A review of economic and social assessment and methodologies of ocean renewable energy: private and public perspectives

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1. Introduction

This paper provides a review and analysis of the relationship between the methods and metrics used by different user groups and by different disciplines to assess the value of an ocean renewable energy (ORE) (defined in this paper as wave and tidal energy) project or farm. The concept for this paper stems from an European Energy Research Alliance (EERA) workshop [1], where it was proposed that that a comprehensive review be undertaken of the current state of the art of the economics and socio-economics of ORE. The identification and address of the research needs of this subject area and the exploration of the synergies between the two strands of economics/social assessment[1] are anticipated to benefit both the sustainable development of the ORE sector and beyond to the renewable and energy sectors as a whole.

Reviews of offshore wind economic and socio-economic analysis have already been conducted and published [2], and a gap in the literature remains for ocean renewables. This paper takes one novel step further, by analysing the perspective of the project funder or private investor (or a firm) and of a number of stakeholders. Sustainable development[2], as conceptualised in 'Our Common Future' [3], requires a convergence between the three pillars of economic development, social equity, and environmental protection, as defined by the UN [4]. The objective of this study is to identify the metrics and methods used in each of these disciplines and to analyse the interconnections between evaluation methods used by

[1] The term 'socio-economics' was the initial term considered for this topic area, but it was decided to change to 'social assessment' due to the current lack of definition of 'socio-economics'.

[2] Sustainable development is defined in this paper as the process that aims to achieve a future state of sustainability

investors and by the wider stakeholder community. The intention is to inform the development of approaches that will support the sustainable development of ocean energy projects.

Many thousands of offshore wind turbines have now been constructed and several tens of GWs of offshore wind turbines are currently at the planning stage in European waters alone [5]. Tidal stream and wave energy systems are at a much earlier stage of development but both could provide a significant contribution to European and global electricity supply [6]. Europe faces a renewable energy target of 20% [7] and 21% of electricity production from renewables by 2020 [8], with some countries, such as Ireland, setting even higher targets of 40% for the same time period [9]**.** A portfolio of electricity generating technologies with low carbon emissions that include nuclear, offshore wind, wave, tidal range and tidal stream are expected to be required to meet these targets. At present tidal stream systems are generally considered to be closer to technical viability, and a handful of prototype technologies are undergoing offshore testing. To-date no large-scale farms have been constructed [10]. Prior to the construction of any large farms, alternative designs must be compared and preferred design solutions identified.

To assess the viability of any infrastructure project, many assessment criteria or techniques may be employed. Within the framework of sustainable development these methods can be considered in three broad categories – economic, environmental and social. There have been many studies of the cost of energy, and potential future cost of energy, from ocean energy systems [11, 12]. Such values are a key input to corporate decision making and strategic energy system planning. Similarly there have been many studies of social acceptance, siting, environmental impact incorporating coastal processes, flora and fauna, and ecosystem services [13-16]. Environmental assessment is a process which seeks to ensure that the environmental implications of decisions on development planning are taken into account by decision-makers before they make their final decision. In the EU, the environmental assessment process is governed primarily by the Environmental Impact Assessment Directive (85/337/EC as amended). The Directive identifies the projects subject to mandatory EIA (Annex I), and those for which EIA can be requested at the discretion of the Member States (Annex II), whereby the national authorities have to decide whether an EIA is needed. Whilst ocean energy (wave and tidal) developments are not explicitly listed in Annex I, where an EIA is mandatory, they have nonetheless been subject to EIA arising from Annex II which lists "industrial installations for the production of electricity" as potentially requiring an EIA. Existing wave and tidal projects have often been subject to EIA because of the uncertainty surrounding their environmental impact on the receiving environment (for an analysis of EIA experience from wave energy see Conley et al. [17].

In this review paper, the range of approaches employed to evaluate an ocean energy project are summarised and the links between methods analysed. Sections 2 and 3 provide a review of the methods and metrics employed for evaluating an ocean energy project in the contexts of:

- An investment decision
- The broader macro- and socio-economic issues related to ocean renewable energy,

In section 3, the interconnectivity between disciplines as well as the relationship between the standard developer view of a project as an investment decision and wider strategic policy are described and presented in the final section of the paper. We consider each method in the context of the three pillars of a sustainability analysis and outline the linkages between key methods. Particular consideration is given to the relationship between the broader macro- and socio-economic issues and those directly considered by private investors. This review and analysis of connectivity of assessment methods is expected to assist in the sustainable development and successful growth of this emerging sector.

2. Economic Assessment: a Private investment perspective

This section provides a current review of the factors and metrics involved and required for a 'local', 'private' or 'firm's' investment in ORE. The review of the factors allows a discussion on how each contribute to a possible micro-economic investment decision, and importantly, how risk, which is inherent in this immature sector, is assessed. (In the present context, economics refers to the allocation of monetary value rather than the allocation of (multiple) resources.)

This section is split into two subsections, broadly following the commonly used term 'techno-economics'. The first subsection defines and discusses the technical factors required to populate the energy output requirement for revenue production. The second subsection analyses the generic economic factors, methods and indicators applied to ORE.

The externalities linking the factors and methods in this section to the public, regional and national considerations in macro-economics and socio-economics for ORE in section 3 are discussed in section 4. Appendix 1 contains summary tables (Table 1&2) of the methods and their limitations related to their adoption in ORE discussed in this section.

2.1. Electricity Production: power and resource estimation

The purpose of a wave or tidal stream project is the generation of electricity. It is expected that commercial scale systems will comprise large numbers of individual tidal turbines or wave energy devices interconnected by electrical cables. Large numbers are required due to the relatively small rated power of each device imposed by theoretical limits to power production. The quantity of electrical energy generated by such systems is an important consideration for many, but not all, economic assessments since this is the primary source of revenue.

Energy yield is a function of many factors and requires understanding of the resource characteristics, the availability of devices for generating electricity and the response and power output of individual devices whilst generating electricity. Hence, the ocean renewable energy converters are normally designed or tuned according to the wave or current conditions at the specific site in such a way so that the devices can extract as much ocean energy as possible. For tidal stream systems, a small range of device types have been proposed. The main two categories of device are transverse axis turbines and horizontal axis turbines. The latter are analogous to wind turbines and to-date have been designed based on similar principles to wind turbines. Notably there are limitations to the power output from a given resource from individual devices within arrays. For wave energy systems, a wide range of diverse concepts have been proposed. Perhaps the two most widely known systems are the articulated attenuator Pelamis device[3] and the shallow water oscillating flap Oyster[4]. The power output of such devices is sensitive to geometry and control system and so there is limited reliable public information on device performance. However, theoretical studies have identified the limits to power output for various categories of device [1, 2, 3]. Since the current state of the ocean energy sector is still pre-commercial, the development of engineering standards for design and certification are relatively recent (e.g. IEC)[18].

2.1.1. Rated power and capacity factor

Similar to other forms of renewable energy, the power produced by ocean energy technologies can vary significantly throughout the year or even within the range of a few days and is directly dependent on the available resource. This means that the sole indication of the rated power is rarely representative of the actual generating capacity of a technology if not associated to a reference value for the capacity factor (defined as the ratio between power produced at a site and the rated power). A first fundamental step for the correct evaluation of the performance of ocean energy converters is therefore the distinction between rated power

[3] http://www.pelamiswave.com/
[4] http://www.aquamarinepower.com/

and average produced power, paying attention, in particular, to the fact that the second one can be very different depending on the site. Secondly, the calculation or measurement itself of the produced power needs to be clarified, in particular the parameters for its calculation.

To-date, the rated power, which is defined as the peak power output of the device at a specific wave height and period (wave devices) or at a specific tidal current velocity (tidal devices) [10], has been reported by most device developers. For tidal energy devices, the rated power may be a good indicator for the device in the ocean renewable energy conversion, because tidal devices are normally regulated to have a peak and stable power output. However, this is not true for wave energy converters, because the peak power output may be simply wave dependent, which means in a specified sea state, the peak power output may occur once or a few times, while the overall average power output in the specific sea state would be much lower that the peak power output (the average power output may be only 1/20th of the rated power, (for example of Pico plant [19]). In addition, sea states at any location have seasonal (yearly and monthly) variations, the daily and hourly changes in wave height and period, and minute and second changes in amplitude and period from wave to wave. It can be seen that the single parameter, rated power, even if it is defined appropriately, cannot be fully representative of the wave energy conversion due to all these different time scale variations.

2.1.2. Power performance indicators

In wave energy conversion, an appropriate power matrix may be the most useful indicator, because it includes the two-dimensional characterisation of the wave resource. Inherently, wave conditions occurring in reality are usually described by spectral models the underlying assumption being that the stochastic process representing the surface elevation at a specified point is ergodic and can be represented by a Gaussian distribution [20]. This allows every sea state to be defined by a set of characteristic parameters (i.e. significant wave height, peak period, mean wave direction) which are statistically-based quantities estimated over a specified duration (normally one hour).

Some of those parameters are the ones used to characterise the energy absorption of wave energy technologies. Typical fundamental parameters for environmental characterisation are significant wave height and the characteristic period. In representing the wave period in the sea waves, Tp (spectrum peak/modal period) is the most commonly used [21], however the energy period Te (as defined in [22]) is argued by many in the research community as being the more appropriate [23].The simplest representation of the power matrix is a table detailing the power produced in each cell corresponding to a set of sea states with significant wave height and energy period listed in the associated bins. In some cases [24], however, more refined descriptions are required, in particular when the device is sensitive to directionality. In those cases the matrix indicator might be extended to more dimensions to allow a more correct representation of the performance.[5]

The methods to characterise the performance in tidal energy devices are very similar to the ones applied in the wind energy industry. In most cases, the resource is identified by the current velocity, which is typically measured in different directions and at different points along the depth through an Acoustic Doppler Current Profiler (ADCP). For energy assessment purposes, following the conventions established by IEC (IEC 62600-200), it is customary to use the power weighted velocity resulting from the integration across the capture area of the cube of the vertical profile weighted against the corresponding section of the capture area. A power curve is then defined by taking the average over several minutes of the power weighted velocity as abscissa and the average electrical power as ordinate.

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[5] IEC's Technical Committees, TC 114[5] has recently published the first technical specification for the measurement of performance of wave energy converters where the minimum parameters for the definition of the power matrix are the significant wave height and the energy period, although additional parameters are recommended whenever required

2.1.3. Resource assessment

Detailed resource data collection and analysis are critical for the development of ocean energy conversion because ocean energy converters are normally tuned to the conditions in the deployment site and are expected to effectively convert the available energy into useful energy, so that the overall cost of the energy production can be minimised, whilst maximising economic returns. Ocean energy devices need to be able to survive in extreme conditions as well as have a lifetime of 20 years [25], whilst being economically feasible. For offshore applications, it is recommended that systems are designed for a 1 in 100 year event, though a shorter return period may be possible [26].

Existing ocean resource assessment methods include numerical simulation models and ocean measurements. The former methods can be easily implemented using open source models or commercial codes. However, the most reliable, but expensive wave resource assessments are the direct measurements. There are many different methods for wave measurements, such as wave buoys (Waverider buoys (developed by Datawell BV[6]) and Wavescan[7] buoys), remote sensing and high frequency radars. Wave buoys are the most popular due to their abilities of long term measurement, easy installation and retrieval, and the applicability to different conditions (water depths, extreme waves). Waverider buoys are developed by Datawell BV, and have been regarded as the standard devices for measuring ocean waves. NOAA[8] (US) and Met Office[9] (UK) are currently managing many wave buoys for long term measurements of ocean waves and regional wave resource measurements are also conducted by some other countries. The most common tidal energy measurement method is by Acoustic Doppler Current Profiler (ADCPs),

2.2. Financial metrics in ORE assessment

Several financial metrics may be employed to quantify the economic viability of an ocean energy project. Present value methods account for the timing as well as the magnitude of costs and revenues. The basis of these methods is the idea that a lower value – a greater discount – should be placed on cash flows in the future than on those occurring today as there is a risk that future cash flows may not occur. A higher perceived risk attracts a higher discount rate. Financial metrics include cost of electricity and net present value and these are used by policy makers and investors. These metrics are dependent on the energy yield of the system (as Section 2.1), and on the expenditures. This is typically subdivided into capital expenditures, incurred prior to energy generation, and operating expenditures, incurred to generate electricity over the design life. Present value metrics and the main expenditure types are detailed in the following sections.

2.2.1. Cost of electricity

Cost of electricity is one of the most commonly used financial indicators to compare the commercial viability of a set of energy projects. However, it is perhaps the most misunderstood and misquoted indicator. The most common misunderstanding of the term is the fact that there are two ways in which the cost of electricity can be quoted:

1. Basic cost of electricity (COE)
2. Levelised cost of electricity (LCOE)

2.2.1.1. Basic cost of electricity

As the name suggests the basic cost of electricity is a rough, simple and immediate costing of energy. There are many ways of interpreting this indicator:

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[6] http://www.datawell.nl/
[7] http://www.oceanor.no/systems/seawatch/buoys-and-sensor/wavescan
[8] http://www.noaa.gov/
[9] http://www.metoffice.gov.uk/

1. Total capital expenditure (Capex) of the project (including the cost of the offshore renewable energy devices) divided by the annual energy yield. This figures leaves out the annual costs. Basic cost of electricity is used in Life Cycle Cost Analysis estimations [27].
2. Capex + Operational Expenditures (OPEX) for one year divided by the annual energy yield. This will produce undiscounted COE.

The disadvantages of this technique are that the project duration is not considered and that the operating expenditures and other annual costs are often excluded.

2.2.1.2. Levelised cost of electricity (LCOE)

The levelised cost of electricity (LCOE) is conventionally defined as the average cost per kWh of useful electrical energy produced by a generation facility: the "ratio of total lifetime expenses versus total expected outputs, expressed in terms of the present value equivalents" [28]. It is widely used by public and private agencies to better understand the factors determining the costs of electricity. Using a standardised method to estimate levelised costs is recognised as "a prerequisite for a fair comparison" [28]. Discussions around the appropriate level of financial support for some technologies typically begin with a comparison of the levelised costs of each technology.

Gross et al., [29] identify two methods to calculate the levelised costs of electricity: the "Discounting" and "Annuitising" methods. In the first of these, the stream of (real) future costs and electrical outputs are discounted to their present value using a discount rate, and the levelised cost is the ratio of the present value of costs to the present value of outputs. In the "Annuitising" method, the present value of the stream of (real) costs is calculated and converted to an equivalent annual cost using a standard annuity formula. The denominator in this method is the average electrical outputs per year of operation from the facility. The ratio of the equivalent annual cost to the average electrical outputs gives the levelised cost of electricity from this method.

As Allan et al., [11] show, the Discounting and Annuitising methods give the same levelised cost when two conditions are met: when the interest rate in the former is the same as that used to calculate the annuity for costs in the latter, and; when annual electrical output is constant over the lifetime of the facility. Most studies satisfy these conditions, as it is assumed for the majority of feasibility studies that the output of a facility is constant in each year. However, where cost models reflect annual variations in electrical output, such as might arise from natural variations in the renewable energy resource, or for maintenance work – these two methods would not give the same results.

Levelised costs are calculated at the level of the electricity generation facility, e.g. wave farm or coal power plant. The method follows the "merchant investor" approach of considering only the (private) costs which would be paid by the owner/operator of the facility. These would typically include investment/construction costs, operations and maintenance costs and fuel expenditures (for non-renewable technologies). Other categories of (private) costs might also be included in a comparison of levelised costs [30]. These might include decommissioning costs or pollution charges[10], where applicable, for non-renewable generation. Some comparative studies of levelised costs have considered additional non-private costs as well, such as additional costs to the electricity system for accommodating intermittent generation, i.e. "capacity to ensure system reliability" [31], or "system integration" costs where these refer to longer-term and shorter-term costs respectively. These costs are non-private as they relate to the electricity system as a whole and so are not included in generators' financial evaluation calculations.

Partly due to the apparent simplicity of an LCOE calculation, this measure of cost has become a starting point for discussions of the economic viability of alternative technologies.

[10] In its 2010 update the IEA includes the cost of carbon in its levelised cost models. This is significant as it will make MRE look relatively better than previously that case.

However, the following are a number of reasons why specific estimates derived from levelised costs measures should be interpreted with care:

- LCOE results are highly dependent on the discount rate used. There is no consensus as to what are the standard rates to use in ORE[11]. Different technologies with different temporal spread of costs will be affected differently by different discount rates.
- Single-point estimates (e.g. €/MWh) of the costs of each technology are sensitive to the assumptions used (for example,[11, 32, 33]). For technologies where investment/construction costs are a large part of all expenditures (such as wave), small changes in construction cost estimates can have significant impacts on the levelised cost obtained. Additionally, generation technologies with a larger portion of their costs in the future (e.g. decommissioning costs or significant ongoing O&M costs) will, other things being equal, have a lower levelised cost that an otherwise identical facility which has more of its costs earlier (and so not reduced significantly by the discounting of costs to a Present Value).
- The method typically assumes that the project characteristics (such as capacity factor, or annual O&M costs) are constant throughout the lifetime of each facility, which might not reflect operational conditions [34].
- The costs included in the calculation sometimes differ across studies so users should be cognisant of the costs considered.
- The value of electricity is assumed constant and this is to the detriment of systems that may be operated when the market value is higher. Therefore the value of intermittent power supplied by ORE may be undervalued due to its high LCOE.

Specifically referring to estimates of the cost of ocean energy, additional factors have been shown to be important for the levelised cost of electricity. Firstly, it has been shown that location is an important driver of cost, although this is typically omitted from comparative cost studies [35]. Additionally, the specific number of devices will be critical for the cost of electricity – as multiple devices are likely to be subject to a bulk discount, as well as accessing economies of scale across other costs, e.g. cheaper average costs of maintenance from purchasing a service boat, rather than renting.

2.2.2. Net Present Value and Internal Rate of Return (NPV & IRR)

Two further conventional investment appraisal tools are Net Present Value (NPV) and Internal Rate of Return (IRR). Both measures are calculated using not only the private expenditures which are included in levelised cost calculations but also the private revenues from sale of the electricity generated as well as any revenues from subsidies. For each year of the facility lifetime, *net* returns are calculated by subtracting annual costs (C) from annual revenues (R), and these net revenues are discounted to a present value in both approaches.

The IRR of a project is the discount rate at which net revenues are discounted such that their net present value equals zero. Costs prior to the commissioning (i.e. the beginning of operation) of the renewable energy projects will mean that in early years, it is likely that net revenues will be negative. From the beginning of the operational lifetime net revenues would be expected to be positive.

The decision rule suggested by NPV and IRR calculations are straightforward: if a project has an NPV greater than zero, it adds to company value and should be considered. If the developer has limited funding to invest and more than one project, the NPV provides a basis for ranking projects. Similarly, projects with an IRR greater than the evaluating companies required return on capital should also be considered. Ideally, both a positive NPV and IRR greater than the evaluating companies' required return on capital will typically suggest an attractive and viable project.

[11] The IEA used 5-10%, however not providing a reference or basis for their choice.

NPV and IRR calculations show whether a project is profitable for a project developer, and so could be considered a superior indicator of the financial returns from investments. The simplicity of the IRR calculations has drawbacks however, as projects with alternating periods of positive and negative cash flows can have more than one IRR, and IRRs do not identify the absolute size of the return, unlike NPV. The alternative use of Modified Internal Rate of Return (MIRR), allows users to set more realistic interim reinvestment rates and therefore to calculate a true annual equivalent yield [36].

2.2.3. Capital Expenditure

Capital costs are vital elements of the overall and relative economics of electricity technologies. While such measures are critical, the share of capital costs in total costs will vary considerably across technologies, making comparisons of capital costs alone of limited use in understanding the relative economics of (for example) different renewable and non-renewable generation technologies.

Capital expenditure (Capex), is sometimes called total project cost or total initial cost and, is typically sub-divided into the following broad categories [11, 12, 32, 37]:

- Device
- Cable/pipeline
- Foundations
- Balance of plant
- Installation (e.g. of device, moorings, cables, or electrical connections)

Cost quotations for Capex are provided and quoted in two common ways: they could be estimated in a “bottom-up” process from individual components to get a direct cost for the item or items, or they could link to references in the literature of Capex on a per kW or MW basis. The latter is typically more commonly found in the academic literature given the paucity of (confidential) project- or device- specific cost information in the public domain.

The cost per kW (or MW) is a convenient costing method to compare prices of different technologies (e.g.[38]). As ORE is a new and diverse industry, cost breakdowns vary substantially with technology, location and other factors. Additionally, installation costs are sometimes reported separately from the capital cost, requiring that users treat figures carefully to ensure they are applicable. Recent reports have occasionally taken Capex figures directly from those of offshore wind [39-41]. However, there are some estimates which vary considerably from the mean [39, 42]. This wide range for wave energy adds uncertainty to Capex estimates [40, 41, 43, 44].

To ensure that Capex per MW figures are being compared on an equitable basis, it is important to take account of the reference year of the source data. Data from earlier years should be converted to the appropriate year; the categories for which the Capex figures relate to (i.e. all five of the points above, or only a subset) and if the scale of the device or farm is comparable. Further, there may be location-specific factors that users should take into account and adjust the Capex figures accordingly (for example, distance to shore, water depth, etc.)

2.2.4. Operating Expenditure (OPEX)

The determination of OPEX for the offshore wind sector and the drive to investigate more efficient methods, thereby reducing costs has been one of the reasons for the improvement in the financial performance of the offshore sector globally [45-47]. Research into ocean energy technologies OPEX, on the other hand, has been negligible to date, with only a few reports quoting costs, often with little or no analysis. The necessary long term investments of ocean energy projects make operational expenditure a key challenge towards developing economically viable projects [48].

OPEX considerations for ocean energy technologies comprises the following five categories:

- Maintenance[12],
- Insurance,
- Site Rent,
- Other rents,
- Annual impact statements.

This section will discuss each of these components of OPEX in detail, and a shorter section on insurance. The remaining three factors are self-explanatory.

2.2.4.1. **Maintenance**

There are two main types of maintenance tasks which are necessary to keep an ocean energy technology project functioning [49];

1. Scheduled maintenance
2. Corrective or unscheduled maintenance

Scheduled maintenance is a scheduled process where scheduling is pre-defined and carried out in accordance with an established time schedule (calendar based) or established operational schedule (hours of actual operation) provided to the operator by the manufacturer of the wind turbine. Examples of scheduled maintenance includes lubrication, tightening bolts, changing filters, and checking safety equipment. Scheduled maintenance also involves all servicing tasks and equipment certification processes. Scheduled maintenance is possible due to the availability of information on all necessary tasks to be undertaken throughout the life-cycle of the device which has been pre-defined by both the manufacturer of the elements installed and based on the responsibilities of the operator. Scheduled maintenance is estimated on the basis of assumed device reliability and the average duration of a maintenance task, whilst unplanned (unscheduled) maintenance can be related to the frequency of occurrence of extreme wave conditions at the project site [50].

Unscheduled maintenance or repair is by definition unplanned, and is necessary to return elements and/or equipment to a defined state and carried out because maintenance persons or users experienced deficiencies or failures [51]. The origins of unscheduled maintenance tasks are directly associated with operational monitoring systems. When a fault occurs, it will register with the operator though the control system. Because it is not possible to predict a failure at a point in time, it is impossible to plan unscheduled maintenance tasks.

2.2.4.2. **Availability**

The two elements of reliability and failure rates (or risk of failure) are determinants in the estimation of availability of a device.

Reliability of a system is defined as the probability that the system will meet its function and perform to its prerequisite specifications, under stated conditions and for a certain period of time [52]. Reliability does not account for any repair actions that may take place, more so the time that it will take a certain component to fail while it is operating.

Failure is the inability of an element to perform its required function under defined conditions [52]. There can be different forms of failures. Repairable failures are those that can be restored back to working order, while non-repairable failure is a failure which is inoperable once the failure has occurred. Certain failures can also have different effects on the system both minor and major. Minor failures can cause difficulties within a device, but the equipment may be able to keep operating. Major failures however, immediately cause the entire operation to shut down; this is to be avoided at all necessary costs. Failure occurrence is not constant or at a fixed time interval. It is a random occurrence. Failure density functions or probability density functions allow manufactures to create an array of failures at realistic intervals. It takes into account that the majority of failures will occur in the middle of the equipment lifecycle, with minor failures in the plant in the first stage of its lifecycle. It is also realistic that increased numbers of failures are found towards the end of the lifecycle as the plant will be winding down. Failure planning needs to account for:

[12] The term 'operations and maintenance' (synopsised to O/M or O&M) is a much used but slightly confusing terminology. The maintenance element is self-explanatory, but the operations part is ambiguous. 'Operations and maintenance' almost always refers to maintenance only and in this article, will only be referred to as 'Maintenance'.

- Mean time to failure
- Mean time to repair
- Mean time between failure

Availability is defined as a fundamental measure of reliability [53]. Availability is dependent on failure rates, downtimes for recovery after failure, lack of access, lack of spare parts and logistical problems which influence availability [54]. It is also a function of the accessibility of the site.

Availability is dependent upon the wave and wind conditions at the location, but also upon the way in which access is obtained to the device. Access is dependent on the ability of either vessel or helicopter to overcome any hindering environmental parameters experienced at the site. The frequency and period of access is also dependant on the sites location and distance offshore. Non-access will affect the availability, as a device which can be accessed more frequently will have more regular maintenance and as a result tend to have lower failure rates [54]. The greater the distance that a device is located offshore will affect the devices availability levels due to the significant reduction in weather windows of availability based on operational parameters of O&M transportation methods. This is outlined by Van Bussel [55], through the use of a comparative O&M scheduling system based on Monte-Carlo simulations (discussed later in the Risk Analysis section).

2.2.4.3. Insurance

Insurance is an arrangement by which a company or the State undertakes to provide a guarantee of compensation for specified loss, damage, illness, or death in return for payment of a specified premium[13]. The underlying tenet behind insurance transactions is the transfer of risk. The purpose of this action is to take a specific risk, which is detailed in the insurance contract, and pass it from one party who does not wish to have this risk (the insured) to a party who is willing to take on the risk for a fee, or premium (the insurer)[14].

There are three instances in ocean energy projects where insurance companies undertake a transfer of risks:

1. Insurance to cover installation phase
2. Insurance to cover unscheduled maintenance during the lifetime of the project.
3. Liability insurance

It is predicted that insurance risk premium for ocean energy technologies will be much higher than their offshore wind counterparts[15], due to the higher perceived risk involved in the installation and maintenance of these projects. The following are some of the major perceived risks:

- Untested procedures for installation and maintenance
- Deeper waters and longer distance out to sea.
- Reduced weather windows
- Lack of vessel availability and bespoke vessels
- Lack of skilled persons in the field.

The Carbon Trust produced a report quoting insurance for ocean technologies. The report quotes a list of insurance types and expenses as follows [56]: All risk insurance at 2% of initial costs, Cost overrun insurance at 3% of the first year revenue, an operational insurance of 0.8% of the initial costs, business interruption insurance of 2% of energy revenue.

2.2.5. Real Options Analysis

[13] Oxford dictionary: www.oxforddictionaries.com/definition/english/insurance
[14] Investopaedia: www.investopedia.com/terms/t/transferofrisk.asp
[15] Personal communication from GCube insurances.

A further investment appraisal technique to which energy and renewable energy projects are increasingly being subjected is real options analysis [57-62]. Real options approaches to valuing the uncertainty in projects have evolved considerably since the initial papers in the 1970s [63, 64]. The specific advantages of real options analysis compared to the levelised cost and NPV techniques is that they explicitly value the uncertainty in each investment and can suggest when it would be optimal to invest. Developers with permission to build, for example, in practice hold an “option” which itself would have a value. This value would not be included in NPV calculations. This is particularly important given the long lifetime of electricity generation facilities and the irreversible nature of investment. To the authors knowledge there is no published application to ocean energy technologies.

2.3. Assessment of Ocean Renewable Energy Prospects

To understand how ORE systems may contribute to future electricity supplies it is important to predict how costs may change as the industry moves from demonstration projects to large-commercial scale deployments. This requires consideration of the change of economic viability due to:

1. Increased project scale: e.g. to understand how the estimated cost of a pre commercial project (1-10 MW installed capacity) relates to a commercial scale project (for example; an installed capacity of 100 MW or greater).
2. Increased development of the technology which may occur due to a variety of factors including Research & Development and learning from experience of either the technology or the sector.

2.3.1. Experience curves and Progress ratios

The wave energy economics studies by the Carbon Trust and Junginger [65, 66] assumed that the cost of electricity will fall with the cumulative installed capacity. This approach is based on the assumption that increased experience of designing and using a technology reduces its cost and is referred to as an experience curve. Details of the approach are given in various texts [6, 66, 67] but the basis is that, for each doubling of cumulative installed capacity, costs fall to a percentage of those in the reference year by a factor defined as the progress ratio. In general, progress ratios in the range 85 – 90% have been applied to the cost of energy from wave energy systems [65, 68]. Since there is no data on which to base wave energy learning curves, these progress ratios have typically been based on those observed for a range of other industry sectors, with particular reliance on data drawn from the wind industry. Progress ratios for the installed cost of onshore wind have been reported as 92 – 94% [69] although variations are observed across countries (90– 96% for several EU Member States;[70]) with sample size (77 – 85% globally [66]), 82-92% observed [71] and with the minimum unit investment cost (82- 89% for wind farms in China [72]. Progress ratios for the unit cost of electricity from offshore wind energy (e.g. €/kWh) are generally lower (~82 %,[69]) since they account for reductions of both installed cost and operating cost as well as increased performance.

Whilst the learning rate approach is of some use for predicting general trends across a sector, many studies caution the use of this approach, particularly for emerging technologies. A recent example of learning curve limitations is given by the UK offshore wind sector - although costs were expected to fall from 2007 to 2010 [73] they have risen [74]. This cost increase seems to have occurred due to several factors including a doubling of average capital costs and 65% increase in operating costs over a five year period. In this case, cost increases appear to be driven by supply chain constraints and, to a lesser extent, real changes in exchange rates [75, 76]. Moreover, newer projects are often installed in deeper water than the previous ones (with consequently larger capital and operational costs)

Principal concerns associated with the application of learning curves are:

- Progress ratios are difficult to transfer between industry sectors [77],

- Progress ratios estimated from historic data are uncertain. Even when the same set of turbine cost data is employed, the learning rate can vary between 1.8-7.9% depending on econometric assumptions [78] so sensitivity ranges are recommended ([69] recommends 2%),
- Progress ratios are time-varying and so it has been suggested that extrapolations should not be made beyond two orders of magnitude from the supporting data [79],
- The cumulative installed capacity at which cost reduction due to experience commences remains unclear. In a study focused on the investment required for wave energy learning, it is noted that experience does not lead to cost reductions until the installed capacity of a single technology type is greater than ~100MW [80].
- If the ORE sector relies on knowledge and expertise (i.e. learning) that has been developed in other sectors (e.g. wind energy) then the cost reductions have already happened and cannot be repeated.

Aside from the limitations noted above, the experience curve approach does not facilitate comparison between different types of wave energy technology since estimates are generally made for an industry sector. An alternative to the top-down industry-wide approach of experience curves is to apply a bottom-up analysis to the costs associated with representative projects of increasing scale. This requires more detailed understanding of the cost breakdown for a particular technology and so is difficult to apply at an early stage. However, for any electricity generating technology, economic viability (based on a discounted measure such as the levelised cost of electricity or net present value) can only be improved through one of three main mechanisms: increase of revenue or reduction of either capital or operating costs (see earlier sections). Estimates of cost reductions or performance increase can therefore inform estimates of change of economic viability.

Many studies report estimates of cost reduction rates for either the installed capital cost, or levelised cost of electricity, based on the cumulative production (or capacity) of an entire industry sector, e.g. wave energy. This provides limited information on the change of costs that could occur between projects that employ similar technologies but at different scales of deployment. An alternative approach is to conduct an engineering analysis of how the costs of individual components may change. For different scales of deployment, costs may change due to only a small number of factors: principally change of procurement costs (or rates) and efficiency of installation processes such that vessel time is reduced. Cost changes due to change of scale of deployment will, to some extent, be caused by experience (of manufacturing and installation respectively) but these cost changes require investment and time to occur.

2.3.2. Number of units per farm

For wave energy project cost estimates, a percentage reduction of unit cost has typically been assumed to represent bulk orders [28, 81, 82], and additional costs for construction of mass fabrication facilities have sometimes been considered [83]. The magnitude of the percentage change employed is typically based on expert estimates but values are not widely reported. Reviews and predictions of cost changes in the offshore wind sector [74, 76, 84] suggest that the following costs may change due to change of deployment scale:

Supply of station- keeping structure: Limited reductions of foundation cost (e.g. €/MW) are expected due to volume production. Savings due to volume production should be possible due to standardisation [85] particularly since this has not previously been possible for companies which traditionally supplied relatively small batch sizes to the oil & gas sector [84]. Wave energy device developers with offshore experience suggest that station-keeping costs could be reduced by up to 20% although small increases of cost could also occur with increasing scale of deployment.

2.3.3. Unit size

Increased unit size for offshore wind is expected to yield cost reductions, per MW, estimated at 15%. This is partly attributed to the increased unit size, i.e. increased swept area and hence capacity of individual turbines, [75, 84]. A comparison of 1 and 5 MW wind turbines indicates 10% reduction of levelised cost using the larger capacity turbines [86] (Table 7.3 p.369 referenced by [75]). For tidal stream devices, similar cost reductions due to increased unit size may occur since increase of swept area increases performance. Alternatively, the number of devices on a single support structure may be increased.

Installation of Station-Keeping Structure: Increased project scale is expected to yield substantial savings due to improved utilisation of installation plant and reduction of fixed costs, such as mobilisation per installed MW or device. Cost reductions of the order of 50% are expected for offshore wind [84]. Developers with experience of deployed devices estimate installation cost reductions of the order of 5 – 20% [32]. However, impact of installation cost reductions may be moderated by the more demanding nature of deeper, further offshore sites and by the variation of vessel rates which tend to be a function of vessel supply and demand [76]. A model for wind turbine vessel installation rates proposed by the ODE [76] assumes rates are proportional to the planned number of installation operations during the year of deployment which suggests that costs can increase during the early, rapid deployment of a technology if similar vessels are required for multiple sites. For offshore wind, increased unit size is expected to yield significant per MW capital cost reduction by reducing the number of installation tasks required for a given installed capacity.

2.3.3.1. Material costs

Change of procurement costs of materials are likely to be important [85], particularly for structure supported devices for which, similar to offshore wind, a major fraction of the capital cost will be associated with unit cost of steel. Historic trends of market prices are publicly available (e.g. steel price from CRU [87] and Copper price from Kitco [88]). Predicted trends for material prices vary depending on source but may significantly influence projected project cost. The most significant recent factor affecting steel price fluctuation has been the increasing demand from China for raw materials, which led to a steel price escalation [89]. Steel price peaked in 2008, and has since stabilised at 2007 prices. It is anticipated that the prices will start to rise again once the current recession of is over. ODE [76] suggest there will be a 60% increase in steel price from 2007 to 2020, whereas Ernst & Young [74] assume prices will reduce in 2013 and remain steady at the long-run average from 2014. The final cost of manufactured steel, typically grade 50 (S355), painted with corrosive protection, can cost anywhere from €5000 to €7000/ton, which is significantly more than the average price of hot rolled steel, popularly quoted on websites .

2.4. Uncertainty and Risk

The objective of conducting a risk analysis is to identify the conditions under which the economic assessment is valid.

- The uncertainties associated with the quantities and unit values employed to estimate financial metrics
- The risks associated with the specific project under consideration.

There are 5 steps to conducting risk assessment [90]:

- Identify risk
- Assess risk
- Analysis risk
- Identify methods to reduce risk
- Control risk

There are two distinct approaches to risk analysis: quantitative and qualitative methods. Quantitative risk assessment methods generate a distribution/range of the input variable in question thereby moving away from single point estimating. Assessment of the risk is defined as the product of the probability of the event occurring, and the impact of the risk on the estimate. The quantification of the risks can be made through a probability distribution function. Approaches are described in Section 2.4.1.

Qualitative risk analyses represents both the probability and utility of an outcome using an interval scale, where each interval includes a range of numerical values (beyond the margin of error) and each interval is typically represented by a non-numerical label (such as the words “High”, “Medium”, “Low”), not the ranges of values those labels represent[16].Such approaches are described in Section 2.4.2.

2.4.1. Quantitative risk: Yield, Expenditures and Discount Factors

Both the levelised cost of electricity and NPV measures detailed previously are typically deterministic – users input parameters and the methods produce costs or returns which are often point estimates for a single project and time. As such, these confer a level of certainty to levelised costs or rates of returns which does not fully reflect the uncertainties associated with a process that is subject to both natural and human uncertainty. Each input assumption, e.g. the annual output of the facility, the annual operating and maintenance costs, the annual level of subsidy, may take many possible values.

Uncertainty can be captured either through formal or informal sensitivity analysis, i.e. Monte Carlo modelling of risks or demonstrating the impact of changes in input assumptions on results (see for example,[11, 33, 35]. Monte Carlo simulation provide a range of possible outcomes and the probabilities that each will occur [91]. In Monte Carlo simulation, a logical tree of the system being analysed is repeatedly evaluated, each run using different values of the distributed parameters. The selection of parameter values is determined by the pre-allocation of random numbers to that variable, but with probabilities governed by the relevant distribution functions [92]. Probability distributions represent an extremely practical way of describing uncertainty in variables. Common probability distributions include: normal, lognormal, uniform, triangular, PERT and discrete.

Monte Carlo methodology is generally based on the following steps:

- Defining ranges for the inputs used
- Take random numbers from the probability distribution of these inputs
- Record the calculated outputs
- Calculate average values for these outputs and analyse the volatility

The energy yield calculation is essential for the economic assessment of ocean energy project. The simplest procedure involves the application of a capacity factor to estimate the annual power output from a determined ocean energy farm. More accurate estimates for the power production are available (either from testing at sea or numerical models), but these remain uncertain due to both natural variability of the resource and the performance of the designed system. Spatial and temporal variability of power must be considered. Smith et al. [93] revealed that the mean annual power density of waves varies by as much as 48% from the 19 year mean. Mackay et al. [94] found significant variations of the annual mean energy output for the Pelamis deployed off Scotland of up to the 15%,. They pointed to the influence that uncertainties in the historic data [95] and climate change could have on the energy production of ocean renewables. It is known from ongoing sea trial experience [96] that many ocean energy developers are testing different control strategies and design configurations in order to improve their performance. The possibility of improving the revenue due to better system design and control is a factor that might have to be included in the economic assessment of early stage projects. Moreover, the little operational experience means that several other elements that might have a non-negligible effect on the energy production are still virtually unknown. Hydrodynamic interactions in wave energy arrays as well as in cabling, moorings and foundations are an example ([97]).

[16] http://www.jefflowder.com/the-difference-between-quantitative-and-qualitative-risk-analysis-and-why-it-matters-part-1/

Unit costs of materials and processes must be identified by a method that is appropriate to the development stage of the technology [98]. The following approaches provide increasing confidence in the stated unit cost:

- A percentage estimate of the total project cost based on comparable projects,
- A single value from a comparable project – only appropriate for concept evaluation,
- Multiple values or an assumed range of values such that a distribution of expected unit costs is determined. If multiple values are employed for each unit costs, the sensitivity of the outcome of the economic assessment to variation of a given input may be assessed using a stochastic model – e.g. Monte Carlo simulation or similar,
- Values obtained from multiple quotations within a competitive market.

Assumptions that affect the accuracy of each unit cost should be identified. For example; unit costs that relate to a particular order size should be identified. It must be recognised that unit costs of materials and processes vary significantly with demand.

The discount rate used in the economic assessment should be defined by the investors based either on the investors overall cost of capital or based on perceived project-specific risks. A single discount rate may be used for all cash flows or different rates assigned based on the risk of individual cash-flows relative to all stocks. Typical discount rate values suggested for ocean energy in the UK are between 8% and 15% [82] with a higher rate applied to less developed technologies to represent the greater uncertainty associated with both design and cost estimation. Cash flow specific discount rates can be defined based on the providing company's risk relative to all stocks using the Capital Asset Pricing model (e.g. Boud and Thorp [81] amongst many others). Although discounting methods are straightforward to apply, they do not fully capture the risks affecting specific ocean energy projects as distinct from any other investment. Project specific risks must also be identified to enable fair comparison between projects.

2.4.2. Qualitative risk

Qualitative risk assessment represents both the probability and utility of an outcome using an interval scale, where each interval includes a range of numerical values (beyond the margin of error) and each interval is typically represented by a non-numerical label (such as the words "High", "Medium", "Low"), not the ranges of values those labels represent[17]. Qualitative methods require evidence and are considered objective analysis. Other common label methods used are red, yellow, green colour codes or simple graphical displays. A disadvantage of the qualitative method is that since evidence is required, the method is expensive and time consuming. On the positive, due to the evidence requirement, the method is more accurate, risk management performance can be tracked objectively and it is easier to prioritise risks.

2.4.3. System risk

The objective of an investor is to identify the conditions under which their assessment of economic viability is valid. Prior to a commercial investment, a high level of confidence must be demonstrated in the quantitative assessment. This requires that all risks that could change the outcome of the economic assessment have been identified and appropriate mitigation applied. A qualitative process would be used to identify such risks. Application of this

[17] http://www.jefflowder.com/the-difference-between-quantitative-and-qualitative-risk-analysis-and-why-it-matters-part-1/

mitigation may incur a quantifiable change of cost or of design parameters (such as energy yield or construction period) and this change can then be included in the quantitative economic assessment.

At all stages of technology development both quantitative and qualitative approaches to risk assessment are important. However, relative importance will alter as the system designs develop. A transition will occur from identification of risks and low confidence in quantitative measures at the concept stage to high confidence in quantitative measures with the cost associated with any project risks included in the assessment at the commercial stage. When considering an early stage of technology development (e.g. concept stage) it is impossible to determine quantitative measures – such as NPV, COE, etc – with a high degree of confidence. The investment criteria will not necessarily be based on commercial viability. A range of qualitative criteria will instead be used to understand the strategic benefit of the project. At this stage, it is therefore important for the economic assessment to identify the risks associated with the project so that these can inform the investment decision. When considering a developed technology (e.g. prototype stage), an economic assessment can be conducted using quantitative methods. Significant risks associated with the project will be identified and improved designs or costs incurred to address these risks. The investment criteria will be related to commercial viability but this will not be the only consideration. Prior to commercial investment it is expected that all risks that could change the outcome of an investment decision will have been identified and mitigated by consideration of their costs. The level to which risks have been mitigated may partly be reflected by the cost of insurance.

Whilst this process is established for many of the engineering and financial aspects that influence an ocean renewable energy project, the influence of wider stakeholders on investment decisions is not always linked to the economic assessment conducted by an investor. In Section 3 a range of approaches used to conduct an assessment of social, economic, and environmental aspects of ocean renewable energy are briefly described. In Section 4, we discuss how these approaches may be linked to the economic assessment of ocean renewable energy projects conducted by investors and the reverse.

Appendix 1 contains a summary table (Table 1) of the methods and limitations discussed in section 2 relative to the local private investor in ORE.

3. Socio-economic Assessment: Public perspectives

Parallel to the economic, principally financial investment, considerations detailed in the previous section there are a number of social and environmental aspects which must be considered to enable the sustainable development of ORE technologies. Hacking and Guthrie [99] are of the opinion that sustainability assessment can most usefully be considered an umbrella term incorporating a range of impact assessment practices. This section reviews these aspects including employment (3.1), wider costs across other sectors (3.2), social impacts across a broad range of communities and stakeholders (3.3) and environmental impacts and assessment (3.4), and finally socio-economic evaluation of an innovation system (3.5).

3.1. Metrics quantifying employment created

When governments are making decisions on support for specific technologies, of increasing importance are the potential economic impacts of these technologies. Economic impacts might come through several routes including: reducing the volatility of energy prices, and by extension, increasing the security of supply for firms using energy in production. Innovation in high-technology energy applications could have spill-over impacts on other areas of the economy; through developing skills in technology, export markets could be opened up, returning an ongoing stimulus to the area where the technology is developed [100]. These offer the potential for a persisting economic boost. However, much of the studies to date on the economic impacts of renewable technologies have focused on more short-term considerations, specifically the impacts which occur as the new technology is deployed.

Metrics typically used in quantifying economic benefits of renewables in a regional and national context include "jobs per MW" or "jobs per cumulative MW". Such economic impacts are linked to changes in renewable capacity. Studies based on detailed "bottom-up" estimates of jobs created or supported at each stage of the technology deployment, e.g. construction, installation, can allow jobs per MW of installed capacity to be calculated. Jobs per MW makes the assumption that the number of jobs created is related to the capacity of the plant installed. One advantage of this metric is that it can compare the job creation potential of different technologies in different renewable sectors.

A study on an assessment of the job creation potential of wave and tidal energy industries in Europe quotes "19 direct and indirect jobs per MW at the start, falling to 7 jobs per MW by 2020" [85]. Direct jobs in device and foundation supply are quoted at around 10 jobs per MW falling to 3.5 jobs per MW. Jobs per MW also provides an indication of job creation potential for aggressive conversion of the existing energy supply to renewable and low carbon sources [101]. Similarly, Sgurr Energy & IPA [102] consider there to be a fixed relationship between jobs and capacity over the duration of construction of ocean energy capacity in Scotland.

A 2003 study on results from the work of the European thematic network on wave energy presents an outline evaluation of the potential socio-economic benefits of wave energy for Scotland [103]. As the manufacture of certain types of devices may employ more people than others, the estimates the study provides are completely indicative. The potential market is estimated assuming all outstanding R&D has been completed and is successful, the devices can be made economically and the market for all devices is sufficient to allow for a reasonably rapid increase in production. They estimate the number of jobs per megawatt installed capacity to be 4-4.5 full-time equivalent (FTE) jobs per MW. This is based on the figure for offshore wind and is considered to be a reasonable comparison and estimation [104]. The Wavenet report concludes by stating that until wave energy becomes fully established and more information on the manufacturing process is known, job creation estimates will be very uncertain. However when the sector is established and mass production occurs, jobs will be created and primary and secondary economies will grow. Dalton and O'Gallachoir [45] reviewed the policy mechanisms that currently exist to promote ORE in Ireland and proposed a raft of measures based on a review of best practice in other countries and technology industries, which could be mapped across to current wave energy policy to promote and stimulate the sector.

There are, however, a number of problems and inconsistencies with linking economic impacts (job, employment) to installed capacity. Dalton and Lewis [105] assess the reliability of the use of the jobs/MW metric with a particular focus on the wind energy industry. The two methods examined in the report are 1) jobs/MW installed for one year; 2) jobs/cumulative MW installed. For the reports reviewed there was confusion and a lack of clarity over a number of issues. This included the exact definition of job (direct, indirect, induced) and whether the jobs created are local only or have an export contingent. In principle, both the mechanism through which the job is created and the location of the job can be addressed by the correct use of modelling approaches, as will be discussed later.

Jobs/MW is often used in reference to national statistics. For example, as most of the wind turbines manufactured in Denmark are exported there is a high jobs rate. A low local deployment rate results in an unrealistically high jobs/MW statistic. Further ambiguity occurs when referring to jobs/MW from wind farms and comparing them to national statistics. Wind farm jobs statistics include installation and operations and maintenance jobs. It is recommended that jobs/MW statistics for wind farm projects be kept separate from national statistics quoting jobs/MW due to differences in scale and input. There is also a lack of clarity in many reports over whether the statistics given refer to cumulative or non-cumulative installed figures. Both of these metrics are commonly used in the literature and it is often difficult to ascertain which method has been used. Dalton and Lewis [105] suggests that jobs/cumulative MW may be a more reliable metric. Alternative metrics such as jobs/1000 head of population or MW/million head of population are also discussed.

A further metric used for comparing the job creation potential of new technologies is job years [106]. Job years is used as a more accurate reflection of the labour market impact than jobs. This is because of the varying length of jobs which will be generated by the different stages of the project. For example, a job that lasts for 10 years is more valuable to the economy than a job that lasts for just two years. However job years can be confused with jobs total and needs to be very clearly specified. Jobs per million €/£/$ invested is another alternative metric and is calculated using Input-Output and Computable General Equilibrium (CGE) modelling. Studies using these methods are discussed in more detail below.

3.2. Modelling socio-economic impacts

As discussed in the previous section, an ex-ante knowledge of the scale and direction of the economic impact that a project or technology could have will be an important factor. In addition, therefore to the anticipated environmental advantages and contributions that additional renewable production might make to energy security, it is increasingly vital that a project's impact on the economy is understood. One way of providing such ex-ante appraisals is through using multi-sectoral economic modelling techniques. Input-Output (IO) and Social Accounting Matrix (SAM) analysis are two such techniques which can be used to understand the consequences for the economy of changes in the level of pattern of demand, as new investments in renewable capacity have typically been modelled. A third model, Computable General Equilibrium, incorporates a range of alternative treatments for the initial impact of the technology or project, and can permit more flexibility with regard to the assumed response of the economy than the "fixed-price" techniques of IO/SAM.

Multi-sectoral economic accounts for a nation or region can identify the inter-linkages between different sectors of the economy in a given time period, usually a year [107]. This can be used for either attribution/accounting analysis or for economic modelling. In attribution and accounting analysis, questions which can be answered include, for example, how much employment or Gross Value Added (GVA) was supported in this year by activity A. Impacts are clearly separated into direct, indirect and induced effects. This analytical approach has been used to quantify the economic value of marine commercial activity in Ireland [108]. That paper estimated that in 2007, the direct employment in ocean renewable energy was 101 FTE, while the sector itself created a GVA of €4.4 million and indirectly supported an additional €2.7 million of GVA. The same approach was used to examine the economic linkages of different electricity generation technologies, including ORE [109].

When using economic accounts for modelling the consequences of expenditures, there are two standard approaches: Fixed-price modelling (such as Input-Output or SAM modelling) or the "flex-price" method of Computable General Equilibrium (CGE) modelling. Both are widely used economy-wide modelling techniques which can translate expenditure injections in the regional economy into economic impacts across that economy.

3.2.1. Input-Output modelling

The Input-Output (IO) method links changes in demand for specific sectors into sectoral and aggregate impacts for the economy. IO sectoral "multipliers" offer a short-hand description of the consequences for aggregate activity of changes in final demand for the output of each sector. Multipliers can be either "Type 1" or "Type 2". Type 1 multipliers reveal the extent to which changes in demand for the output of a specific sector impact on aggregate activity across the sector itself (the direct effect) and other interlinked sectors which must change their output to permit the output of the directly affected sector to change (the indirect effect). The scale of the Type 1 multiplier for a sector will depend, ceteris paribus on that sectors embeddeddness into the economy through links with other sectors. Type 2 multipliers will be larger than Type 1 multipliers as they additionally include the impact of changes in the level of household wage income on household consumption (the induced effect). In addition to embeddedness, the sectoral labour-intensity and its share in the household consumption basket will be critical for the Type 2 multiplier.

A socio-economic impact assessment of Aquamarine Power's Oyster project found that the projects would result in positive impacts on both direct and indirect employment and GVA for the local community in Orkney and Scotland as a whole [106]. Using IO multipliers, the report estimates that the total net additional job years, which include the direct, indirect and induced jobs, created by the projects would amount to 1,345 job years for Orkney and 7,158 job years for the rest of Scotland [95].

A study was commissioned by SEAI and conducted by SQW Energy outlining the potential economic benefits of supporting the development of an ocean energy industry in Ireland and includes a roadmap for development of the sector [110]. Using IO multipliers, the report states that at 500 MW capacity by 2020, at least 1,431 FTE jobs could be created and this could potentially increase to between 17,000 and 52,000 FTE jobs by 2030. Using three baseline technology and deployment scenarios the report found that the largest economic gains for the island are to be achieved by not only harnessing the energy resource but also by developing a fully-fledged indigenous supply chain to service the sector.

An impact study used the IO method to explore the impact on the US economy of expenditure on renewable energy projects out to 2050 [111]. The report estimates that an investment of $150 billion would result in the creation of approximately 2.5 million new jobs.

There have also been a number of roadmaps published forecasting the effects on economic indicators such as employment and GDP. This includes FREDS Marine Energy Group [112] at a Scottish level and the EU-OEA [113] at a European level. FREDS estimated that up to 10,000 jobs in total may be created by 2020 [112].

Allan et al [114] use a SAM approach to explore how a new onshore windfarm could impact on the Shetland economy. Given low (input) linkages between the project and the local economy, a SAM approach is used to capture the impacts of non-wage income flows with the local economy. Such non-wage income is not typically included in IO models, but are found to be important for the scale of economic impact. To the authors knowledge there are no applications for ocean energy of SAM analysis.

Underlying the (demand-driven) IO and SAM method are critical assumptions about the way in which the economy responds to demand changes. Principally, and most importantly for the scale and timing of impacts, the supply-side of the economy is assumed to be entirely passive and so can respond immediately to changed levels of demand through, for instance, finding unemployed labour and capital resources. Pollin et al. [111] argue that this assumption for the US economy in a recession (2009) is not problematic, however this assumption is typically assumed to apply more to regional than national economies. Supply constraints should be considered before it is decided to proceed with an IO model, unless these are not assumed to apply to the economy being modelled. Secondly, the implication of (short-run) supply constraints are that expenditures in specific sectors will “crowd out” activity in other sectors. This will not be captured within IO systems, but will explicitly be modelled in CGE approaches. Thirdly, IO modelling assumes fixed technical coefficients for all sectors. That is, each sectors inputs are assumed to respond linearly with changes in output, such as would be consistent with unchanged relative prices.

3.2.2. Computable General Equilibrium (CGE) modelling

The Computable General Equilibrium approach relaxes the assumptions of IO modelling by specifying both the demand- and supply-sides of the economy, and permitting the relaxation of the assumptions described above. A number of studies have used regional CGE models to demonstrate that expenditures associated with ocean energy development can have significant impacts on the regional economy. These have demonstrated that short-run “crowding-out” and wage increases lead to in-migration occurring, expanding the supply-side of the economy and producing “legacy” impacts on the economy, i.e. positive impacts on employment and economic activity which persist beyond the end of the expenditures themselves. In a recent paper, these effects have been shown to be robust to assumptions about agents within the model having myopic or forward-looking expectations [100]. A further finding of that paper was that IO models generally overstate the employment and value added impacts of expenditures during the period of expenditures, relative to CGE approaches. CGE models can also be used to explore the system-wide consequences of changes to the supply-side of the economy, though, for example, innovation in specific technologies or differential subsidy or support schemes which change the relative prices of electricity technologies. The flexibility offered by these models offers potential for increased applications.

3.3. Communities and Stakeholders

3.3.1. Impact of stakeholder perceptions to ORE

Public perceptions about the potential technological risk associated with renewable energy arise from an interplay between the nature of the technologies themselves and the social and procedural aspects of their siting [115]. Public acceptability is key and those public and private institutions that pursue a 'knowledge deficit' approach to the public's perception of risk may well hinder the deployment of projects by not using a communication strategy that is perceived to be fair by stakeholders. Much of the literature has moved away from framing potential land use conflicts in terms of a 'There Is No Alternative' (TINA) viewpoint from a developers' perspective versus 'Not In My Back Yard' (NIMBY) from the communities. Successful deployment typically requires a degree of trust in local governance structures which can convey political legitimacy to a project as it enters the public arena. The wave and tidal research literature cited here offers interdisciplinary insights into understanding public perceptions of risk, trust and social justice that are both generic and technology-specific. Some practical suggestions about conflict resolution are also reported.

Literature on public perceptions and attitudes towards ocean energy is limited. This is despite the fact that there is extensive literature on public attitudes towards energy projects in general and towards other forms of renewable energy, like wind, in particular [116] This is because wave and tidal technologies are still in development, there is no dominant design, and only a relatively small number of pilot projects have been undertaken, all of which accounts for low levels of public awareness. The few studies that have been conducted either look at very generic perception of ocean energy in comparison to other renewable sources or focus on specific case studies of pilot projects. The literature reviewed in detail below reflects responses to projects in the UK (SeaGen demonstration, Strangford Lough [2], Wave Hub, Cornwall [117, 118], Wave Dragon, Pembrokeshire [119]), Norway (Kvitsøy island pilot [119]), the US (Douglas, Lincoln and Tillamook counties, Oregon [119-121]), Spain (Mutriku pilot, Bilbao [119]) and Chile [122].

Wave and tidal stream power generation are new technologies and consequently public awareness about them is low relative to other forms of renewable energy generation. As these technologies reach the demonstration stage and come to the attention of the wider public, both supportive and opposing attitudes are starting to emerge [14, 116, 117]. It is expected that lessons learned from other renewable energy projects will also apply to ocean energy, but may differentiate for tidal and wave projects as the technologies mature [116, 117]. While renewable energy acceptability in general is high, attitudes may change to opposition towards specific individual projects [119], however, ocean energy projects could potentially be better received than, for example, offshore wind energy developments, if for example they have reduced visual impact [123], but this may not always be the case. Certain technologies will be visible, especially in large scale deployment, in which case seascapes may be perceived to have been disrupted [124]. Currently the studies on attitudes toward ocean energy projects depict views towards the technology in general rather than a specific device but this may change along with the development of different concepts [119]. Future attitudes may depend upon the perceptions formed on the basis of early or demonstration projects, so their performance could have a substantial impact.

Unlike the resistance encountered by on-shore wind farms, recent research into ocean energy projects has shown attitudes towards these technologies tended to be predominantly positive. This was based on the belief that the technology was effective, had no obvious negative impacts and held the potential to bring gains to the area [13, 14, 117, 118, 121, 123]. However, low levels of response from the public may also indicate lack of interest or awareness; consequently attitudes may change if expected benefits are not realised for the locality, or if negative impacts – or perceived as such – are to emerge in future [14].

This initial lack of conflict, fragile or temporary as it may be, may not have attracted a wealth of research on the subject, but it has enhanced a research trend to move past knowledge deficit and NIMBY models. In general terms, with renewables, research suggests that the NIMBY concept is much more diffuse and harder to pin down than previously thought. This can be because of a democratic deficit, where opponents prove to be particularly vocal, and individuals' qualified support, where people are not against a technology as such but would only support projects in a local context under very specific conditions [125]. In the case of ocean technologies, researchers have sought to explain positive as well as negative responses to renewable energy developments, whilst at the same time looking past visual and physical characteristics to symbolic interpretations of the place and technology [13, 117]. Both McLachlan [117] and Devine-Wright [13] use interpretations associated with different places and technologies to explain public attitudes to wave and tidal energy projects, considering supportive as well as opposing positions. Their work highlights place attachment and place-related symbolic meaning as significant predictors of public response to energy projects, the implication being that opposition arises when associations made with the projects do not fit well with meanings attributed to particular locations [13, 117]. Given that overall public opinion was positive and in support of the particular projects, this research also looked for correlations between place symbolism and positive public response to change, in the form of enhancing this emotional place attachment. It is argued that change in that respect is not necessarily disruptive and it is the context and interpretation in relation to the local sense of place that are critical in terms of public acceptance [13].

Ocean energy is not universally supported, opposition free or exempt from the public acceptance issues faced by other renewable technologies [116, 117]. What is more, socio-demographic variables do not seem to be important predictors of public acceptance [13]. Initial observations show that ocean energy may be viewed as an opportunity by those focused on global concerns (e.g. energy and environmental stakeholders [117]); conversely it may appear as a threat to those focused on more immediate, localised impacts [121]. While the main stakeholder groups expressing concern or opposition are those involved in the tourism and fishing industry, along with recreational user groups such as surfers [117, 119, 121], which may perceive ocean energy developments as a potential threat to their activities, concern in the wider public may also arise in connection with ecological impacts and environmental protection issues [117, 121, 123]. Perceived impacts to the economics for the locality, as well as the sense of local ownership for the project, play a big part on the discussions and background of public attitudes [117]. This 'topophilia', or love of place, healthy environment and community well-being, are social aspects emerging as important in shaping public attitudes towards wave project developments [121], and are suggestive of research into attitudes of qualified support [125, 126].

The perceived benefit from the development and deployment of energy technologies is connected to the economic capacity displayed within a certain region. For example, the lack of UK manufacturing capacity and supply chain development raises concerns on the ability to ensure that activities would not predominantly be supplied from overseas [127]. At the local level stakeholders can be supportive if it is made clear that the devices would not interfere with current practices or if synergies can be developed with the operators that could offer an additional source of income e.g. allowing the fishing community to harvest mussels off of a wave device [128]. Local community support can also be ensured through participation in project ownership or tax revenues paid to local authorities, which translate to tangible benefits for the community [129]. Issues relating to community ownership and benefits are discussed further in later sections of this paper.

Bronfman et al. [122] investigated public acceptability of electricity generation technologies (including tidal power generation) through a causal trust-acceptability model, where public attitudes were based on perceived risk, perceived benefit, social trust in regulatory institutions and acceptability of the options. While that model does not fit well with non-conventional renewable generation technologies, where public acceptance, benefit, and risk perception do not correlate with public trust in regulatory institutions, tidal energy was viewed as non-threatening for current and future generations and therefore enjoyed more acceptability. The public felt they need not rely on regulatory institutions in order to make judgements on the risks and benefits associated with the technology. This would imply that tidal energy (and ocean energy in general) could be less susceptible to regulatory trust issues; nonetheless stakeholders can be dissatisfied with the level of inclusiveness of the planning and communication process associated with ocean energy projects [123]. While these concerns do not necessarily translate to objections towards the technology itself, they underline the importance of the methods of interaction at the local level. Direct and targeted consultations appear to be more successful and appreciated by stakeholders than general advertising strategies [118].

Public perception has been classed as a non-critical barrier to wave energy projects with the caveat that measures are taken to inform and establish a dialogue between all relevant stakeholders, including the public, during project development and deployment. Fernandez Chozas et al. [119] examine best strategies to achieve endorsement for wave energy projects from a developer's perspective, based on case studies of developments up to date, and recommend early public involvement, engaging directly with special interest groups, establishing early two-way communication and planning participation as universal best practices. The fact that a different public needs to be addressed with connection to each project, requires a stakeholder and target group analysis relevant to that locality, and thus it is suggested that local authorities are best placed to advise developers on acceptance issues for specific sites. Even though developers have to work within different regulatory frameworks depending on the project siting, there are indications that a detailed Environmental Impact Assessment (EIA), placed in the public domain could make project acceptance more likely. This latter point is very much dependent on the reliability and robustness of the scientific assessments presented to the public [118]. When contentious developments are proposed, risk assessments are typically keenly disputed.

The limitations of the research conducted so far lie in the fact that they are based on a small or very specific population groups and are conducted around small demonstration projects with a limited life-span. The nature of such projects may instigate a more modest response from the public and the timing and scale of the studies may not be best placed to capture the full dynamic of public attitudes. Aside from the particular limitations of each study, there is a general consensus that transferring the results between different localities may not be straightforward. Site-specific studies are nevertheless still advised with researchers looking at responses to renewable projects in the local rather than the abstract context.

While wave and tidal energy receives a generally positive response in the literature cited here, the environmental credentials of certain ORE technologies may still not be universally accepted when developments are scaled up. However, if as is suggested, public acceptance is more important than attitudes to specific technologies, ocean developers will need to be mindful of building trust and legitimacy for their technologies [115]. There are both positive and negative connotations to ocean energy developments, and for community acceptance these must successfully mesh with a sense of place, identity and symbolism, as well as offering tangible, locally-based socio-economic benefits.

3.3.2. Distribution of benefits to local communities

The economic, social and environmental costs and benefits of ORE projects will be distributed across a range of stakeholders [130]. Construction, operation and maintenance may impact on the environment [131]. Completed projects may result in a loss of access for fishers and navigation [132]. Aesthetic impacts may have a negative non-market impact on local communities in addition to market impacts on tourism and property values [133]. It is also the case that many ocean energy technologies will involve substantial onshore coastal development in the form of cable landfall, transformer stations, ports and harbours development and even power take-off in the case of devices which pump water ashore.

As plans are made for commercial scale deployments of ORE technology expectations of financial remuneration to coastal communities are being raised. Recent proposals for a tidal energy development in the west of Scotland were met with calls from community leaders for direct action if appropriate payments were not built in to the development proposal [134]. Community benefit schemes associated with onshore wind development may provide a precedent, however, the applicability of these schemes in a marine context must be considered.

3.3.2.1. Community Benefits

The UK government has developed a "toolkit" guide on the delivery of community benefits from onshore wind farms [135]. Four different types of community benefit scheme are identified. These are:

1. Community funds, where the developer delivers a lump sum or regular payment into some sort of fund for the benefit of local residents;
2. Benefits in kind, where the developer directly provides or pays for local community facility improvements, environmental improvements, educational support, etc;
3. Local ownership in the energy project. Through personal equity investment opportunities, profit-sharing or part-ownership schemes linking community benefits to project performance;
4. Local contracting and associated local employment during construction and operation.

Cass et al. [136] note that the provision of community benefits is increasingly widespread for onshore developments in the UK. While the normative case for providing community benefits appears to be accepted by all involved, the exact mechanisms for doing so remain problematic. In 2003 the Highland Council (HC) in Scotland was the first in the UK to make specific recommendations for community payments from onshore wind. This lead has now been followed by eight other local authorities. In 2012 the HC recommended annual payments of £5000 per installed megawatt describing payments as "*a goodwill voluntary contribution donated by a developer for the benefit of communities affected by development where this will have a long term impact on the environment*". Cass et al. [136] noted that early schemes were faced with the difficulty of establishing appropriate mechanisms for making payments. In an attempt to overcome this problem several local authority trust funds have been established to receive and distribute funds (e.g. Argyll & Bute "Community Wind Farm Trust" [137]).

It is important to note that onshore community benefit payments are voluntary. Furthermore payments are not a material planning consideration and should not be a material consideration in planning decisions [138]. However it is tacitly understood by all parties that where local objections have the potential to impact on outcomes, payments do *influence* the land planning process [139]. In contrast many offshore wind farms do not provide community benefits schemes. Where community benefits are made they have often been 'benefits in kind'. Where annual payments exist they are significantly below levels made by onshore schemes, generally less that £1000/MW. Emphasis is usually placed on job creation and supply chain benefits. It is noteworthy that the existing consents procedure for offshore development (Section 36, Electricity Act 1989 (UK)) and proposed future planning arrangements are heavily centralised compared to onshore planning. In Ireland, for example, under proposed new legislation ocean renewable developments will be considered as 'strategic infrastructure development' (SID) projects and as such applications will be processed by a central authority with limited local government involvement [140].

The obvious inference from the above is that where local communities have additional leverage through planning there is more incentive for developers to consider community payments. The balance of executive power between local government and the State in marine planning arrangements may be a critical factor in determining the scale of community benefit. The Cass [136] study only revealed one case of active argument against community benefits from a wave power project. Here the developer stressed the financial fragility and high risk nature of the sector at this pre-commercial stage. The possibility of offering significant shares in the benefits seems to be a form of altruism to be deferred to a later date, although the need to keep the local public on side is acutely recognised [141].

Interestingly Cass et al. [136] noted that the idea of projects carrying "local contracting" and employment benefits were often rejected as of being of no real significance, even in the cases where specific numbers were known to respondents. Any anticipated job creation from the projects was generally considered to be of low value, certainly in relation to those that were available to local people. Overall, the evidence shows that community benefits are conceived and provided in various ways, and demonstrates that in the onshore wind sector, in particular, developing a community benefits package is becoming an established and routine part of terrestrial project development.

3.3.2.2. Community Ownership

Cass [136] claims that the (inherently political) process of deployment of renewable energy projects can better overcome resistance if projects can be implemented in a way that increases local community "ownership", literal or symbolic. It is worth noting that community ownership can take many forms. Broadly speaking existing onshore projects fall into three forms.

- Model 1: Developer-led scheme. Communities and individuals are offered the opportunity to take a modest equity share [142]. This is effectively an alternative form of community benefit: a 'goodwill gesture' to gain planning leverage.
- Model 2: Partnership scheme. Project developed jointly with the local community. The community group or local authority provides funds (or land). Community participation is essential for project viability e.g. Shetland Viking Energy project, a 370 MW wind farm with 50:50 local authority/utility partnership.
- Model 3: Community-led and owned projects e.g. community wind projects on the islands of Gigha and Westray in Scotland (single turbines in the region of 1 MW).

Allan et al. [143] studied the Viking Energy wind project in Shetland concluding that revenues to the community associated with an ownership role would be substantially greater than typical community benefit payments and that such revenues could be considered compensation for the community taking on larger risks in the early stages of onshore wind farm development. Warren and McFadyen [144] examined the public attitudes to onshore windfarm development in south-west Scotland. Public attitudes towards a community-owned wind farm on the Isle of Gigha were consistently more positive than attitudes towards several developer-owned windfarms on the adjacent Kintyre peninsula. O'Connor et al. [145] found that successful community ownership of renewable energy is dependent on five critical factors: (i) unity in the community, (ii) ability to negotiate the planning process, (iii) issues relating to capital, equity and risk (iv), strategic fit and (v) the policy framework around rural development and renewable energy policies.

In the context of ocean energy development both Rodwell et al. [146] and Alexander et al. [147] suggest that increased local control and local ownership and a flow of community benefits may go some way to compensating for loss of access to fisheries. However the scope to replicate onshore benefit schemes in the context of ORE must be considered. Model 1 above (offer of equity share) is reliant on the goodwill of companies and/or the perceived need to gain planning leverage. A more centralised planning regime in the marine environment with less emphasis on local planning decisions reduces the incentive for companies to make the offer of equity shares.

There are important differences between ORE technologies and onshore wind. Onshore wind devices are available in sizes ranging from a few hundred watts to 5 MW or more. Single device projects, in the region of 0.5-1 MW or less, are viable prospects. This offers a continuum of possible investment opportunities from thousands to millions of pounds. Device and project development in the wave and tidal energy sector is characterised by a drive for economies of scale. With few exceptions technology developers are aiming for devices in excess of 1 MW. Furthermore development proposals are characterised by large arrays of multiple devices. For example, the 1.6 GW of planned ORE development around Orkney involves projects ranging from 50 to 200 MW. The high cost of ocean operations (installation, cables, connections, servicing and maintenance) necessitates a drive for economies of scale and militates against small scale or single device developments. The consequence of this is that Model 2 above would require community partners with very deep pockets and Model 3 (community developed and owned projects) look increasingly unlikely.

3.3.2.3. Compensation or fair returns

So far, this discussion of community benefits has made an implicit assumption that payments are in lieu of lost environmental services or, put another way, compensation for negative externalities. It must be recognised that in reality benefit payments are not linked to any assessment of these effects and, even if such a valuation were possible, no mechanism exists to enforce such payments. Such community payments that do exist reflect the relative balance of power and the voluntary nature of payments. Existing benefit payments reflect the value to developers of community goodwill rather than lost environmental services. As noted above there may even be less incentive to enter into such arrangements in the marine environment.

A negotiation method using a more even balance of power, based on the exchange of property rights, may lead to a different outcome. Johnson et al. [148] consider the case of oil development in Shetland in the 1970s where an Act of Parliament allowed the local authority to compulsorily purchase land to be used for the Sullom Voe oil terminal and then negotiate royalties on every barrel of oil landed at the terminal. Securing property rights allowed the community to negotiate from a position of strength delivering what was described as a "*fair share of the income that will arise…*" [149]. Subsequent payments have exceeded £100m.

With ownership of the seabed typically held by the State there appears to be little opportunity for this. However in the UK the monopoly control of the seabed by the Crown Estate is being openly questioned (Scottish Affairs Committee [150]). This is a direct result of the potential for rental income from ocean energy development and the perceived need for these to be returned to local communities. The fact the ORE developments like offshore oil and gas require landfall sites could provide an alternative route by which communities can gain leverage in negotiations over community benefits.

3.4. Environmental Impacts and Assessment

3.4.1. Environmental Assessment

In most circumstances, ocean renewable energy developments will be subject to some form of environmental assessment depending on the nature, size and location of the development. This is a legal requirement[18] deriving from a number of EU legal instruments including the Environmental Impact Assessment (EIA) Directive (2011/92/EU), the Strategic Environmental Assessment (SEA) Directive (2001/42/EC) and the Habitats Directive (92/43/EEC). The purpose of environmental assessment is to ensure that the environmental implications of a decision are taken into account before a decision is made. Environmental Assessment can apply at three levels: at site level through the EIA Directive; at a more strategic level, public plans or programmes require an environmental assessment under the provisions of the SEA Directive and finally a third form of assessment, known as an Appropriate Assessment may be necessary if a development is likely to have a significant effect on a site designated under the Habitats and/or Birds Directive, either individually or in combination with other plans or projects.

The EIA Directive requires an assessment of the environmental impact (an EIA) of any project likely to have significant effects on the environment before permission can be granted. Most wave and tidal energy developments to date have come under Annex II of Directive, as they are regarded as "industrial installations for the production of electricity". This means the decision on whether an EIA is required is at the discretion of the competent authority in each Member State. This discretion may explain why ORE developments have undergone EIA in some countries and not others. According to Article 3 of the Directive, an EIA must include a description of the aspects of the environment likely to be significantly affected by the proposed development, including:

- human beings, fauna and flora;
- soil, water, air, climate and the landscape;
- material assets and the cultural heritage;

[18] For SEA, EIA is the responsibility of the State. In EIA the developer (private firm) supplies the information but the decision-maker (public State authority) conducts the assessment. For Appropriate Assessment (AA), the firm supplies the requested information and the competent authority conducts the assessment but the result is binding i.e. if the authority finds that the development will have implications on the integrity of a Natura 2000 site in view of its conservation objectives, then the authority cannot grant consent.

- the interaction between the factors mentioned in the first, second and third indents.

Socio-economics is not included explicitly in the Article. EIA is generally regarded as having a strong biophysical emphasis, often neglecting social impacts [151]. Some EIAs, however, include socio-economic aspects as a matter of course. Such aspects generally, relate to the effects that the construction, operation and decommissioning of the existing or future ORE project will have on the society and the economy at a local, regional or national level. Specifically elements like demography, employment and regional income; sea and land use; aesthetics; infrastructure; socio-cultural systems and other maritime activities such as fisheries; tourism and recreation will be addressed [152].

The non-mandatory nature of application of the EIA process to ORE projects, coupled with the absence of socio-economics in the text of the Directive, means that there is no formal requirement to assess the socio-economic impacts of a proposed ORE development. The same could be said of pure economic information. Consequently, information relating to both the economic and socio-economic impacts of an ORE project tends to be prepared either in support of a development proposal through local planning procedures, as additional material prepared on behalf of the developer to promote the project and its acceptance by the local community, or most commonly for the developers own information and knowledge. Evidence from six wave energy test centres across Europe confirms that, of the parameters included in the EIA, socio-economic impacts of wave energy developments were scarcely addressed in existing consenting processes and accordingly remain largely unknown [153]. Despite the lack of a formal requirement to assess the socio-economic impacts, it is recommended that the most critical of these are assessed for two reasons:

1. it can help to obtain a wider perspective on the effects of the project on the regional community and economy and,
2. it may help foster a positive opinion from the consenting authorities and stakeholders.

The latter is important is important as it may alleviate the perceived “barriers” in the project development process [153]. In the UK, for example, [14] found that in the vicinity of the WaveHub development, the general public supported wave energy development and viewed it as an economically beneficial method of power generation with few adverse side-effects.

SEA applies to a higher decision-making level namely to programmes and plans in specific sectors, such as energy, and those which set the framework for future development consent of projects listed in the EIA Directive or plans and programmes which, in view of the likely effect on sites, have been determined to require an Appropriate Assessment (Habitats Directive). For this reason it tends to be conducted by State departments / competent authorities, with significant elements of the work often conducted by specialised environmental consultants. One of the key objectives of an SEA is to guide development towards areas where the environmental effects of a development are minimal or can be avoided. The Environmental Report associated with the SEA process examines both the technical and environmental constraints within the area concerned under that plan or programme. This is primarily where socio-economic aspects are included, for example, other uses such as aquaculture sites; shipping lanes; oil and gas lease areas; etc. In a similar way to EIA, the SEA Directive does not explicitly mention socio-economic impacts though the likely significant effects of the development on biodiversity, population, human health and landscape are included in addition to those factors listed previously for EIA. Arguably SEA can facilitate a proactive approach to considering all the pillars of sustainability in the early stages of the strategic decision-making process. SEA is an inherently flexible approach which could easily be adapted to include, for example, environmental limits, ecosystem services and climate change issues. The key challenge lies in its interpretation and implementation both of which can vary at Member State level.

Both the EIA and SEA Directives require formal public consultation. This remains one of the key ways in which stakeholders are involved in the decision-making process. Unfortunately under both processes, consultation is top-down whereby information is disseminated but there is little opportunity for true participation and limited ability to influence the decision to be made. Findings from the SOWFIA project show that informal approaches to stakeholder consultation are also utilised by developers particularly where a specific issue is causing concern for a certain user group, for example, where a development is likely to restrict fishing direct communication with the affected fishermen has proved more successful [154]. Participation in the SEA process can inform stakeholders of the environmental impacts of strategic decisions thereby contributing to communication and helping to reduce the risk of litigation by affected stakeholder groups, which in turn can help to avoid implementation delays [155].

3.4.2. Ecosystem services

An ecosystem service approach [156] can be used to ensure the assessment of the socio-economic impacts is holistic and all encompassing. This approach documents all the benefits which we receive from the marine environment and investigates how these benefits are likely to change following the implementation of a given technology, in this case ORE. This wider assessment is critical if all the costs and benefits of ORE are to be considered. This approach is particularly useful in translating the outputs from standard EIA into terms which are societally relevant.

Each of the different services, and related benefits, are discussed below, within the context of ORE and how the implementation of ORE may impact their continued provision. The Millennium Ecosystem Assessment (MEA) [157] classed services as provisioning, regulating, cultural and supporting. Supporting services are not discussed here as the benefits resulting from these are reflected in the other categories. An additional section on abiotic services is included as these tend not to be included in the usual ecosystem service frameworks.

Provisioning services are the products provided by ecosystems and include food and raw materials [157]. The extraction of marine organisms, including fish for human consumption is a significant provisioning service. The value aspects associated with this service include the commercial value of food from the sea, and also employment and associated income from this.

The exact potential impact of ORE on food provisioning is unknown, there have been numerous studies on these impacts but, as detailed below, the results are inconclusive. As energy (in the form of waves and tides) is key to the distribution of marine habitats it is expected that altering this energy regime will have an effect on sea life and provisioning services [148]. The construction, installation, operation and maintenance of such projects may result in habitat loss [131]. However there is the counter argument that the installation of ocean energy devices can help create habitats by providing new ecological space through the physical presence of devices [158]. They discuss the habitat creation potential of offshore wind farms.

The extraction of raw materials is another important provisioning service of marine ecosystems. This includes materials such as salt, ornamentals (shells), fish meal for aquaculture and farming, medicines, bio-fuels, fertiliser, feeds, aggregates, and seaweed. The raw materials present will be site specific and the extraction of each raw material will generate a different range of values including employment, income and health [156]. As with food, the value of the raw material benefits can be determined using commercial markets for these goods. However, the effects of ORE on the provision of raw materials is also still inconclusive.

Regulating services are the benefits obtained from the regulation of ecosystem processes, including air quality regulation, climate regulation, and erosion regulation, The oceans play an important role in climate regulation, and any impact on the ability of the marine environment to sequester carbon will reduce the overall effectiveness of ORE devices as a carbon mitigation tool. The species present on and within the sediments, and their levels of activity, are fundamental to the sediment biogeochemistry. Any reduction in bioturbation by benthic fauna could result in increased microbial activity, causing carbon dioxide to be respired back into the water column rather than buried deeper in the sediment [159]. The impacts of ORE devices on the overlying water column may also have implications for carbon sequestration. Carbon cycling within the ocean is affected by the physical properties of the water column as well as the nutrients and biota within it [160], for example, the physiological state of the plankton affects the transport of carbon into deeper water [161].

As yet, there is only limited understanding of the ways in which ORE devices may affect carbon sequestration. Impacts of ORE devices on the other regulating services are equally poorly understood [88]. Modelling studies have been undertaken, which suggest, for example, that tidal streams arrays could have far-field effects on sedimentation patterns [162, 163], which may impact erosion control and natural hazard protection, but at present little is known about these impacts.

Cultural services are the non-material benefits provided by ecosystems and include amenities, recreational activities and aesthetic, educational and spiritual benefits [157]. The cultural benefit arises from the fact that marine environments are of inherent significance to the multiple cultural identities of a community [156], and are intrinsically linked to the community impacts discussed in the previous section The economic, social and cultural identity of many coastal communities is heavily influenced by marine ecosystems. The value aspects of these cultural benefits are among the most difficult of ecosystem services to quantify.

Recreational benefits can be defined as “the refreshment and stimulation of the human body and mind through the perusal and engagement with the marine environment” [88, 156]. Recreational activities will be site specific but can include bird watching, rock pooling, beachcombing, sport fishing, scuba diving and whale watching. The values associated with recreational activities can be determined in terms of employment, income, expenditure and health benefits. The impact of ORE on recreation is still undefined. The physical scale of ocean energy developments and the need to locate in specific areas to optimise use of the resource creates challenges for planning processes which typically try to separate conflicting land uses [164]. Near-shore projects have potential to conflict with other users and local values. As detailed in the previous section early research indicates limited opposition to ocean renewables and the deployment of prototype devices [147]. However, such projects may be viewed through a lens of specific “symbolic meaning” [13]. The public reaction to ocean energy may become less positive in the move from prototype deployments to commercial projects involving large arrays of devices. These commercial projects will likely result in aesthetic impacts. The aesthetic impacts may have a negative non-market impact on local communities in addition to market impacts on tourism and property values [133].

There has previously been some variation regarding the inclusion of abiotic and biotic services within ecosystem service classifications. Within the academic literature there has been a tendency to only include biotic or ecosystem services. Ecosystem, or biotic, services tend to be a result of living resources and are renewable, as opposed to abiotic, or environmental services, which generally arise from non-living resources and are extractable and non-renewable.

Abiotic marine and coastal services include oil and gas, aggregates, cooling water, salt, ship and boat building, marine equipment and materials, construction, shipping operations, ports, navigation and safety, cables, business services, licence and rental, defence. Many ocean energy technologies will involve substantial onshore coastal development in the form of cable landfall, transformer stations, ports and harbours development and even power take-off in the case of devices which pump water ashore [148]. The development of ORE thus will certainly impact the provision of these abiotic services although the extent of these impacts currently is unknown.

3.4.3. Life Cycle Environmental Impact Assessment

Life Cycle Assessment (LCA) is a methodology used to evaluate the environmental impacts of a product, process or service. LCA takes into account upstream and downstream activities relevant to all the stages of a product’s life cycle. The methodology is a tool aimed to inform and guide decision making and is regulated by the ISO 14000 environmental management standards [165, 166]. In addition, the EquiMar project has produced advice on the application of LCA specifically aimed to the Environmental Impact Assessment of ocean devices [87].

The design of ocean energy converters is constantly evolving and has not reached a phase of commercial production or disclosure for most of the devices, which makes environmental impact over the lifecycle as difficult to decipher as cost. Reviewing the literature on LCA of ocean renewable energy technologies reveals only a small number of efforts to account for the carbon and energy payback and very little in the way of considering other impact categories. Furthermore, the limited number of studies that are in the public domain are based on a large number of assumptions due to the early stage of the technology.

Soerensen et al. [167, 168] enhanced a previous study reported in Callaghan and Boud [44] and undertook a full LCA on the Wave Dragon as a first attempt to produce a carbon and energy balance for a wave energy converter. It was followed by work regarding the Pelamis in the form of an initial investigation of the construction stage [169], a carbon audit [170] and a full LCA [171], as well as a study for the Oyster wave energy converter [172]. Studies have also been conducted on the LCA of a hypothetical large scale wave power plant, taking into account different deployment locations and power absorption rates [173]. In terms of tidal power, Douglas et al [174] have produced a study for the SeaGen tidal current turbine, and Cavallaro and Coiro [175] investigated the Kobold system, a hydraulic vertical axis turbine. Tidal electricity generation was also included in a comparative LCA study conducted by Rule et al [176] but due to common components being omitted for all technologies in that particular study the results cannot be treated as definitive and are not included in the range of results quoted in this review.

In the majority of the research listed above, the focus is on embodied energy and carbon emissions. Energy intensity ranges from 144 kJ/kWh [175] to 381 kJ/kWh [171] for single devices with wave energy converters having generally higher embodied energy than tidal stream devices. Despite economies of scale the best case of the wave power plant records higher environmental impacts than the studies on individual wave devices. This highlights the extent to which the quality of the resource can influence the results as the impacts between the two locations studied varied by a factor of three [173]. The carbon intensity is not always reported; the results reviewed range between approximately 15 gCO_2/kWh [168, 174] and 50 gCO_2/kWh [44, 173, 177].

These LCA results are highly sensitive to the energy mix, and more specifically the electricity mix assumed. This is both in the locality and time period relevant for sourcing materials, device construction and installation, as well as during the operational stage, as the generation substituted defines the potential gains in terms of global warming potential. A number of the studies reviewed assume UK grid electricity with carbon intensity between 0.43 $kgCO_2$/kWh [170, 174] and 0.499 $kgCO_2$/kWh [171] and mostly UK-based processes for the construction of the devices. On the basis of that, the carbon payback times have been estimated at eight months for the SeaGen [174] and Oyster [172] devices and 13-14 months for the Pelamis [170, 171].The lack of depth and detail in published LCAs on wave and tidal energy devices means that the topic has not been included in recent attempts to harmonise LCA results for energy technologies [178]. As such the values quoted above are to be treated as indicative and are not necessarily directly comparable either between the studies or with other literature.

This also applies to other environmental impact categories, when reported, where direct comparison is not possible due to the difference in environmental impact methodology and allocation. For example, Cavallaro and Coiro [175] apply the Ecoindicator methodology, Dahlsten [173] follows the product category rules for environmental declaration, while Soerensen et al [167] and Thomson et al [171] both use the EDIP methodology but with difference in normalisation, weighting and crediting. However, all studies regardless of scope and methodology, point to the materials and manufacturing stage as the source of the greatest impacts. This in turn leads to suggestions for high recycling rates, efficient processes and careful consideration of the materials chosen in order to minimise impact potential.

Other sensitivities arise from the assumed lifetime and output of the technologies, as well as the materials employed in their design and construction and their fate in terms of end of life recycling. As these are novel technologies, not tested for a long period of time under real operating conditions in specific locations, the above studies can only serve as an indicator of potential benefits or impacts in terms of lifecycle energy and carbon balance.

As devices at this stage are built for survivability rather than efficiency [170], learning and efficiency changes in future may also improve environmental impact. However, apart from introducing measures to mitigate immediate impact to marine life and ecosystems or reduce cost, the industry is perhaps at too early a stage to be considering changes solely based on environmental life cycle impact assessments. Nonetheless, this is not to say these should not be carried out to reveal energy and carbon intensities as well as other high impact categories and highlight where there is weakness or scope for improvement through alternative design. Moreover, such improvements may have concomitant effects on the production cost of the devices through the introduction of efficiency measures. Soerensen et al [168] have also reported on the potential impact of future device developments on the life cycle environmental performance based on a number of development scenarios. However, given all the unknowns of assessing the technologies at present, it follows that these projections are highly uncertain.

3.4.4. Cumulative Impact Assessment

The EU EIA Directive (85/337/EEC, as amended) requires not only consideration of the direct impacts of a project, but also any indirect, secondary and cumulative effects of a project. Cumulative effects are also included in the EU Strategic Environmental Assessment Directive (2001/42/EC) and Habitats Directive (92/43/EEC, as amended). In practice cumulative impacts are often not addressed or are handled inadequately in both EIA and SEA processes [179, 180]. It is difficult to separate indirect impacts from cumulative impacts and hence definitions and methodologies tend to be interlinked. The European Commission has recognised that there are no agreed and accepted definitions of cumulative impacts. For the purposes of their general guidance they have defined cumulative impacts as "impacts that result from incremental changes caused by other past, present or reasonably foreseeable actions together with the project" [181]. Examples of cumulative impacts include incremental noise from a number of separate sources; combined effect of individual impacts on a particular receptor; insignificant effects which together have a cumulative impact: one wind farm, for example, may have an insignificant impact but several wind farms together could have a significant impact on the local ecology and landscape. Increasing numbers of proposed developments create greater pressures on the environment, making cumulative impacts a pressing issue [182].

Cumulative impacts tend to be assessed because it is a legal requirement to do so but their assessment is also important in the broader planning and decision-making processes as well as in contributing to sustainable development. Unresolved cumulative impact issues during the consenting process can put projects at risk of delay or at worst, be refused consent. Direct impacts tend to be easier to assess and state with greater certainty. Cumulative impacts are much more difficult to assess as they are more uncertain and, therefore, tend to be based on assumptions. This is particularly true for developments in the marine environment where interactions are more complex and, in some case, less understood. Whilst this makes assessment difficult, it does ensure that the potential for impacts are at least considered in, rather than omitted from, the decision making-process entirely. Lack of scientific certainty on cumulative impacts could, however, lead to overly precautionary consenting terms and conditions. Given the complexities involved in defining cumulative impacts, methodologies for their assessment tend to be underdeveloped. In addition to the guidance published by the European Commission [181], other general guidance documents include Cumulative Impact of Wind Turbines [183], A Guide to Assessing the Cumulative Effects of Wind Energy Development [184] and Handy Hints on Impact Assessment Issues for Renewable Energy Developments in Orkney [185]. The majority of these guidance documents focus on visual impacts in both the landscape and seascape. Cumulative impacts also tend to be mentioned in general EIA and SEA guidance documents but more in terms of the need to consider them rather than how to assess them.

There is no standard or accepted methodology for undertaking Cumulative Impact Assessment (CIA) of ocean energy developments. The guidance produced by the European Commission provides information on eight methods and tools, from case studies and literature review, which could be used for cumulative impact assessment. These fall into two groups: scoping and impact assessment techniques and evaluation techniques. Scoping and impact assessment techniques identify how and where an indirect or cumulative impact or impact interaction would occur whereas evaluation techniques quantify and predict the magnitude and significance of impacts based on their context and intensity [8]. The approach adopted will depend on the project in question as well as the nature of the expected impacts and availability and quality of both data and resources. Significant work on cumulative impacts has been carried out through the Collaborative Offshore Wind Research into the Environment (COWRIE) initiative. Initial research concluded that developers have taken a wide range of approaches to CIA in which assessment has often been qualitative rather than quantitative. This raises questions about the robustness of the conclusions made. Key issues have been identified in a number of previous documents as: inadequate scoping, lack of understanding of the species involved, difficulties in assigning the range of projects which should be included within the assessment and the methods by which CIA should be undertaken [186, 187]. COWRIE has produced specific guidance on the assessment of cumulative impacts on the historic environment from offshore renewable energy [188] and a publication on developing guidance on ornithological cumulative impact assessment for offshore wind farm developers [187].

Most recently, the Oregon Wave Energy Trust has funded the development of a Cumulative Effects Analysis Framework centred on a multi-criteria decision making tool for evaluating the potential impacts of various ocean renewable energy technologies [190]. This tool is designed to offer decision makers, stakeholders and the public more information on the potential impacts associated with various ocean energy development scenarios. The current tool is comprised of three elements: a data library of applicable resource data; a resource and development interaction database; and a user interface that combines the data and interaction to assist in the analysis of alternatives. The final product is a GIS tool for assessing various development scenarios and the potential impacts and benefits [189]. The next stage of this work will test the framework in a real-life situation, a case study site will be selected and results of the modelling analysis used to identify areas within the Territorial Sea that, if developed for wave energy, would result in the greatest change and/or generate the most impact [189]. A greater emphasis will be placed on spatial scale with a view to reconciling these thereby allowing for more effective comparison across data layers.

As more marine areas are ear-marked for ocean renewable energy development, the relative importance of cumulative impact assessment will increase with regulatory authorities becoming more and more reliant on scientific data submitted by developers. Current consenting procedures tend to focus on the impact of one development at a local level and, it is debatable whether large scale cumulative assessments have yet taken place under existing consenting systems. Equally it could be argued that cumulative impacts may not be directly associated with the impacts of any individual development project and consequently many authors have argued that cumulative effects are best assessed in a more regional and strategic context, through the Strategic Environmental Assessment (SEA) process (e.g. [190-192]. However Gunn and Noble [180] highlight the potential difficulties associated with inclusion of cumulative impacts in an SEA framework. Either way, if cumulative impacts are to continue to be addressed through strategic or site level impact assessment processes then ultimately there is a need for more consistent and systematic approach to their assessment supported by dedicated industry guidance.

3.5. Socio-economic modelling of innovation and learning in an ocean innovation system

Ocean energy can support national transitions to low-carbon energy supplies. As such, ocean energy stakeholders (researchers, industrialists, the public and policymakers) are increasingly making evaluations of the social processes which can both help and hinder innovation and learning at a variety of levels and so contribute to sustainable energy system change [193-195].

Innovation studies are a policy perspective rooted in evolutionary economics and systems theory. Used by the Department for Energy and Climate Change (DECC) amongst others, it has been used to examine potential long-term energy transitions in the UK. This approach involves a recognition that while economic factors are important in any analysis, potential energy transitions are *co-evolutionary, enacted*, *relational* and *interactional*. This means that they are dependent upon social processes including the creation of new innovation systems, technological novelties, networks, visions, expectations, niche markets, user-practices and preferences, regulations, institutions, social learning, and competitive strategies. Moreover, in an increasingly globalised world, new technological developments are rarely embodied in, or confined to, a single national or sectoral context. The global rate and direction of innovation in ocean energy, for example, is heavily influenced by the specific resources in and governance of individual national, regional, sectoral and technological innovation systems. Innovation is also influenced by the strategic decision-making of local, regional, national and supranational institutions, the transnational energy companies as well as other private institutions, such as private financiers, which span and link these systems.

The Innovation Studies approach draws directly on qualitative and quantitative data – chiefly the types of data in section 2 above - and suggests that ocean energy stakeholders are institutionally embedded within regional, national and global innovation systems. Their behaviour can be analysed for a number of innovation *functions* [196, 197]. These include an ability to form advocacy coalitions, raise finance, boost market growth, contribute to a guiding vision for the sector's growth, create knowledge and disseminate that knowledge [198]. Whilst some of these factors have been highlighted in the existing more general marine literature, some studies have begun to offer a picture of a coherent ocean innovation system that identifies how such processes could work in concert (these include [193-195, 199]).

In the existing ocean energy literature, analyses of the barriers to improved market penetration of ocean energy, for example, tend to be technical and/or socio-economic in nature (these include [44, 102, 119, 200-207]. Two of these studies, undertaken by the European Waveplam project consortium [152], suggest that the greatest perceived non-technical market concerns amongst ocean energy stakeholders lie in the areas of regulation, financial incentives, and infrastructure and logistics. Other non-technical barriers were felt by stakeholders to be potentially less troublesome. These factors include: conflicts of use, environmental issues, and public perception [200, 204].

While such existing insights in the literature are extremely useful, not least when so few ocean-only, socio-economic and technical studies have been undertaken, it is unclear how such analyses relate innovation and energy policy-making to innovative activity at the regional, national and global scales. Apart from rare examples (for example [45]), what is missing from the current ocean energy literature is more coherent linkage between empirically-informed theorising about the nature of ORE innovation and policymaking in the sector [194, 196]. This sort of clarity and relevance is in ever-greater demand as ocean energy technologies are moving downstream from the research bench to the marketplace (via the UK's technological readiness levels or TRLs originally developed in US – by NASA – make sense for components but don't seem to be very useful for an entire system[19].

For example, ORE has been receiving a lot of interest in recent years and this has resulted in an increase of research teams, entrepreneurs and start-up companies active in the field. However, most ocean energy conversion technologies are still in the development stage with only a few pilot and full-scale demonstration projects. A dominant design has yet to emerge. Some commentators believe that the currently large number of designs and small number of players in the sector is hindering technological deployment and commercialisation by reducing the resources available to the most promising devices [127]. However, reviews based on the early stages of development of the wind industry [194] suggest that design variety, a long learning period and network building are among the key success factors for countries which themselves come to dominate an industry. Other key factors include strong university-industry links and flexible policies which offer financial support. One policy implication is that, given the multiple technologies under development and being brought to the demonstration stage, the favouring of a technological portfolio approach over an extended period of time allows the most economically viable concepts to emerge [129].

To conclude, a socio-economic approach expands and enlarges upon socio-economic data, linking understanding of innovation with policy guidance that can help to bring about and/or maintain what is in this case an emerging global ocean energy innovation system.

Appendix 1 contains a summary table (Table 2) of the methods and limitations discussed in section 3 relative to the public perspective in ORE.

[19] http://www.publications.parliament.uk/pa/cm201011/cmselect/cmsctech/619/61913.htm

4. Integrated assessment methodologies between private investment and public in ORE

A holistic approach to the evaluation of an ocean renewable energy technology type or specific project is very important in order to provide a comprehensive overall valuation. Such an assessment should incorporate methods relevant to three discipline areas:

- Economic - financial returns and efficient use of resources
- Social - variables such as employment, social and community cohesion and identity,
- Environmental - including the physical environment and pollution.

The methods and parameters that have typically been associated with each of these disciplines have been reviewed in earlier sections. It is useful to understand how these methods and parameters are, or might be, related. To facilitate this discussion we consider a parameter space defined by the three disciplines and by the scale of the system under evaluation. The scale of the system considered varies from the components of an ocean energy project, to a project comprising a number of devices installed at a particular location, through to a geographic or economic region in which multiple farms may be deployed on a national scale. This parameter space is illustrated in Figure 1 on which:

- the inner solid circle at the centre of the axis are placed methods which are within the boundary of interest for a private investor, or a firm, developing an ocean energy project. This includes the “private” consequences of a project. In the socio-economic section, this is labelled ‘local’.

- the outer circle denotes the methods typically employed at the broader stakeholder level including economic, social and environmental issues that can be employed at local, regional or national scale and which are typically employed to inform policy and decision making. These are, of course, therefore much wider than the impacts to the firm undertaking the project but will take into account “externalities” of the project across the three fields. In the socio-economic section, this is labelled ‘public’.

In the following sections, key methods identified in the preceding sections are mapped onto this parameter space and the connectivity explored. Methods may identify impacts within a specific discipline only – and so would be placed on an axis – or identify impacts at the interface between disciplines – and so are placed between axes. Connectivity between methods is then considered. For example, the assessments employed by some stakeholders are of direct relevance to the private investor; stakeholder ownership of a firm or project will influence the acceptable level of project risk and the process and outcomes of the Environmental Impact Assessment are clearly defined stages of project development. Similarly, private companies have interests at the policy level – innovation systems. This framework is presented to facilitate the discussion rather than to provide a definitive location for each of the methods considered. Therefore, only a small number of the methods mentioned earlier in the paper have been displayed and located in Figure 1.

Insert Figure 1 here

4.1. Economic axis and relationships

From the perspective of a private investor, the fundamental question needing to be addressed is; does the project provide an acceptable return at an acceptable risk. The methods used in answering these questions are typically financial indicators Cost of Electricity (COE), Net Present Value (NPV) and Internal Rate of Return (IRR), and are placed in the inner circle. In order to output financial results and indicators, models are created by firms to estimate costs and revenues across the project’s lifetime, which will include Capex, OPEX, and any financial support mechanism, such as tariffs or certificates, on the revenue side. The electricity sales will also be considered on the revenue side.

Input-Output and Computable General Equilibrium (CGE) models can capture the economic, social (e.g. employment) and environmental consequences of specific projects, and thus are placed between the inner circle and the outer policy circle. Such measured effects will be external to the firm seeking to undertake the project. Additionally, there may be other external impacts which are not directly captured by the firm's decision, e.g. its contribution to the energy mix, energy security, innovation, green jobs in the supply chain, etc. Renewable energy subsidies and grants, for example, may be ways by which policy (represented on the outer circle) currently acts to compensate firms (on the inner circle) for these positive externalities that their projects confer on wider economic, social and environmental variables. In Figure 1, for example, there are no feedbacks from GDP impacts or national job creation from a project to a firm's financial evaluation metric, i.e. NPV or IRR. However, the diagram connects these factors through IO and CGE modelling methods. Appropriately designed industrial/sectoral policy – tax breaks, etc. - could take such external impacts into account and could act as compensation and/or a stimulus for companies and firms to develop renewable energy portfolios.

4.2. Environmental axis and relationships

This section discusses how the assessments of environmental impacts of an ocean renewable energy project may be connected to factors in the economics and social disciplines and identifies connections between private and non-private assessments.

The concept of Ecosystem Services (ES) has been developed to determine how changes at the ecosystem level can affect the health and well-being of humans. At an environmental management level, it can be used to ensure that environmental, economic and social issues are regarded equally when decisions on developments (such as ocean renewable energy projects) are made. In Figure 1, ecosystem services would be placed on the policy/planning level (outer ring) and links the environmental axis across to factors on the economic and social axes. Environmental Impact Assessment (EIA) requires information to be gathered on fish resources, fisheries (provisioning services), benthic environment (supporting services) and recreational uses (cultural services) among others. This would be represented in the diagram by an arrow linking ES at the policy/planning level and EIA at the firm level. The ability of the public to participate in the EIA process is legally prescribed through EIA legislation, thus EIA lies between and links both the environmental and social axes.

ES economic valuation provides a link between the environmental and economic axes, linking the largely qualitative aspects of ES into quantitative measures. ES valuation involves assigning monetary values to non-market goods and services. Ecosystem benefits are identified in this valuation so that these values are not ignored or overlooked when it comes to resource management decision made on a policy level. ES monetary valuations can be used as a basis for understanding and developing appropriate economic instruments for sustainable use of resources. These monetary values are linked directly to both trade-off analysis and cost benefit analysis (CBA), and these links would be graphically located between the Economic and Social axis of Figure 1. Trade-off analysis and CBA therefore provide socio-economic frameworks through which the impacts of ocean renewable energy developments can be assessed for policy and planning, and thus these links would be located closer to the outer policy/planning ring.

Life Cycle Assessment is a method that lies firmly on the environmental axis as it estimates impacts to the environment throughout the technology lifecycle with the purpose of ensuring that impacts are not displaced or substituted rather than avoided. The outputs are potential impacts on areas of protection that can be of local (e.g. toxicity), regional (e.g. acidification) or global importance (e.g. global warming) and as such are of interest to stakeholders at each level from the general public through the levels of governance. At the same time the method is a way for developers to prove the environmental credentials of a technology or project and identify areas of improvement which often lead to monetary savings along with the reduction of environmental impacts. While the outputs of the method itself are environmental, they could serve to inform the assessments described above, as well as contribute to the positive perception of the technology by the public, and as such we could envisage links towards both the economic and social axes. In some cases the links might be indirect; i.e. going through another method or process to derive economic or social impact.

4.3. Social axis and relationships

This section discusses how the social impacts of an ocean renewable project may be linked to factors in the economic and environmental areas. Public perception of ocean renewable energy development will be influenced by a number of factors: public attitude towards a form of power generation or a particular project, the predictors of public response and the explanation of the underlying perceptions. Public perception findings are of interest to planners and developers as the goodwill and support of local communities might be essential to avoid disruption for projects and ensure their success. The difficulty lies in assessing the predictors of the behaviour which draw from the results of methods operating on both the economic and environmental axes, as well as the multiple levels these may act on. These can be influenced by the level of stakeholder engagement that is carried out. Stakeholder engagement is a process that the developer undertakes to involve key stakeholders in the development of a project; it is a legal requirement and would be placed on the developer circle in the diagram. This engagement generally involves a dedicated communication strategy developed at an early stage of project development planning.

Public perception is one of the factors in stakeholder perception and will also be influenced by the costs and benefits an ocean renewable development will bring to the local community. Perceived economic risk for particular groups is weighed against local or wider (national) socio-economic gains in formulating public attitude. Thus public perception would be placed mid-way between local inner circle and outer public circles in Figure 1. Public perception studies and models of community involvement form informative precedents in predicting and avoiding conflict as well as examples of shared benefits. Community benefit schemes are often used by renewable energy developers to ensure that local communities receive benefits from projects. Direct local economic benefits can be difficult to prove and thus more easily disregarded, especially since community payments are on a voluntary basis and decided on an arbitrary model as to their level and format. Community benefits schemes can be divided into four main categories – community funds, local ownership of the energy project, local contracting and benefits in kind. Community funds, local ownership and local jobs are predominantly economic benefits and, as such, they link the social and economic axes. Benefits in kind are those that a developer directly provides to the local community, for example a new facility or improvements to an existing one, environmental improvements such as the creation of a park etc. These would be placed between the social and environmental axes.

Similarly, potential environmental impacts or benefits at the local or global scale bear different weights given the perspective of the members of public and the acceptability of a technology at a generic level can be different from that of a specific project at local level.

Despite the fact that developers work within different regulatory frameworks depending on where the project is sited, there are indications that a detailed Environmental Impact Assessment (EIA), available in the public domain, although they do not form a direct input, could increase project acceptance [208]. As such, EIA could provide a further link between the social and environmental axes. The EU EIA Directive does not include social impacts but some Member States, e.g. Portugal, have included a requirement for an assessment of social impacts in their transposing legislation.

5. Conclusions

A review has been presented of a diverse set of methods that may be employed to assess the viability, and impacts, of an ORE project. The approaches covered include techno-economic assessments that are typically employed to inform private investment decisions, and a range of approaches for assessing different aspects of the socio-economic and environmental aspects of an ORE project. This range is reflected by consideration of economic assessment methods from, in turn, the perspective of a private, or firm-level, investment decision-maker and socio-economic assessment methods from the perspective of the wider, stakeholder, community that do not have direct ownership of the project. For each assessment method, the methodologies employed and input data required are briefly discussed and applications to ORE projects are summarised. Weaknesses of particular methods are highlighted.

The review of economic assessment methods described the number, type and detail of the inputs required to describe an ORE project. There was identified a large range of tools used by private investors in deciding whether to invest in ORE, each with specific characteristics and potential limitations. Inputs may be selected on the basis of an assessment of the overall project, or system, risks and these may change with development of the project design and of the technology. The review revealed two key weaknesses in current assessment techniques. The first is that the nascent ORE sector cannot provide a high degree of accurate deterministic inputs for economic assessment, thus leading to uncertain outputs and feasibility results. The second is that the current metrics and methods have not been fully developed and standardised for the sector producing economic results that are lacking in accuracy and confidence. Techniques and related costs concerning installation and maintenance of ORE were identified as both one of the most significant areas of technical importance but simultaneously the least known due to lack of commercial devices in the water. The large range of other unknowns, both technical (resource and power estimation) and economic inputs, lead to uncertain feasibility results eventuating in significant barriers for investors seeking funding and insurance for ORE development.

Socio-economic and environmental assessment methods and their application to ORE projects were also reviewed. These approaches provided a mix of qualitative and quantitative information on the impact or effect of ORE that are of relevance to policy makers, members of the public and other stakeholders. The various metrics for measuring the job creation potential of the development of ORE were discussed, identifying that a standard reliable jobs metric be adopted to allow comparability across renewable technologies. Of the methodologies used for the calculation of the job creation potential of ORE, CGE was identified as offering greater modelling flexibility, when compared to the Input-Output method. Also reviewed were the stakeholder perceptions, community benefits and compensation related to ORE. Finally environmental impacts, and in turn impacts on associated ecosystem service were discussed, and it was recognised that although ORE is likely to impact all ocean ecosystems services, the extent of this impact is unclear and approaches to measuring this impact are poorly defined.

The connectivity between the economics and socio-economics assessment methods for ORE was analysed in relation to project developments and to policy and planning decisions. To facilitate this analysis, methods were considered in terms of key criteria of sustainability – economic, social and environmental considerations – and in terms of the type of end user, or stakeholder. Broadly the stakeholders considered range from private investors with direct influence on the design of a single project to stakeholders within the broader public domain, with indirect influence on a specific project. An idealised, and novel, visualisation of this assessment method classification and connectivity is presented in the form of Figure 1.

The analysis section revealed the multiple dimensions of connectivity that exist, both between stakeholder levels in ORE, and between the topics of economics, society and environment. This analysis led to insights on existing best practice, but also revealed the potential for disconnect between an ORE project’s commercial viability and its contribution to environmental and social goals. The ability to establish the benefits arising from the connectivity identified remains difficult to quantify. The goal of sustainable development process for ORE is normative and therefore the process needs to respond to differing stakeholder aspirations and interpretations. Evidence from practice tends to revolve around traditional forms of assessment such as EIA and SEA and the uptake of newer forms of assessment is less common. EIA traditionally has a strong biophysical (ecological) emphasis and consequently does not usually include, and arguably neglects, socio-economic impacts of development. Environmental Assessment was founded on the basis of providing evidence-based decision-making, but in the context of ORE development, practice is still limited and consequently it is difficult to provide evidence of benefits for a particular project at this time.

Ecosystem Services and life cycle assessment are increasingly recognised as enabling linkages between EIA and socio-economic impacts, as well as providing an opportunity to integrate more pure economic and social aspects of a development. However, the reality is that these approaches are not yet fully understood and are not habitually utilised or required to be employed in development planning. This leaves the social impacts of a development as a somewhat outstanding issue, addressed in some places in the usual EIA process or included by developers if thought to improve the "attractiveness" of their development to the local community or the decision-maker.

In conclusion, the review revealed that the current study of economics and socio-economics of ORE remain separate and discrete areas of research. The economic methods utilised are typically limited to project (or private investor) level so arguably are not strategic and conducted purely for the purposes of the investor and consequently there is minimal need for these to integrate with other (social and environmental) assessments. However, the paper also demonstrated that these research areas are inter-connected and synergistic and must be examined in a holistic manner if an analysis of the over-arching sustainability of a project is to be determined. An integrated assessment approach has the ability to address both the private and the public aspects of an ORE development, provided an enabling framework exists. Further analysis of the connections of the three pillars of environment, economy and society, and their related synergies will be essential to ensure the sustainable development of this nascent but emerging sector. Further work needs to focus on such a framework as currently issues of scale, lack of appropriate data, risk and uncertainty compromise the adoption of an integrated approach to the assessment of the sustainability of a project. The over-arching approaches and conclusions of this paper are expected to be transferable across the renewables sector, and indeed beyond to the wider energy sector.

6. Acknowledgements

The contributions of Gordon Dalton, Anne Marie O'Hagan, Wanan Sheng and Kieran Reilly are based upon works supported by Science Foundation Ireland (SFI) under the Charles Parsons Award for Ocean Energy Research (Grant number 06/CP/E003). Grant Allan acknowledges the support of ClimateXChange, the Scottish Government funded centre of expertise in climate change. The views expressed here are the solely responsibility of the authors and not necessarily those of ClimateXChange or the Scottish Government. Aliki Georgakaki and Nick Hacking would like to acknowledge the support of the Welsh European Funding Office (WEFO) through the LCRI Convergence Energy Programme. The same authors would also like to thank Wouter Poortinga for his support and his constructive comments on the subject of stakeholder perceptions. The contribution of Pierpaolo Ricci was mostly developed at Tecnalia Research and Innovation under the financial support from the Department of Industry, Innovation, Commerce and Tourism of the Basque Government (ETORTEK Program).

All authors wish to acknowledge the European Energy Research Alliance (EERA) Joint Programme on Ocean Energy through which the motivation for this paper was identified.

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