of Yell Sound for 'Stingray' project.

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Developers/Researchers	Date	Type	Comments
Lunar Energy: UK	2002 - present	Ducted Axial Turbine	R & D in ducted turbine system. Plans underway for conceptual stage of development with view to construct prototype and initiate demonstration project[33]. 1MW prototype due to be commissioned at EMEC. Lunar Energy Ltd. and Rotech have just secured backing from the german engineering group, Bosch for its 1MW prototype[34]
The Robert Gordon University (Tidal Current Energy Research Group)	2002		Environmental scoping study completed on behalf of the DTI, UK[35].
The Robert Gordon University (Tidal Current Energy Research Group)	2002		Market Survey into the development potential for tidal current energy - Project to determine the market potential of tidal current energy funded by Scottish Enterprise.
The Robert Gordon University (Tidal Current Energy Research Group)	2002 - present	Any	Proof of concept project to develop support structure technology in order to minimise depth constraints of existing technology in addition to having no surface piercing.
Hammerfest Strom AK, Norway	2002 to present	Axial	"The Blue Concept". Pilot project launched in Kvalsundet, Norway. Initiated co-operations with Akvaplan NIVA and the Norwegian Institute for Nature Research to investigate environmental impact issues[36].
Richard Ayres (Marine Engineer) Tidal Hydraulic Generators	2002	Axial	Successfully piloted a programme for a full size turbine in the Cleddau estuary off the pembrokeshire coast with plans to build a 5-turbine system.
Clean Energy (Power Systems) British Columbia, Canada	2002 - present	Ducted Axial Turbine	Testing 1-metre diameter model and a 3-metre twin rotor to be installed at Race Rocks[37].
Hydrohelix Energies, France	2002 - present	Axial	Pilot 60W scheme. Plans to demonstrate 4 underwater turbines[38].
Seapower Group, Poland	1998 - present	Savonious	Development of the EXIM tidal stream device for commission in 2004 off the Shetland Isles – a joint venture with Delta Marine, Lerwick.[39]
MCT Ltd.	2002 - present	Twin Horizontal Axial	"Seagen" project. Plan to install full scale project in Strangford Lough Narrows. Proposed plans for two schemes off the coast of Anglesey.
Subsea Energy (Scotland) Ltd.	2003-present		"Aquamedies". Plan to sea test at EMEC.
Hydroventuri Ltd	2003-present	Venturi	Formerly RVco Ltd. Plans are being made for a pilot project off San Francisco, however lack of investment means project is on hold at present.
SMD Hydrovision	2004-present	TidEl	After 30 months of R&D, a 1:10 scale, partly funded by the DTI successfully completed a 7-week trial program at NaREC, Blyth.

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39 www.seapower.se [Accessed: 09/2003].

Developers/Researchers	Date	Type	Comments
Statkraft	2004-present	Horizontal axial	Developing and testing a tidal power plant based on a floating, anchored steel structure which will generate electricity via four large turbines driven by marine currents.
Tidal Sails AS, Norway	2004-present	Harmonica Model	Tidal Sail AS have already received a Norwegian Patent in May 2006 and completed tank testing at the University of Hertfordshire. It was planned to have a prototype design completed by August 2006.
Openhydro	2004	Open-centred	In 2004, Openhydro negotiated the acquisition of the world technology rights to the Open-Centre Turbine from Florida Hydro and a grid connected Open Centred Turbine was installed at EMEC.
Kinetic Energy Systems	2004	Hydrokinetic	Have developed a number of concepts designed to harness tidal current energy.
THG Limited	Not Known	Horizontal Axial	An axial-type prototype has been successfully in the Cleddau estuary with plans to build a 3.5MW turbine system for the Ramsey Sound in Pembrokeshire, Wales
Oxford Oceanics	2004		Developing tidal system to co-exist with coastal defence mechanisms.
QinetiQ	2004	Cycloidal	Early stages of development
Oceantecs Ltd.	2005-present	Mermede	Mermede still in development stage, but scale model is underway for testing.
The Engineering Business	2005	Stingray	Due to financial constraints "Stingray" development was put on hold.
Tidal Generation Ltd.	2005-present	Horizontal Axial	Developing a 1MW fully submerged tidal turbine. Once the concept design is complete, the company plan is to install a 500 kW prototype at EMEC.
Scotrenewables UK	2005-present	Horizontal axial	
GCK Technology	2005	Helical	Texas-based renewable energy company has bought the worldwide rights to the turbine. At present it is in the process of installing a permanent turbine array in the Uldomok Strait off the southwestern coast of South Korea.
Neptune Systems, Netherlands	2005	MHD	Develop tidal current systems based upon magneto hydro dynamic concepts. Neptune Systems are in the process of planning the development of a larger prototype to further assess the technical and economic feasibility of the Neptune tidal current converter system.
Marine Energy Power	2005		Plans to demonstrate their system on the west coast of Scotland in 2006.
WWTurbine, USA	2006		Developers of the Water Wall Turbine.

APPENDIX 9

Skills Base Index

Company Name	RE Interest	Skill/Expertise																	
		Design	Manufacture			Component		Marketing	Product Development	R&D	Consultancy/Offshore Survey	Installation/Maintenance Services	Project Management/Operations	Pipeline/Cabling	Marine Equip/Technology	Finance & Lew	Key Stakholders	Power Generators/Transmission	Other
			Fabrication	Machinary	Assembly	Drive	Control												
ABB Offshore							•												
Abercorn Engineering				•													•		
Aberdeen City Council	Yes																•	•	
Aberdeenshire Council																			
Aberdeen Harbour																	•		
Aberdeen Offshore Tech Park		•	•	•	•	•	•	•	•	•	•	•	•	•	•				•
AEA Technology	Yes							•											•
Agip (UK) Ltd																			•
AJT Engineering Ltd			•	•	•		•												
Aker Oil & Gas Tech												•	•		•				
Alba Power Ltd							•												•
All Oceans Engineering	Yes	•	•	•									•		•				
Allan Partnership											•								
Amec Services	Yes	•										•	•						•
Amerada Services Ltd								•											•
Ampliflaire	Yes		•	•	•														•
Andaray Engineering	Yes		•	•	•														•
Anderson Lyall											•		•						
Angrew Palmer & Assoc		•												•					
Andrews Survey														•					

Company Name	RE Interest	Skill/Expertise																	
		Design	Manufacture			Component		Marketing	Product Development	R&D	Consultancy/Offshore Survey	Installation/Maintenance Services	Project Management/Operations	Pipeline/Cabling	Marine Equip/Technology	Finance & Lew	Key Stakholders	Power Generators/Transmission	Other
			Fabrication	Machinary	Assembly	Drive	Control												
ANGLE Technology	Possibly								•		•								
Anglo-Scottish Turbine Services																			•
Angus Contro Engineering							•												•
Angus Council																			•
Arch Henderson & Prts											•								
Atlas Diving & Marine Services																			•
Aubin Ltd																			•
Aquatron Marine																			•
Babcock Engineering		•		•			•		•										
Babtie Group	Yes	•							•		•	•	•						
BAeSEMA	Yes							•			•								
Dougall Ballie Assoc	Yes							•			•					•			•
Baker Atlas																			•
Balfour Kilpatrick Ltd		•							•			•	•	•				•	
Balmoral Group		•																	•
Bank of Scotland	Yes							•								•			
Barmac	Yes		•																
Belmar Engineering															•				
BG Group	Yes							•									•	•	

Bielski Associates																			•
Bluewater																			•
Bowen Tools																			•

Company Name	RE Interest	Skill/Expertise																	
		Design	Manufacture			Component		Marketing	Product Development	R&D	Consultancy/Offshore Survey	Installation/Maintenance Services	Project Management/Operations	Pipeline/Cabling	Marine Equip/Technology	Finance & Lew	Key Stakholders	Power Generators/Transmission	Other
			Fabrication	Machinary	Assembly	Drive	Control												
BP plc	Yes							•									•		•
Braid Consulting											•							•	
Bredero Price Coaters																			•
British Energy	Yes																•	•	
British Geological Survey											•								•
Broad Energy Development													•						•
Brown and Root	Yes	•						•				•						•	
Brown & Root McDermot	Yes		•					•											
Brown Bro. & Co.																			•
Bryan J Rendall Ltd	Yes		•	•			•												
Buchan Technical Services														•					•
Burness Solicitors	Yes															•			
Cadagon Consultants	Yes							•			•								
Caledonian Energy Managament	Yes							•			•		•						
Chevron Texaco	Yes							•											•
Circle Technical Services															•				•
Clean Ocean Ltd	Yes		•	•				•			•	•	•						•

C-MAR Services									●		●		●						
Cns Subsea Ltd		●	●									●	●						
Coda Technology											●								
Coflexip Stena Offshore			●									●	●						
Concept Systems											●								

Company Name	RE Interest	Skill/Expertise																	
		Design	Manufacture			Component		Marketing	Product Development	R&D	Consultancy/Offshore Survey	Installation/Maintenance Services	Project Management/Operations	Pipeline/Cabling	Marine Equip/Technology	Finance & Lew	Key Stakholders	Power Generators/Transmission	Other
			Fabrication	Machinary	Assembly	Drive	Control												
Conoco Ltd	Yes	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Consafe Ltd			•	•							•	•							
Cordah Ltd	Yes									•	•								
Crown Estates	Yes															•	•		
Cutting Underwater Technologies									•	•									
Dales Engineering	Yes		•	•				•				•							
David R Murray & Associates											•								
DBM Consultants Ltd											•								
DNO Heather Ltd																			•
Doherty Eng. Services	Yes		•	•	•			•											
DSND Subsea Ltd											•			•					
Dynamic Positioning Services Ltd															•				•
Edda Supply Ships																			•
Electricity Association	Yes																•		
Energy Unlimited	Yes	•						•		•	•	•	•			•			
Enterprise Oil plc																			•
Environment and Resource Technology	Yes									•	•								
ESL Contracting	Yes																		•

Environmentally Sustainable Systems																			
Expro North Sea Ltd																			•
Fife Council	Yes																•		
Firscot Ltd																			•

Company Name	RE Interest	Skill/Expertise																	
		Design	Manufacture			Component		Market	Product Development	R&D	Consultancy/Offshore Survey	Installation/Maintenance Services	Project Management/Operations	Pipeline/Cabling	Marine Equip/Technology	Finance & Lew	Key Stakholders	Power Generators/Transmission	Other
			Fabrication	Machinary	Assembly	Drive	Control												
Firthandel Ltd																			•
Floyd & Assoc Ltd											•								
Forsyths Ltd		•	•			•	•												
Forth Tool & Valve			•	•									•						
Friends of the Earth	Yes																•		
Furmanite International																			•
Garbhaig Hydro Power	Yes							•											•
Gardline Surveys	Yes										•								
Garrad Hassan & Prts	Yes							•		•	•								
Gemini Corrosion Services	Yes							•				•			•				•
George Meller Ltd																			•
Green Electricity Marketplace Ltd.	Yes										•								
Greenpeace	Yes																•		
GRM Rigging Services																			•
GS-Hydro UK Ltd																			•
GSE Rentals Ltd															•				
H&G Automation																			•
Halcrow Crouch	Yes										•		•			•			
Halliburton Group	Yes							•			•		•	•					

Highland Council	Yes																•		
Highland Galvanisers	Yes							•											•
Highland Light & Power	Yes							•								•			
Highlands and Islands Enterprise	Yes																•		

Company Name	RE Interest	Skill/Expertise																	
		Design	Manufacture			Component		Marketing	Product Development	R&D	Consultancy/Offshore Survey	Installation/Maintenance Services	Project Management/Operations	Pipeline/Cabling	Marine Equip/Technology	Finance & Lew	Key Stakholders	Power Generators/Transmission	Other
			Fabrication	Machinary	Assembly	Drive	Control												
HTL																			•
Hughes Offshore Grp																			•
Hydro-bond Engineering														•					
ICIT	Yes							•			•								
Ingenco Ltd	Yes	•						•			•	•	•						
Isleburn Grp	Yes		•	•															•
John Mason Ltd	Yes																		•
JNCC	Yes										•						•		
Kerr-McGee North Sea																			•
Kolfor Plant															•				
Kongsberg Simrad Ltd															•				•
Labtech Services																			•
Lerwick Eng. & Fabrication			•																
Lewis Offshore			•																
Lerwick Port Authority																	•		
Lobnitz Marine Holdongs		•	•								•		•						
Lothian Eng Co. Ltd			•								•								
MacDonald Energy Projects											•								

MacGregor Energy Services	Yes		•								•		•						
MacKellar Eng. Ltd	Yes		•	•															
Magnum Power Solutions	Yes					•	•												
Marathon Oil UK																			•

Company Name	RE Interest	Skill/Expertise: Design	Manufacture: Fabrication	Manufacture: Machinary	Manufacture: Assembly	Component: Drive	Component: Control	Marketing	Product Development	R&D	Consultancy/Offshore Survey	Installation/Maintenance Services	Project Management/Operations	Pipeline/Cabling	Marine Equip/Technology	Finance & Lew	Key Stakeholders	Power Generators/Transmission	Other
Marine Conservation Society																	•		
Marketing Technical Services											•								
Masons	Yes							•								•			
Masterpower Electronics	Yes		•	•		•	•												
Matrix Intern. Ltd		•		•	•														
Medlock ltd	Yes							•											•
Merpro Ltd	Yes		•	•	•														
Montrose Port Authority	Yes																•		
Moray Council	Yes																•		
Mott MacDonald	Yes	•						•			•		•	•		•			
Munro & Miller Fittings		•	•									•		•					
Murray Inter. Metals	Yes		•	•				•					•						
Nan Gall technology		•		•			•												
National Eng. Lab	Yes										•								
National Grid Group	Yes																•		
National Power	Yes																•	•	
Nautronix Ltd															•				
Nifes Consulting grp											•							•	
Noble Denton Europe											•								

North Sea Lifting											•								•
NORWEB																	•	•	

Company Name	RE Interest	Skill/Expertise																	
		Design	Manufacture			Component		Marketing	Product Development	R&D	Consultancy/Offshore Survey	Installation/Maintenance Services	Project Management/Operations	Pipeline/Cabling	Marine Equip/Technology	Finance & Lew	Key Stakholders	Power Generators/Transmission	Other
			Fabrication	Machinary	Assembly	Drive	Control												
npower	Yes																•	•	
NSW technology																			•
Oceaneering Int. Services																			•
Oceanfix Int. ltd											•		•						•
Ocean Power Delivery	Yes			•				•		•		•							•
Orion Eng Services	Yes	•	•	•								•							
Orkney Council	Yes																•		
Orkney RE Forum	Yes																•		
Orkney Sustainable Energy ltd	Yes							•			•		•						
Park Tool & Engineering																			•
Passell Ltd															•				
PDQ QMIS Ltd	Yes	•									•	•							
Pearsie Estate Co.	Yes																		•
Peebles Electrical machines	Yes	•									•								•
Pell Frischmann MvGovern Ltd																			•
Petrology Ltd														•					•
PGS Production																			•
Posford Duvivier										•						•			

Powergen Renewables	Yes																•	•	
Proven Eng. Products	Yes	•			•								•						
Racal Survey											•				•				
Renewable Energy Development (RED)	Yes							•			•								

Company Name	RE Interest	Skill/Expertise																	
		Design	Manufacture			Component		Marketing	Product Development	R&D	Consultancy/Offshore Survey	Installation/Maintenance Services	Project Management/Operations	Pipeline/Cabling	Marine Equip/Technology	Finance & Lew	Key Stakeholders	Power Generators/Transmission	Other
			Fabrication	Machinary	Assembly	Drive	Control												
Richard Irvin Services			•						•										
Richard Morris Assoc	Yes							•			•								
Ross Deeptech	Yes	•	•						•				•						
RSPB	Yes										•						•		
S & D Fabricators			•																
Scoraig Wind Electric	Yes									•	•								
Scot Waste	Yes	•						•					•			•			
Scotia Energy	Yes							•					•			•			
Scotland Electronics		•			•		•												
Scottish Coastal Forum	Yes										•						•		
Scottish Hydro-electric	Yes																•	•	
Scottish&Southern Electric	Yes																•	•	
Scottish Enterprise Energy Group	Yes										•						•		
Scottish Parliament RE Grp	Yes																•		
Scottish Power	Yes																•	•	
Scottish Subsea Technology																			•
SEPA	Yes										•						•		
SERAD	Yes																•		

Shell renewables	Yes																•	•	
Shetland Energy Club	Yes										•								
Seimens Power Generation			•	•			•											•	
SLK Engineering						•	•												

Company Name	RE Interest	Skill/Expertise																	
		Design	Manufacture			Component		Marketing	Product Development	R&D	Consultancy/Offshore Survey	Installation/Maintenance Services	Project Management/Operations	Pipeline/Cabling	Marine Equip/Technology	Finance & Lew	Key Stakholders	Power Generators/Transmission	Other
			Fabrication	Machinary	Assembly	Drive	Control												
Strategic Offshore Research										•	•								
Sub-Atlantic Ltd																			•
Subsea Protection Systems																			•
Sustainable Business	Yes										•								
Talisman Energy																			•
Tourism & Env. Forum	Yes										•								
Trident Eng. Consultants																			•
UiE Scotland Ltd			•									•							
UKOOA																			•
University of Strathclyde ESRU	Yes									•	•								
Vertec Engineering Ltd		•	•																
Wavegen	Yes									•							•	•	
Weir Pumps Ltd																			•
Westerm Isles Council	Yes																•		
Wood & Davidson Ltd			•																
WWF	Yes																•		

Company Name	RE Interest	Skill/Expertise																	
		Design	Manufacture			Component		Marketing	Product Development	R&D	Consultancy/Offshore Survey	Installation/Maintenance Services	Project Management/Operations	Pipeline/Cabling	Marine Equip/Technology	Finance & Lew	Key Stakholders	Power Generators/Transmission	Other
			Fabrication	Machinary	Assembly	Drive	Control												
Wright, Johnston & MacKenzie	Yes							•								•			
XM Services			•	•					•										
ZKL Bearings Ltd	Yes		•	•															

APPENDIX 10

Summary of Current Legislation

Key Stages of Development	Relevant Legislation	Purpose/Description
Consents Process		
Planning Permission	Town and Country Planning (Scotland) Acts 1947 to 1997	▪ land covered by the Planning Permission extends to MLWS ▪ scope of permission includes the temporary and permanent onshore cabling works, pre-construction survey activities, access, land drainage and foreshore arrangments
Works Licence	County Council Acts	▪ area covered extends from MHWS to 12 miles seaward from that point ▪ scope of the Works Licence includes any temporary and permanent cabling/pipeline works, foreshore excavation and dredging
Foreshore Works Consent	Crown Estate Act 1961	▪ development plans need to be submitted to the Crown Estate Office for the consent of foreshore cable landfall works
Seabed Lease	Crown Estate Act 1961	▪ required to submit development plans to the Crown Estate Office to support the negotiation for a seabed lease in collaboration with the UKOOA (UK Offshore Operators Association).
Installation Consent	Coastal Protection Act 1949	▪ required to submit development plans to the Scottish Executive Development Dept. (SEDD) ▪ consent would cover marine activities within the Pentland Firth for the purposes for installation and cabling landfall ▪ requirements are administered by SEDD in collaboration with DETR ▪ provides for the safety of other users of the sea area; concerned with the safety of navigation through the DTI (Dept. of Trade and Industry)
	Transport and Works Act (TWA) 1992	▪ this is instead of the CPA (above) (not Scotland) ▪ gives the possibility of an exclusion zone around the turbines and legal protection against being sued for nuisance or obstruction ▪ this route is encouraged
Land-based Construction		
Contaminated Land	The Contaminated Land (Scotland) Regulations 2000	▪ applies in the event the onshore cabling would pass over reclaimed land and contamination was encountered during excavation activities
Waste Management	Environmental Protection (Duty of Care) Regulations 1991	▪ ensures waste products are stored/contained/packaged properly; ▪ that authorised personnel are used to collect, carry and dispose of waste

Key Stages of Development	Relevant Legislation	Purpose/Description
Offshore Deployment/Installation		
Presence of Tidal Current Energy device	Food and Environment Protection Act 1985	▪ regulated by SOAEFD (Scottish Office of Agriculture, Environment and Fisheries Dept.) ▪ to protect the marine environment, human health and other sea users ▪ need to obtain FEPA licence to deposit anything in the sea
	Coastal Protection Act 1949	▪ concerned with the safety of navigation through SEDD ▪ this is instead of the CPA (above)
	Transport and Works Act (TWA) 1992	▪ gives the possibility of an exclusion zone around the turbines and legal protection against being sued for nuisance or obstruction ▪ this route is encouraged
	Model Clauses of Licence HSE Offshore Safety Division Operations Notice 3	▪ fisheries liaison ▪ required to appoint a fisheries liaison officer to liaise with the fishing industry and government fisheries departments on activities ▪ initiates communication between operator and other users of the sea
Installation ▪ **Transportation**	The Merchant Shipping (Prevention of Oil Pollution) Regulations 1996	▪ oil content of discharged water must not exceed 15ppm ▪ vessels must be equipped with oil filtering systems, automatic cut offs and oil retention systems ▪ all vessels must hold an approved Shipboard Oil Pollution Emergency Plan ▪ all vessels must maintain a current Oil Record Book
	The Merchant Shipping (Prevention of Pollution by Garbage) Regulations 1996	▪ all wastes must be segregated and disposed of on return to shore ▪ food waste can only be discharged in a vicinity greater than 12 miles from coastline
	MARPOL 73/78 Annex IV Regulations for the Prevention of Pollution by Sewage from Ships	▪ requirement for ships to discharge sewage only under certain conditions
	PROPOSED additional Annex to *MARPOL 73/78* regarding anti-fouling paint use	▪ TBT banned on new vessels from 2003 ▪ total ban on all hulls from 2008

▪ **Rock Dumping; disposal of spoil etc.**	Food and Environment Protection Act 1985 Model Clauses of Licence Petroleum Operations Notice 2	▪ all deposits in the sea are prohibited, unless an exemption is granted ▪ a FEPA licence is required if anything is to be deposited in the sea as a result of the development ▪ required to locate and remove any debris resulting from licensed activities

Key Stages of Development	Relevant Legislation	Purpose/Description
Wildlife and Environmental Protection		
Directives and Acts	The Conservation Regulations 1994 Transpose the requirements of the EC Habitats and Species Directive 92/43/EEC into National Law.	▪ prohibits the killing, injuring or disturbance of specific birds, animals and mammals ▪ requires the conservation of specified habitats and species of flora and fauna ▪ particularly relevant to the project are the requirements relating to Otters, Cetaceans and Reefs ▪ regulations now go beyond 12nm and implementation of offshore regulations are in progress
	The Environmental Protection Act 1990	▪ provides further protection
	Wildlife and Countryside Act 1981 Implements the EC Council Directive 79/409/EEC on the Conservation of Wild Birds [The Birds Directive]	▪ anyone who kills, injures or takes from the wild or disturbs certain, birds, animals or mammals commits an offence ▪ Birds Directive aims to protect ranges of species incl., the breeding of populations ▪ extends to 12nm ▪ provides the establishment of SSSI's ▪ includes the establishment of SPA's (both land and marine areas)
	Convention of Wetlands of International Importance (RAMSAR Convention)	▪ requires the conservation of wetlands ▪ includes areas of marine water to a depth of 6 metres at low tide ▪ areas greater than 6 metres recognised as important waterfowl habitat
	EC Council Directive on the Assessment of the Effects of Certain Public and Private Projects on the Environment 97/11/EC (EIA Directive)	▪ requires environmental assessment to be undertaken before development consent can be issued ▪ only required for projects that may have significant affects on the environment
	Water Framework Directive 2000/60/EC	▪ required for controls on all significant adverse impacts on the ecological status of waters (including coastal waters)

Key Stages of Development	Relevant Legislation	Purpose/Description
International Obligations	Biodiversity Convention	▪ focuses on the recognition of the vital importance of the worlds biological resources for the economy and social development ▪ particular reference to marine habitat preservation
	The 'BERN' Convention on the Conservation of European Wildlife and Natural Habitats	▪ imposes obligations to conserve wild fauna and flora, with particular emphasis on endangered and vulnerable species and their habitats ▪ underlies the EC Habitats Directive
	'ASCOBANS' Agreement on the Conservation off Small Cetaceans of the Baltic and North Seas (1991)	▪ requires governments to undertake habitat management, conduct surveys and research and to enforce legislation to protect small cetaceans
Designated Areas ▪ Statutory Designations	Ramsar Sites	▪ under the UK statutory designation of SSSI and listed under the Convention of Wetlands
	Special Protection Areas (SPA's)	▪ classified under the EC Directive on the Conservation of Wild Birds ▪ aim is to safeguard rare or vulnerable bird species; migratory birds; protection of their habitats ▪ firstly notified as SSSI's; NNR's; then SPA's
	Special Areas of Conservation (SAC's)	▪ designated under the Habitats Directive ▪ identified as areas of outstanding examples of selected habitat types or areas important for the continuing well-being or survival of selected non-bird species ▪ SAC's are to be afforded absolute protection subject to imperative reasons of overriding public interest, including those of a social or economic nature ▪ SSSI's; SAC's **NB.** SAC's together with SPA's will eventually form a European-wide network of sites known as NATURA 2000
	National Nature Reserves (NNR's)	▪ represent some of the most important natural and semi-natural ecosystems; aim to conserve flora, fauna, features of geological, physiographical or other scientific or special interest
	Sites of Special Scientific Interest Areas of Special Scientific Interest	▪ bases for SPA's, SAC's and NNR's ▪ defined in the Wildlife and Countryside Act 1981 ▪ designated for their special nature conservation interest; representing unique areas of land or water that are of special interest with respect to flora, fauna, geological features or landforms

Key Stages of Development	Relevant Legislation	Purpose/Description
▪ Statutory Designations continued	Marine Nature Reserves (MNR's)	▪ provision is made in the Wildlife and Countryside Act 1981 to designate marine areas in order to conserve their marine flora and fauna ▪ only statutory designation that specifically relates to marine areas ▪ aim to conserve especially important marine habitats and wildlife and other unique features along the shore or on the seabed
▪ Non-Statutory Designations	Local Nature Reserves (LNR's)	▪ declared and managed by local authorities ▪ provided for the same purposes as NNR's ▪ represent areas that are 'special' in a local context
	Marine Consultation Areas (MCA's)	▪ introduced in 1986 by SNH ▪ areas that deserve particular distinction in respect of the quality and sensitivity of the marine environment within them ▪ SNH need to be consulted with respect to potential development
	Sensitive Marine Areas (SMA's)	▪ areas that are nationally important and notable for their natural marine animal and plant communities or which provide ecological support to adjacent statutory sites
	Preferred Conservation Zones (PCZ's)	▪ coastal areas in Scotland of particular national, scenic, environmental or ecological importance, where tourism and recreation take priority over industrial development ▪ areas with distinctive aesthetic appeal, heritage and character ▪ unique areas where the inhabitants are dependant on the natural state of the area
	Regional Landscape Designations (RLD's)	▪ provide a mechanism whereby Scottish Planning authorities can identify sites where there should be a strong presumption against development
	National Scenic Areas (NSA's)	▪ identified by the Countryside Commission for Scotland in 1978 ▪ identified by SNH as being representative of the country's most unique, natural sites of historic value
	Geological Conservation Review Sites (GCR's)	▪ unique natural areas that represent examples of geology, palaeontology, mineralogy or geomorphology that are of national or international importance

	Royal Society for the Protection of Birds (RSPB) County Wildlife Trust (WT)	▪ most sites designated by other legislation, such as SSSI's, NNR's etc ▪ promotes nature conservation at a local level