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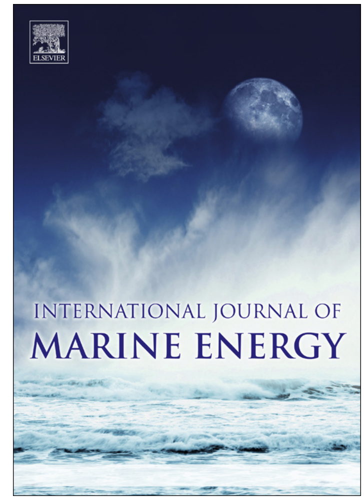

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Integrated methodologies of economics and socio-economics assessments in Ocean Renewable Energy: private and public perspectives

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Abstract—

This paper offers a holistic approach to the evaluation of an ocean renewable energy (ORE) technology type or specific project in order to provide a comprehensive assessment of both narrow economic and broader socio-economic performance. This assessment incorporates methods from three pillars areas: Economic - financial returns and efficient use of resources, Social - employment, social and community cohesion and identity, and Environmental - including the physical environment and pollution. These three pillars are then considered in the broader context of governance. In order to structure this evaluation, a novel parameter space model was created, defined by the three pillars and by the scale of the system under assessment. The scale of the system ranged from individual components of an ORE project; to projects comprising of a number of devices; through to a geographic regions in which multiple farms may be deployed. The parameter space consists of an inner circle representing the boundary of interest for a private investor, or a firm, developing an ORE project. The outer circle is characterised by assessment tools typically employed at the broader stakeholder level including economic, social, and environmental methods that can be employed at local, regional or national scale and which are typically employed to inform policy and decision making regarding ORE. Governance sets the stage within which management occurs. Wider impacts to the firm undertaking the project will take into account "externalities" of the project across the three fields. In this model, key methods identified are mapped onto this parameter space and the connectivity explored. The paper demonstrates that the three pillars are inter-connected and each must be considered in any meaningful assessment of ORE sustainability. An integrated assessment approach has the ability to address both the private and the public aspects of an ORE development, This analysis provides insights on existing best practice, but also reveals the potential for disconnect between an ORE project's commercial viability and its contribution to environmental and social goals.

***Keywords*— Economics, Social, Environment, Governance, Assessment, Sustainable Development, Connectivity**

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I. Introduction

This paper provides a holistic approach to the evaluation of an ocean renewable energy (ORE) (defined in this paper as wave and tidal energy) technology type or specific project. This analysis takes the novel approach of considering economic and socio-economic (E&SE) analysis from the perspective of the project funder or private investor or a firm (called *Private*) and of a wider societal stakeholders (called *Public*). *Private* systems (considerations and aspects) can vary from the components of an ORE project, including 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 with clear associations to *Public* considerations. Such an assessment incorporates methods relevant to three pillar areas: Economic - financial returns and efficient use of resources, Social - variables such as employment, social and community cohesion and identity, and Environmental - including the physical environment and pollution. In addition the overarching governance system will also be discussed, to complete the assessment.

The methods and metrics used in *Public* and *Private* spheres, and by different pillars, to assess the performance of ORE projects are reviewed. The objective of this review is to catalogue the principal methods used and to identify any gaps and weaknesses in these.

The paper then progresses to integrate the assessment methodologies between the *Private* and *Public* by creating a novel parameter space model, defined by the three pillars and by the scale of the system under evaluation. The interconnectivity between pillars as well as the relationship between the broader macro-economic, social and environmental issues and those directly considered by private investors are assessed.

In context of this work 'economic assessment' refers to the appraisal of financial and economic performance of a project or technology. Such assessments are typically undertaken to inform developers, sponsors or policy makers about the financial viability of specific projects or technologies. In contrast the macro-economic, social and environmental assessment generally refers to the wider external impacts of development; for example, employment multipliers, environmental impacts, ecosystem services, community benefits, and lifecycle analysis. These issues are still economic in consequence, but they are experienced by wider society beyond the confines of the project.

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 [1]. 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 [2]. Europe faces a renewable energy target of 20% [3] of electricity production from renewables by 2020 [4], with some countries, such as Ireland, setting even higher targets of 40% for 2040 [5]**.** 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 OE farms have been constructed [6]. Prior to the construction of any large farms, alternative designs must be compared and preferred design solutions identified.

Reviews of offshore wind economic and socio-economic analysis have already been conducted and published [7, 8]. To assess the viability of any infrastructure project, a variety of assessment criteria or techniques may be employed. Seen through the lens of sustainable development these methods can be considered in three broad categories – economic, environmental and social. Sustainable development, as conceptualised in 'Our Common Future' [9], requires a convergence between the three pillars of economic development, social equity, and environmental protection, as defined by the UN [10]. 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 legal requirement 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) which list projects for which EIA is mandatory (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].

The intention of this analysis is to inform the development of approaches that will support the sustainable development of ocean energy projects, relating to economics, social science and environmental factors, along with their inherent synergies. Transferable lessons for other renewable energy sectors can also be taken from this analysis, as well as it assisting in the sustainable development and successful growth of this emerging sector.

II. Analysis of private and public assessment methods in economic and socio-economic of ORE

A. Private assessment methods in ORE

E&SE assessment is never an exact science.. In the context of ORE uncertainties concerning physical parameters such as resource assessment; reliability and device efficiency compound the difficulties. This is particularly so for wave energy. Unlike wind and tidal, which is defined by one dimensional parameter, wave energy's two dimensional parameters present significant problems to resource engineers attempting to quantify the resource. Problems occur both in the physical measurement techniques as well as in the mathematical interpretation used to produce the hourly average data. Like wind, the annual resource varies from year to year, with current studies indicating that at least 15 years of data is required to provide reliable statistics for that location. Wave energy power is represented in a two dimensional matrix format, to correspond with the two dimensionality of the resource. The history of its development has unfortunately led to the creation and use of multiple parameter techniques particularly in representing wave period measurements; either using Tz, Tp or Te. There are many other inconsistencies occurring with the use of scatter diagrams, such as the dependency of the matrix on location and wave directionality. The IEC standards committee is a very important initiative that endeavours to standardise the parameters used for wave energy calculation [18-22].

Capex analysis for ORE is similarly not an exact science, especially considering that the technologies have not reached commercialisation phase yet. Quotes on Capex made in reports and studies, still suffer the same lack of clarity in definition that their counterpart studies on offshore wind and other renewables; namely lack of clarity in quantification, and qualification of Capex pertaining to the item discussed [23]. A major common error is lack definition of whether costs are for a device only, device plus installation costs, or whether it infers all installation and balance of plant i.e. total Capex. This ambiguity is particularly relevant in quotations of Capex/ MW, where the exact content of the Capex is extremely important. Comparison analysis of costs to other technologies both wave, and other RE as well as fossil energies is meaningless unless confident direct comparisons can be made [24-26].

Capex dependencies on volume and time are similar to other renewables, and yet are parameters rarely discussed at levels appropriate to their importance [27, 28]. The drive to larger size devices to achieve what is considered a more economic product is as popular in wave energy as any other technology. However, this has not been proven yet in ocean energy sphere. Certainly, larger volume of product should provide a cheaper bulk purchasing cost, and this will be purely market driven. However there is still uncertainty whether balance of plant costs will reduce inline with other costs. Reduction in Capex due to progress rations due to learning is another contentious area still under research. Experience could be similar to that of offshore wind where costs reductions from innovation and skills learnt in manufacturing were offset by excessive demand and peaks in commodity prices. Ambitious targets for ocean as well as renewables will certainly provide a ready market for the product if it ever gets to commercial stage. However, ancillary supporting mechanisms will be required for some time to sustain the path to commercialisation.

Similar to offshore wind, wave energy operations and maintenance will be an unknown quantity and risk for the industry [29]. Many research projects are being financed by the EU to try and quantify and mitigate this risk. The technology poses unique challenges when compared to offshore wind and these are likely to increase the annual costs over and above that of offshore wind [23]. Indeed, OSW demand may make access to competing vessel seven more expensive, jeopardising the already tenuous weather window volatility that wave energy faces. This combined with the requirement of far offshore farms located in the worlds most inclement environments will make for challenging technical and financial operations and maintenance (O/M) logistics [26, 30].

B. Public assessment methods in ORE

The public attributes of ORE are divided in three separate study categories: macro-economic and social and environment impact studies. Hacking and Guthrie [31] are of the opinion that sustainability assessment can most usefully be considered an umbrella term incorporating a range of impact assessment practices.

Macro-economic studies are essential for all technologies in order to provide justification for state and federal support for the promotion of the sector, as well as provide guidance for future planning and road-maps. There have been numerous comprehensive studies conducted for offshore wind. However, there are many short-comings in these studies due to a lack of clarity in the definition of variables and benchmarks which has led to confusing results being reported; e.g. the use of jobs/MW. Recent papers are now promoting the use of the more robust metrics such as jobs/€M invested, job years, and cumulative jobs metrics, which will hopefully clarify and standardise future statistics [32, 33]. Studies investigating Gross value added (GVA) and employment are becoming increasingly complex. Input/Output (I/O) studies are now progressing to computer general equilibrium (CGE) studies, often requiring large datasets and equally large project teams to complete the task. As yet few European countries have completed CGE studies for ORE and this endeavour could be the source for future cross national collaborative projects, perhaps via EU Horizon 2020 [34, 35].

Social impact studies are now broadening to incorporate socio-technical, indirect socio-economic and innovation studies.

As ORE comprises of emerging technologies, early public opinion will be significantly influenced by the performance of demonstration projects and the first commercial projects. Attitudes are predominantly positive but there is also concern from a number of directly affected stakeholder groups. It also emerges that place attachment could be a greater factor in public acceptance and support of a project than other socio-demographic variables. It follows that transferring results and practices between different communities and geographical areas of deployment may not prove successful. Early local involvement and consultation with communities and stakeholders affected is increasingly seen as the norm. Consequently, the amount and quality of information volunteered, in terms of the performance and impacts of any project, seems to be a significant factor in securing support. To that extent, it is critical that information contained in EIAs, and any other information introduced into the public domain is trustworthy, understandable, credible and independent [36, 37].

Linked to the issue of stakeholder acceptability is an increasingly common assumption that communities need to see benefits from the introduction of renewable energy into their environment [38]. Acceptance by the community should be voluntary, transforming the community's perception of ORE on the overall benefit of the technology to the entire community. Promoting job creation on its own is unlikely to be sufficient justification for a project and will be insufficient to gain the community acceptance based solely on that premise. Indeed, it has been demonstrated that the larger the project, the greater the difficulty in obtaining local support of the community. This will be a significant problem for ocean energy which will require development of very large scale projects to be profitable. Compensation is one method that some developers have used to gain support or access to space. This concept is gaining popularity in North America for other forms of RE, but is not gaining much consideration in Europe. Estimation of compensation required is extremely complex and in Europe is made more difficult by state ownership of the seabed.

ORE 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 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 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. Both the EIA and SEA Directives require formal public consultation. 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. 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 [39].

An ecosystem service approach [38] 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 not solely its financial aspects. This approach is particularly useful in translating the outputs from standard EIA into terms which are societally relevant.

Life Cycle Assessment (LCA) is a methodology used to evaluate the environmental aspects and 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 [40, 41]. Legal requirements arising from 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 [42, 43] further limiting a holistic assessment of a project's impacts.

III. Integrated Assessment Methodologies Between Private and Public Investment in ORE

A holistic approach to the evaluation of an ORE technology type or specific project is very important in order to provide a comprehensive assessment. Such an assessment should incorporate methods relevant to the three pillars of sustainability:

- 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.

This section attempts to identify connections between the assessment methods applying a parameter space characterised by the three pillars and by the scale of the system under evaluation. The scale of the system considered varies from the components of a ORE project, to a project comprising a number of devices installed at a particular location, to a geographic or economic region in which multiple farms may be deployed by a state.

This parameter space is illustrated in following four figures, 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 a marine energy project. This includes the “private” consequences of a project.
- 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.

Location for Figure 1&2

- which methods are typically employed to inform policy. 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 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 pillar only – and so would be placed on an axis – or identify impacts at the interface between pillars – and so are placed between axes. Within the solid circle at the centre of the axis are methods which are within the boundary of interest for the ‘firm‘ developing the project, and so relate to the “private” consequences of the project. At the end of each axis are the impacts at the aggregate level, which might be the region or nation, and which is within the interest of the policy maker. 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.

Connectivity between all methods is then considered via this methodology. 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, for example, 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.

A. Economic Axis

Within the ‘firm’ or agents interest, the simple question to be address is: does the project make financial sense? The methods here will be the Net Present Value and Internal Rate of Return (NPV/IRR). These will require firms to estimate costs and revenues across the project’s lifetime, which will include OPEX, CAPEX on the cost side, 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.

IO and CGE models can capture the economic, social (e.g. employment) and environmental (including pollution) consequences of specific projects. Such measured effects though will be external to the firm seeking to undertake the project. Additionally, there may be other external benefits which are not included in the firms decision, e.g. its contribution to the energy mix, energy security, innovation, green jobs in the supply chain, etc. Excluding such externalities are likely to result in firms concluding that certain project are not financially viable. Renewable energy subsidies and grants may, for example, be ways through which policy currently acts to compensate firms for these resultant positive externalities. On 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, appropriately designed industrial/sectoral policy – tax breaks, etc. - could take such external impacts into account, and could act as compensation and/or stimulus for companies and firms to develop renewable energy portfolios.

B. Environmental Axis

Figure 2 shows how the environmental impacts of an ORE project (represented on the environmental axis) may be linked to factors on the economics and social axes. The concept of Ecosystem Services 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 are made. As such ecosystem services are placed on the policy/planning level (outer ring) and links the environmental axis across to factors on the economic and social axes.

The impacts on ecosystem services that are considered at a firm level (inner ring) are those that are covered in an Environmental Impact Assessment (EIA). An EIA usually requires information to be gathered on fish resources, fisheries (provisioning services), benthic environment (supporting services) and recreational uses (cultural services) among others. This is represented in the diagram by the arrow linking Ecosystem Services at the policy/planning level and EIA at the firm level. The ability of the public to participate in the consenting process is also legally prescribed through EIA legislation which is why EIA is positioned between the environmental and social axes.

Ecosystem Services economic valuation provides a link between the environmental and economic axes, linking the largely qualitative aspects of Ecosystem Services 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 as well 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 have been located in Economic and Social one-third of Figure 2. Trade-off analysis and CBA therefore provide socio-economic frameworks through which the impacts of ORE developments can be assessed for policy and planning, and these links are therefore located closer to the outer policy/planning ring.

Location for Figure 3&4

C. Social Axis

Figure 3 shows how the social impacts of an ORE project (represented on the social axis) may be linked to factors on the economic and environmental axes. Public perception of ORE development will be influenced by a number of factors. This

can be influenced by the level of stakeholder engagement that is carried out. Stakeholder engagement is a method that the developer undertakes to involve key stakeholders in the development process, is a legal requirement and is 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 will also be influenced by the costs and benefits an ORE development will bring to the local community. Community benefit is increasingly used to as an argument to ensure local support for renewable energy developments. Community benefit can be in the form of direct financial reward e.g. community payments or promotion of local ownership. Less direct benefits include 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 are placed between the social and environmental axes on the graph.

Evidence suggests that a consultative and publically available Environmental Impact Assessment (EIA), could increase project acceptance. As such, EIA could provide a further link between the social and environmental axes. While the EU EIA Directive does not explicitly include social impacts but that some Member States have included social impacts in their transposing legislation

D. Governance

Governance is the way in which power is exercised in the management of a country's economic, social and environmental resources for development and addresses the values, policies, laws and institutions, by which a set of issues are addressed. Governance is different to management. Governance sets the stage within which management occurs [44]. Management is the process by which human resources and material resources are harnessed to achieve a known goal within a known institutional structure. Simplistically governance arrangements are represented in Figure 4.

Location for Figure 5

Figure 5 presents an illustration of how governance frameworks interact and inform project level actions. For this purpose, the diagram separates governance into different levels of application: from supranational level to site level with national and regional levels in between (outside to inside). Supranational level is represented by the outermost circle and can include legislation and policy at EU level which has the potential to act as a driver for development and, in relation to the environment, determines the over-arching legislation that is applicable and that may filter down to site level such as EIA and Appropriate Assessment (under Habitats Directive). National governance also has a role here in that national legislation and policy can impact upon site level actions, though in some respects this will remain slightly tangential or remote given that it is strategic in nature as opposed to operational.

The impact of regional governance is variable and will depend on national characteristics and the extent to which government power is devolved between administrations. In some countries with a strongly devolved system of government, regional authorities will have a pronounced effect on site level activity. This could, for example, take the form of regional level economic development policy, objectives for community cohesion, or guidance on the implementation of [a specific] national environmental policy. Alternatively in countries with strongly centralised government structure actions will be much more centralised potentially resulting in less community involvement in decision-making, for example.

All of the foregoing scales will have some level of implication for site level activity. Generally it is at site level where the supranational and national legal obligations will translate into practice. Likewise in terms of policy this could act as a key stimulus for a developer to develop at a particular site. Policy guidance may also inform how a project development is carried out not only in relation to meeting legal obligations but also how to engage with stakeholders, other regulatory authorities etc.

Taking the example of EIA, this was first enactment in legislation in the USA and subsequently in Europe. From supranational governance level, in the form of the EU Directive on EIA, national government are tasked with transposing the provisions of this over-arching EU Directive into national law. In Ireland, for example, the Directive is implemented by the Planning and Development Acts, 2000-2010, the Planning and Development Regulations 2001-2014 and the European Union (Environmental Impact Assessment) Regulations 2014 etc. Depending on where the project development is to be located these Regulations may result in the need for an Environmental Impact Assessment to be conducted at the site level.

IV. Conclusions

This paper has proposed a novel and idealised visualisation method of connecting and integrating the assessment methods for Private and Public assessments in ORE. Methods were considered in terms of the three pillars of sustainability – economy; environment and society. These methods were then analysed within the broader context of governance before being considered in terms of the type of end user, or stakeholder. 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.

Section III 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, Within a governance context, the benefits arising from the connectivity identified are clear as understanding these linkages will ensure more effective and efficient application of methods in the future, in particular preventing double application. Evidence from practice tends to revolve 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, the socio-economic impacts of development and governance considerations. 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 and governance, 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 still in development 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 the economics, social and environmental science 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, within a governance context, 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.

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Figure

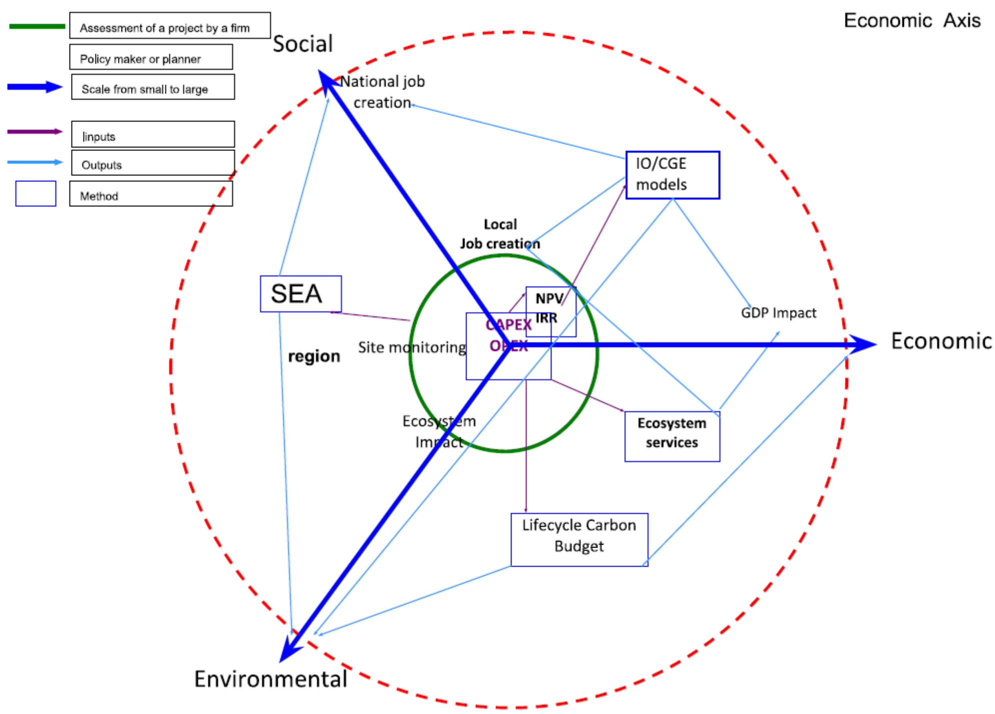

Fig 1: Economic axis considerations

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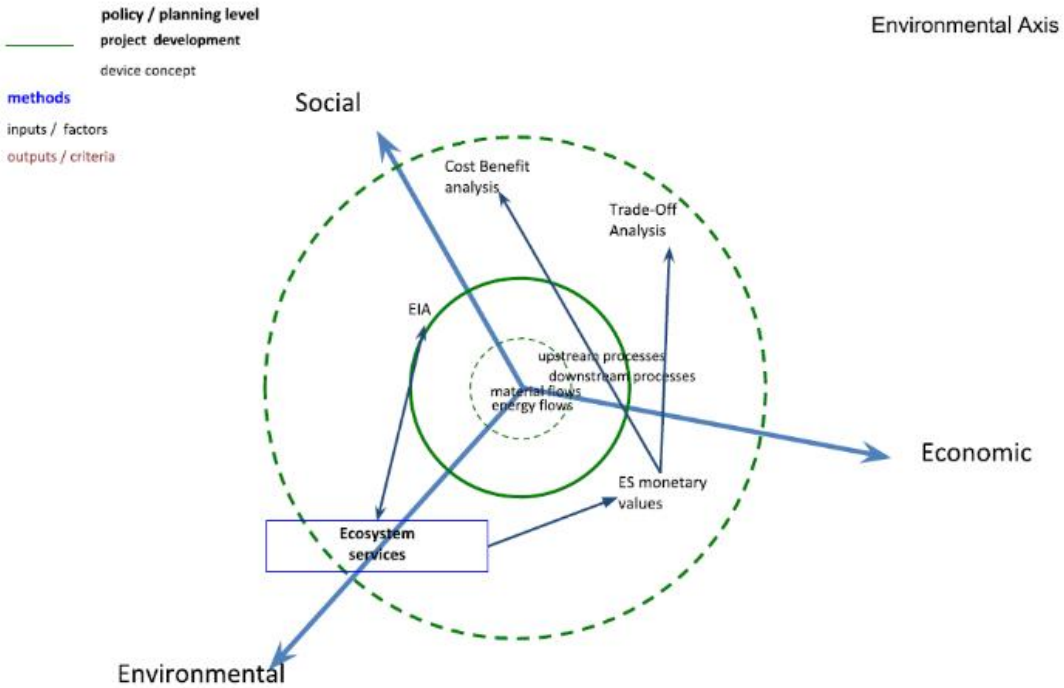

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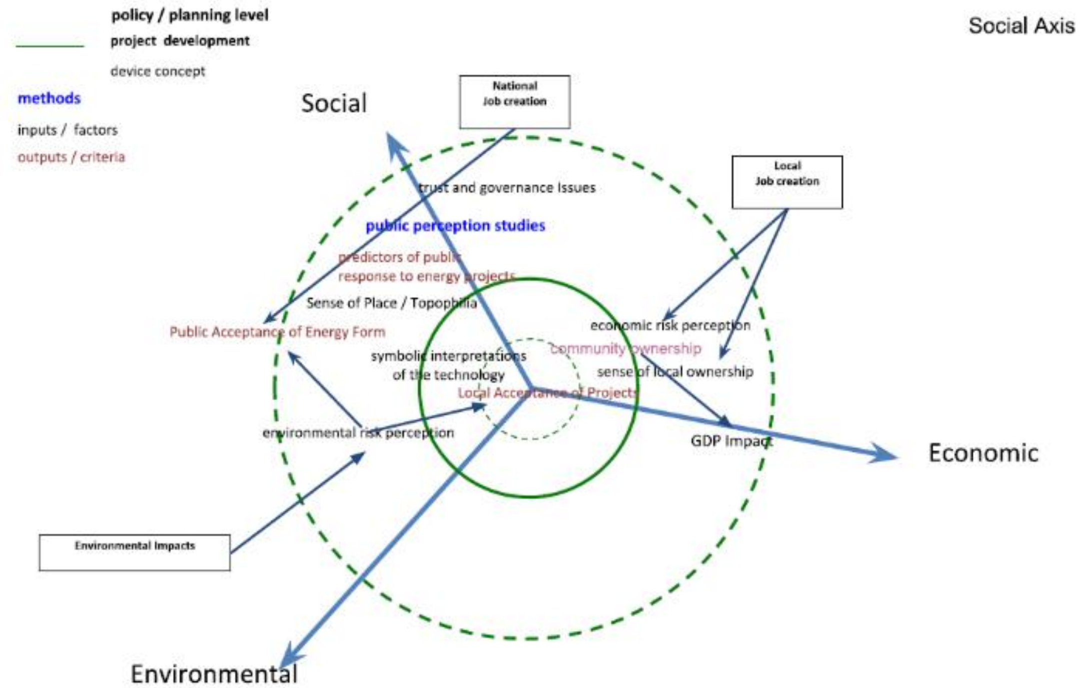

Fig 3: Social axis considerations.

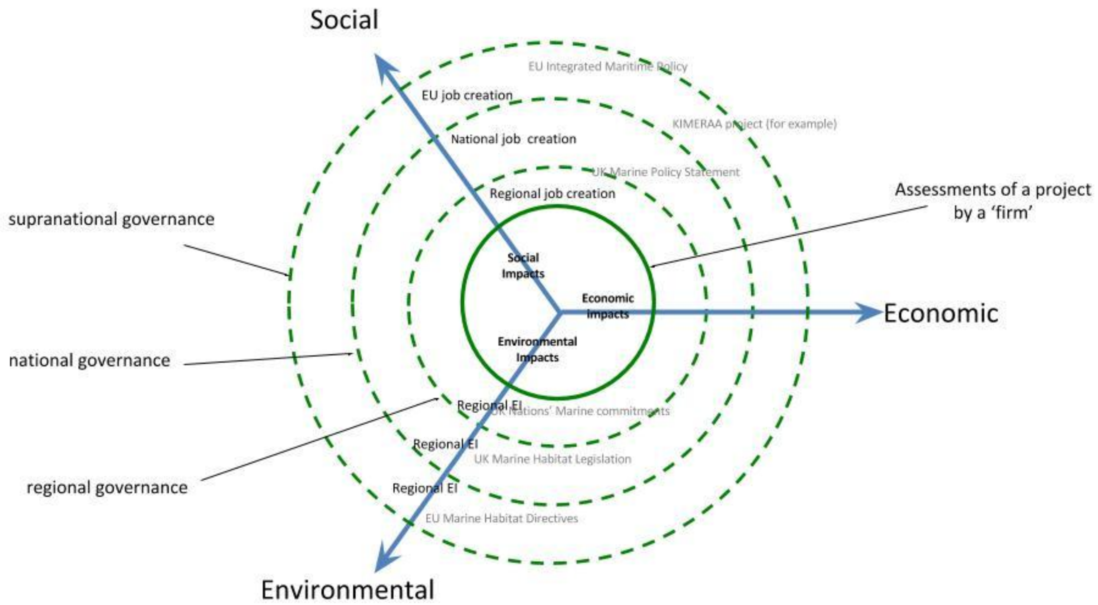

Fig 5: Governance axis considerations.

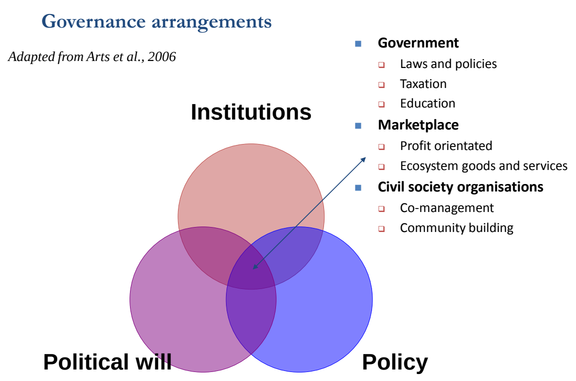

Fig 5: Governance arrangements (adapted from [45])