D Financing and economics

D 1 FINANCING OF WAVE ENERGY PROJECTS

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D 1.1 Introduction

This paper discusses the financing criteria applicable to wave energy devices and explains some of the principles behind the most widely accepted method of assessing these, the paper then reviews the various mechanisms for funding other renewable energy technologies and assesses their applicability to wave energy.

There is a widely accepted approach to the appraisal of investment decisions based on discounted cash flows. This comprises—

- identifying the incremental after-tax cash flows that arise from the decision to invest
- forming expected values of those cash flows
- estimating a Required Rate of Return (RRR) for the decision
- computing the Net Present Value (NPV) of the decision

The main source of confusion in implementing this approach lies in the selection of the RRR and, in particular, the treatment of risk. Risk arises because the future is uncertain, so there is a risk that the outcome of an investment decision will not be as expected.

This section describes current best practice for estimating the RRR on a risky investment. It uses the Capital Asset Pricing Model (CAPM) as a framework for the analysis. CAPM is recognised as the best-established method of considering risk and return. It incorporates two main ideas—

- investors require an extra return for taking on risk
- investors are concerned predominantly with the risk that cannot be eliminated by diversification

D 1.2 Risk and return

Even in the complete absence of risk, the RRR would be positive, because, in general, people prefer to consume now rather than later. If they are to forgo present consumption and channel the value of it into investment, they must be rewarded for doing so. The RRR is the return on an investment need to attract investors. Too low and investors will invest their money elsewhere.

If the outcome of a project is certain, so that it has no risk, there is no problem in deciding what the RRR should be. It would simply be the interest rate on zero risk investments (say index-linked government bonds). Unless a company can earn more from its project than investors would obtain from a risk-free investment in the market, the project would probably not be undertaken.

On the other hand, if the outcome of an investment if uncertain, the investors will need to be offered the prospect of a higher rate of return to compensate for taking on the risk involved. Clearly, the RRR on a project should reflect this. Therefore, the RRR on a project should be equal to the risk-free rate plus a premium for risk. The size of the risk premium will depend on the ‘riskiness’ of the project and how investors as a group price each unit of risk in terms of the additional return required. Information about risk and return can be found by close examination of the behaviour of the capital markets. Since the cost of funds is the rate that must be earned to satisfy investors, it is natural to look to the market where these investors trade to provide an estimate of the cost of funds.

D 1.3 Risk in the capital markets

A company’s risk manifests itself as variability in the returns it makes to shareholders. Shareholders can reduce risk to themselves in two ways—they can avoid single shares, which are risky, and they can reduce the risk of single shares by diversification (i.e. pooling shares with different profiles of risk to form a portfolio). The risk of the portfolio is less than a weighted average of the risk of the component investments, since diversification reduces variability. Whilst investing in less risky investments will reduce the expected return of the portfolio, diversification can reduce portfolio risk without a consequent reduction in expected return.

The greatest possible risk reduction occurs when the portfolio includes investments in the shares of all quoted companies, i.e. the market portfolio. However, not all risk is capable of being diversified away and so the market portfolio does contain a significant element of risk. The market portfolio, in terms of its risk reduction characteristics, can be easily approximated by a portfolio of approximately 20 investments in different segments of the stock market. This is because the risk reduction benefits of diversification arise rapidly and most of the risk reduction effect is achieved with only a relatively small amount of diversification.

D 1.3.1 Market risk and specific risk

Variability can be split into two parts—market risk and specific risk.

- **Market risk** is related to general market movements and is determined by the extent to which a company’s performance is affected by macro-economic factors (e.g. the level of consumer demand, movements in exchange rates, corporate tax rates, etc.). Diversification does not reduce market risk.
- **Specific risk** arises from all those events that are specific to an individual company and perhaps its immediate competitors (e.g. the quality of management, the exposure to research and development risks, specific legislation, etc.). Diversification reduces specific risk.

Some shares are very responsive to market conditions while others are relatively unresponsive. Just how sensitive a share is to stock market movements is measured by its β coefficient, which is calculated by plotting the share’s monthly returns against the corresponding returns on the market index. Up to date estimates of equity β are published quarterly in the LBS Risk Management Service. Table D-1 shows estimates of equity beta for the shares of a number of well-known companies. Equity β generally lie in the range of 0.5-1.5.

It is important to understand that an equity β measures both the operating risk of a company (an asset β), and the financial risk arising from that company's gearing (use of debt finance). For a company financed solely from equity, the asset β and equity β will be the same, but for a geared company the equity β will be greater than the asset β. This distinction between asset β and equity β is important in relation to the use of β values to estimate an RRR on a project.

Company	β
Anglican Water	0.49
FKI	1.51
Avon Rubber	1.02
GEC	0.81
Babcock	1.33
GKN	1.23
BICC	1.08
Hansons	0.97
BOC Group	1.17
Howden Group	1.31
British Airways	1.17
Ibstock Johnson	1.49
British Gas	0.82
Johnson Matthey	1.42
British Petroleum	0.85
McAlpine	1.01
British Telecom	0.74
Manweb	1.00
Cable & Wireless	1.28
Northern Electricity	1.04

Cookson Group	1.54
RTZ	1.19
Dowding & Mills	0.65
Southern Water	0.66
Eastern Electricity	0.60
Taylor Woodrow	1.13
Enterprise Oil	1.17
Vickers	1.03

Table D-1 Equity β of selected UK companies

D 1.3.2 Relevance of risk

The distinction between market risk and specific risk is crucial to an understanding of required returns. Investors will not demand a higher return from shares that have above average specific risk, since this can be costlessly eliminated by diversification. But they will demand the prospect of a higher return from shares with above average market risk. Market risk is the fundamental risk of British industry which shareholders as a group have to bear.

This is equally true for individual investment projects within companies. Thus, a wave power project will involve two types of risk.

- Its market risk will depend on factors such as the extent to which electricity demand varies with general economic conditions.
- Its specific risk on the other hand will encompass a whole range of uncertainties such as potential delays in bringing the plant on stream, cost escalation, technical performance and so on.

Management should take account of the risks associated with all these uncertainties in the appraisal of an investment. But only the project’s market risk (measured by its β) should be considered when it comes to setting the RRR.

An illustration of the difference between total risk of a company’s equity and its market risk is given in Table D-2.

Company	Market Risk (Equity β)	Total Risk (standard deviation/year)
Anglian Water	0.49	17 %
British Petroleum	0.85	25 %
British Steel	1.16	33 %

Eastern Electricity	0.79	21 %
Kelt Energy	1.25	90 %
Johnson Matthey	1.42	41 %
Northern Electricity	1.04	23 %
Southern Water	0.66	19 %
Taylor Woodrow	1.13	38 %
United Energy	1.05	169 %
Vickers	1.03	31 %
FTA INDEX	*1.00*	*22 %*

Table D-2 Market risk and total risk of selected UK companies

The Financial Times All-Share (FTA) Index had a total risk equivalent to a standard deviation of 22 %. The difference between total risk and specific risk was most starkly illustrated by a company such as United Energy. In terms of market risk this share is 1.05 times as risky as the index and so has a β of 1.05. In terms of total risk, however, it has a standard deviation which is 7.7 times that of the market. The difference lies in the fact that most of the risk of holding of this share (its specific risk) can be diversified.

D 1.4 The capital asset pricing model

Once we have established a share’s β, we can calculate its cost of equity. For example, a share with a β of one would have the same market risk as the All-Share Index and should therefore offer the same expected returns. A share with a β of zero, on the other hand, would be free of risk and should offer the risk-free interest rate. Generally, a β greater than one indicates that a share is riskier than the market portfolio and so should offer greater returns, while a β less than one indicates that the share is safer than the market portfolio and so should offer lower returns.

The Capital Asset Pricing Model asserts that the cost of equity is given by—

$$\textit{Cost of Equity} \quad = \quad \textit{Interest rate} + \beta \times \textit{Expected Market Risk Premium}$$

Equation D.1

This formula shows the return which can be expected from a comparatively risky investment in the capital market. It formalises the earlier assertion that the return should be equal to the risk free rate (to compensate for the time value of money) plus a premium for unavoidable risk.

To calculate a project’s cost of capital we therefore need three items of data—

- risk-free interest rate
- project β
- market risk premium

D 1.4.1 Risk-free returns

Indexed-linked government bonds (indexed gilts) provide an estimate of the minimum acceptable return on a marketable risk-free investment. These generated an annual real return before tax of around 4 % per year over 10, 20, or 30 years, equating to a rate of 3 % net of personal tax at the basic rate. This figure must be the minimum RRR on a project which involves no risk.

D 1.4.2 Project β

The overall risk of the company, as measured by its equity β, is a reflection of the assets that it holds and its financial gearing. Each project may have a level of risk which is different from the average of the company and this should be reflected in the selection of RRRs on projects. If a company wide RRR is used to appraise projects then some higher-risk projects will be wrongly accepted and some lower-risk projects will be incorrectly rejected.

Since individual projects are not traded in the stock market, it is not possible to measure their β values directly. In trying to decide what beta a project has, it is useful to start from the published figures, which will show the β value of a typical risk project for the company or sector. Then the difference of the project from this norm will have to be determined. For example, projects which have a high proportion of fixed costs or which are particularly sensitive to general economic conditions will generally have above average betas. Cost savings exercises and preventative maintenance programmes on the other hand tend to have below average betas.

In some cases, it is straightforward to evaluate the beta of the project. If, for example, the project in question replicates the existing business of the company then the company's equity β should be used as the β for the project (since the risk of the project is the same as that of the company as a whole, assuming that the project is financed by the same proportion of equity and debt as the company as a whole).

Published risk measures can be used to determine the risk of a project that is typical of its industry. In this case the average β for all firms within the industry can be adopted. Table D-3 shows the risks of the main industrial groupings in the UK. They range from the water industry with an average β under 0.8 to mining finance with an average β of over 1.2.

Industry	Average β
Contracting and construction	1.11
Electricity	0.89
Oil & Gas	0.85
Industrial plant engineers	0.99
Cement and concrete	1.04
Electrical	1.07
Mechanical engineering	1.14
Steels	1.15
Shipping	0.95

Table D-3 β Values for Industries in Energy, Materials and Engineering Sectors

Of course, it is often not possible to find companies that operate only in a single industry, so the estimates are contaminated to the extent that the operations of the comparison group of companies include activities outside the industry of interest. Equity β for similar companies will also differ because of differences in gearing. Therefore, a considerable element of judgement is involved in estimating project β.

D 1.4.3 Market risk premium

Experience can be used as a guide to how much more investors are expecting to obtain from investing in the equity market rather than in risk-free investments. It is necessary to use a long period of data, since over short periods of time equity returns are so uncertain that the average gives little clue as to the returns required ex-ante by shareholders.

The arithmetic average of annual gross returns on UK equities over the period 1955-1990 (based on the BZW Equity Index) was 9.7 %. These returns incorporate both dividend and capital gains and are adjusted for retail price inflation. During this period, the annual real returns from gilts was 0.5 %. The difference between these two returns provides an estimate of the risk premium on UK equities, which in real terms is approximately 9 %.

The LBS Risk Measurement Service have also measured the average annual risk premium at about 9 % over the same period using a different index. The estimate would be similar if calculated net of personal income tax. Nor is the estimate significantly affected by the choice of period; the corresponding figure for the period 1919-54 is 8 %. Finally, the estimate of the risk premium is consistent with overseas evidence. For example, Ibbotson Associates have calculated the market risk premium for US stocks as approximately 9 % over the period from 1926 to 1986.

Therefore 9 % appears to be a reasonable estimate of the real after-tax risk premium on UK equities.

D 1.5 RRR on a wave power project

The Required Rate of Return (RRR) on a wave power project will be given by its Weighted Average Cost of Capital:

$$RRR = \mathit{Return\ on\ equity} \times \mathit{Proportion\ of\ equity} + \mathit{Interest\ rate\ on\ debt} \times \mathit{Proportion\ of\ debt}$$

Equation D.2

where the return on equity will be given by—

$$\mathit{Return\ on\ equity} = \mathit{Risk\ free\ interest\ rate} + \beta \times \mathit{Market\ risk\ premium}$$

Equation D.3

To assess the value of β for a wave power project we draw upon a variety of industries, particularly those in the energy, materials and engineering sectors as shown in Table D-4.

$\beta<0.8$	$0.8<\beta<0.9$	$0.9<\beta<1.0$	$1.0<\beta<1.1$	$1.1<\beta<1.2$	$\beta>1.2$
Water	Oil & Gas	Industrial plants	Electrical	Chemicals	Mining finance
Rubbers	Electricity	Transport & freight	Cement & concrete	Contracting & construction	Motor components
Gold	Food manufacturers	Industrial conglomerates	Textiles	Aerospace	Metallurgy
	Machine tools	Telephone networks	Motor vehicles	Building materials	
		Electronics		Mechanical engineering	

Table D-4 Equity β of the main UK industrial groupings

These equity betas lie in the range 0.85-1.15, while the gearing ratio for the industries concerned lie in the range 20-30 %. The β for a wave power project, with comparable gearing, might be expected to lie within this range.

Therefore, it is suggested that a β of 1 (the average of the range listed in Table D-3) should be adopted as the equity β for a wave project. This value of β will only be appropriate for a project with a gearing ratio comparable with the average for the above industries i.e. about 25 %. However, the project’s total cost of capital will not be significantly affected by a change in the gearing ratio. For example, if a company were to increase its gearing in order to take advantage of cheaper debt finance, then the cost of equity would rise to reflect the increased financial risk.

The required return on equity then becomes—

$$\textit{Return on equity} = 3 + 1 \times 9 = 12\ \%$$

Equation D.4

The cost of debt finance is likely to include a margin over and above the risk-free rate. This will depend on a number of factors, including—

- the financial strength and status of the company,
- the gearing ratio,
- the lender's perspective of risk,
- projected payback period.

A 2 % premium is assumed to apply to a wave power project's real after-tax cost of debt finance to larger companies. The real after-tax cost of debt finance will then be 5 %. The cost of debt finance for smaller companies might be 2 % higher.

If a company can borrow internationally in other currencies at lower interest rates than are available in their native currency, it would incorrect to use these lower rates as the cost of debt finance for native currency investments. This is because interest rates in different countries are the same once the impact of foreign exchange transactions are taken into account. So, taking out a contract that eliminates currency exchange risk and borrowing in foreign currency has no benefit compared to borrowing in native currency.

Therefore, assuming a gearing ratio of 0.25 the project's total cost of capital becomes

$$\textit{Cost of capital} = 12 \times 0.75 + 5 \times 0.25 = 10.3\ \%$$

Equation D.5

Thus, the real after-tax RRR on a wave power project should be at least 10 %. Pre-tax returns would be higher.

D 1.6 RRR and discount rate

Discount rates used to estimate the present value of projects are based on the perceived risk in a project. Typically, discount rates of 15 % apply to projects with technical risk, whilst rates of 8 % apply to projects using mature technology. The discount rate that should be used to compare costs of a technology should be based on the RRR associated with that technology's risk, although sometimes higher returns are required if contingencies are included in the business plan whether these are used or not. Neglecting contingencies, the discount rate applicable to wave energy cost projections should be around 10 %. The value of 8 % is used widely in this report and reflects a technology of much greater maturity. These estimates therefore err on the side of lower costs and higher market size. The use of 8 % therefore represents an optimistic scenario for wave energy.

D 2 ECONOMICS OF WAVE ENERGY

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D 2.1 Introduction

IMPORTANT - PLEASE READ THIS BOX FIRST!

This chapter asks the question - *can wave energy ever be commercially competitive with other forms of renewable energy?* To answer this question it uses estimates of what the capital and operating costs of wave energy devices **might be in the future**, assuming all R&D challenges have been overcome, that economies of scale have been realised and that efficiencies in production and operation due to the 'learning curve' effect have been achieved. The reason for asking this question was to enable government policy-makers to decide whether or not to continue public funding of wave energy research. The current state of wave energy technology is such that the first large-scale prototype devices are presently being deployed. These devices are **not expected to achieve energy capture efficiencies as high, or capital and operating costs as low, as those presented in this chapter**. They are, however, the first step on the road to achieving these levels of performance.

Wave energy converters have the typical pattern of renewable energy sources: high investment cost and low running expenses. Despite the reduction in generating costs over recent years, electricity from wave energy schemes is still more expensive that that from large-scale, fossil fuel plants. Therefore, the financing of such projects is critical to their viability. This has been addressed by the European Thematic Network on Wave Energy in making 'Financing and Economic Issues' one of its main Tasks.

One of the first issues facing the Task Group working in this area is to evaluate the financing, economics and monetary issues for developing wave energy schemes, including the internalisation of external costs. This will include a review the various approaches used throughout Europe to support RES, an assessment of their applicability to wave energy and a study of the financing of current demonstration schemes.

This chapter presents the findings of this review. After a brief evaluation of the current market status for wave energy, the paper will review the various mechanisms for funding other renewable energy technologies and assess their applicability to wave energy.

D 2.2 Potential market for wave energy

The first commercial and demonstration wave energy schemes are currently being built. Therefore, wave energy is far from a mature technology. This makes it difficult to estimate potential market. This Chapter presents the initial evaluation of the economics of wave energy and the corresponding markets.

D 2.3 Economics of wave energy devices

There are very few, independent evaluations of the economics of wave energy schemes. An example of the results from one of the very few detailed studies[16] is listed in Table D-5.

	Shoreline OWC	Nearshore OWC	Sloped IPS Buoy
Unit Costs [€/kW]	2,240	1,680	1,920-3,200
O&M and Insurance Costs [€/kW/year]	46	51	30
Availability [%]	96	96	90
Annual Output [kWh/kW]	3,680	4,000	4,800-8,000

Table D-5 Representative Cost and Performance Estimates for Wave Power Devices[*16]

In order to provide more data for this Thematic Network Task, an evaluation has been carried out of a number of devices that have already been built or for which there are contracts in place. This gives a good estimate of the current economics of wave energy but makes no allowance for potential future improvements. There are two sets of devices: oscillating water columns (OWCs) for shoreline/nearshore deployment and offshore point absorbers. Because of commercial sensitivity, these devices are currently depicted by anonymous titles (e.g. OWC1, OWC2, PA1, PA2, etc.).

The cost of generation from wave energy is presented in terms of €/kWh and is calculated in the following manner—

D 2.3.1 Capital costs

The capital cost of the wave energy devices is determined using a peer reviewed costing model that has been developed over 13 years and which has been used on numerous schemes by Future Energy Solutions and the UK Department of Trade and Industry[17,18]. It comprises a spreadsheet, which employs a modular approach to define the four major cost centres for any wave power scheme—

- Device structure
- Mechanical and electrical plant[a]
- Electrical transmission
- Transportation and installation.

The scheme is described by three sets of parameters—

- Project Parameters. These define the type, scale, location and time scale of the project (e.g. device type, total output etc.)
- Independent Parameters. These describe the location of the construction yard, area for deployment and point of connection to the National Grid, as well as the water depth and seabed condition at the device site.
- Dependent Parameters. These can be deduced from the foregoing parameters by algorithms or defaults. One example of an algorithm is how the device type, total output and project duration would define the total number of devices, the number to be built each year, and hence the size of the construction facility. Typical

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[*] A currency conversion rate of €1.6 to £1 has been used throughout this analysis.

[a] All other parts associated with the operation of the device, these depend greatly on the nature of the device

defaults would be the type of M&E plant or the amount of concrete used in construction for each device type.

Costs are calculated by assigning default values to various parameters or algorithms derived from them. This approach allows designs, which are in their early stages of development to be assessed. However, for more developed designs, a 'What if' facility was incorporated in the spreadsheet, which permits the user to override the defaults used. This allows the model to accommodate increasing levels of detailed design information as and when the device developers can make it available.

It should be emphasised that the capital costs calculated in such a manor represent the expected costs from large-scale deployment of full researched and mature wave energy technologies. The capital costs of early schemes are expected to be much higher (possibly by a factor of 2-3), because of a number of factors—

- Technical immaturity (learning curve benefits will follow)
- Perceived risk (which will inflate the costs of the initial schemes)
- Lack of economies of scale initially
- Mobilization costs for small schemes are disproportionately high.

D 2.3.2 Availability

The system availability has been defined as the probability of the whole system functioning at any specific time and is therefore taken to include the effects of scheduled maintenance and breakdowns (i.e. both unforced and forced outages). In simple systems requiring no maintenance, the fractional availability, A, can be calculated as—

$$A = \frac{\mathrm{MTBF}}{\mathrm{MTBF} + \mathrm{MTTR}}$$

Equation D.6

where MTBF is the mean time between failures and MTTR is the mean time to repair a failure.

A simple, spreadsheet-based availability model was developed for the previous UK Review of Wave Energy[17,18], which used failure rate and repair time data from a wide range of sources to predict the availability. The model also predicts the repair loading, which is the number of hours repair activity required for each hour of the scheme's operation. For instance, a repair loading of 10 hours/hour implied that 10 repair crews were required to work full-time (24 hours per day) or 30 repair crews were required to work normal eight-hour shifts. Two types of repair loading were calculated—

- ***Active Repair Time.*** This covered the time actually spent at the various fault sites carrying out the repairs.
- ***Active Plus Transit Repair Time.*** This covered not only the active repair time outlined above but also the time spent reaching the fault location. For failures in offshore items, this included both the time required for a repair ship to reach the fault location and any delays which could arise from waiting for a suitable weather window.

D 2.3.3 Operation and maintenance costs

Good maintenance procedures are essential if any energy technology is to perform successfully. However, in addition to this planned maintenance there will be other, unscheduled outages due to component failure. Therefore, any estimation of annual O&M costs has to encompass both these aspects. This assessment evaluates four main components of O&M costs.

- ***Cost of Spares***. These are the costs associated with providing spares to replace faulty equipment. In order to ensure that the wave power scheme has an adequate supply of replacement parts, it has been assumed that M&E spares sufficient for one year would be held. A simple estimate of the one-off cost associated with complete replacement of equipment failing during one year’s operation was obtained from multiplying failure rates by replacement costs. The annual number of failures of each major M&E and transmission subsystem was derived from the MTBF calculated in the availability assessment. The capital cost associated with each subsystem was calculated using the parametric capital cost model.
- ***Repair Costs***. In practice, the faulty equipment replaced by the spares in the paragraph above would be repaired and used as spares in the future. This would entail an additional repair cost which would be some fraction of the above figure. For the purposes of the review, this fractional replacement cost factor for M&E plant was taken to be 10 % of the capital costs obtained from the parametric capital cost model.
- ***Operational Costs***. These are the costs associated with providing maintenance crews and vessels to enable repairs to be carried out. The availability assessment provided an estimation of the number and types of repair crews required to provide the level of availability for each device as calculated in Section D 2.3.2. The parametric capital cost model provided data on manpower costs, vessel hire rates etc.
- **Insurance Costs** were taken to be 1-2 % of capital costs per annum.

D 2.3.4 Annual output

The average annual output has been determined in four main steps.

- ***Available Wave Power.*** The amount of wave energy available for capture has a strong influence on the amount of energy any device can generate. It is a function of location, water depth and local seabed topography and has been studied for a number of locations (see Figure D-10).
- ***Captured Wave Power.*** The efficiency with which a particular device captures wave power is a function of the sea state. Most devices have been tested in wave tanks to determine this aspect of their performance. In those cases where no such data are available, theoretical analysis had to be used. The applicability of such data to the performance of full-size devices is an area of uncertainty.
- ***Maximum Annual Output***. The amount of energy delivered to the grid from a particular device in a given sea state depends on the losses in the power chain (turbines, generators, rectifiers, transformers, transmission lines etc.). Data exist on the relative losses as a function of power level and rating of electrical equipment but often the performance of mechanical plant had to be estimated from theoretical assessments.
- ***Actual Annual Output***. The amount of energy predicted by the above calculations assumes that the wave energy scheme functions continuously (i.e. without

failure). In practice there will be periods of reduced output due to breakdown and maintenance and an availability model was developed to model these and their effect on electrical output, as outlined above.

D 2.3.5 Generating costs

There are three main factors which make up the annual running cost of any power station—fuel, repayment of capital costs and payment of recurrent costs such as insurance and O&M.

The annual sum involved in repayment of the capital cost of a wave power scheme can be assessed in a number of ways. The approach adopted here was that used in previous appraisals, namely amortisation of the capital costs over the complete lifetime of the scheme using various discount rates. Therefore, if a scheme can be built in one year for a capital cost of C, then the annual sum repaid (Ann) at a discount rate (r) is given by—

$$Ann = \frac{Cr}{\left[1-(1+r)^{-n}\right]}$$

Equation D.7

where n is the lifetime of the project (in years). Therefore, for such a simple scheme, the cost of electricity (E) is given by—

$$E = \frac{Ann + O\,\&\,M\,Costs}{Annual\ Output}$$

Equation D.8

The capital cost is discounted over the lifetime of the project at 8 % discount rate. This is in keeping with the practice long adopted in the UK Department of Trade and Industry's programme on Renewable Energy[a], which assesses generating costs at 8 % and 15 % discount rate. An assessment of the likely discount rate is made in Section D 1.6, which indicates that a discount rate of 10 % is more likely. In practice, the test discount rate applied will vary with the source of finance. Future Energy Solutions from AEA Technology has carried out due diligence on a variety of wave energy schemes for a range of potential investors. The test discount rates used by the investors ranged from 10 %-25 % over 10-20 years.

D 2.3.6 Shoreline and near shore OWCs

Three different types of OWC were evaluated for both shoreline and nearshore deployment. Since the costs and output are site specific, these results should be taken as indicative and not representative of the optimum location of each device. In particular, siting OWCs in 'hot spots' can significantly enhance its economic performance.

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[a] Previously the Department of Trade and Industry New and Renewable Energy Programme and before that the Department of Energy New and Renewable Energy Programme

While the capital cost breakdown for these OWCs are very similar (Figure D-1), the capital costs per unit rating (€/kW) are very different (Figure D-2). However, as noted above, these devices are not optimised, so the ratings of their mechanical and electrical (M&E) plant might not be the best for the selected locations. This view is supported when the cost are expressed in terms of unit output (i.e. €/MWh/year)—the average deviation is less than half that found in cost per unit rating (24 %-56 %).

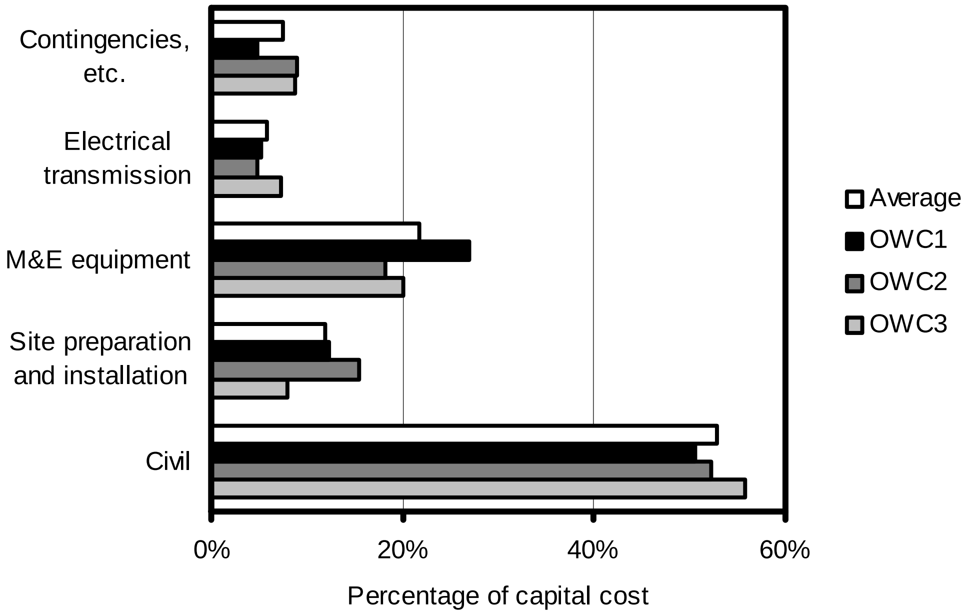

Figure D-1 Capital Cost Breakdown for OWCs

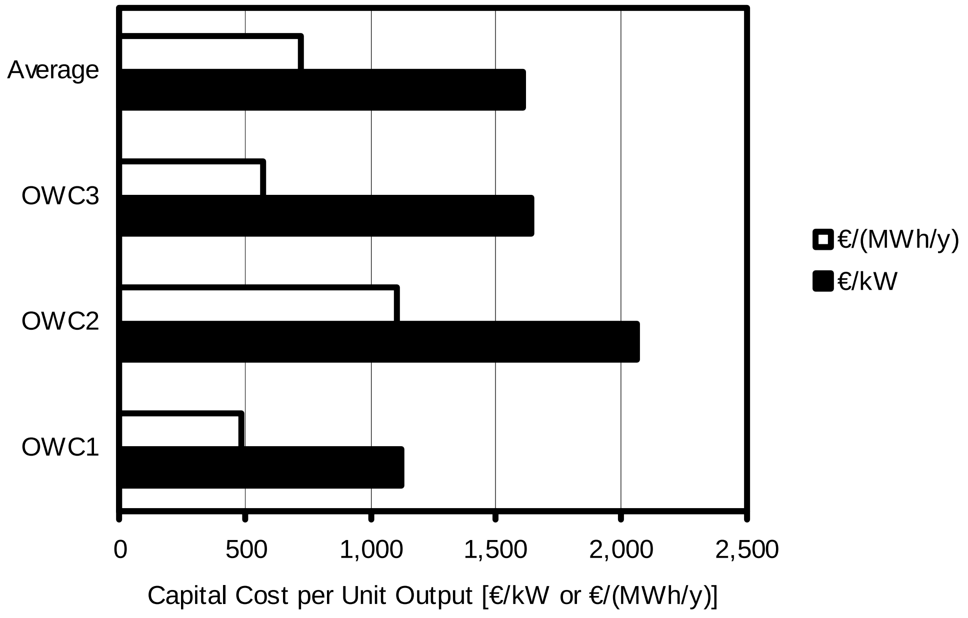

Figure D-2 Comparison of Capital Cost per Unit Output and Rating for OWCs

This comparison suggests that more confidence can be placed in costs when expressed in terms of output. Therefore, it is this range of values, which will be used in assessing the market.

The likely generating costs of the OWCs were calculated as a function of the average offshore wave power level (taking a representative range of transformation of offshore to nearshore/shoreline wave power levels). The range of resulting generating costs is shown in Figure D-3. The predicted characteristics of a number of OWCs in representative locations have been listed in Table D-6, so that the reader can apply their own economic analysis.

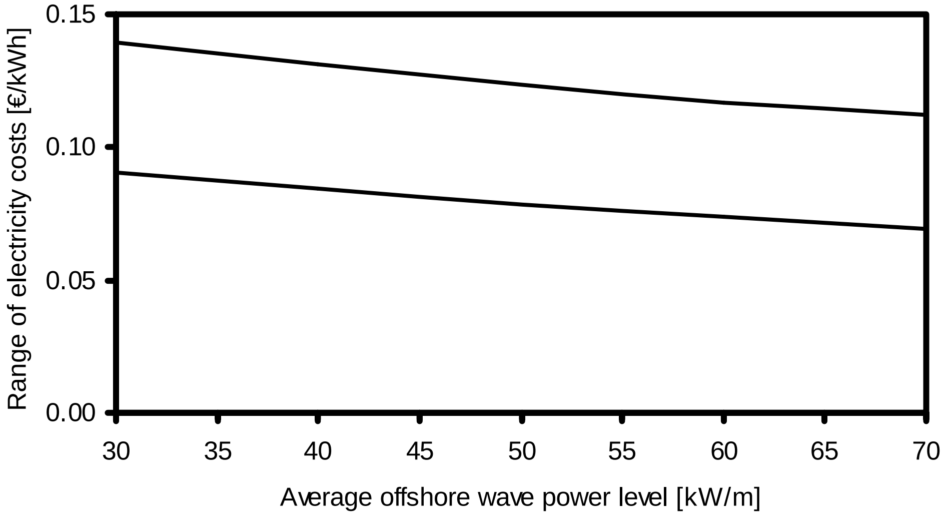

Figure D-3 Range of Likely Generating Costs for OWCs (@8 % Discount Rate)

	Capital cost [€m]	Output [GWh/year]	Annual cost [€]
OWC1	57.3	99.3	1,780,960
OWC2	2.1	1.9	41,280
OWC3	11.3	23.2	160,000

Table D-6 Summary of OWC characteristics in representative locations

D 2.3.7 Offshore devices

There are three, very different types of offshore point absorber currently being deployed (Devices 1-3), each designed for a different location and ranging in size from under 100 kW to over 5 MW. In addition, there are two other point absorbers currently at the design stage—the PS Frog and the Sloped IPS Buoy[18].

Since the costs and output are site specific, these results should be taken as **indicative** and not **representative** of the optimum location of each device.

The capital cost breakdown for these devices are very different (Figure D-4), reflecting the disparate technologies and size of device. The capital costs per unit rating (€/kW) are also different (Figure D-5). However, as noted above, these devices are not optimised, so the ratings of their mechanical and electrical (M&E) plant might not be the best for the selected locations. This view is supported when the cost are expressed in terms of unit output (i.e. €/MWh/year), as also shown in Figure D-5—the average deviation is less than half that found in cost per unit rating (26 % v 57 %).

This comparison suggests that more confidence can be placed in costs when expressed in terms of output. Therefore, it is this range of values, which will be used in assessing the market.

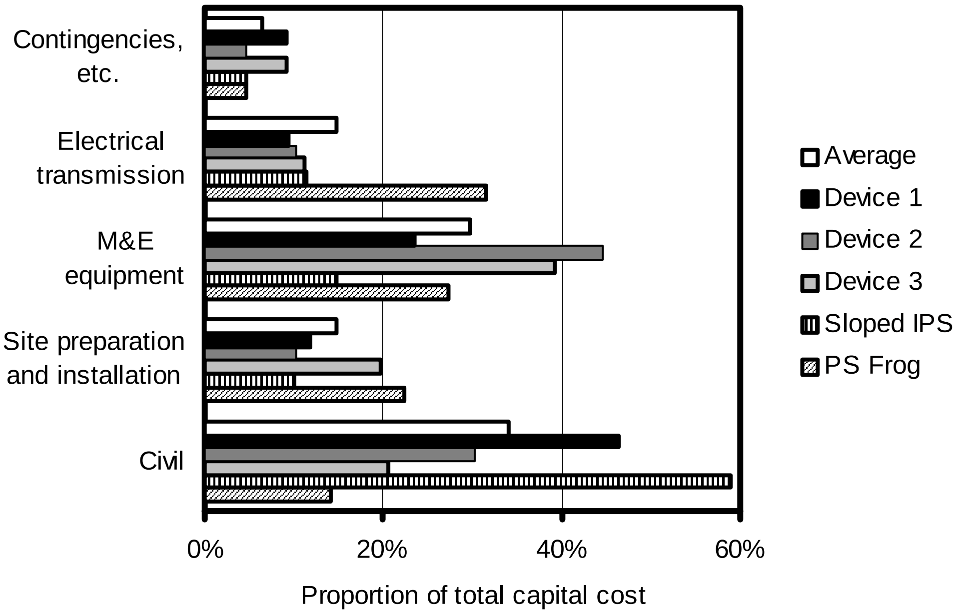

Figure D-4 Capital cost breakdown for Point Absorbers

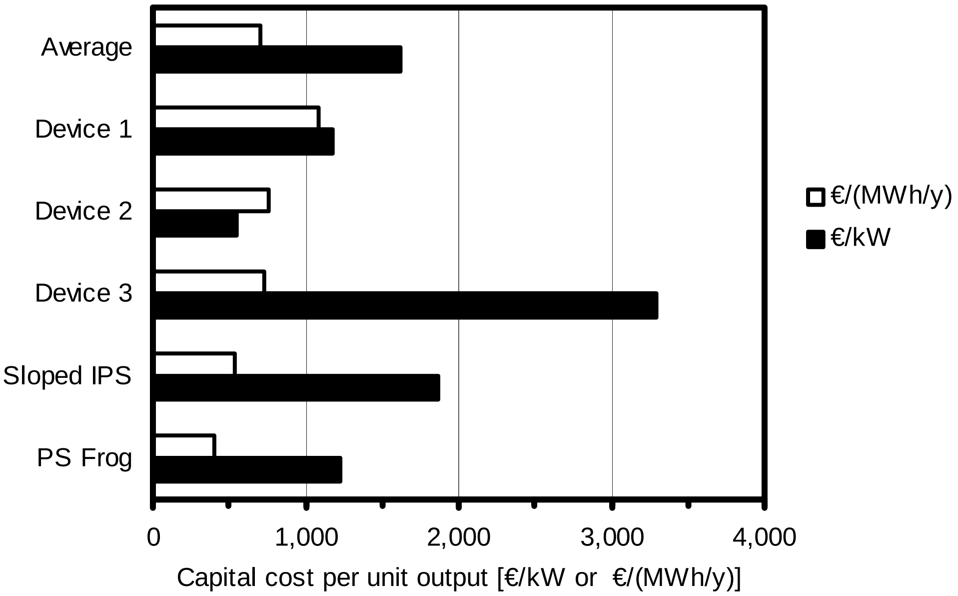

Figure D-5 Comparison of cost per unit output and rating for Point Absorbers

The likely generating costs of the point absorbers were calculated as a function of the average offshore wave power level. The range of resulting generating costs is shown in Figure D-6. The predicted characteristics of a number of offshore devices in representative[a] locations have been listed in Table D-7, so that the reader can apply their own economic analysis. It should be noted that there are other offshore devices that appear to have lower predicted generating costs (when assessed by the same methodology) but they were at an early stage in their development when this analysis was carried out and so have been excluded.

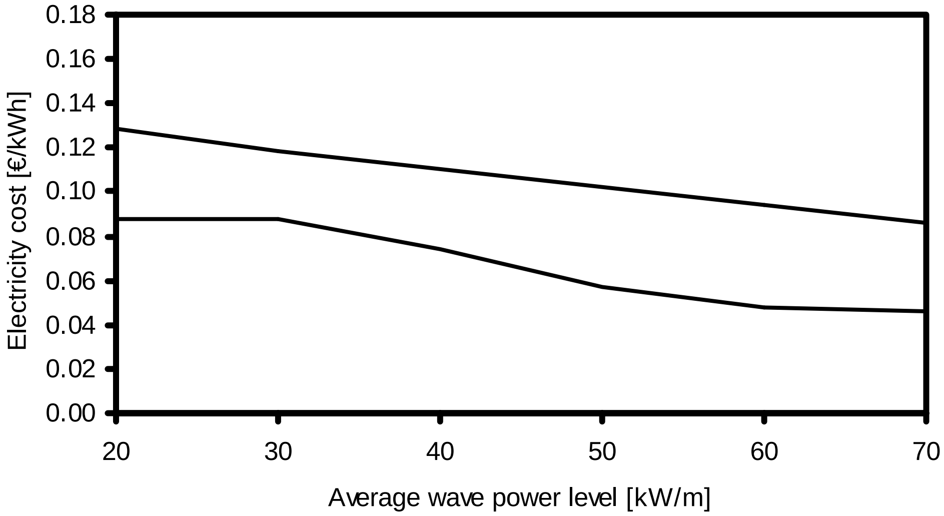

Figure D-6 Range of Likely Generating Costs for Point Absorbers (@8 % Discount Rate)

	Capital cost [€m]	Output [GWh/year]	Annual cost [€]
Device1	47.3	43.4	1,514,080
Device2	42.0	55.5	923,040
MWP	16.5	22.5	496,800
Sloped IPS	56.2	103.6	1,299,680
PS Frog	18.5	45.7	92,320

Table D-7 Summary of offshore device characteristics in representative locations.

D 2.3.8 Development of wave energy

The devices evaluated above represent a considerable improvement on the devices developed as part of the original UK Wave Energy Programme until 1982[19]. This is shown by the lower costs per unit output in Figure D-7.

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[a] Representative of the location for which the energy assessment was made and to for which the device was designed.

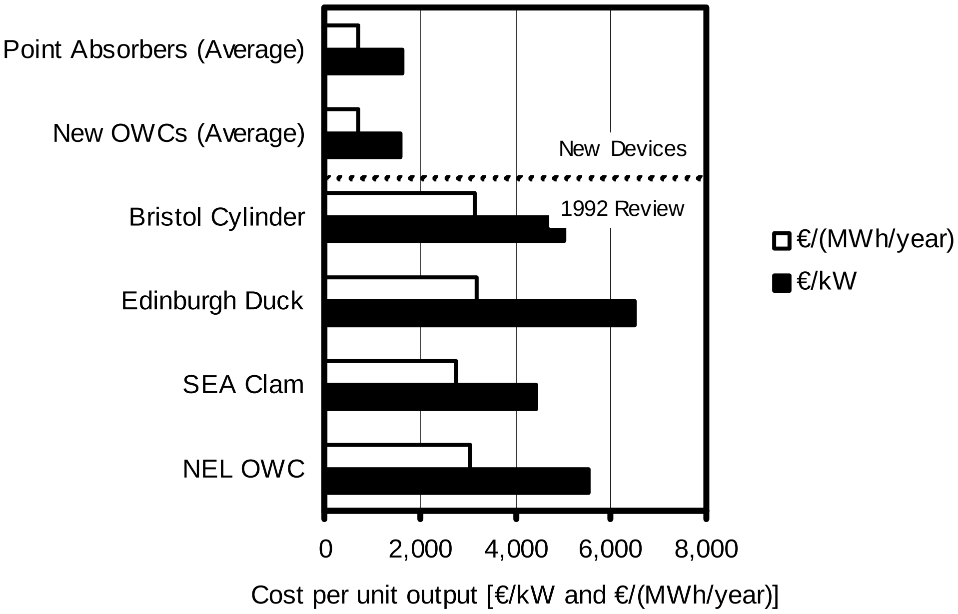

Figure D-7 Improvement in Wave Energy Devices

The same methodology used above for calculating generating costs was applied to a range of devices designed from 1982 onwards[16,18,20]. The resulting improvements in economics with time are illustrated in Figure D-8 and Figure D-9.

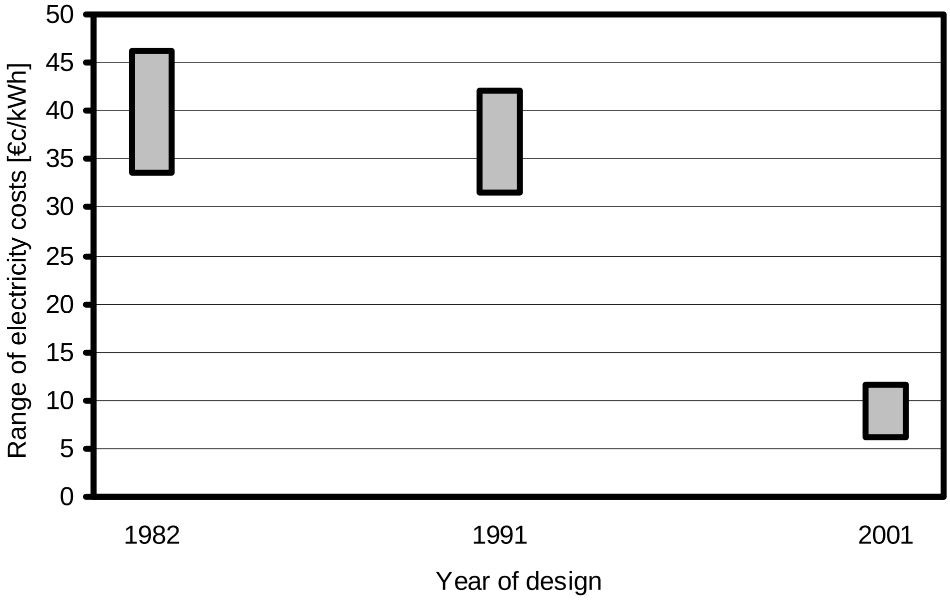

Figure D-8 Development of Generating Costs for OWCs (@8 % Discount Rate)

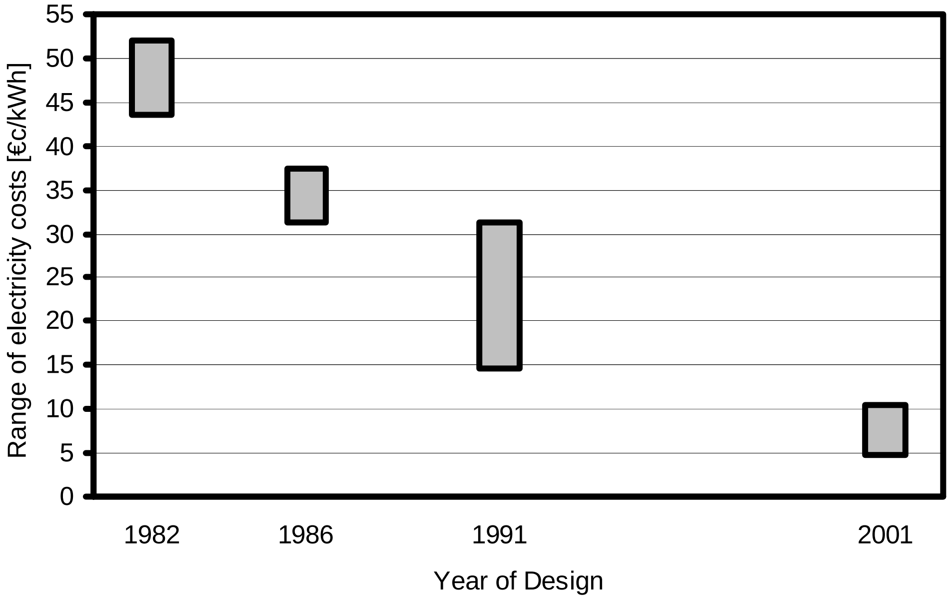

Figure D-9 Development of Generating Costs for Offshore Devices (@8 % Discount Rate)

The source of the cost reductions for 1982-1991 are described in the 1991 UK Wave Energy Review. The analyses carried out in that review highlighted some significant problem areas associated with each particular device. The review looked at these problem areas and—with the approval of the device developers—suggested solutions. The impact of these solutions was then evaluated. These problem areas could be with the capital cost (as in the case for the SEA Clam, which was resolved by changing the construction material from welded tubular steel to concrete). However, they were mainly associated with availability.

The cost reductions post 1991 have derived from a number of sources—

- Devices have become smaller in rating. The UK Wave energy Programme developed devices which were multi-megawatt, with large capital costs arising from significant problems involved in construction and deployment. Since then, device developers have followed the trends in wind energy and started small, which reduced construction problems and eased deployment.
- Devices benefiting from technical developments elsewhere. There are ongoing developments in the areas of civil construction, hydraulics, electrical generation and transmission that are transferable to wave energy. This allows device developers to use cheaper, more efficient construction methods and components. An illustration of this is that all the devices developed in the UK Wave Energy Programme required significant R&D before they could be deployed even as prototypes[21]. In contrast, Ocean Power Delivery intends to construct its Pelamis wave energy device using 'off the shelf' components thus avoiding the need to do R&D for some of the sub-system components.
- Learning curve. It is sometimes forgotten that the activities undertaken between 1975 and 1990 marked the beginning of a whole range of technical developments that are associated with wave energy; it marked the birth of a new science (so to say). Understanding of these various areas has continued to progress. This has had

> implications for improvements in the design of wave energy devices. This is illustrated by the design of offshore devices, which have moved away from large monoliths towards smaller, highly efficient devices, many of which now function as point absorbers.

However, as noted earlier, these cost predictions (and associated reductions) assume that the devices achieve their full potential and benefit from economies of scale—prototypes and the first schemes will have higher generating costs than indicated in Figure D-8 and Figure D-9.

These predicted cost reductions are similar to those in other new, renewable energy technologies; for instance, in the USA ‘The cost of energy from wind has decreased from more than \$0.35/kilowatt-hour (kWh) in the seventies to less than \$0.05/kWh today’[22].

D 2.4 The market for wave energy

As emphasised before, the above results are indicative; actual device costs and output will vary with wave power level and location (e.g. distance offshore). These variations have been modelled for the new class of OWCs and point absorbers in order to evaluate their likely market.

D 2.4.1 Global wave power levels

The global wave power resource is taken to be the power intercepted by a line along the coasts of countries facing the major oceans (i.e. it avoids assuming advanced schemes such as devices strung out in mid-ocean and it ignores the resource in small seas such as the Mediterranean). The wave power levels around most of the world are known only approximately. The available information has been drawn together and is reproduced in Figure D-10. On the basis of this information, the global wave energy resource in deep water is ~1.3 TW[a].(ignoring those coastlines with very low wave power levels). This figure is close to previous estimates of this resource[23]. It could be increased if lines of wave energy devices were deployed in stages across the major oceans but (at present) the costs of transmitting electricity from such remote locations would be prohibitive.

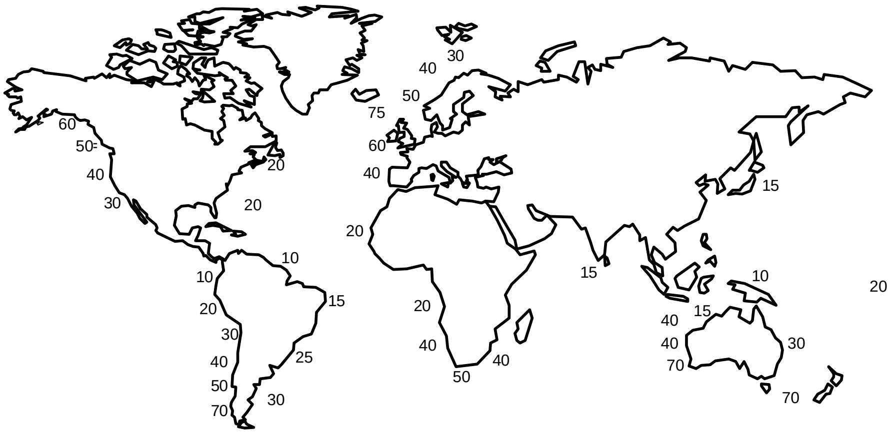

Figure D-10 Approximate Distribution of Wave Power Levels

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[a] 1 TW (terawatt) is equivalent to 1,000,000,000,000 kW.

D 2.4.2 The technical wave energy resource

The Technical Resource is taken to be the total amount of electricity that can be converted from wave energy regardless of economics. This value will take into account various factors, including—

- Variation of wave power level
- Capture efficiency
- Losses in the power chain (including transmission losses)
- Availability
- Limitations of density of deployment arising from sociological and ecological factors (e.g. allowance for shipping, fishing, etc.).

It is assumed that wave energy devices are unlikely to be deployed unless there are at least moderate offshore wave power levels (i.e. 10 kW/m or greater). Whilst this might appear to be a low threshold value, some devices are designed to work best in conditions of low but constant swell, representative of low average annual wave power levels. The electrical output from the various devices evaluated in the last section was determined for a range of wave power levels and conservative assumptions were made concerning the maximum deployment density. The demand for wave energy was assumed to depend on the population density using very conservative estimates—

- High population density would allow one scheme every 5 kilometres
- Medium population density would require one scheme every 10 kilometres
- Low population density would require one scheme every 100 kilometres.

These deployment densities were reduced by a further factor of 10 for shoreline/nearshore OWCs.

Depending on the device, the Technical Resource for shoreline/nearshore OWCs varied from 5-20 TWh/year. This corresponds to a potential global market of €400 m-€1,600 m. Depending on the device, the Technical Resource for offshore point absorbers varied from 140-750 TWh/year. This corresponds to a potential global market of €100 b-€800 b[a].

D 2.4.3 The economic wave energy resource

The Economic Wave Energy Resource is lower than the Technical resource, because it takes into account whether the device is economically competitive with other forms of electricity generation.

All the devices studied above were found to be economically competitive for either primary or secondary electricity supply, depending on the wave power level. At present, these findings are commercially sensitive and their release would have to be agreed with the device developers. Therefore, in order to present a realistic view of the likely economic potential, the Economic Resource has been defined for each device as the Technical Resource for various cut-off wave power levels (i.e. the offshore wave power levels at which the various devices would become economic).

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[a] 1 b corresponds to 1,000,000,000.

The results for the shoreline/nearshore wave power devices are shown in Figure D-11 and Figure D-12. Since most of these devices start to become economically competitive at offshore wave power levels of 40 kW/m and above, the likely Economic Resource is €1,000 m-€6,000 m.

The results for the offshore wave power devices are shown in Figure D-13 and Figure D-14. Since some of these devices also start to become economically competitive at offshore wave power levels of 30 kW/m and above, the Economic Resource could be as high as €50 b-€280 b.

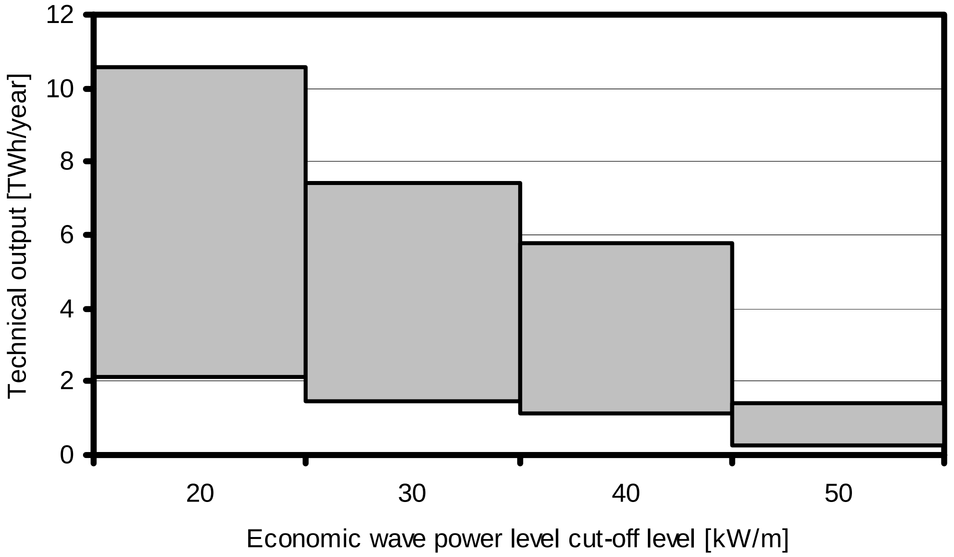


Figure D-11 Effect of Offshore Wave Power Level on Shoreline/Nearshore Economic Resource

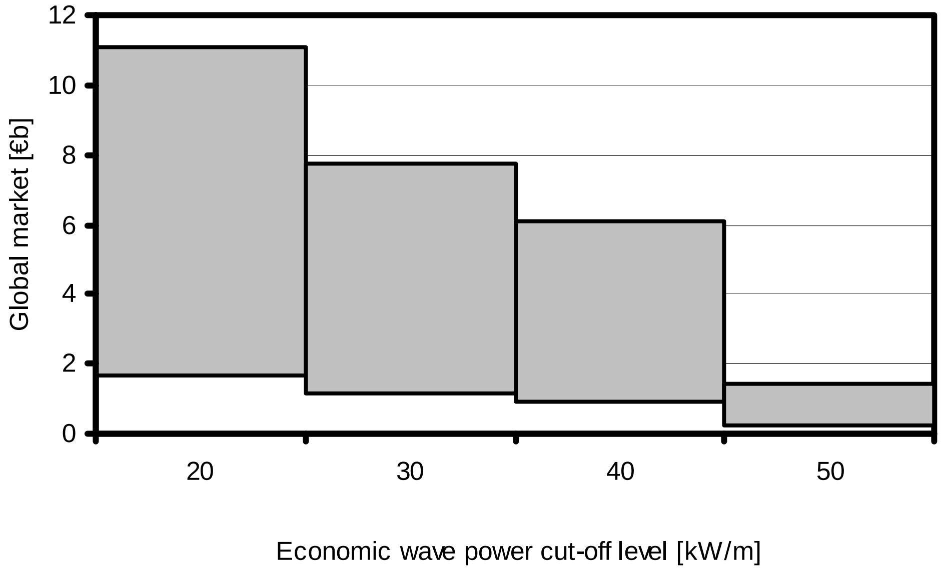


Figure D-12 Effect of Offshore Wave Power Level on Shoreline/Nearshore Market

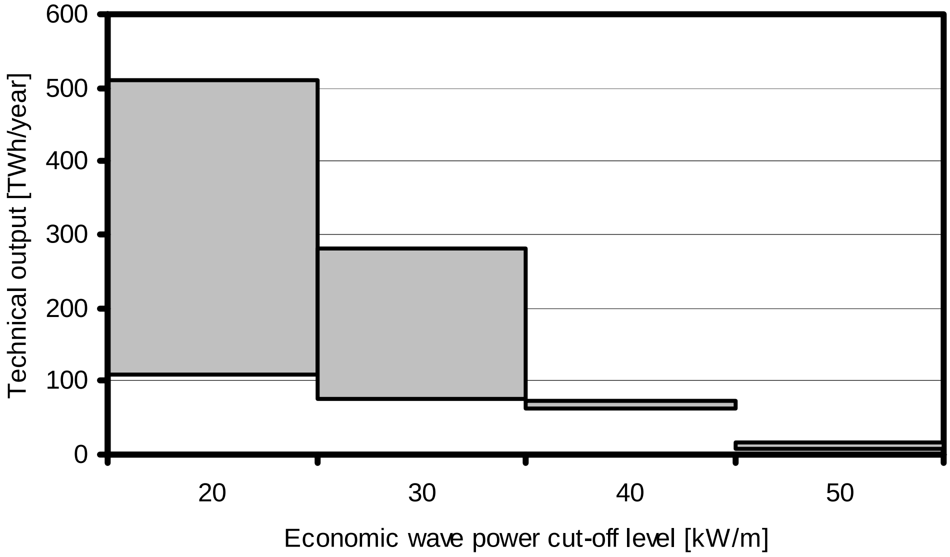


Figure D-13 Effect of Offshore Wave Power Level on Offshore Economic Resource

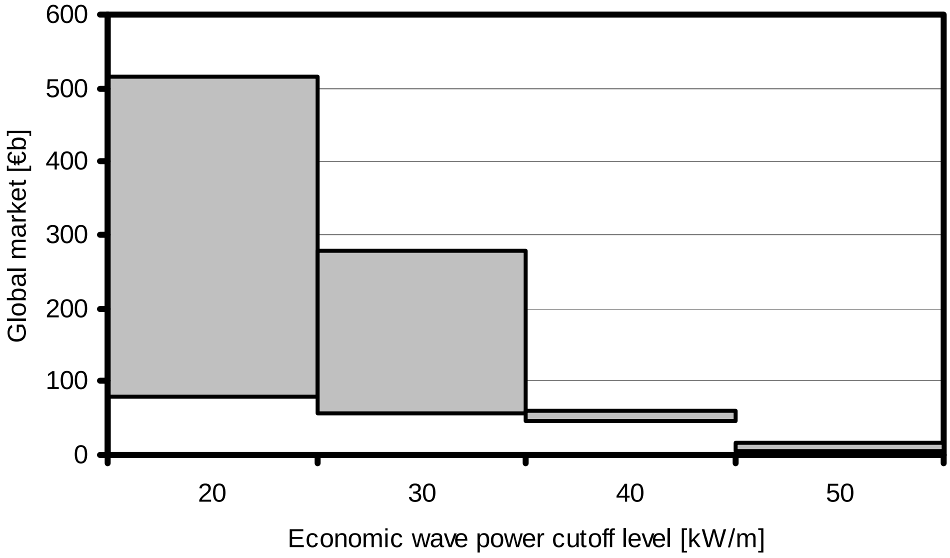


Figure D-14 Effect of Offshore Wave Power Level on Offshore Market

D 2.5 Market status of wave energy

D 2.5.1 EU activities

Technologies for extracting energy from waves are currently being developed in several European countries: Denmark, Eire, Greece, the Netherlands, Portugal and the UK. Other countries (France, Germany and Spain) have a suitable wave energy resources, which could be exploited using these technologies.

The development work is being undertaken by both Governments and private industry (primarily SMEs). Table D-8 shows a summary of the main European SMEs and organisations active in the commercial development of a wave energy device. Those companies marked with an asterisk (*) have either deployed demonstration schemes or have developed plans for deployment of full size devices in the next two years.

In addition to these, there are numerous academic establishments that make a substantial contribution to this technology as well as important, government supported programmes in Denmark, Portugal and the UK.

Sufficient manufacturing capability exists within the EU to make it self-sufficient for this technology, although there is likely to be trading/technology transfer between EU countries and exports to non-EU countries as the technology approaches commercialisation. However, use has already been made of cheaper construction costs in former CIS states for a demonstration scheme by an EU company to be deployed in Portugal.

D 2.5.2 Activities outside EU

The last few years has seen a considerable increase in wave energy outside the EU. There have been government programmes in China, India and Japan. However, most of the activity has taken place in industry (see Table D-9). This varies from several companies offering off-the-shelf wave energy devices at a small scale up to several companies engaged in commercial demonstration schemes of larger scale devices (the latter are marked with an asterisk, *).

Whilst lagging many years behind Europe in wave energy, some of the overseas companies are very active in this area (in both a technical and commercial sense) and are likely to have commercial schemes deployed before most European companies.

Country	Company	Address	Tel No	Fax No	Web site or emaill address
Denmark	KN Consult ApS,	Kolding, Jernbanegade 32A, 6000 Kolding	+45 75 50 91 04	+45 75 50 91 94	www.kn-consult@vip.cybercity.dk.
	Waveplane International A/S	Tagesmindevej 1, DK 2820 Gentofte	+45 3975 1213	+45 3975 1214	www.waveplane.com
	EMU Consult	Blegdamsvej 4—1. tv.DK- 2200 Copenhagen	+45 3536 0219	+45 3537 4537	www.emu-consult.dk
Eire	Hydam Ltd*	White Lodge, Ballymaquirke, Kanturk, Co. Cork	+353-2956064		
	DuQuense Environmental Ltd.	Blessington, Co. Wicklow	+353-45865233	+353-45891271	
Greece	DAEDALUS Informatics Ltd	22 Ikarias str., Glyfada 16675, Athens	+30-19643 355	+30-19627 444	www.daedalus.gr
	CRES		+301 603 9900		glemon@cres.gr
Netherlands	AWS B.V.*	De Weel 20, 1736 KB Zijdewind	+31-226423411	+31-226423433	teamwork@multiweb.nl
Portugal	INETI*		+351-1712 7201	+351-1712 7195	teresa.pontes@mail.ineti.pt
Sweden	Interproject Service AB*	Gripensnäs S-640 Bettna	+46-15770380	+46-15770303	
	Sea Power International AB*	Odengatan 7, 114 24 STOCKHOLM	+46-8-100656	+46-8-109069	www.seapower.se/i
	Oceanor	N-7462 Trondheim,	+47 73 54 52 00	+47 73 54 52 01.	oblea.oceanor.no
UK	Ocean Power Delivery Ltd*	2 Commercial St, Edinburgh, EH6 6JA, Scotland, UK	+44-1315548444	44-1315548544	www.oceanpd.com
	Wavegen*	50 Seafield Road, Longman Industrial Estate, Inverness, IV1 1LZ	+44-1463238094	+44-1463238096	www.wavegen.co.uk

Table D-8 Main SMEs and Governmental Establishments Active in Deploying Wave Energy in Europe

Country	Company	Address	Tel No.	Fax No.	Web site or emaill address
Australia	Energetech Pty. Ltd*	100 Frenchmans Road, Randwick 2031	+61-293264237	+61-293264237	www.energetech.com.au
Israel	SDE Energy & Desalination Ltd.	19 Lubetkin St., Tel-Aviv, Israel 67532	+972-37397107	+972-36319239	www.beacon.co.il/SDE/
Japan	Ryokuseisha Corporation	Export Marketing div. 15-14, Tsukiji 2-Chome, Chuoku, Tokyo 104	+81-335424751	81-3-3542-4757	www.ryokusei.co.jp
Japan	Takenaka Corporation	1-13, 4-chome, Hommachi, Chuo-ku, Osaka 541-0053	+81-662521201	+81-662710398	www.takenaka.co.jp
Japan	JAMSTEC				
Switzerland	ATI Alternative Technological Innovation Ltd,	Tösstalstrasse 345, CH-8496 Steg	+41-55-245 22 21	41-55-2452221	
USA	Ocean Power Technologies*	1590 Reed Road, Pennington, NJ 08534	001-6097300400	001-6097300404	gtaylor@oceanpowertech.com
USA	Ocean Motion International	525 Kern Ave., Morro Bay, CA 93442)			
USA	Ocean Wave Energy Company	2 Rhode Island Avenue, Providence, RI 02906	001-4012534488		http://www.owec.com/
USA	Kepler Buoy	250 D South Lyon Avenue # 216, Hemet, California [92543]	001-8013709977		www.jeffry.com/technology/bwt/avail_now/kepler.htm
USA	Eberle Energy Enterprises	1351 Westpark Way, Euless, Texas 76040	001-2146306751		

Table D-9 Main Non-European Companies Active in Deploying Wave Energy Devices

D 2.5.3 Implementation support measures in the EU

After the run down of the national programmes of the 1970s and 1980s, the principal support measures used to encourage wave energy development by the EU have been—

- Wave studies leading to the development of a resource evaluation methodology and a wave energy ‘atlas’;
- Generic technical evaluation studies of wave energy converters;
- Development of a European pilot plant on the Azores (together with assorted M&E plant);
- Establishing a European wave energy research network.

Now, two countries are providing further implementation support—

- **Denmark.** Following its support of the DWP float-pump device, the Danish Government has established a wave energy programme to support research into other wave energy devices.

- **UK.** Within the last year, wave energy has received direct funding from the UK Government for specific R&D activities which has been supplemented by the EU Joule programme. The UK Government will cease further funding of the programme once current commitments end in 1997. Wave energy does not receive NFFO or SRO support as yet.

Therefore, there no support measures to report other than the backing of R&D by the EU and Governments.

D 2.6 Environmental economics

Prepared by:	**Richard Boud, Tom Thorpe, Future Energy Solutions**

D 2.6.1 Introduction

Another factor affecting the economics of wave energy (and other renewables) is potential environmental cost. Renewable energy technologies are currently at a disadvantage compared to conventional methods of electricity generation. The latter can cause environmental damage to a wide range of receptors, including human health, natural ecosystems and the built environment. Such damages are referred to as ‘external costs’ or ‘externalities’, because they are not reflected in the market price of energy. Traditional economic assessment has ignored externalities. However, there is a growing interest in adopting a more sophisticated approach involving the quantification of the environmental and health impacts of energy use and their related external costs. This is being driven by factors such as the need to integrate environmental concerns when choosing between different fuels and energy technologies and the increased attention to the use of economic instruments for environmental policy (making the polluter pay). As a result, there has been an increasing recognition of the importance of external costs and the need to incorporate them in policy and decision making within the European Union. This led the European Commission to fund a major R&D Research Programme (known as the ExternE Project) to attempt to use a consistent ‘bottom-up’ approach to evaluate external costs associated with energy use[24].

The results of the first phase of the project (Table D-10) show indicative external costs from the fossil-fuel generating technologies. In addition to the values in Table D-10, there is also the contribution of fossil-fuel cycles to global warming. There is considerably greater uncertainties associated with these values but they are likely to be similar in magnitude to those listed in Table D-10 (i.e. giving a total of more than 3 ¢/kWh US).

If these external costs are incorporated into the generating costs for conventional technologies, they will increase the economic competitiveness of wave energy devices.

	Damage* (US ¢/kWh)		
	Coal	**Oil**	**Gas**
Public health	1.28	1.41	0.27
Occupational health	0.20	0.06	0.01
Crops	0.00	0.01	0.00
Timber	0.00	0.01	0.00
Marine ecosystems	0.00	0.03	0.00
Materials	0.06	0.09	0.01
Noise	0.03	0.03	0.00
Sub-total	1.54	1.66	0.17
Other Impacts	-	-	-

* Excludes global warming, whose inclusion is likely to double the values (at least).

Table D-10 Indicative estimates of external costs for fossil-fuel cycles

D 2.6.2 Environmental effects of wave energy

Wave energy devices produce no gaseous, liquid or solid emissions and hence, in normal operation, wave energy is virtually a non-polluting source. However, the deployment of wave power schemes could have a varied impact on the environment. Some of the effects may be beneficial and some potentially adverse. These will be assessed with reference to a typical nearshore device, the OSPREY. In general, these impacts will be greatly reduced for floating offshore devices and increased for shore-based devices.

D 2.6.3 Near-shore devices

The limited experience with wave power schemes makes it possible to form only an incomplete picture of possible environmental effects caused by wave power devices. This is reflected in Table D-11, which summarises potential impacts. Many of the potential impacts would be site-specific and could not be evaluated until a location for the wave energy scheme is chosen. The main effects that wave devices may have are discussed below, together with areas of uncertainty with our present level of knowledge.

Hydrodynamic environment

Wave energy converters may have a variety of effects on the wave climate, patterns of vertical mixing, tidal propagation and residual drift currents. The most pronounced effect is likely to be on the wave regime. A decrease in incident wave energy could influence the nature of the shore and shallow sub-tidal area and the communities of plants and animals they support. Fixed structures such as the OSPREY are more likely to alter the wave climate than floating devices.

Previous modelling work in this area is limited, although modelling carried out for the assessment of wave energy converters off the coast of the Outer Hebrides indicated that devices tuned to medium period waves and sited less than 30 km offshore would reduce wave steepness at the shore and affect the sedimentary budget, favouring accretion[25]. However, the extent of this accretion may be minimal as material available for mobilisation may be limited.

Environmental Effect	Size
Construction/maintenance sites	S
Recreation	S
Coastal erosion	S-M
Sedimentary flow patterns	S
Navigation hazard	S
Fish & marine biota	S
Acoustic noise	S
Endangered species	S
Device/mooring damage	S-M

Key: S—small, M—medium, L—large

Table D-11 Possible environmental impacts of near-shore wave energy devices

Changes to the wave regime along the shoreline would change the composition of the shoreline and possible near shore sub-tidal communities. Any large-scale scheme would require a full feasibility study to determine the effects on sedimentary processes within the region and the flora and fauna typical of the region.

Devices as artificial habitats

Interactions between devices and the marine environment are made more complex by the fact that the devices would represent new habitats. Offshore oil and gas installations provide attachment surfaces for a variety of algae and invertebrates, so wave energy converters would be colonised by fouling organisms. The species recruited to these sites would depend on the species communities within the vicinity of the device, distance offshore, water depth and clarity, prevailing weather conditions and position relative to coastal currents and the speed of those currents[26]. There would be a seasonal factor involved in the build up of this community with the main build up of fouling extending from about April to November.

It is inevitable that anti-fouling measures would be necessary where, for instance, attached organisms cause changes in corrosion and fatigue behaviour, hinder inspection and maintenance, etc. Fouling prevention measures specific to wave energy converters have yet to be developed, but could include the use of anti-fouling paints or direct injection of biocides. Fouling of seawater conduits at coastal power stations has been controlled by injection or electrolytic generation of chlorine. Due to the effects of dilution, it is not clear if the use of this measure at a more open sea location might be environmentally harmful. Certainly chronic impacts may result if the chlorine was allowed to react to form chlorinated organics that tend to bioaccumulate and persist in the environment, although this would appear to be unlikely in open waters. There are numerous options for the removal of marine fouling, each of which has its relative merits. None of these poses any significant environmental problem although some (e.g. high-pressure jets) could be hazardous to the user.

Artificial structures can be very effective in concentrating pelagic fish depending on such factors as water clarity (i.e. visible range of the structure), distance offshore and depth, which influence the species likely to be available. It is nevertheless probable that if fish were to use such structures for shelter, fish eating seabirds and marine mammals would be attracted to device arrays. Both these aspects could enhance opportunities for local employment by increased fishing and tourism.

There is a need to consider what would happen to the wave converter arrays at the end of their working life. Relinquishing seabed mounted devices to natural erosion or reducing them to rubble on the seabed would cause a permanent alteration to the inshore environment; they would in effect become reefs. Construction of artificial reefs to increase habitat diversity of an area of seabed and attract fish is a widely used technique globally, although it is still in its infancy in the UK[27]. However, diversity is not always an attribute when assessing the marine conservation of an area and the influence of artificial reefs on the population of marine creatures can be unpredictable and vary from species to species[28]. Creation of reefs may also affect the ability to fish an area using trawl nets, due to snagging of nets on submerged structures. Nevertheless, the overall environmental influence of such reefs is likely to be positive, providing they are not situated in environmentally sensitive or important areas.

Noise

Wave energy devices are likely to be noisy especially in rough conditions. Noise travels long distances underwater and this may have implications for the navigation and communication system of certain animals principally seals and cetaceans. It is thought unlikely that cetaceans would be affected as much of the noise likely to be generated is below the threshold hearing level (frequency) for dolphins. Whales use a number of wavelengths for communication and sonar. Simple experimental evidence could be derived using hydrophones to measure both whale and device sound spectrum in order to determine if there are any areas of overlap, which may cause interference to, whales. Whales and dolphins manage to miss most barriers placed in the water, except possibly for fine monofilament nets, which would obviously not be used in wave energy devices. However, care needs to be exercised that the devices do not cause interruptions to migratory pathways or breeding grounds. The degree of such interruptions is likely to be matched by the size of the device and would most likely to be a problem if long lengths (tens of kilometres) of wave energy converters were deployed.

Noise levels from near shore (and shoreline) devices may potentially constitute a nuisance on the shore. However, when the device is fully operational the device noise is likely to be masked by the noise of the wind and waves, providing adequate sound baffling is used.

Navigational hazards

Wave energy devices may be potential navigational hazards to shipping as their low freeboard could result in their being difficult to detect visually or by radar. Detailed recording of the positions of devices together with proper marking of devices using lights and transponders should minimise this risk. In large arrays, navigational channels would have to be allowed for. Many of the areas proposed for wave energy devices, around European coasts are in major shipping channels and hence there is always an element of risk of collision. The result, for example, of an oil tanker colliding with an array may have consequences for colonies of seabirds in the locality.

Visual effects

In some areas, the water depth required by the near shore devices might be attained only a few hundred yards offshore with consequent intrusion into the seascape. In these cases, it has been proposed that the power cables reach the land by catenary (rather than being submerged on the seabed) and access for maintenance crews by walkway or cable car (rather than by boat). Such schemes may be particularly sensitive in areas of designated coastline and those used for recreational purposes. Some near shore devices may prove to be obstacles for some forms of recreation and are likely, therefore, to be unpopular with local authorities in these regions. Considerable work is now being done by national and local authorities and voluntary organisations, to examine the issue of coastal zone management and it may be necessary to plan for the future inclusion of wave power in management plans developed.

Leisure amenity

Wave energy devices could have an effect on some forms of recreation. The precise effect would vary with the type of recreation (e.g. sub-aqua diving and water skiing might benefit from the shelter provided by these devices but sailing and wind surfing might suffer).

Device construction

Other major impacts of wave energy conversion on the natural environment would result from the construction and maintenance of devices and any general associated development. Many of these implications are unlikely to be peculiar to wave energy devices but it is essential that they are taken into account in the environmental assessment process. It is probable that existing shipyard sites would be used with minimal additional environmental impact.

Conversion and transmission of energy

Transmission lines are required to transfer the electricity generated to the places it is required. Initially cables are likely to run on the seabed and, although laying underground may be possible on particular shorelines, the cost implications suggest that overhead lines may be required with the consequent problems of visual intrusion in areas of high landscape value.

On certain shorelines which may hold significant populations of waterfowl, overhead transmission lines can have an effect on the mortality of certain species, especially large migratory species which have limited manoeuvrability. Most collisions appear to occur where lines intersect flyways between roosting and feeding grounds.

D 2.6.4 Environmental effects of the prototype device

An environmental assessment of an OWC prototype device off Dounreay in Scotland has been carried out[29]. In general the assessment indicated few environmental impacts for the scheme, although this could change if more than one device were to be built there. The main impacts anticipated were as follows—

- **Local fisheries—**Whilst the area is of little importance for commercial fishing (i.e. it is neither an area for trawling nor a spawning/nursery ground) it supports a creel fishery. The device could lead to loss of access, especially during the installation phase.
- **Sediment disturbance—**There was insufficient information on the behaviour of sediments at these water depths to allow for a quantitative assessment of the likely disturbance. Nevertheless, it was considered unlikely that there would be any significant build up of sediment in area of reduced wave activity behind the device.
- **Visual impact—**The assessment was carried out on an earlier design of device and concluded that ‘the device would not be particularly intrusive to the existing view in daylight or at night time’. However, since then the device has undergone further development. To comply with Northern Lighthouse Board requirements, it would have been painted yellow and fitted with a revolving yellow light with a range of 2-3 miles. In addition, the design was to incorporate a wind turbine. These features would have significantly increased the visual impact of the device. However, it was to be located close to the existing Dounreay Nuclear establishment and so the marginal visual impact is likely to be minimal.

D 2.6.5 Emissions

Unlike conventional fossil fuel technologies, wave energy produces no greenhouse gases or other atmospheric pollutants whilst generating electricity. However, emissions do arise from other stages in its life cycle (i.e. during the chain of processes required to manufacture, transport, construct and install the wave energy plant and transmission equipment). Emissions from these stages need to be evaluated if a fair comparison of emissions from fossil fuel based generation and wave energy generation is to be made.

For wave energy technologies, the typical stages of the life cycle are—

- Resource extraction
- Resource transportation
- Materials processing
- Component manufacture
- Component transportation
- Plant construction
- Plant operation
- Decommissioning
- Product disposal

Ideally, each of the life-cycle stages listed above should be considered, in order to evaluate the total emissions from the life cycle of the technology. However, an exact analysis of every stage is neither possible nor necessary. The emissions of most of the major air pollutants (particularly carbon dioxide, sulphur dioxide, oxides of nitrogen and particulates) are expected to be broadly proportional to energy use. Therefore, the most important life-cycle stages for atmospheric emissions are those with the highest energy use. Detailed studies of the main renewable energy technologies have been carried out using this approach within the ExternE study (e.g. Eyre[30]) and elsewhere in the literature. This has shown that, for most renewables—

- The emissions released during the manufacture of the materials are the most important

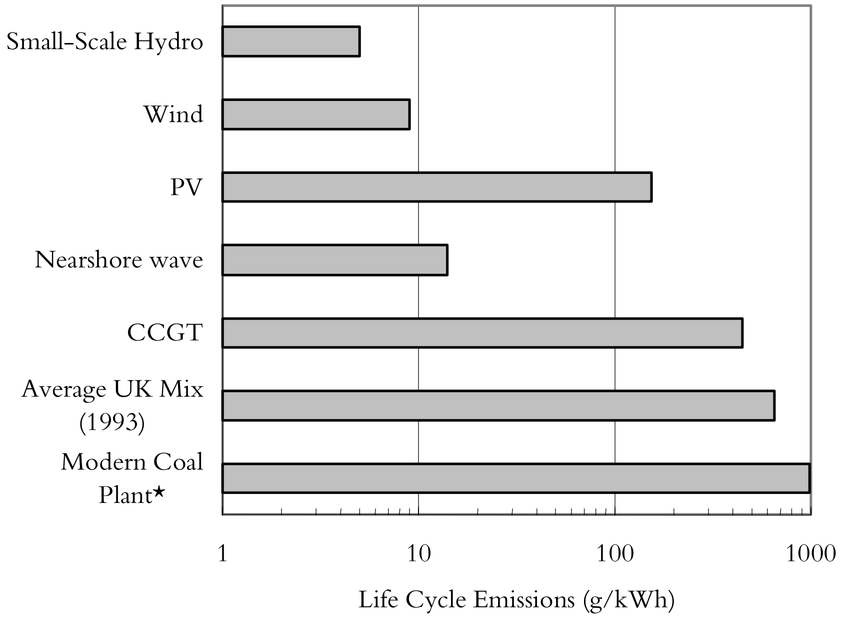
- Energy use in all of the transportation stages is likely to be negligible; energy use in freight transport is typically only 1 mJ/t/km for rail[31] and in road transport is typically 3 mJ/t/km
- Energy use in the extraction of the primary materials used in construction (e.g. limestone and aggregates) or in components (e.g. iron ore and copper ore) is typically an order of magnitude lower than energy use in their primary processing;
- Energy use in the construction, decommissioning and disposal processes is also likely to be at least an order of magnitude lower than for material manufacturing

In assessing the energy use and emissions for technologies, data relating to realistic sites and technologies should be used, in recognition of the fact that these factors are important in determining the magnitude of some emissions. Emissions associated with the manufacture of materials and components are dependent (to some extent) on industrial practices, the generation mix and pollution control regime in the country of manufacture.

The above evaluation has been carried out for a range of technologies [32,33]. The same methodology was used to determine the life cycle emissions of a representative wave energy device: the ART OSPREY. The results for some renewables and wave energy are shown in Figure D-15 to Figure D-17. In order to compare with the range of possible fossil fuel stations, three different fossil fuel technologies were chosen—

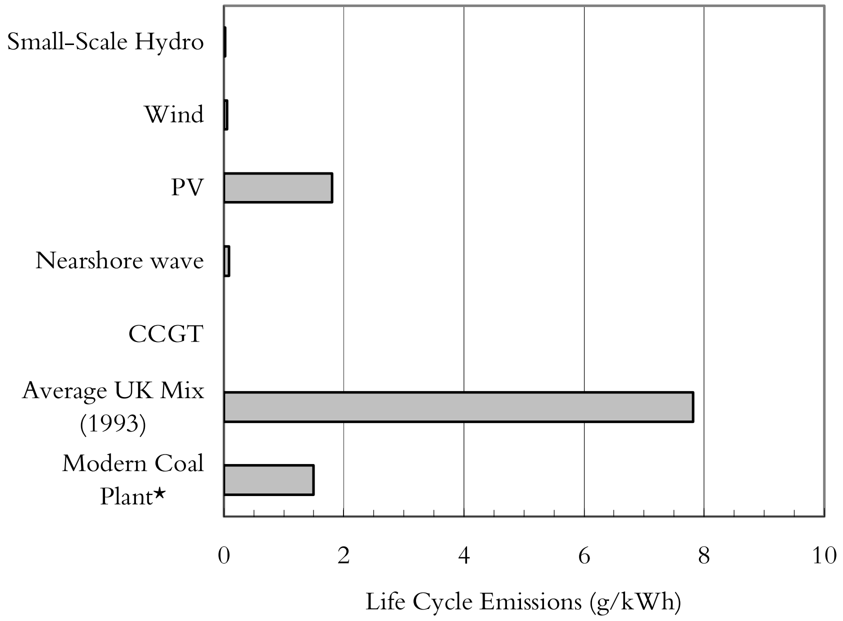
- Combined cycle gas turbines (CCGT)
- Modern coal plant (i.e. pulverised fuel with flue gas desulphurisation—PF+FGD)
- The UK generating mix[33]

It can clearly be seen that wave energy (and the other renewables) can offer significant reductions in the omissions of gaseous pollutants when compared to fossil-fuel-based generation. The only exception to this is for CCGT, whose emissions of SO_2 are effectively zero.



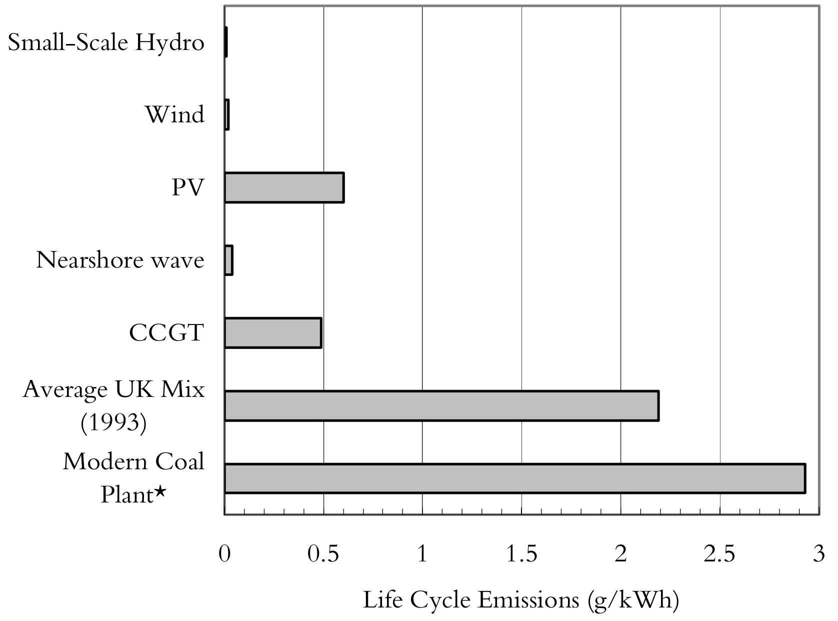
Key—* = coal plant with flue gas desulphurisation and low NO_x burners.

Figure D-15 Comparison of Life Cycle Emissions of CO_2



Key—* = coal plant with flue gas desulphurisation and low NO_x burners.

Figure D-16 Comparison of life cycle emissions of SO_2



Key—* = coal plant with flue gas desulphurisation and low NO_x burners.

Figure D-17 Comparison of life cycle emissions of NO_X

D 2.6.6 Costing environmental impacts

Quantifying the externalities associated with energy production (and their application in the market) has been an important obstacle in realising the full potential of renewables. A methodology has been developed for estimating these externalities[24], which has been adopted to give an approximate indication of the external costs likely to be associated with wave energy.

The results presented below are preliminary. They are calculated for two types of device (shoreline OWC and offshore floating device) and two locations (NE Scotland and SW England). These two locations have different population densities, visual amenities, etc.

Category	**External Cost (m€/kWh)**		**Reliability**
	SW England	**NE Scotland**	
Noise	0.04	0.01	Medium
Visual Amenity	0.15	0.04	Low
Global Warming	0.14	0.14	Low
Acidification	0.6	0.6	Low
Public Accidents	0.04	0.04	Low
Occupational Accidents	0-0.2	0-0.2	Medium
Total	**1.21**	**1.07**	

Figure D-18 Indicative external costs for shoreline OWC devices

Category	**External Cost (m€/kWh)**		**Reliability**
	SW England	**NE Scotland**	
Noise	0.00	0.00	High
Visual Amenity	0.02	0.01	Low
Global Warming	0.14	0.14	Low
Acidification	0.6	0.6	Low
Public Accidents	0.01	0.01	Low
Occupational Accidents	0-0.1	0-0.1	Medium
Total	**0.87**	**0.86**	

Figure D-19 Indicative external costs for offshore wave energy devices