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FULL ARTICLE

Regional income and wave energy deployment in Ireland

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Abstract

Alongside environmental benefits, renewable energy deployment is often evaluated on grounds of regional development. Focusing on wave energy deployment in Ireland, this paper quantifies employment-related welfare change net of associated subsidy costs. Although the added employment reduces inter-regional inequality, certain subsidies increase total income inequality by a greater extent. Total inequality increases by 0.25% in the preferred scenario. This pattern of incidence persists under an optimistic scenario where all manufacturing activity is carried out locally. This finding highlights that policies of regional development should consider the spatial distribution of associated subsidy costs.

KEYWORDS

inequality, spatial microsimulation, regional development, renewable energy

JEL CLASSIFICATION

D31; H23; Q42; Q43; Q48; R12

1 | INTRODUCTION

Renewable energy deployment is often promoted on grounds of regional development. Additional employment is created, often in rural areas (Cai, Wang, Chen, & Wang, 2011; Lewis & Wiser, 2007; Yi, 2013). While this increases incomes and reduces between-region inequality, it is often financed by public subsidy. Focusing on wave energy deployment in Ireland, this paper quantifies employment-related welfare change net of associated subsidy costs using a spatial microsimulation framework. This is the first quantification of these micro-level effects and is a novel application of spatial microsimulation. More generally, this paper highlights the importance of considering subsidy cost incidence in the evaluation of regional development initiatives.

Policies of regional development comprise a large share of total public expenditure. In the United States, $20–30bn in state/local government spending, and $6bn in federal spending, is devoted to supporting regional development (Dupont & Martin, 2006). One-third of the EU budget is spent on regional development initiatives while EU member states spend an average of 1% of GDP supporting regional development (Dupont & Martin, 2006). €213 million was allocated to IDA Ireland, the industrial development authority, for expenditure in 2018, with 79% of this funding going to projects outside Dublin. (Keogh & Brassil, 2018).

The economic rationale for this paper is clear; policies promoted on the basis of aiding regional development may have the opposite effect when the distribution of the cost is taken into account. Such policies are commonplace, especially when one considers policies with an alternate primary purpose. Renewable energy and agricultural policies, for example, are often motivated by regional development objectives (DCENR, 2014; Moretti, 2014). The development of ocean energy in Ireland is an excellent case study in this regard as it is a deployment decision where additional subsidies are at least partly motivated by regional industrial development opportunities. This is evidenced by a literature both quantifying these potential impacts (MRIA, 2013; SEI, 2004; SEI & MI, 2005) and incorporating these and similar quantifications in a cost–benefit analysis of policy support (DCENR, 2014; SEI, 2002). Similar motivation has inspired policy literature in Scotland and Wales (Scottish Government, 2011, 2015, 2010; Welsh Government, 2014), while Lewis and Wiser (2007) review energy-related policies to support industrial development more generally.

The spatial microsimulation approach adopted in this paper provides unique distributional insight. It quantifies welfare effects at the individual level and the spatial dimension allows for those who benefit from the employment effects to be separated from those who do not. This micro-level insight has not featured in the literature to date. Much research has focused on quantifying aggregated economic impacts for affected regions (Allan et al., 2008; Allan, McGregor, & Swales, 2011; Allan, McGregor, Swales, & Turner, 2007; Cecere & Mazzanti, 2017; Connolly, Allan, & McIntyre, 2016; Dalton et al., 2015; Fanning, Jones, & Munday, 2014; Gilmartin & Allan, 2015; Scheer, Stanley, & Clancy, 2014; SEI, 2004, 2002; SEI & MI, 2005; Shamsuzzoha, Grant, & Clarke, 2012). However, these aggregated methodologies fail to capture the change in the distribution of household welfare net of associated subsidy costs. This insight is important; deployment is only worthwhile if employment benefits exceed the welfare cost of raising those funds (Browning, 1976; Schmalensee, 2012), while the spatial distribution of economic impacts is important to understand the impact both within and between regions.

Subsidy-free solar and offshore wind are close to becoming a reality in many countries (Al-Ezzi, 2017; Welisch & Poudineh, 2019), while wave energy costs still require large price supports (Farrell, O'Donoghue, & Morrissey, 2015; Iglesias, Astariz, & Vazquez, 2018). It is therefore important to ask the question; are wave energy price supports justified on non-environmental grounds such as regional development? In providing this insight, this paper proceeds as follows. Section 2 reviews the literature. Section 3 outlines the spatial microsimulation framework and data used for this analysis. Section 4 outlines the results; we discuss the distributional impact of both renewable energy subsidies and additional employment. The net distributional impact of both these costs and benefits are assessed together, with the distributional impact quantified using common inequality metrics. Section 5 offers a conclusion.

2 | LITERATURE REVIEW

Much research has explored the determinants of effective regional development policy. At an EU-level, Pellegrini, Terribile, Tarola, Muccigrosso, and Busillo (2013) show that EU structural funds have been effective in stimulating economic growth. Certain factors have been found to be more effective than others in realising growth, with a strong institutional framework and sufficient public and human capital among the key determinants of success (Becker, Egger, & von Ehrlich, 2013; de la Fuente & Vives, 1995; Ederveen, de Groot, & Nahuis, 2006). Furthermore, policies should focus on developing skills complementary to a region (Fratesi & Perucca, 2019). While this, and other theoretical[1], research has explored the development of regional clusters as drivers of economic activity, the potential benefits must be weighed against the cost of incentives. When clustering is incentivized by public expenditure which does not discriminate by space, such evaluation becomes increasingly important (Dupont and Martin (2006). Dupont and Martin (2006) found that subsidising development in a poor region by a national-level levy increases both within and between-region inequality. Ulltveit-Moe (2007) show that policy-maker attitude to inequality is a key determinant of efficient policy choice. This paper provides applied insight into the theoretical findings of Dupont and Martin (2006), while also showing how an *ex ante* spatial microsimulation framework may be used to incorporate impacts on income inequality into policy decision-making.

The literature analysing energy investment and regional development is relatively sparse. Adami, Antunes Júnior, and Sellitto (2017) provide a qualitative analysis of regional industrial policy and wind energy development in Brazil, highlighting the factors important in facilitating successful intervention. Figus, Lecca, McGregor, and Turner (2019) consider the impact of improved energy efficiency on the regional economy of Scotland, finding an increase and change in the pattern of aggregate demand. Similar positive impacts have been found by Allan et al. (2007, 2008, 2011); Connolly et al. (2016); and Gilmartin and Allan (2015). While providing important insight, these analyses focused on the impact at the national or regional level. In contrast, a disaggregated, household-level analysis of both benefits and costs is lacking in the literature. Research at this disaggregated level has instead focussed on the impacts of costs alone, assessing the distribution of subsidy incidence in isolation of potential economic benefits (Chawla & Pollitt, 2013; Farrell et al., 2015, 2013; Neuhoff et al., 2013; Verde and Pazienza, 2013, Hynes et al., 2009). This paper brings these disparate strands together to consider the distribution of household-level welfare change arising from both benefits and costs of a policy intervention. This insight is made possible through the use of spatial microsimulation.

Over the last two decades, Spatial Microsimulation (SM) has been increasingly applied to topics of regional development, however, greater integration with macro-level economic data is important to widen the scope of future application. A number of papers have begun the process of bridging this gap. O'Donoghue, Ballas, Clarke, Hynes, and Morrissey (2012) outline how an SM model may be integrated with spatial models of energy and agricultural output to optimize biomass production. Ballas, Clarke, and Dewhurst (2006) and Rephann, Mäkilä, and Holm (2005) have linked an SM model with a hypothetical factory closure to elicit the effect on the spatial distribution of employment and population dynamics. Lindgren, Strömgren, Holm, and Häggström Lundevaller (2007) consider the first-round employment effects as a result of a hypothetical investment. This paper builds on this foundation to consider both costs and benefits of a proposed real-world stimulus. As Ballas et al. (2006) state, linking a spatial microsimulation model to a real-world, macro-level profile of employment is an important next step.

3 | METHODOLOGY

This paper quantifies the spatial distribution of welfare change associated with wave energy deployment. For the purpose of this paper, we focus on the household-level welfare change associated with industrial development, net of subsidy costs. In this context, economic welfare effects constitute additional household disposable income on foot of employment and reduced income on foot of an increased subsidy burden.

As this paper is concerned with the impacts for regional development, we wish to quantify not only the average national-level effect, but the distribution of both costs and benefits across space and by socioeconomic group. A

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[1] The benefits of clustering and resulting drivers of regional economic growth are well established in the theoretical literature; economic growth is driven by the shared costs of collective resources (Venables, 2005), local labour markets for specialised skills (Brueckner, Thisse, & Zenou, 2002; Krugman, 1991), reduced interfirm transactions (Venables, 2005; Malmberg & Maskell, 2002; Porter, 1998) and the creation of knowledge spillovers (Malmberg & Maskell, 2002).

TABLE 1 Steps in Modelling procedure

Step	Description
1	Quantify employment impact
2	Quantify subsidy cost.
3	Link (1) and (2) with a spatial microsimulation model.

number of factors must be considered when choosing the methodology for this analysis. As deployment has not yet occurred, *expost* analysis cannot be used. Indeed, many datasets are representative at a national level and do not give the local-level precision required for spatially-explicit insight. We therefore use an *ex ante* spatial microsimulation of costs and benefits to provide the required insight.

Microsimulation is a method of analysis at the individual level. Taking a baseline population of spatially-explicit household units, a counterfactual scenario is simulated individually for each household. From this, one can quantify the distributional effect. The spatial component of analysis allows for spatially heterogeneous impacts, such as spatially heterogeneous employment change, to be modelled.

This paper provides a methodological contribution to the SM literature by integrating a real-world macroeconomic shock into a SM framework. The macroeconomic shock comprises an employment and household expenditure shock, both derived from wave energy deployment. The employment shock is derived from the economic activity required to facilitate deployment. The household expenditure shock is derived from the increased subsidy required to finance deployment, levied uniformly on each household's electricity bill. Modelling these shocks comprises a number of constituent steps, each outlined in Table 1 and addressed in turn in the following discussion.

3.1 | Quantify employment impact

The first step of this analysis is to quantify the spatial distribution of an employment impact from macroeconomic data. This comprises three constituent processes. First, the proportion of expenditure on each cost component that is directly attributable to the remuneration of labour must be identified. This is carried out by first disaggregating total expenditure on wave energy deployment by cost component. Then, each cost component is disaggregated further by input. Once this has been carried out, wage data may be used to convert total labour costs into additional direct “Full-Time Equivalent” (FTE) working hours. This is the equivalent of one employee working full time for one year. A supplier database can then be used to identify the location of employment. Additional jobs are then assigned to their spatial location.

3.1.1 | Disaggregate total expenditure by cost component

A 125 unit Pelamis installation scenario is considered and this is outlined in Table 2. This is chosen as it is relatively small scale, representative of early-stage deployment and large enough to allow for quantifiable distributional effects. Costs may be divided into capital costs and operation and maintenance costs. Table 3 outlines the 2006 capital cost components and their quantities for the “Pelamis” Wave Energy Conversion (WEC) device[2] deployed in Ireland. Previsic et al. (2004) give insight into O&M (operation and maintenance) costs, finding that 0.1 FTE individuals are employed for O&M for each Pelamis unit installed and we employ this figure for our analysis. Following Allan et al. (2008) this paper assumes employment during decommissioning is negligible.

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[2] For more detail on how these are derived, please see the Appendix.

TABLE 2 125-unit installation scenario

Site	Location	Stage	Installation size
Belmullet, co. Galway	West	1	5 unit
Killard point, co. Clare	Mid-south west	2	5 unit
Belmullet, co. Galway	West	3	15 unit
Killard point, co. Clare	Mid-south west	4	50 unit
Dingle peninsula, co. Kerry	South-west	5	50 units

TABLE 3 "Pelamis" wave energy conversion (WEC) device capital cost components

Parameter	Cost		Source
Costs per WEC device unit			
Pelamis wave energy power conversion modules	€1,623,127	Total per WEC	Previsic et al., 2004; Dalton et al., 2010
Steel	€6,000/t	280 t/WEC	Previsic et al., 2004; Dalton et al., 2010
Mooring purchase	€552,165	Total per WEC	Previsic et al., 2004; Allan et al., 2011b
Device/mooring installation (per day)	€35,228	7 days per unit	Kaiser & Snyder, 2011; SQW, 2011
O&M	0.1FTE/unit	Per annum; for 15 years	Previsic et al., 2004
Offshore substation	€60,000/MW		O'Connor et al., 2013
Costs per site			
Export cable purchase	€288/m	8.7 km per installation	O'Connor et al., 2013
Export cable installation (per day)	€88,036	8.7 km @ 0.73 km/day	Kaiser and Snyder, 2011
Admin and onshore works	€5,457,925	Total per installation	Industry communication
Surveys	€225,000	Total per installation	Industry communication
Further modelling parameters			
Learning rate	90%	Cost reduction of WEC device per doubling of capacity	Dalton et al., 2010; SQW, 2010.
Discount rate	6%		Dalton et al., 2012

3.1.2 | Disaggregate each cost component by input

We use an input–output-based methodology as employed by DTI (2004) and SQW (2010) to identify the proportion of this total expenditure attributable to employee compensation. An input–output table characterizes the interdependencies between sectors of the economy, allowing for each unit of expenditure to be disaggregated by constituent input. Using this data, we identify the proportion of total expenditure that goes to employee compensation. We use Ireland's 2005 input output (IO) data (CSO, 2005) for this purpose. Each expenditure item in Table 3 is categorized by industry. For each industry, the proportion of total expenditure attributable to employee compensation is presented in Table 4. For the purposes of this paper, we term this an 'employee compensation coefficient'. For each industry, total compensation is calculated by multiplying expenditure by the relevant employee compensation coefficient. The number of additional persons employed is then calculated by dividing the total additional employee compensation by the average total labour cost per employee (CSO, 2012), shown in Table 5.

TABLE 4 Employee compensation coefficients for wave energy sectors

NACE	Employee compensation coefficient
Other business services	0.2348
Real estate, renting and business activities	0.023
Construction work	0.244
Other transport activity/water transport services	0.248
Electrical machinery and apparatus n.e.c.	0.1596
Fabricated metal products	0.2468

Source: Derived from CSO (2005).

3.1.3 | Identify the location of employment using a supplier database

Table 2 shows that installation is split across four sites, with five stages of installation simulated.[3] The four sites are chosen based on sites currently being developed or envisaged as locations for initial development (MRIA, 2013) and the order of installation follows expected installation plans.[4] A supplier database was used to assign each FTE job created to an appropriate location for each supply chain activity (Enterprise Ireland (EI) and Sustainable Energy Authority of Ireland (SEAI), 2011). Where there are multiple suppliers for a given supply chain activity, we chose a rural supplier. In this way, we maximize the potential positive impact on regional development.

3.2 | Identify subsidy cost

The second stage of this modelling procedure is to calculate the subsidy cost. Wave energy is more expensive than traditional energy sources and requires a subsidy to incentivize investment. The proposed subsidy analysed in this paper is known as a Renewable Energy Feed-in Tariff (REFIT).[5] This is a guaranteed price per unit of electricity generation. If the market price is less than the guaranteed price, there is a public top-up through REFIT. The REFIT top-up is financed by a public service obligation levy on all consumers. This is a fixed charge on all consumers' electricity bill. Devitt and Malaguzzi Valeri (2011) have calculated the expected total subsidy cost for a 75 MW Wave and Tidal installation scenario using the 2006 guaranteed price of €0.22/kWh, under a number of assumed fuel prices. This is converted into the total REFIT cost required for a 125 unit (93.75 MW) Pelamis installation scenario by assuming a constant ratio of subsidisation per MW installed. This results in an annual cost of €9.74 per household, or a total discounted cost of €100.74 over the 15-year period.[6]

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[3] The order of installation is important as initial costs fall according to a learning rate outlined in Table 3.

[4] First the effects of a 5-unit installation in Belmullet, Co. Mayo are simulated, representing the first full scale installation currently being developed (SEAI, 2012). The second stage is a 5-unit installation at Killard Point, Co. Clare. This small-scale initial installation corresponds to existing small-scale testing being carried out. It is assumed that the next two stages will comprise expansion of existing sites, with an additional 15 units and 50 units deployed at Belmullet and Killard Point respectively. Finally, it is assumed that a 50-unit installation is deployed at a third site on the Dingle Peninsula, Co. Kerry.

[5] In 2018, renewable subsidies in Ireland switched to a competitive tender format, where investors reveal the price guarantee required for viability. The findings of this paper may be interpreted in the context of a competitive tender program, where the winning bid for wave energy deployment is €0.22/kWh.

[6] Devitt and Malaguzzi Valeri (2011) state that total REFIT costs amount to €25.9 m for 75 MW. Scaled to 93.75 MW, this comes to €32.375 m. This cost is apportioned amongst residential, commercial and household users as part of the annual Public Service Obligation levy (PSO). This is a flat-rate charge on all electricity users to finance renewables, peat and other security of supply obligations (CER, 2011). Costs are apportioned according to use. Domestic consumers paid 44% of the PSO levy in 2011/2012 (CER, 2011), 43% of the 2010/2011 calculation (CER, 2010); 43% of the, 2009/2010 calculation (CER, 2009) and 41% of the, 2008/2009 calculation (CER, 2008). Thus, household-level charges are calculated by apportioning 44% of the total wave energy REFIT requirement among 1,462,296 permanent Irish households in Census, 2006 to give a household-level cost of €9.74 per annum, or €100.28 over the 15-year lifetime of the installations, discounted according to a 6% discount rate. Some households are beneficiaries of a 'Household Benefits Package' from the Department of Social Protection (Department of Social Protection, 2012). All qualifying household did not pay the levy in, 2006.

TABLE 5 Average labour cost per employee

CSO industrial disaggregation	Average employee compensation
Industry	€50,894
Professional scientific and technical	€47,839
Transport and storage	€43,380
Construction	€43,044
Financial, insurance and real estate	€63,869

Note: 2006 data used from the 2006–2010 data series. *Source*: Derived from CSO (2012).

3.3 | Link with spatial microsimulation model

The final step is to link these impacts of additional employment and additional subsidy burden with each household in Ireland produced by the spatial microsimulation of the Irish local economy (SMILE) model. SMILE provides a rich profile of spatially-referenced microdata, created by reweighting EU Survey of Income and Living Conditions (EU SILC) (Eurostat, 2007) to be spatially representative at the Electoral District (ED) level[7] using census of population small area population statistics (CSO SAPS; CSO, 2007a). SMILE employs a statistical reweighting procedure known as quota sampling to sample from the EU SILC microdata according to key socioeconomic constraints drawn from the CSO SAPS data. A detailed outline of this procedure is offered in Farrell, Morrissey, and O'Donoghue et al. (2012) and the appendix. Once quota sampling has simulated a representative population, the spatial income distribution is then further calibrated to known population totals using a calibration procedure outlined in Morrissey and O'Donoghue (2011). This calibration procedure draws on methods commonly employed in dynamic microsimulation modelling.

For this application, we take 2006 as a demonstrative case study year as the data produced has previously been validated (Farrell, Morrissey, & O'Donoghue, 2013; Morrissey, O'Donoghue, & Farrell, 2014) and therefore provides a reliable basis for the novel methodological contributions of this paper. In 2006, there were 3409 electoral districts in Ireland. A full outline of the creation of SMILE is provided by Farrell et al. (2013) and summarized in the Appendix.

Linking the subsidy cost to households in SMILE is straightforward. As the PSO levy is a uniform charge per household, we subtract each household's total income by the levy amount. However, linking households with the employment change comprises two steps. First, the ED of work for each additional job is specified. This data is contained within the SEAI supplier survey (EI & SEAI, 2011). Conditional on the employment location, an ED of residence is identified using travel to work data. Second, the individual within that ED who takes the additional job must be identified and income adjusted accordingly.

To identify the ED of residence for each additional worker, we implement the methodology proposed by Ballas et al. (2006) to consider job gain conditional on employment location. To provide this contribution, we must calculate the probability of residence conditional on work location. Formally, this may be characterized as:

$$P\mathit{Live\ in\ ED}_j|\mathit{Work\ in\ ED}_i. \tag{1}$$

This is calculated using Place of Work Census of Anonymised Records (POWCAR) data (CSO, 2007a), a population dataset detailing the commuting pattern from each ED of work to each ED of residence for all individuals working in Ireland. Based on this probability distribution, an ED of residence is simulated for each additional

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[7] Since 2011, electoral districts have been superseded by 'small areas' as the smallest unit of disaggregation. In 2011, there were 3,409 electoral districts and 18,488 small areas. Electoral Districts, however, are an adequate degree of disaggregation for the purposes of this analysis.

worker. The next step is to choose the person within that ED that will now be deemed employed. To provide an upper bound on the potential redistributive effect, the person selected is the unemployed person deemed most likely to be employed.[8] The labour force participation model developed by Morrissey and O'Donoghue (2011) is augmented to carry this out, with the procedure detailed in the Appendix. A different regression is run for each county to incorporate the spatial variability of potential incomes. Once gross incomes have been simulated, the tax benefit model produced by O'Donoghue et al. (2012) is used to simulate disposable income for each newly simulated individual, capturing welfare effects net of benefits and taxes.

4 | RESULTS

The results of this analysis are presented as follows. The spatial distribution of additional employment is presented in Section 4.1.[9] The impact net of subsidy burden is quantified in Section 4.2. A descriptive analysis is first offered to give insight into the spatial distribution of this impact. This is followed by a quantitative results; we test the impact of the policy on income inequality and mobility across the income spectrum. Section 4.3 offers a sensitivity analysis to show that the conclusions of this paper are not sensitive to the deployment scenario chosen.

4.1 | Employment change

4.1.1 | Total employment change

The first contribution of this paper is to calculate the additional first-round FTE employment generated by a wave energy sector using the methodology outlined in Section 3. These results are displayed in Table 6, where primary sources of employment are in the manufacturing industry. This is in contrast to Ireland's position as a service-based economy (Conefrey, O'Reilly, & Walsh, 2018; Healy, 2018). The manufacture of steel and power conversion modules generates the most employment while other significant employment drivers include device installation and the provision of infrastructure and civil construction activities. SEAI note that, in order for power conversion modules and export cable activity to be manufactured locally, local manufacturing capacity must be augmented (Enterprise Ireland (EI) and Sustainable Energy Authority of Ireland (SEAI), 2011).

4.1.2 | Spatial distribution of employment change

Table 7 presents the spatial distribution of additional FTE employment, broken down by location. Onshore civil work, operations and maintenance and infrastructural upgrades are carried out close to the deployment sites. A great deal of additional employment occurs in urban locations where it is assumed that capacity has been augmented to accommodate steel component manufacture.[10] Surveying work is carried out by companies in both urban and rural locations. There is also considerable employment in Killybegs, Co. Donegal, Galway and Cork to serve the provision of marine vessels, participation in installation activities, communications equipment, moorings and navigation aids. Companies located in Sligo and Dublin are assumed to provide project management and public relations services.

Much of the generated employment is imported from the UK and abroad as Ireland does not have the industrial capacity in many of the primary manufacturing activities. These are the activities that generate the greatest

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[8] A number of displacement rates may be used. As the results of Section 4 show, total net income inequality increases. The regressive effect holds for all potential degrees of displacement. This can most clearly be demonstrated by assuming there is no displacement.

[9] to complete the analysis, the distribution of subsidy burden is outlined in the Appendix.

[10] These locations contain companies which may best augment capacity to serve manufacture of steel components whilst also being located near a suitable dock, a requirement for deployment (EI & SEAI, 2011; RPS Group, 2009). Galway, Cork and Dublin each serve the manufacture and installation of mooring systems and the provision of electronic equipment.

TABLE 6 Full-time equivalent (FTE) employment by activity

Primary activity	FTE
Mooring manufacture	223.4
Mooring and WEC device installation	201.2
Steel	574.8
Power conversion module manufacture	250.1
Environmental surveys	19.0
Resource assessment	3.7
Markers/buoys	9.2
Camera and communications equipment	0.7
Radar station	1.7
Radar station power supply	2.1
Onshore sub site procurement, landscaping, construction, office rental	27.8
Hardstanding/pier/sipway facilities	9.4
Project management and PR	9.4
Ancillary boat hire	2.3
Licencing and planning application	0.7
Onshore grid connection	27.2
Cable installation	8.7
Cable purchase	23.6
Offshore substations	17.6
Operation and maintenance	12.5
Total	1425

proportion of additional employment. Therefore, the successful development of wave energy in Ireland is likely to have greater industrial benefit to regions outside of Ireland than those regions within.

Figure 1 presents the spatial distribution of welfare impacts relative to pre-existing income. There is an interesting spatial dependence driven by the difference in rural vs urban commuting patterns and the underlying distribution of income. Rural commuting patterns tend to be more dispersed with workers travelling to areas that generally have lower income levels. These spatial dependencies result in the following observations. Deployment has the greatest positive impact in areas surrounding the deployment sites. Welfare increases considerably relative to pre-existing income in these locations and these impacts are isolated due to localized commuting patterns. The additional employment in Letterkenny, Killybegs, Galway, Waterford and Cork is characterized by greater dispersion, reflecting the longer commuting distances common to these areas. This result will be of interest to policy-makers; it indicates that policies centred around development in regional towns may also be beneficial to rural communities. This added income will aid a diverse range of local communities on foot of a dispersed commuting pattern coupled with relatively low levels of underlying income. This impact is less prevalent in Dublin, however, as the 21 FTE jobs created by a wave energy sector there had a negligible impact relative to a high pre-existing income level.

Table 6 has shown that much of the added employment takes the form of manufacturing activity. This is shown in Figure 1, where regions of Donegal and Waterford benefit from primary manufacturing activity in the analysed scenario. This is a considerable increase in employment. For this to be realized, it is therefore important that the required capacity increase be facilitated.

TABLE 7 Spatial distribution of additional FTE employment

Location	FTE	Activities
Cork City, co. Cork	128	Environmental survey, WEC device installation mooring installation, electronic equipment provision, boat hire
Waterford City, co. Waterford	255	Steel manufacture
Letterkenny, co. Donegal	319	Steel manufacture
Killybegs, co. Donegal	178	Boat hire, device installation, mooring installation, electronic equipment provision
Galway City, co. Galway	131	Environmental survey, mooring manufacture and installation, electronic equipment provision, boat hire.
Belmullet, co. Mayo	24	Onshore civil engineering; operation, maintenance
Dingle peninsula, co. Kerry	27	Onshore civil engineering, operation, maintenance
Killard point, co. Clare	28	Onshore civil engineering, operation, maintenance
Dublin City, co. Dublin	21	Environmental survey, electronic equipment provision, project management, public relations
Tipperary	3	Environmental survey
Sligo, co. Sligo	3	Project management
Ballina, co. Mayo	4	Environmental survey
Cavan	4	Environmental survey
UK and abroad	300	PCM manufacture, export cable manufacture and installation, offshore substation manufacture and installation
Total	1,425	

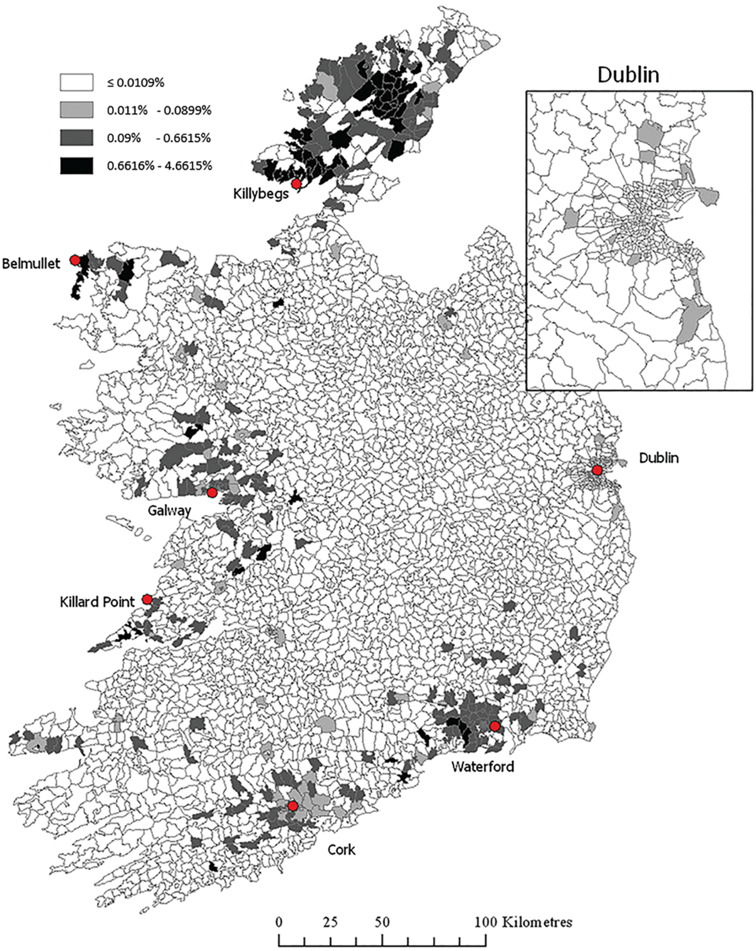
4.2 | Net impact of both cost and benefit

This section analyses the welfare impact of additional employment, net of subsidy cost, an added insight made possible only by the use of a spatial microsimulation framework. This is grouped into two sections. First, welfare simulations by region are presented in Section 4.2.1. Second, the impact on economic inequality is quantified in Section 4.2.2.

4.2.1 | The spatial distribution of net impacts

The welfare change due to added employment, net of total discounted 15-year costs is presented in Figure 2. As observed in Figure 1, spatial dependencies associated with commuting patterns and the underlying distribution of welfare determine the spatial distribution of positive welfare effects. Negative welfare effects of driven by the underlying spatial distribution of income, where subsidy costs impose a greater burden for those with lower incomes. This creates the spatial pattern observed, where EDs in the immediate vicinity of those that benefit incur a higher than average burden of subsidy cost. This suggests a broad trend of income redistribution from areas with a low subsidy burden to areas with a high subsidy burden. This is particularly evident in the north-west (Donegal), the South East (Waterford) and the hinterland of the five deployment sites. Aside from deployment and manufacturing-related activity, the remaining employment benefit is concentrated in more urban areas and their hinterland, where this added employment has a negligible impact on regional income.

From this pattern of impact, a number of conclusions may be inferred. Positive effects accruing from regional employment are undermined by the regressive nature of the scheme through which they are financed, with only



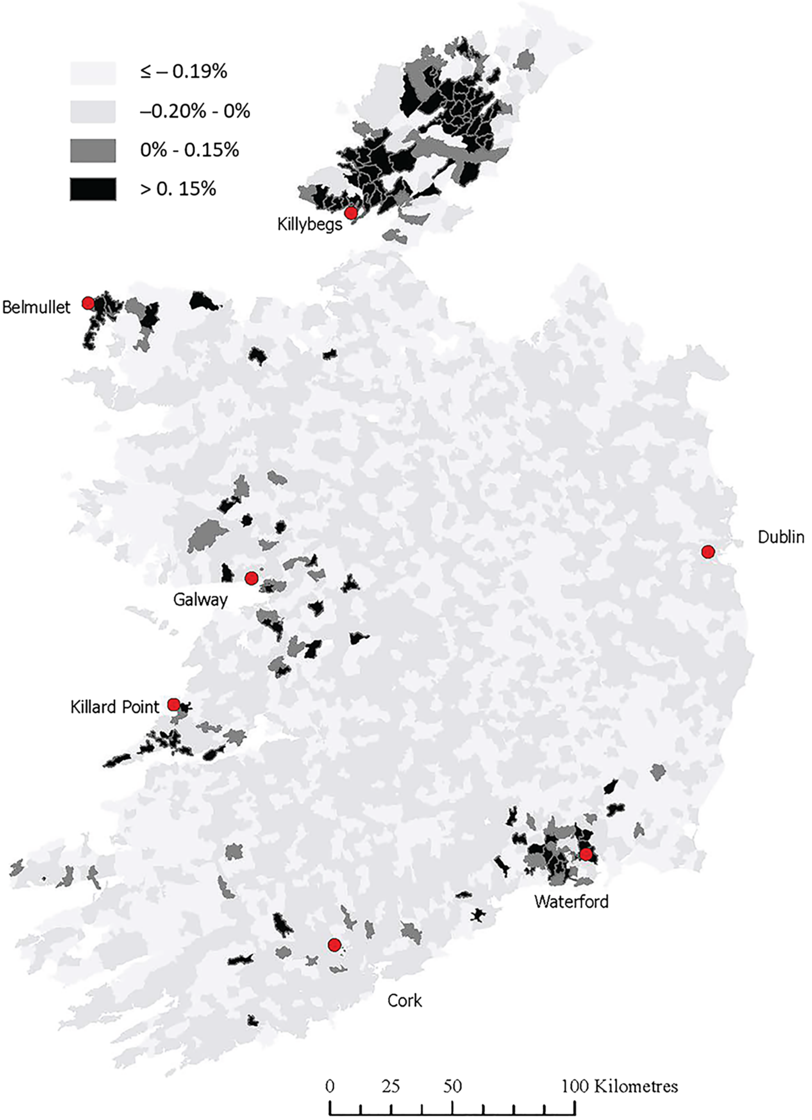
Note: Figure illustrates the spatial distribution of proportional disposable income change by ED, calculated as a proportion of pre-Wave, pre-REFIT disposable income. Results are expressed in terms of equivalised disposable income, evenly split by geometric quantiles.

FIGURE 1 Proportional increase in ED disposable income from 125 MW wave energy deployment Note: Figure illustrates the spatial distribution of proportional disposable income change by ED, calculated as a proportion of pre-Wave, pre-REFIT disposable income. Results are expressed in terms of equivalised disposable income, evenly split by geometric quantiles

concentrated levels of activity providing a means by which a net regional benefit is realized. Primary deployment activity provides such a boost but represents a small proportion of total added employment. Device manufacturing provides a concentrated employment effort in areas for which subsidy costs impose a greater burden. A concerted policy effort may be required to ensure this activity occurs in such areas. If carried out abroad, the remaining employment impacts are of a small magnitude and concentrated in population centres for which these impacts are small relative to the overall activity in the locality.

4.2.2 | Quantification of net impact

The final step is to quantify the effects observed in Figures 1 and 2. We use a measure of spatial inequality to quantify the effect of wave energy deployment, and associated subsidies, on regional incomes. This provides two



Note: The data demonstrates both positive and negative income change. Legend intervals one and two split the negative impacts at approximately the median point. Legend intervals three and four split the positive impacts at approximately the median point. Results are expressed in terms of equivalised disposable income.

FIGURE 2 Identifying the pattern of income redistribution: Net proportional change of ED-level disposable income due to additional employment and 15 year REFIT cost Note: The data demonstrates both positive and negative income change. Legend intervals one and two split the negative impacts at approximately the median point. Legend intervals three and four split the positive impacts at approximately the median point. Results are expressed in terms of equivalised disposable income.

important insights. First, it tells us whether the policy is effective in reducing between-region inequality. Second, it tells us the extent with which national-level inequality changes. If national-level inequality increases, then any effort to reduce inter-regional disparities is at the cost of increasing disparities between the wealthy and the poor. We also

TABLE 8 Net change in income inequality under different REFIT cost scenarios

Constant	5% annual decline	10% annual decline
+0.24080%	+0.16679%	+0.11448%

Notes: Table 8 displays the percentage change in I_1-measured total inequality proportional to total inequality before REFIT and additional employment. ‘Constant’ assumes the REFIT required to finance 15 years of WEC operation is constant throughout the lifetime of the plant; 5% and 10% annual decline assume the REFIT requirement falls by 5% and 10% per annum respectively.

quantify the number of “winners” and “losers” to further emphasize the effects of employment change, net of subsidy burden.

We first quantify the effects relative to income inequality. The *Iα* class of generalized entropy indices are employed to quantify how the preceding impacts affect both overall and between-region inequality. The I1 index is employed.[11] Total I1 measured income inequality may be defined as;

$$I_1 y = \frac{1}{n}\sum_{i=1}^{n}\frac{\mu_i}{\bar{\mu}}\ln\frac{\mu_i}{\bar{\mu}}. \tag{2}$$

This may be decomposed to between-region and within-region inequality:

$$I_1 y = \left[\sum_j S_j \frac{\mu_j}{\bar{\mu}}\ln\frac{\mu_j}{\bar{\mu}}\right] + \sum_j I_1 S_j \frac{\mu_j}{\bar{\mu}}, \tag{3}$$

where μ_i is the household disposable income for household *i*; $\bar{\mu}$ is the mean household disposable income for the entire population; S_j is the population share of ED_j and μ_j is the mean household disposable income for ED_j. The first term of (8.6) in square brackets represents between-region inequality. Between-region inequality falls in all scenarios, by 0.19% to 0.34% less than between-region inequality before added employment and REFIT cost. Table 8 presents the change in total inequality.[12] A net increase in total inequality is observed, as the within-region component of income inequality increases to a greater extent than the reduction of between-region inequality. This is due to the regressive effect of the REFIT charge being of much greater magnitude than the positive effect of wave energy employment. A sensitivity analysis is carried out, where annual costs are assumed to fall at a rate of 5% and 10% per annum.[13] Interpreting both in the context of overall inequality, it is found that reductions in between-region inequality result in total income inequality falling by 0.006–0.010%, while the net impact of REFIT and wave energy employment leads to a net increase in total income inequality by 0.11% to 0.24%. Thus, efforts to reduce regional inequality are somewhat effective but greatly outweighed by the added burden required to finance this policy.

The next step is to quantify the numbers of winners and losers. Table 9 and Table 10 respectively quantify the winners and net winners/losers as a result of wave energy deployment, determined according to the net changes in membership of different income groups. We compare membership of income quintiles relative to the distribution before deployment, to show clear income mobility.

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[11] A number of *Iα* specifications may be used. The *I1* index is more sensitive to changes at the top end of the distribution than alternative specifications such as the *I0*. Using this metric therefore provides a bound as to the potential negative welfare effect, providing more robust inference.

[12] It should be noted when interpreting Tables 8–15 that the quantified changes in inequality are of a small magnitude. The small magnitude in this paper is due to the small nature of the case study assessed. As demonstrated by the number of sensitivities, the pattern persists across deployment scenarios and, should large-scale deployment occur, change in inequality are likely to be of a larger magnitude. As Table 9 outlines, income inequality changes by 0.11 to 0.25 percentage points due to discounted total REFIT costs. While this is a small change, it is between one tenth and one quarter of the total reduction in disposable income inequality in Ireland between 2007 and 2011, measured by the Gini coefficient.. O'Donoghue, Loughrey, and Sologon (2018) show that total disposable income inequality in Ireland fell from a Gini of 0.304 in 2007 0.292 in 2011. This is a change on 0.96%.

[13] Subsidy costs are calculated as the difference between the guaranteed price floor offered as part of the subsidy and the average annual market price. If market prices rise, as one may expect, then the subsidy cost will fall. Therefore, the sensitivity analysis may be interpreted as scenarios of higher market prices

TABLE 9 Change in household income distribution due to wave employment alone: Initial scenario

Household income quintile	Proportional change in membership of this income quintile
1 (low)	−0.066%
2	−0.072%
3	−0.013%
4	+0.056%
5 (high)	+0.095%

Notes: Results display the proportional change in households in household income quintiles, defined as those income thresholds that evenly split the pre-wave energy deployment income distribution. Results are expressed in terms of equivalized disposable income.

TABLE 10 Net change in distribution of household income after both wave employment and REFIT cost: Initial scenario

Quintile	Proportional change in income
1 (low)	+1.29%
2	−0.74%
3	−0.06%
4	−0.25%
5 (high)	−0.24%

Notes: Results display the proportional change in households in household income quintiles, defined as those income thresholds that evenly split the pre-wave energy deployment income distribution. Results are expressed in terms of equivalized disposable income.

Table 9 elicits the impact of added employment. Quintiles 1–3 show a net fall, reflecting the movement of previously unemployed persons to becoming employed and moving to higher income quintiles. The net fall for quintile 3 is less than quintiles 1–2 as there is mobility in and out of this quintile; households in lower income quintiles move into this group upon employment, while other households (such as two-person households where one is unemployed) move out of this quintile to higher quintiles upon employment in WEC-related activities. However, Table 9 only tells part of this story, with Table 10 demonstrating how positive impacts are of a much lesser magnitude than negative impacts. One can see that households in lower income groups bear the greatest cost of WEC deployment as membership of quintiles 2–5 falls and membership of quintile 1 grows once the impact of REFIT costs are taken into account. The difference in magnitude is striking; with the number of households in the lowest quintile increasing by 1.33%–0.55% while those in the upper quintiles (4–5) fall by a much lesser degree, in the order of 0.30%–0.10%. These changes suggest a highly regressive pattern of incidence, as while households may drop from quintile 5 to quintile 4, increasing the number of households in quintile 4, this is outweighed by the numbers dropping from quintile 4 to quintile 3. This patterns persists to quintile 2.

The policy implications of Tables 8–10 are far-reaching; there is a negative net first-round welfare effect of subsidising wave energy deployment, relative to the benefits of regional development. These findings should not be confused with the environmental benefits of wave energy deployment. Wave energy subsidies may be wholly justified on environmental grounds, and it may be the case that environmental benefits outweighing the social costs quantified here. However, different technologies create a different subsidy burden, with more expensive technologies such as wave energy placing a greater burden than more advanced technologies such as wind and solar. With the cost of mature renewables falling, a greater emphasis must be placed on the ancillary benefits to justify deployment of wave energy conversion devices. Tables 7–9 give strong evidence to suggest that on the grounds of regional development alone, the first-round welfare effects are likely to be welfare-reducing.

4.3 | Sensitivity analysis

This section presents a sensitivity analysis to ensure that our conclusion is robust to alternate scenarios of local employment creation and alternative cost scenarios.

4.3.1 | Sensitivity analysis: Policy costs

REFIT policy is a price floor, with the subsidy amount calculated according to the difference between the market price and the subsidy amount. Similarly, a higher observed fossil fuel price leads to a lower subsidy. We test different scenarios of baseline fuel price. Similarly, fuel prices may rise at different rates of growth, with subsidy requirements falling accordingly. We therefore test our central results to differing rates of annual decline in cost requirements to give a full complement of potential subsidy burden. Huber et al. (2007) have employed a 5% rate of annual decline when assuming future REFIT requirements. A similar rate of decline is thus used for this analysis, alongside a 10% annual decline as a lower bound. Used in conjunction with the alternate fuel scenarios of Devitt and Malaguzzi Valeri (2011), a range of potential future REFIT costs are evaluated to consider many REFIT cost eventualities.

Table 11 outlines the calculation of a 15 year REFIT requirement per household, whereby values are given as present value, with future costs discounted according to a 6% rate of time preference. One can see that the total cost comes to €10.83–€9.10 per household, per annum. The total discounted 15 year cost is particularly sensitive to the fuel price and annual rate of decline and, as such, examination of a number of scenarios allows for a more comprehensive assessment of potential outcomes.

4.3.2 | Sensitivity analysis: Employment creation

In this sensitivity analysis, we consider a deployment scenario where the manufacture of all components is in Ireland, following suggestions by RPS Group (2009). Alongside this, the transport of export cable from abroad presents a potential logistical limitation in cost effective deployment, while supply chain 'bottlenecks' in the manufacture of cable represents a potential constraint to industry development (Wavepalm, 2008). To account for the large-scale manufacture of these components in Ireland, this scenario considers the additional employment as a result of the operation of a bespoke facility.

TABLE 11 Calculation of household REFIT incidence

Fuel Price scenario	National level			Household level			
	REFIT Total	REFIT Total	Domestic share	Single year	15 year	15 year	15 year
	75 MW	93.75 MW	44%	Per annum	Constant REFIT	5% annual decline	10% annual
Low	€28.8 m	€36 m	€15.84 m	€10.83	€111.51	€84.20	€65.59
Med	€25.9 m	€32.375 m	€14.245 m	€9.74	€100.28	€75.72	€58.99
High	€24.2 m	€30.25 m	€13.31 m	€9.10	€93.70	€70.75	€55.12

Notes: This table illustrates how values calculated by Devitt and Malaguzzi Valeri (2011) are adapted to household level costs. REFIT total for 75 MW is the total aggregate cost calculated by Devitt and Malaguzzi Valeri (2011). This is scaled assuming a constant share per MW to 125 unit (93.75 MW) Pelamis REFIT support. Census 2006 documents 1,462,296 permanent households in the State in 2006 (CSO, 2007b). The household-level charge is calculated as the total domestic share divided by the number of households in the state. Discounted sums are calculated by assuming a 6% discount rate.

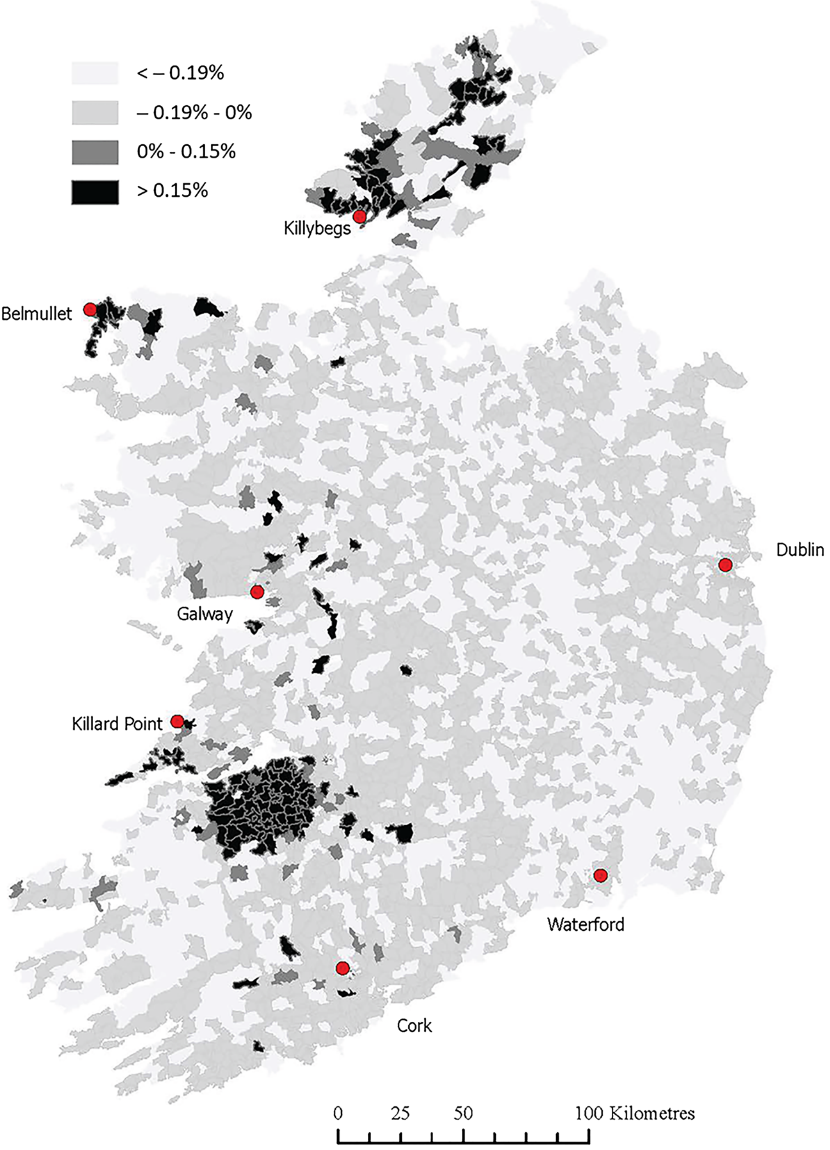
It is assumed that such a bespoke facility would be established near a coastal port to allow for easy deployment (RPS Group, 2009). This facility will comprise the manufacture of PCM, offshore substation, cable and steel components. Cable installation activities will also operate from this facility, which is assumed to be located at the Foynes port in the Shannon estuary. This has been cited as a site with good potential to serve future wave energy development and deployment (RPS Group, 2009). It should be noted that the co-location of steel with PCM manufacture removes the additional employment that is generated from the Letterkenny and Waterford regions. It is assumed that vacant premises are used or pre-existing premises are expanded to cater for this activity, allowing for the analysis to focus on the employment created due to WEC-related activities alone.

4.3.3 | Sensitivity analysis: Results

The updated spatial profile of FTE employment for the alternate scenario is outlined in Table 12. Figure 3 displays the net distribution of income under the central fuel price and constant REFIT scenario where the change in pattern for net benefit may be observed. Relative to Figures 1 and 2, employment is largely centralized around the bespoke Limerick facility. The difference in spatial dependence is driven by commuting patterns. Commuting patterns are less dispersed than regional towns and the distribution of welfare change (and any further effects, such as subsequent spillover effects) are concentrated in the Limerick area. Again the areas of net benefit are located along the deployment sites, Killybegs (south Donegal) and at the Shannon Estuary (east). Urban areas receive a smaller proportion of benefit, as once again the benefits for regions such as Cork, Galway and Dublin are overshadowed by the concentration of individuals incurring REFIT cost. Finally, this development has shifted much

TABLE 12 Spatial distribution of additional FTE employment optimistic development scenario

Location of work	FTE	Activities
Bespoke Facility in co. Limerick	874	Steel manufacture, PCM manufacture, offshore substation manufacture, cable manufacture and installation
Cork City, co. Cork	128	Environmental survey, WEC device installation mooring installation, electronic equipment provision, boat hire
Killybegs, co. Donegal	178	Boat hire, device installation, mooring installation, electronic equipment provision
Galway City, co. Galway	131	Environmental survey, mooring manufacture and installation, electronic equipment provision, boat hire
Belmullet, co. Mayo	24	Onshore civil engineering; operation, maintenance
Dingle peninsula, co. Kerry	27	Onshore civil engineering, operations, maintenance
Killard point, co. Clare	28	Onshore civil engineering, operations, maintenance
Dublin City, co. Dublin	21	Environmental survey, electronic equipment provision, project management, public relations
Sligo, co. Sligo	3	Project management
Ballina, co. Mayo	4	Environmental survey
Cavan	4	Environmental survey
Tipperary	3	Environmental survey
Letterkenny, co. Donegal	0	Steel manufacture
Waterford City, co. Waterford	0	Steel manufacture



Note: The data demonstrates both positive and negative income change. Legend intervals one and two split the negative impacts at approximately the median point. Legend intervals three and four split the positive impacts at approximately the median point. Results are expressed in terms of equivalised disposable income.

FIGURE 3 Net spatial distribution of disposable income change under optimistic scenario Note: The data demonstrates both positive and negative income change. Legend intervals one and two split the negative impacts at approximately the median point. Legend intervals three and four split the positive impacts at approximately the median point. Results are expressed in terms of equivalized disposable income.

of the economic benefit from Ireland's smaller urban centres of Letterkenny and Waterford to one single location on the western seaboard.

Table 13 and 14 present the change of income relative to pre-deployment distributions as a result of this scenario. The general trend observed is similar to that observed in the primary analysis. Of particular interest is the fact that there are 0.013% fewer households in the bottom quintile and 0.012% fewer individuals in the middle quintile than

TABLE 13 Change in household income distribution due to wave employment alone: Central cost estimate with constant fuel price

Household income quintile	Proportional change in membership of this income quintile
1 (low)	−0.079%
2	−0.078%
3	−0.025%
4	+0.062%
5 (high)	+0.120%

Notes: Results display the proportional change in individuals in household income quintiles, defined as those income thresholds that evenly split the pre-wave energy deployment income distribution. Results are expressed in terms of equivalized disposable income.

TABLE 14 Net change in distribution of household income after both wave employment and REFIT cost: Alternate scenario

Household income quintile	Low fuel			Med fuel			High fuel		
	Cons.	5%	10%	Cons.	5%	10%	Cons.	5%	10%
1 (low)	+1.32%	+1.14%	+0.59%	+1.27%	+0.70%	+0.57%	+1.20%	+0.64%	+0.54%
2	−0.76%	−0.73%	−0.35%	−0.75%	−0.35%	−0.35%	−0.71%	−0.31%	−0.35%
3	−0.06%	−0.03%	+0.06%	−0.07%	−0.02%	+0.03%	−0.08%	0.00%	+0.05%
4	−0.22%	−0.24%	−0.19%	−0.24%	−0.21%	−0.16%	−0.23%	−0.21%	−0.17%
5 (high)	−0.27%	−0.15%	−0.11%	−0.21%	−0.12%	−0.09%	−0.18%	−0.12%	−0.08%

Notes: Results display the proportional change in membership of household income quintiles, defined as those income thresholds that evenly split the pre-wave energy deployment income distribution. Results are expressed in terms of equivalized disposable income. Fuel scenarios refer to the constant fuel price, 5% rate of annual decline and 10% rate of annual decline outlined in Table 11.

in the previous scenario, while the upper quintile has grown by 0.025%. Nevertheless, the regressive pattern identified in Tables 9, 10 persists.

Table 14 shows that this positive mobility across the income distribution is still outweighed by the cost imposed to all, with a net impact of downward mobility. This is consistent across scenarios, the results of the main analysis therefore are robust to assumed policy costs and profile of indigenous industrial development.

Even if all employment were located locally, costs still outweigh benefits. Table 15 shows the proportional change in income inequality due to the alternate deployment scenario. The degree of total income inequality is 0.0016%–

TABLE 15 Change in total income inequality for the alternate deployment scenario

Annual REFIT requirement	Constant	5% annual decline	10% annual decline
Low fuel	0.27127%	0.19224%	0.13412%
Medium fuel	0.23933%	0.16562%	0.11347%
High fuel	0.21910%	0.15028%	0.10237%

Notes: Table A5 displays the percentage change in I_1-measured total inequality proportional to inequality before REFIT and additional employment. ‘Constant’ assumes the REFIT required to finance 15 years of WEC operation is constant throughout the lifetime of the plant; 5% and 10% annual decline assume the REFIT requirement falls by 5% and 10% per annum respectively. These requirements are calculated for three 2020 fuel scenarios, outlined in Section 8.2.

0.0009% less under the alternate scenario than the primary scenario. This is due to the additional employment generated. However the reduction in between-region inequality is less and falls by 0.18 percentage points, on average. As the preceding scenario reduced between-region inequality by −0.19 to −0.34%, this is a considerable reduction. This demonstrates that the expansion of existing services provides a more spatially equitable pattern of welfare change than the co-location of services at a bespoke facility.

5 | DISCUSSION AND CONCLUSION

Using a wave energy case study in Ireland this paper shows that while renewable energy development may reduce regional inequality, total income inequality grows if subsidized by the electricity consumer. In doing so, this paper provides an identification strategy to quantify the distributional effect of regional subsidies, analysed in the theoretical literature. A macroeconomic shock is disaggregated to the small area level (ED) level using a combination of national accounts, commuting data and a spatial microsimulation model. A procedure for quantifying additional employment and location assignment has been proposed, a key contribution to the spatial microsimulation literature.

This framework has provided some important insight for renewable energy policy in Ireland. First, while wave energy deployment serves to reduce between-region inequality, within region inequality grows by a greater extent, confirming propositions contained within the theoretical literature. Wave energy deployment for regional development is both inefficient and inequitable and is not justified on grounds of regional development. A net reduction in between-region inequality was observed, however this was less than the overall increase in inequality due to subsidy cost incidence. We calculate an alternative upper-bound case study where all employment is sourced locally through a bespoke site, while also testing sensitivity to alternative price and subsidy cost assumptions. Even when all employment is sourced locally and subsidy incidence is lowest, the general conclusions of this paper still hold. In an Irish context, this finding is applicable to other novel technologies with a proposed subsidy burden of similar magnitude.

Second, should wave energy deployment be pursued in spite of the overwhelming negative impacts, the results of Section 4.2 and 4.3 show that manufacturing activity must be located domestically in order to benefit regional development. This may require further policy support, particularly when one considers that manufacturing activity is not a natural strength for the Irish economy. The ancillary services best served by indigenous industry are located in urban centres and have negligible impact on regional development relative to existing patterns of well-being. In the context of Ireland's position as a service-led economy and the cost imposed on foot of wave energy support, the merits of such a policy may come into question. Irish policy should consider this cost relative to the next best alternative price support for industrial and regional development. While deployment supports for regional development are shown to be inefficient, this should not have a bearing on innovation supports. Research and Development and similar supports for innovation in this space should remain unaffected commensurate with environmental policy objectives. This paper provides an important general insight; one must consider the distribution of applicable subsidy costs when evaluating energy policy in the context of regional development.

This paper has highlighted avenues for further research. In particular, the means through which subsidies are financed warrants considerable attention. Section 4.2 has shown that assisting WEC development by means of a regressive flat rate REFIT charge has the potential to increase inequality to the extent that more people lose out than gain. This finding provides evidence to motivate a more progressive means of financing renewable energy subsidies.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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