The Regional Employment Returns from Wave and Tidal Energy: A Welsh Analysis

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Abstract

The paper examines the expected regional employment returns connected to the development of tidal stream and wave-based electricity generation in a UK region - Wales. New employment provides economic development opportunities and the paper demonstrates that there is a need to develop the evidence base on these regional employment impacts. It addresses how far a region which is adjacent to significant marine resources is likely to benefit from a change in the energy generation mix which could feature more wave and tidal stream technologies.

Key words: Wave power; Tidal power; Employment creation

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Highlights:

- The paper examines the regional employment effects associated with wave and tidal power projects.
- Regions close to quality marine resources face challenges in capitalising on this proximity.
- Welsh case reveals challenges of using wave and tidal energy projects to lever employment.

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1. Introduction

The objective of this paper is to examine the expected regional employment returns connected to the development of tidal stream and wave-based electricity generation in the UK. New employment provides economic development opportunities. Renewables in general link to three major policy goals: an energy goal, an environmental goal and an economic goal (Shen et al., 2011). In terms of the economic goal, understanding the economic development dimensions of wave and tidal energy in terms of employment is becoming more important in Europe. Here there are debates on the extent to which new patterns of electricity generation can be transformative for more needy peripheral parts of Europe in terms of providing new economic opportunities (Allan et al., 2007; Llera et al., 2010; Kerr et al., 2014). These issues are particularly important in relation to wave and tidal energy where European regions adjacent to the best-quality resource sometimes face real challenges in capitalising on their proximity to this resource.

In examining the employment potential from marine renewables, the focus is on tidal stream and wave-based electricity technology in Wales (UK) an area long recognised as having a major resource (Voss, 1979). While these technologies are at an early commercial stage, it is important to consider how the structure of the evolving industry might determine regional employment and economic returns. Precisely how growth in marine renewables in general might be transformative in terms of job creation in needy areas is unclear with prior analysis of renewables technologies revealing limited regional economic returns (Munday et al., 2011), but with a series of regional strategies in the UK targeting marine renewables such as wave and tidal energy as a source of growth opportunities and employment (Welsh Government 2011, 2012). Whilst the leverage of local socio-economic returns from renewable energy generation is not the chief aim of regional, national and EU renewables policy, due attention still needs to be given to potential economic consequences such that planners and policymakers can better understand the competing claims of firms developing marine renewables schemes.

The remainder of the paper is structured as follows. Section 2 reviews research that has explored the economic and employment effects associated with changing patterns of electricity generation, and examines some of the analytical problems involved. Section 3 provides some background on the development of the wave and tidal energy sector in the UK in general and Wales in particular. Section 4 focuses on the method employed in this study. Section 5 reports the findings from the analysis and the final section concludes the paper.

2. Wave and tidal power: employment effects

The development of renewable energy technologies can be linked to a series of energy, environmental and economic goals (Shen et al., 2011), and under the latter come issues relating to the role of renewables in meeting socio-economic goals such as employment creation or employment diversification. Indeed Lund and Hvelplund (2012) show that the desire for sustainable energy during times of economic recession can be used as a development tool. In the Danish case they revealed that investment in decreasing fossil fuel use and reducing harmful emissions can be undertaken such that there is a stronger influence on employment creation and general economic development.

Kerr et al (2014) argue that research on marine renewables in particular, has been focused upon issues of resource assessment (Iglesias and Carballo, 2010), technical viability and environmental impacts. There is rather less of an evidence base available relating to issues of economic and employment consequences of such technologies (Miranda and Larcombe, 2012). This is surprising given that social acceptability of marine renewables schemes is likely to be an important determinant of project success (Devine-Wright, 2011; Lim and Lam, 2014), and that factors that can influence social acceptability include job creation potential (Munday et al., 2011). Indeed Kerr et al (2014) argue that the current balance of research effort, and funding, inadequately reflects the role of society in the development of marine renewables or its potential for socio-economic impacts on coastal communities. Employment is among the most critical of the socio-economic impacts to understand, and the paucity of evidence in this respect is one of the issues that this paper addresses.

Estimating the employment effects associated with wave and tidal power is complicated. In making connections between marine renewables and employment it is unlikely that close parallels can be drawn from on-shore renewable electricity generation technologies because of the different nature of the technological challenge, the different policy/governance context, and different natural environment (Allan et al., 2014).

In addition to the above there are a series of general issues that the analyst seeking to explore the employment effects of increases in wave and tidal energy have to contend with. One issue is how far a study can provide a complete system-wide accounting of economic and employment effects. Wei *et al* (2010) show that critiques of 'green job' studies often cite incomplete accounting, poor understanding of opportunity costs, and with renewable technologies sometimes working to crowd out other business investment. Similarly Wei et al. also note the limited attention given to lower environmental costs associated with low carbon electricity generation technologies, together with more difficult-to-value savings in terms of healthcare and benefits in terms of reduced risk and reduced dependency on energy imports. Comprehensive research might also explore the effects linked to changes in household spending connected to higher electricity prices (Lessor, 2010); the loss of activity in conventional power generation; and give due consideration to the direct and indirect employment connected to changes in the energy generation mix (Apergis and Payne, 2007; Lehr et al., 2008, 2012; Frondel et al. 2010).

Care is also required in terms of how the employment benefits of new electricity production technologies such as wave and tidal power are denominated. Studies point to low carbon electricity generation producing a relatively higher number of jobs per unit of installed capacity (Llera et al. 2013). However, Frondel et al. (2010) show that the common conflation of labour-intensive energy provision with efficient climate protection works to sully the waters in the debate on the economic costs and benefits of renewable energy technologies.

General analysis of the employment effects of electricity production tends to separate the development and construction phase, from operation and maintenance. This allows differentiation of shorter-term from longer-term effects which can be important for economic development policy. Common approaches are to use job ratios in terms of direct employment per MW installed capacity during the operation phase of the life of the power station, and then person years of employment through development phases (Llera et al., 2013). The distinction is important as the employment supported during the installation phase can be significant particularly for more peripheral economies, but short lived and unsustainable. Moreover, several studies have pointed to the very small number of regional economic opportunities associated with on-shore wind operation and maintenance, but have pointed to a greater level of relative economic impact for marine-based renewables connected to the more severe environmental conditions around devices, and resulting transportation and handling issues (Munday et al., 2011; Cowell et al., 2012). In addition while studies commonly produce employment factors these are rarely analysed to explore the distribution between local jobs and jobs for immigrant workers, which is an important consideration for small regions with a limited supply side capability such as that examined later in this paper.

A further issue confronting studies examining the economic effects is how far they can identify indirect economic effects associated with the development and operation of power generation facilities. For example, this includes employment and activity supported in regional supply chains, and induced wage effects associated with regional employment (Miller and Blair, 2009; Markaki et al., 2013; Cai et al., 2011; Winning, 2013).

To conclude, the review reveals that there is a need to better understand the employment effects associated with marine renewables such as wave and tidal power, particularly given links to issues of the social acceptability of projects. It is likely that studies investigating the employment effects associated with marine renewables face similar issues to more general studies of the employment effects of different renewable electricity production. Variation in methods employed results in few benchmarks on which to examine the expected employment and economic effects of the take-up of new methods of electricity production, particularly where regional supply sides are limited in their ability to meet the demands during development phases. Moreover, the early evolutionary stage of wave and tidal power technologies means that there are relatively few studies exploring employment impacts in this specific case, although a rather larger number of studies that have explored the consequences of tidal impoundment projects, and with interest in the latter driven in the UK by initial plans for a Severn Barrage (Hooper and Austen, 2013).

3. Background: Wave and Tidal Power in the UK and Wales

The focus here is on electricity generation linked with wave and tidal stream devices rather than tidal impoundment. The UK is committed to an 80% reduction in greenhouse gas emissions by 2050 (Climate Change Act, 2008). Meeting these targets requires major transformation in the technologies adopted for electricity generation. While the employment effects associated with renewables such as onshore/offshore wind are fairly well understood, marine technologies around wave power, and tidal stream (and tidal impoundment) are less well understood because of limited activity at anything near commercial scale.

Interest in the scope of wave and tidal stream technologies is associated with the size of the potential UK resource. The UK wave resource is estimated at between 40 and 70 TWh/year, while the tidal stream resource is variously estimated at between 12 and 29 TWh/year (Energy and Climate Change Committee, 2012). Unfortunately, harnessing greater-velocity tidal streams often goes hand in hand with high installation, servicing and design costs. For example, the Carbon Trust et al (2012) estimated that (in 2012) the cost of electricity from wave and tidal power would need to fall by up to 75% to around £100/MWh by 2025 to be competitive, and that this would require considerable innovation and the achievement of significant economies of scale.

The UK Government recognising that private capital will not likely be forthcoming because of the risks, costs and uncertainties involved has set in place a number of funds to leverage new development in marine renewables. Alongside various capital assists (for example the £22m Marine Renewable Proving Fund and the £20m Marine Energy Array Demonstrator Fund) the main public subsidies for developers are Renewables Obligation Certificates (ROCs). Wave and tidal stream energy in England and Wales are currently subject to 5 Renewable Obligation Certificates (ROC) per MWh, but with plans in development to replace the ROC framework with a Contract for Difference mechanism.

While the technology is still evolving there are projections on the short-term contribution of marine renewables as a whole. For example, the UK Renewable Energy Roadmap (DECC, 2012) reveals an expectation that by 2020 there will be around 200-300 MW of installed marine (wave and tidal stream) capacity. RenewableUK (2013) suggests that the tidal and wave sector is forecast to be worth £6.1 billion to the UK by 2035, and connected to the creation of up to 20,000 jobs (for other impact studies see Public Interest Research Centre, 2010; PMSS, 2010; Allan et al., 2014).

The potential of wave and tidal energy has not been lost in Wales, the case examined in this paper. This is a devolved region of the UK and has its own ambitious targets for renewable electricity generation. For the Welsh Government there is belief in a potential to become a leading player in marine renewables. The Welsh Government's Energy Policy Statement (Welsh Assembly Government, 2010) revealed that given the relative strength of 'regional' wind and marine resources, it will seek to meet almost all energy needs from low carbon sources by 2050. It is focusing strongly on wave and tidal power believing that the region has potential to be a world leader. It has already funded the Marine Renewable Energy Strategic Framework to explore the potential marine resource available to Wales, along with studies into the industry's infrastructure requirements and R&D potential (Halcrow and BVG Associates, 2012). It has also supported Marine Energy Pembrokeshire in West Wales, a collaborative public-private partnership to develop a marine Centre of Excellence.

The Marine Renewable Strategic Energy Framework (Welsh Assembly Government, 2011) examined the Welsh marine resource and found a potential for between 1.5 to 6.5 GW of installed capacity and with resources focused in Anglesey, the Llyn Peninsula, Pembrokeshire and Glamorgan. The Welsh Government has committed itself to a goal of gaining at least 10% (9 TWh/year) of the potential tidal stream and wave energy off the Welsh coastline by 2025. To date, development and testing have been focussed in Pembrokeshire, which has a large amount of the practical resource in Wales and offers research centres, port facilities and good grid connections.

The theme of the Welsh Government strategy documents is that the region needs to capture opportunities connected with new wave and tidal energy generation technologies, particularly within emerging clusters of marine renewables activity in North West and South West Wales. Moreover, in the European Union structural funding programme for West Wales and the Valleys there is a specific objective to increase the number of renewable energy devices being tested in Welsh waters, including multi-device array deployment, thereby establishing Wales as a centre for wave and tidal energy production (WEFO, 2013). The vision is that successful demonstration will eventually leverage economic and employment benefits in more needy parts of Wales in terms of new research and development (R&D), device manufacture, and then operation and maintenance of developed facilities. To this end the Welsh Government plans to assist private investments in developing the emerging wave and tidal energy sector, and this will include investments to encourage wave and tidal energy innovation and R&D with commercial potential, and assistance to improve the capability to test wave and tidal energy devices off the Welsh coast.

In 2013 there were 4 demonstration projects planned off the Pembrokeshire coast (see Table 1). In addition Marine Current Turbines (MCT) having developed and tested prototype tidal devices in Northern Ireland hope to develop a full-scale commercial tidal turbine array in Welsh waters by 2015. It is planned that there will be 9 turbines with a total capacity of 10MW off the coast of Anglesey between the Skerries and Carmel Head, providing up to 20% of the Island's power at a cost of £70m.

Table 1: Marine Energy pre-commercial devices in Wales

Sector	***Developer & Location***
Tidal	*Tidal Energy Ltd : 1.2MW device, consisting of 3 horizontal axis tidal turbines Pembrokeshire. The technology was developed at Cranfield University. UK firm DesignCraft supplies rotors, GE Energy the generator and electrical systems and Siemens the gear systems. Planned installation Summer 2014.*
	E.ON/ Lunar Energy, Pembrokeshire E.ON in partnership with Lunar Energy Ltd plans to install a device which will consist of six turbines totalling 8 MW, but is currently awaiting the results of a Strategic Environmental Assessment (SEA).
Wave	*Pembrokeshire Coast Wave Dragon Wales Ltd planned to install a temporary 7 MW device off the Pembrokeshire coast to test its proprietary technology in 2011/12 with the aim of scaling up by a factor of 10 to a commercial size array. Project delayed due to a lack of financing. The company is currently testing a 1.5MW device at a test centre in Denmark. Project seeking finance.*
	Marine Energy Ltd: has plans for a 10 MW wave energy system off the coast of Pembrokeshire. Currently in the process of making applications. The technology has been developed at the University of Uppsala in Sweden.

There is a series of issues facing developers. These are related both to barriers in installing new capacity (i.e. challenges to reduce costs, alongside issues of the level of national subsidy offered to projects) together with questions on how far the regional economy is able to benefit from the presence of this new capacity. Halcrow and BVG Associates (2012) also stress the challenging marine environments in which future projects would have to operate in Wales and problems of working in environmentally-sensitive areas (see also Warren, 2010) where the impacts of devices on marine ecology are still unclear. A related issue is that the grid infrastructure in Wales is not always adjacent to the marine resource, a problem that also affects offshore wind development around the Welsh coast line. Further problems relate to regional supply chain development: larger commercial-scale projects are expected to require larger-scale suppliers for production capacity, quality management systems, technical accreditation and insurance, and this could favour larger firms from outside of the region restricting the regional employment potential of projects.

Given the scale of the potential wave and tidal stream resource in Wales it is recognised that wave and tidal energy could represent a significant economic opportunity. There has been no real analysis of the potential economic benefits for Wales resulting from the growth of electricity generation capacity from this source. What follows is an early stage assessment based on a series of assumptions. We believe such analysis provides a useful check on the determinants of local economic/employment effects from wave and tidal power.

4. Method

4.1 Method for examining regional economic impact

Research examining the regional economic effects of renewable electricity technologies commonly uses Input-Output methods. This method allows the analyst to examine the effects of changes in final demand for the goods produced by one sector of the economy on all other sectors of the economy, and households (Miller and Blair, 2009).

In this paper the Input-Output method is used to estimate three types of effects relating to the development and operations of wave-power and tidal stream devices. These are direct, indirect (and then induced) economic effects.

The direct effects are associated with the activity itself. An increase in final demand for the products of an industry will result in an increase in the output of that industry, as producers react to meet the increased demand. This direct effect might be understood in terms of the initial expenditure injection into a region associated with the future development/construction and then operation of wave and tidal devices. As these industries increase output, there will also be an increase in demand on their suppliers and so on down the supply chain; this is the indirect effect. For example in constructing a wave power facility the construction sector might need to use the outputs of the metals industry. As a result of the direct and indirect effects the level of household income throughout the economy will increase as a result of increased employment. A proportion of this increased income will be re-spent on final goods and services creating further economic benefits: this is the induced effect.

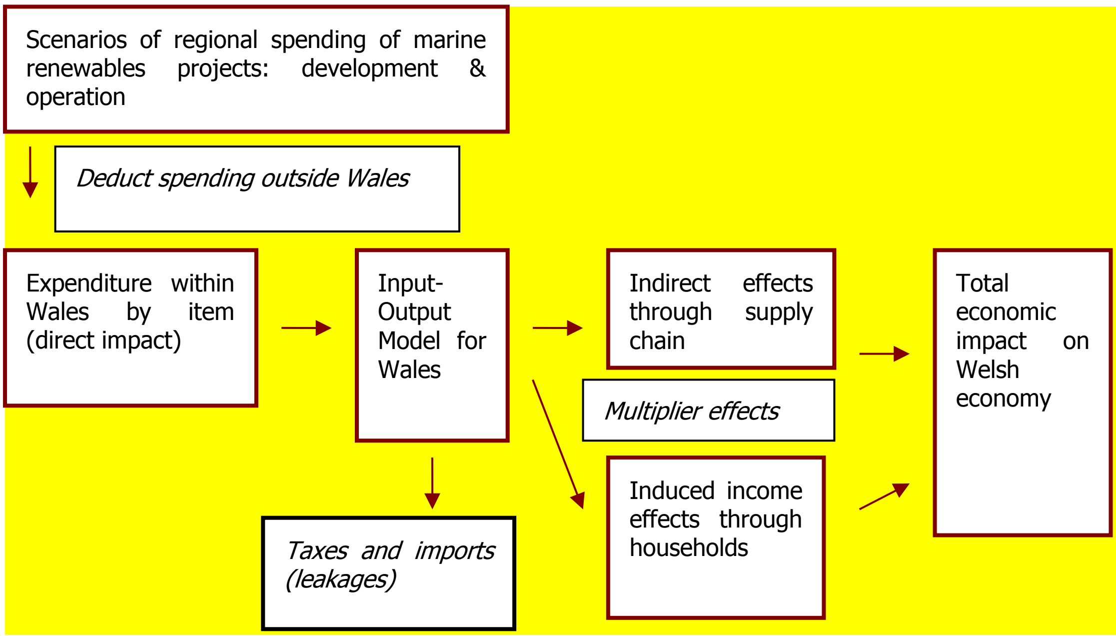
To estimate these indirect and induced effects we use the framework provided by the Welsh

Input-Output Tables (Jones et al., 2011). These are essentially a spreadsheet detailing transactions between different sectors of the Welsh economy and beyond.

There are limits to the use of Input-Output analysis that need to be noted. First the accuracy of the approach depends on the coefficients that describe how different industry sectors purchase goods and services from one another. These coefficients can change through time as a result of technological changes, producers substituting imports for local production, and price changes through time. The Input-Output approach also assumes that there are no limits to what a given industry can produce, and they ignore the effects of increasing returns to scale. A full discussion of these limitations is found in Miller and Blair (2009). The use of Input-Output tables is a common means of assessing the economic implications of energy generation projects (Llera et al., 2013; Markaki et al., 2013) and there are a number of studies that investigate how electricity production is described and disaggregated in Input-Output tables and then investigation of the typical patterns of goods and services purchases connected to different electricity production methods (Winning, 2013).

In summary then this study examines the regional economic impacts of a series of wave and tidal technology scenarios (see below) using the Input-Output method, and with the challenge being to use the method to estimate regional economic impact in terms of gross value added and employment (direct, indirect and induced) for both construction and operation phases of the wave and tidal power technologies. Employment here is understood as the number of jobs that are created within Wales. These are expressed both as Full Time Equivalents, a measure that converts full- and part-time jobs into a common currency and, for temporary construction impacts, as person years of employment. A summary of the approach is shown in Figure 1.

Figure 4.1 Summary of Input-Output Approach



4.2 Development scenarios

Given that wave and tidal energy is at an early stage in its development there is considerable uncertainty regarding the development pipeline. Therefore, three scenarios for future capacity are explored and modelled using the Input-Output approach: A 30MW wave installation and a 30MW tidal stream installation; 300MW in wave and tidal energy capacity (two 30MW wave installations and eight 30MW tidal stream installations, reflecting the relatively advanced state of tidal energy); 1GW of wave and tidal energy capacity (250MW of wave and 750MW of tidal energy). Whilst it is difficult to judge when this capacity may come on-stream, it is quite likely that it could take another decade for 300MW capacity to be installed in Welsh waters. Based on other assessments, the 1GW scenario might not be achieved for many decades. Implicit in these scenarios is the need for the capital and operational costs to have fallen sharply to ensure that the roll-out of these much higher levels of capacity is economically viable.

4.3 Regional spending on wave and tidal power projects

Following from the review in the second section of the paper we expect each development scenario to result in a series of expenditures causing regional economic impacts. Spending on wave and/or tidal stream installation/operation could support regional economic activity over five phases:

- Development and Consents: covering the design and feasibility work, physical and environmental surveys and planning consent.
- Device manufacturing: Device types have common principles: a hydrodynamic system is required to interact with the water to extract energy from it; a reaction system holds the device in place; and a power take-off system converts the energy extracted into electricity. A control system provides supervisory and closed-loop control. The manufacture of these devices is a significant component of the overall capital cost associated with wave and tidal projects.
- Balance of plant manufacturing: Components not part of the device itself but required for its operation. This includes foundations, mooring, cabling, electrical equipment, and onshore infrastructure.
- Installation and commissioning: Devices need to be assembled onshore and installed offshore. Typical activities required include port services, installation of electrical systems, foundations and moorings, and finally device installation.
- Operation and maintenance: on-going activities including monitoring, maintenance, insurance, and grid charges.

There are issues of uncertainty on capital and operational spending associated with future projects. Since no projects have been developed at commercial scale to date there is a paucity of evidence on costs associated with the development and operation of wave and tidal energy projects. A further complication is uncertainty on the future mix of technologies (both between and within wave and tidal stream) that could come forward.

Assumptions on capital and operational costs were derived from a desktop review, but complemented with information derived from a consultation process with device/project developers (see below and Appendix 1) in Wales in order to arrive at reasonable estimates. From the collected evidence it was estimated (see Table 2) that gross capital spending associated with tidal installations is £4.2m per installed MW and £5m for wave energy in 2013/14 prices). Table 2 also shows the estimates of operational expenditure for wave and tidal stream – again per installed MW – although here there is potentially more uncertainty over the size and direction of spending.

Table 2 Estimated Gross Baseline Capital Expenditure & Operational Expenditure per Installed Megawatt (£m & £s, 2013/14 prices)

	Tidal Stream	Wave
Capital spending £m		
Development and consent	170	220
Device manufacture	2,390	2,580
Other equipment and electrical	460	1,110
Installation and commissioning	1,180	1,090
Total	**4,200**	**5,000**
Operational £		
Maintenance	95,000	85,000
Insurance	25,000	40,000
Other inc. Grid	45,000	50,000
Total	**165,000**	**175,000**
Note: Capital spend excludes R&D costs and other operational includes seabed lease and grid related costs.		

An important factor determining the level of regional economic impacts (indirect and induced effects) is uncertainty on the goods and services that project developers can purchase in the regional economy. How far regional firms might benefit from opportunities depends on factors, including the developer procurement approach, the capabilities of the Welsh supply side, the extent to which Welsh firms already serving other sectors such as oil and gas can adapt to the requirements of wave and tidal energy and their ability to form strategic alliances in order to bid for large packages of work and so on. In developing local sourcing assumptions we used the findings from structured consultations with device/project developers to understand their procurement routes and views on the availability of suitable goods and services in Wales. Selected developers completed a pro forma detailing their expectations on potential spend in Wales (see Appendix 1). Moreover a detailed assessment of supply side potential in Wales was completed, mapping the regional supply potential in goods and services known to be required by developers (Appendix 2 and Table A1 summarises). It was also possible to check results against studies on wave and tidal energy (Allan et al., 2014), where some local sourcing evidence was available.

The analysis suggested that it is unlikely that the highest value components in devices would be produced in Wales and the greatest regional opportunities could instead be in terms of balance of plant manufacturing, and in supporting elements of installation, local assembly of imported products and maintenance. The analysis showed that around half of total capital expenditure required to bring forward wave and tidal projects is accounted for by the hydrodynamic system, the reaction systems and then the power take-off system. There is already significant employment within sectors that have related activities to this in Wales. For example, in 2011 there were around 15,000 people in Wales employed in firms whose principal activities aligned them partially with categories relating to the manufacturing of devices. However, currently the volumes of business likely to be offered in developing 10-30 MW of wave and tidal power capacity in Wales might discourage these firms from targeting new business opportunities in marine renewables.

Activities under the umbrella of construction and installation are expected to comprise close to a third of total capital spending. There is some regional capacity for onshore installation and electrical work connected to offshore wind. However, wave and tidal arrays are expected to require specialist barges and installation equipment with this equipment likely owned and managed by firms outside of Wales, but still leaving opportunities for local subcontractors. In the services sector (which includes design and feasibility, surveys etc.), the industry consultations suggested that expertise is available locally at competitive rates.

Table 3 provides the local sourcing scenarios. It is to be noted that these figures represent a best estimate at the current most likely level of local sourcing. This potential may increase (or indeed prove optimistic) as the sector develops. Clearly there is potential for bias with a relatively small number of interviews and questionnaires, particularly where impacts are likely to vary between technology types *within* wave or tidal themselves. Finally here there is uncertainty on the extent to which the wave and tidal energy sector will achieve efficiency gains. The 2012 Technology Innovation Needs Assessment for Marine Energy (see Carbon Trust et al., 2012) provides some indication of electricity cost savings (per MWh generated), as a result of learning, economies of scale and innovation. Carbon Trust et al (2012) assumptions on savings by cost centre for each technology were examined and applied to the intra-Wales expenditure categories for wave and tidal development. Table 4 shows the developed cost reduction assumptions and assumes that significant cost savings are associated even with a move to 60MW installed from current experimental arrays. It is important to note here that improvement in financial efficiency improves viability but works to reduce regional economic impact per MW installed (given the lower expenditure per MW of capacity developed).

Table 3 Summary: Regional Sourcing Assumptions

	Tidal stream	Wave
Grid connection and installation	70%	50%
Device manufacture	30%	30%
Other Electrical	20%	20%
Metalworks	10%	10%
Foundations, mooring and other site & port works	40%	70%
Planning, project management, surveys, consultancy	70%	90%
Maintenance inc. port operations and on-going surveys	90%	70%
Grid connection charges	0%	0%
Insurance	0%	0%
Other	0%	0%
Rates/seabed lease etc.	0%	0%

Note: These percentages and classes of expenditure should be considered indicative only due to differences in the nature of developments across technologies. They comprise estimates of most likely regional sourcing behaviours in aggregate and do not relate to specific current or future developments.

Table 4: Cost Reduction Assumptions (Percent of Current Baseline Cost of Energy)

Tidal Stream			
Modelled Elements	**Scenario 1**	**Scenario 2**	**Scenario 3**
Development & consent	72%	52%	38%
Device Manufacture	77%	60%	46%
Other Equipment & electrical	76%	57%	43%
Installation & commissioning	92%	78%	67%
Wave			
	Scenario 1	**Scenario 2**	**Scenario 3**
Development & consent	85%	72%	66%
Device Manufacture	83%	69%	62%
Other Equipment & electrical	86%	75%	70%
Installation & commissioning	96%	87%	84%

Source: Carbon Trust (2012) TINA
Note: This effectively assumes that Welsh capacity doubles at the same rate as in the Rest of the World/UK

5. Findings

In what follows the regional economic effects for development and construction phases are combined and reported as regional person-years of employment and regional total cumulative gross value added (GVA), to represent the 'one off' impact of the associated capital expenditure. Subsequently operation and maintenance effects are presented as regional full-time equivalent (FTE) jobs and GVA supported in each year of operation. The results in the following tables are also presented to combine direct, supply chain (indirect) and personal expenditure (induced) effects (i.e. including a modelled element). Within each of these phases the results are presented in line with the scenarios highlighted earlier.

The economic effects associated with the development and construction phase are limited by the large amounts of expenditure that leak out of the Welsh economy. The most substantial leakages are in terms of specialised services and devices. It is estimated that the current expected level of Welsh expenditure from tidal is around £2.75m and for wave £2.35m per MW installed. While wave power is expected to be more expensive in gross terms per MW (see Table 2) there is greater spending leakage expected with this technology outside of Wales. Therefore it is estimated here that during the development and installation phases some 35% of all tidal expenditure and just over 50% of wave expenditure could leak out of the region.

Table 5 reveals the GVA impact estimates for the three scenarios through the development and construction phase. This reveals that Scenario 1 could support over £70m of Welsh GVA. Recall that this includes both on- and off-site economic activity (based on total investment in Wales of the order of £150m in 2013 prices – see Table 2). In the case of Scenario 2 (300MW, with a preponderance of tidal) around £300m of GVA is levered for Wales, with the economic impact per megawatt declining somewhat (from £1.2m in Scenario 1 to £1m) as cost reductions come further into play (based on total investment in Wales of over £500m in 2013 prices). Scenario 3 and the significant 1GW in wave and tidal could deliver £840m of GVA impact on Wales (based on total investment in Wales of the order of £1.5bn in 2013/14 prices). Within Scenario 3 the economic effects (GVA per Megawatt) are higher from wave than in tidal due to the assumed slower cost reductions. However, with significant uncertainty on technological development and local sourcing, the differences reported in Table 5 between wave and tidal impacts are relatively minor and should be treated as indicative only.

Table 5: The Economic Impact of Marine Renewables in Wales – Development and Construction Phase: Gross Value Added (£m, 2013/14 prices)

	Scenario 1 - 60MW			Scenario 2 - 300MW			Scenario 3 - 1GW		
	Tidal 30MW	Wave 30MW	Total 60MW	Tidal 240MW	Wave 60MW	Total 300MW	Tidal 750MW	Wave 250MW	Total 1GW
Manufacturing and Energy	16	14	30	98	25	123	240	87	327
Construction and Maintenance	8	8	16	56	15	71	152	61	213
Distribution, Transport and Communications	5	4	9	35	7	42	91	28	118
Professional and Public Services	9	8	17	52	14	67	128	53	181
Total	**38**	**34**	**72**	**241**	**62**	**303**	**611**	**229**	**840**
GVA/MW (£m)	*1.28*	*1.13*	*1.20*	*1.01*	*1.03*	*1.01*	*0.81*	*0.91*	*0.84*

Table 6: The Economic Impact of Marine Renewables in Wales: Person-Years of Employment

	Scenario 1 - 60MW			Scenario 2 - 300MW			Scenario 3 - 1GW		
	Tidal 30MW	Wave 30MW	Total 60MW	Tidal 240MW	Wave 60MW	Total 300MW	Tidal 750MW	Wave 250MW	Total 1GW
Manufacturing and Energy	370	310	680	2,250	580	2,830	5,500	2,000	7,500
Construction and Maintenance	340	350	690	2,310	630	2,940	6,260	2,520	8,780
Distribution, transport and communications	120	100	220	760	180	940	1,960	670	2,630
Professional and Public Services	230	210	440	1,420	380	1,800	3,430	1,420	4,850
Total	**1,060**	**970**	**2,030**	**6,740**	**1,770**	**8,510**	**17,150**	**6,610**	**23,760**
FTE/MW	35.3	32.3	33.8	28.1	29.5	28.4	22.9	26.4	23.8

What these projections mean in terms of employment impacts is shown in Table 6. For Scenario 1 a total of around 2,000 person-years of employment are estimated to be associated with development and installation phases, rising to 8,500 person-years in Scenario 2, and around 24,000 person-years in Scenario 3. The per-MW impact on Welsh employment associated with development declines from 34 FTEs in Scenario 1 to 24 FTEs in the 1GW (Scenario 3). In this latter case it is important to note that this could be in terms of jobs supported over a period of up to 20 years. In each of the Scenarios greater employment effects tend to focus around construction-type activities, and in manufacturing and energy (largely expected to be ancillary devices and electrical and cabling materials). Distribution and transport account for around 10% of employment impacts, with much of this in ports and transport services.

The analysis now shifts to consider regional economic activity estimated to be supported during operation and maintenance phases. Table 2 revealed an estimated gross operation cost currently of £165,000 per MW for tidal and £175,000 for wave. Much of the operation spend relates to charges for grid connection, seabed leasing costs and insurance - an estimated 42% for tidal and 52% for wave. There is limited opportunity for Wales to benefit directly from spending in these categories, although there may be limited potential for selected monies to re-enter Wales through spending by national organisations such as Crown Estate Trust and National Grid, although this is at an uncertain scale and hence not assessed here.

Table 7: The Economic Impact of Marine Renewables in Wales: Operation and Maintenance

	Scenario 1		**Scenario 2**		**Scenario 3**	
	GVA (£m)	**Emp (FTE/yr)**	**GVA (£m)**	**Emp (FTE/yr)**	**GVA (£m)**	**Emp (FTE/yr)**
Tidal Stream	1.2	25	6.3	145	13.2	310
Wave	1.0	25	1.5	35	5.5	130
Total	**2.1**	**50**	**7.8**	**180**	**18.7**	**440**
Per MW	0.04	0.8	0.03	0.6	0.02	0.4

Table 7 reveals that the operational phase effects associated with wave and tidal power installations are more moderate than those estimated for development/installation. In Scenario 1, with 60MW in operation, it is estimated that a total of £2m in GVA and 50 FTE jobs per annum would be supported across Wales throughout the period of generation. For the 1GW Scenario 3, it is estimated that £19m of GVA and 440 FTE jobs per annum would be supported through generation activities. The regional economic effects of operational activities on Wales are moderated, as capacity increases, by the cost saving that will be necessary to make the generated power commercially viable. Drawing on the Carbon Trust et al. (2012) analysis and survey returns, it is estimated that regional operational spend per MW will, by Scenario 3, be less than a third its current estimated level for tidal stream, and around 50% its current level for wave.

6. Conclusions and discussion

The purpose of the paper was to examine the expected regional employment returns connected to the development of tidal stream and wave-based electricity generation in the UK using the case of region of Wales.

The context of the paper was a paucity of research that explores the regional employment and economic effects associated with wave and tidal energy, and that understanding this was important because of links with public acceptability, and with existing work focusing much more on assessment of the resource, technical feasibility and environmental impacts.

The paper finds that much of the economic impacts of wave and tidal energy in terms of both GVA and employment is realised through the development and construction process.

Three scenarios of wave and tidal development in Wales were developed. Under scenario 1 with 30 MW of tidal and 30 MW of wave the paper reveals that tidal could deliver 35.3 FTE jobs per MW for the region compared to 32.3 FTE jobs per MW for wave during the development and construction process. Under scenario 1 this would equate to an estimated 2,030 FTE jobs for the region. Under scenario 2 of 240 MW of tidal and 60 MW of wave efficiency improvements would mean tidal could deliver 28.1 FTE jobs per MW and wave 29.5 FTE jobs per MW during development and construction. Under scenario 2 this would equate to an estimated 8,510 FTE jobs for Wales. Under scenario 3 of 750 MW of tidal and 250 MW of wave, it is estimated that development and construction would leverage 22.9 FTE jobs per MW for tidal and 26.4 for wave equating to an estimated 23,760 FTE jobs for Wales. Under each of the scenarios much of the regional employment impact of tidal and wave power development would be seen in the manufacturing and energy industries, and in construction and maintenance.

The analysis confirmed that jobs supported during operation of tidal and wave power facilities were limited ranging from 50 FTE jobs per annum under scenario 1 to 440 under scenario 3. However, these jobs would be sustained longer term.

The estimated employment effects are not insignificant in terms of the economic needs of parts of Wales, where the creation of new employment opportunities is a major objective of government, and where there is expected to be employment losses in the future in coal and gas-fired electricity generation. A key issue for policy makers in Wales arising from the findings is to ensure that tidal and wave power developers are aware of opportunities to purchase goods and services locally, and where possible to alert local suppliers to these same opportunities with any extension of tidal and wave power development.

In concluding it is important to recall the uncertainty underlying the analysis. As was shown in the methodology section the Input-Output analysis on which the indirect and induced employment and GVA effects were estimated is subject to theoretical limitations based on the method supply side and price assumptions. In further work it would be valuable to examine the impacts on job creation potential from such development of relaxing these assumptions, and research has already taken place in Scotland along related lines (Allan et al., 2014). It is also important to state that this analysis was not able to meet all of the problems of establishing employment effects highlighted in the review in Section 2, particularly in terms of providing a system wide accounting of employment effects.

It is also important to reflect upon uncertainty with respect to the future costs of wave and tidal energy development and how far the regional supply chain can respond to developer requirements. Moreover, the progress of wave and tidal power technologies is expected to be a function of the relative progress of other technologies, and the nature of UK and global energy markets. Notwithstanding this type of ex-ante research into regional potentials is important to reveal something of the scale of the economic opportunities and the constraints on realising these opportunities.

Given the uncertainties outlined above our conclusions are tentative. However, we would question how far the expansion of wave and tidal stream technologies in Wales can really be connected with significant and sustainable employment effects. The historical pattern in Wales with respect to renewables such as wind power is for much of the technology to be imported and with short term regional opportunities focused in device installation and civil engineering (Munday et al., 2011). There is a likelihood that device manufacture (the highest value added aspect of construction) will take place outside of Wales, albeit with potential for some elements of device manufacture to be localised. Our analysis that formed part of the development of the local sourcing assumptions showed that there is an existing regional presence of firms that could diversify to serve the emerging wave and tidal power sector. However, the willingness of local suppliers to engage will be linked to their expectations on the growth of the sector.

In addition to the capabilities of the regional supply chain, the extent to which Welsh firms benefit from opportunities will depend on the developers' procurement approach. Previous analysis of other renewable technologies in Wales have revealed that large energy developers typically have established supply chains and networks outside the UK (or at least Wales) that may disadvantage Welsh firms (Munday et al., 2011). This noted, this ex-ante research would suggest that strategic directions for policy include engaging with the potential supply chain to highlight potentials from marine renewables. In particular there could be value in revealing the opportunities from marine renewables as a whole and with this including offshore wind and tidal impoundment where a series of large projects have either been completed in Wales or are in commercial development.

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Appendix 1: Consultations

As part of this study consultations were undertaken with a range of relevant stakeholders including:

- Device/project developers in Wales, in order to understand plans and developments, and to gain views on plans for regional sourcing of goods and services, constraints, opportunities, support needs and the future development of the sector in Wales. This took the form of structured interviews to gather data on costs.
- Industry experts and stakeholders, including RenewableUK (the trade body for the renewable energy sector), and support organisations in Wales.
- Policy and strategy leads in Welsh Government, DECC and Scotland, to gain their perspective on the potential development of the sector, and the support currently on offer and planned.

Organisations consulted included.

- Welsh Government
- DECC
- RenewableUK
- Carbon Trust
- The Crown Estate
- Scottish Enterprise
- Marine Current Turbines/Siemens
- Tidal Energy Ltd.
- Marine Power Systems
- Marine Energy Pembrokeshire
- University of Swansea

Appendix 2: Analysis of Potential Welsh Supply Chain to Inform Local Sourcing Assumptions

The local sourcing assumptions used were based on currently known features of the wave and tidal energy supply chain, but subject to the considerable uncertainties on the precise future requirements of the industry in Wales. Using an analysis of the Welsh supply side we examined the extent to which regional industries might form part of this future supply chain.

Mapping the marine renewables supply chain: the process began by examining the activities involved in the process of development and then operations and maintenance phases (derived from BVG for Crown Estate (2011): which also includes some description of the underlying activity and needs). Table A1 shows the main activity elements and their estimated proportion of capital cost.

Mapping activities to SIC codes. We then matched activities in Table A-1 with Standard Industrial Classifications (2007). Due to the large number of industries we separated out manufacturing and related categories. It is stressed that these are where there are possible connections between a marine renewable supply chain and an SIC code. Although we adopted a fine level of disaggregation here (5 digit SIC codes) each industry code could still embrace a great deal of variation.

Analysing existing capacity. We then collated information on existing Welsh capacity in these industries. First, identifying Welsh Employment in each identified SIC code from the ONS Business Register and Employment Survey for 2011; and simple location quotients (LQs) for each identified industry in Wales - based on the Welsh share of GB employment in the industry as compared to the Welsh share of all GB employment. Second, we developed an estimate of the number of firms operating in Wales at the current time from the Jordan FAME database.

Table A-1: Main Cost Elements in Wave and Tidal Stream Development & Summary Conclusions from Supply Chain Analysis

<table>
<tr><th>Development</th><th>Estimated proportion of Capital expenditure</th><th>Summary conclusions from supply chain analysis</th></tr>
<tr><td>Design and feasibility</td><td>0.3</td><td rowspan="5">• Strong scope for purchasing services from firms in Wales recognised by developers.
• Potential for some elements of survey work to be carried through into operation phases.
• Elements of detailed design expected to be centred around where devices are manufactured.
• Selected providers able to capitalise on prior expertise in offshore wind development.</td></tr>
<tr><td>Physical surveys</td><td>0.4</td></tr>
<tr><td>Environmental surveys</td><td>0.4</td></tr>
<tr><td>Meteorological and resource monitoring</td><td>0.2</td></tr>
<tr><td>Applications and consents</td><td>0.4</td></tr>
<tr><td>Device manufacturing</td><td></td><td></td></tr>
<tr><td>Hydrodynamic system</td><td>19.0</td><td rowspan="4">• Supply chain impacts in Wales might be increased where devices are finally assembled close to final destinations
• Some evidence from consultations that Scotland gaining expertise and that while cutting edge research being undertaken in Wales in terms of device design, placement, and monitoring, limited evidence that device manufacture will take place locally.
• Device manufacturing expected to be associated with high relative wages and greater indirect and induced effects in Wales were region to successfully gain facilities.</td></tr>
<tr><td>Reaction system</td><td>17.0</td></tr>
<tr><td>Power take-off system</td><td>12.0</td></tr>
<tr><td>Control system</td><td>3.0</td></tr>
<tr><td>Balance of plant manufacturing</td><td></td><td></td></tr>
<tr><td>Foundations and mooring</td><td>9.0</td><td rowspan="4">• Stronger scope for involvement of regional suppliers. Some commonalities with regional supply chain for other renewables.
• Issue on whether small initial volumes would attract interest from Welsh suppliers.
• Issue that device manufacturers may select solutions to balance of plant proximate to where they are based during early development.</td></tr>
<tr><td>Cabling</td><td>4.0</td></tr>
<tr><td>Electrical equipment</td><td>4.0</td></tr>
<tr><td>Onshore infrastructure</td><td>3.0</td></tr>
<tr><td>Installation and commissioning</td><td></td><td></td></tr>
<tr><td>General installation</td><td>0.0</td><td rowspan="5">• Installation of some tidal stream devices expected to require specialist plant and barges.
• Strong expectation that if technology moves to greater scale that pattern of purchasing during installation phase parallels that in offshore wind.
• Opportunities for Welsh contractors in servicing needs of managing contractors.
• Regional effects here linked to gateway port location.</td></tr>
<tr><td>Port services</td><td>3.0</td></tr>
<tr><td>Installation of electrical systems</td><td>7.0</td></tr>
<tr><td>Installation of foundations and moorings</td><td>7.0</td></tr>
<tr><td>Installation of marine energy device</td><td>11.0</td></tr>
<tr><td>Total capital spending</td><td>c.100.0</td><td></td></tr>
<tr><td>Operations and maintenance categories</td><td>na</td><td>• Inspection and monitoring provides potential opportunities for firms in Wales.
• Maintenance contracts potentially reside with device manufacturer.
• Potentially greater employment effects through operations compared to other land based renewable due to environment in which devices sit.</td></tr>
</table>

To the editor.

Thank you for the opportunity to revise the paper for Energy.

We have provided a separate response for each of Referees 1 and 3 below. Referee 2 asked for no changes. We have changed the title of the paper to better reflect contents, and made a series of changes to meet the comments by Referee 3. Selected comments from Referee 3 appeared to contradict those made by the other Referees, but we have still attempted to address each of them as far as possible.

We have provided two versions of the paper. In one we have marked in yellow elements that have been significantly changed to meet the response to Referee 3, but we have not marked up more minor changes we made to the references and to improve the readability of the manuscript following comments from Referee 1. The other copy is the final one with no coloured mark up.

Response to Referee 1
The Regional Employment Returns from Marine Renewables? A Welsh Analysis

We are grateful to the referee for the comments in terms of revisions in the text and we have incorporated as many of these as possible given other revisions that were required. We have also changed the title of the paper to reflect a comment from Referee 1 regarding how we referred to marine renewables in the main text. We now focus far more in terms of wave and tidal power and this is reflected in the title.

Response to Referee 2
The Regional Employment Returns from Marine Renewables? A Welsh Analysis

We are grateful to the referee for the comments on our paper.

Response to Referee 3
The Regional Employment Returns from Marine Renewables? A Welsh Analysis

We thank the referee for the comments on our paper. Below we outline the nature of the comment and place our response in italics.

1.Objectives of the paper were unclear, and organisation needed to be improved
We have in the revision tried to make the objectives of the paper much clearer in the introduction, abstract, and through the literature review in Section 2 (see pp 2-3 in the revised paper). We have argued from the literature that the employment effects associated with wave and tidal power have not been well investigated, and showed why it is important to understand these effects in the light of recent debates. This has meant that the Introduction and Section 2 have been reorganised. We have also reorganised Section 4 on the methods (see below), and restructured the conclusions to draw attention to the most important findings from the analysis.

2. The paper needed to be revised to comply with journal format and requirement.
We have attempted a thorough revision of our paper. There was a problem before that we had separated the tables from the main text and this would have made it a difficult read. We

have now placed the tables close to the text to which they relate. We have also followed the journal style in terms of introducing sub sections to the part of the paper dealing with the method. We have also checked the references for consistency in presentation.

3. The literature review needed to be updated.

We have revised Section 2. In the first submission we had made Section 2 more of a review of the problems associated with the estimation of employment effects without providing enough context of why it is important to consider employment effects from wave and tidal power in the first place. In the revision (p3 particularly) we seek to show that the development of renewable energy technologies can be linked to a series of energy, environmental and economic goals and that under the latter come issues relating to the role of renewables in meeting socio-economic goals such as employment creation or employment diversification. We also highlight that prior research on marine renewables in particular, has been focused upon issues of resource assessment, technical viability and environmental impacts, rather than issues of economic and employment consequences of such technologies. We show that this is a problem because employment provided by development and operation of such facilities can connect through to issues of public acceptability. We then go on to consider the general problems of analysing employment numbers connected to renewables developments. In section 2 we have added a series of new references also.

4. Inclusion of Energy publications in our literature review.

In the revised paper we have included new references to papers in Energy including material by Lund and Helpklund (2012), and Voss (1979).

5. References of the literature.

We have been back though the references and checked that these are in a consistent format as required by the journal. In the Submission notes on Elsevier Guidance to Authors it says there are no strict requirements of reference formatting at submission. However, we have tried to make the references as consistent as possible in presentation. We have also removed some references and added some others to meet comments above.

6. The authors had not clearly provided the research methods.

We have reorganised the methods Section 4. The Section is now subdivided for greater clarity. It now starts with the Input-Output economic method (pp.9-11) used showing what it estimates in terms of indirect and induced economic effects resulting from a change in the final demand for the goods and services produced by industries. We explain the nature of the indirect and induced effects that are estimated, but then go on to show the limitations of the approach. We also return to these limitations in the conclusions. We have also added a new Figure 4.1 which summarises the Input-Output approach adopted. Section 4 then addresses the three scenarios in a separate section, before we turn in the final sub section to the analysis of the types of regional spending connected to wave and tidal power projects, and the determinants of these spending levels.

7. Consideration of theoretical limitations of the approach adopted

In the revision we have on p10 para 4 highlighted the weaknesses of the Input-Output approach that we have adopted in terms of the stability of technical coefficients and the supply side assumptions of the model. We return to discuss these theoretical considerations of the approach in the revised conclusions on p21 para 2.

8. Revision needed to discussion and conclusions section to more accurately focus on the results.

The revised conclusions on pp20-21 now start by revisiting the objectives of the paper, the context, and then going back over the main results as they relate to employment, before showing what these estimates mean in the Welsh economic context. The conclusions have also been revised to consider the weaknesses of the adopted method, and then how far we can address the general problems of estimating employment connected to renewable technologies following from Section 2.