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The socio-economic benefits of tidal power to the European economy

Donald R. Noble, Kristofer Grattan, and Henry Jeffrey

Abstract—**Tidal stream power offers a predictable source of renewable energy, contributing to energy security and Net Zero. There is also significant socio-economic benefit to Europe from building and operating tidal farms, which this paper aims to quantify. Europe is at the forefront of developing and deploying tidal stream technology, with a significant pipeline of projects to be built over the coming years. The socio-economic benefits resulting from developing, building and operating tidal stream projects are modelled. They are quantified using two common metrics, gross value added and full-time equivalent jobs. Depending on supply chain competitiveness and rate of deployment, the economic benefit to the European economy from building and operating tidal stream projects in Europe could be €15bn to €46.5bn, with exports worth €2bn to €26bn. By 2050 there could be almost 70,000 jobs in the tidal sector from projects in Europe, and a further 40,000 from international exports, totalling nearly 1.2 million job-years of employment between now and 2050. Almost half of the jobs are associated with device construction, and by 2050, operation and maintenance of turbines and farms could be almost a quarter of sector jobs. A significant proportion of jobs are in manufacturing, offering opportunity for transfer of skilled workforce from the oil & gas and other sectors as part of the Just Transition.**

Index Terms—**Economic benefit, Gross Value Added, FTE jobs, Tidal stream power.**

I. Introduction

HARNESSING energy from tidal currents is an emerging technology, with the first commercial tidal stream farms planned to be built in Europe over the next few years. As well as being a source of predictable renewable energy, there are considerable socio-economic benefits to countries developing and building tidal turbines and projects. This paper aims to quantify these, using Orbital Marine Power as a case study in a European context.

Globally, there has been over 40 MW of grid-connected tidal stream turbines deployed and tested since 2010 [1], with 11.5 MW operational capacity at the end of 2023 [2]. Europe is at the global forefront in developing and deploying tidal stream technology, with almost 75% of all turbines tested at sea since 2010 being in European waters [1]. At the time of writing, there is a pipeline of over 150 MW of commercial tidal farms to be built in Europe over the next four years, with many more projects being developed beyond. Of this, over 120 MW is in the UK and nearly 30 MW is being constructed in France.

The International Energy Agency's technology collaboration programme on Ocean Energy Systems (IEA-OES) recently published a roadmap to deploy 300 GW of ocean energy globally by 2050, of this 120 GW is projected to be tidal stream [3]. While ambitious, this follows a similar trajectory seen in other renewable energy sectors; for context, both onshore and offshore wind grew from 10 MW to 10 GW installed capacity in Europe in under two decades.

Tides are a predictable movement of water around the oceans, driven by the gravitational forces of the moon and the sun. In most places around Europe, the tides are semi-diurnal, with two high and two low tides every 24 hours 50 minutes. There is also a pattern of larger (spring) and smaller (neap) tides every lunar month. These and other more complex factors lead to a varying but predictable tidal energy resource. This predictability leads to power systems benefits, as tidal power can be available at different times to other renewable energy sources such as wind and solar [4]–[9]. The cyclic pattern of the tides, with typically four periods of generation per day, is also well matched with short-term battery storage to provide continuous renewable energy [8].

Over the past decade, several studies have sought to quantify the socio-economic benefits of tidal power, both globally and regionally. These benefits are typically quantified in terms of Gross Value Added (GVA), plus Full-Time-Equivalent (FTE) jobs and cumulative job-years. Other studies have quantified benefits of a tidal stream technology or project, although often at a relatively small scale or in combination with other renewable energy technologies. These studies are summarised in Table I, noting that the scope and results of each study varies. Where multiple scenarios are presented, the highest/most ambitious is quoted, and the deployment reflects that of tidal stream only unless noted. GVA figures are given as reported, without currency conversion, and they have not been adjusted for inflation even though this has been significant in the past few years.

This paper builds on these studies, providing an up-to-date quantification of the potential economic benefits of tidal stream power to the European and UK economies, uniquely considering both regional and technology level analyses.

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TABLE I
PREVIOUS STUDIES QUANTIFYING ECONOMIC BENEFITS OF TIDAL STREAM ENERGY IN EUROPE

Study	Year	Scope*	Deployment	GVA & Jobs (highest scenario)
Allan et al. – The economic impacts of marine energy developments: A case study from Scotland [10].	2014	Scotland, W&TS	1.6 GW† (1.0 GW TS)	£2.1bn† and 50,200 job-years† for period 2010–2020.
Fanning et al. – The regional employment returns from wave and tidal energy: A Welsh analysis [11].	2014	Wales, W/TS	0.75 GW	£611m and 17,150 job-years
ORE Catapult – Tidal stream and wave energy cost reduction and industrial benefit [12].	2018	UK, W/TS	1.0 GW (UK)	£1.6bn (domestic) and £1.1bn (exports) between 2021 and 2030. Almost 4,000 jobs by 2030 and 14,500 by 2040.
EMEC Socio-Economic Report [13]	2019	Orkney, H&I, Scot., UK	Testing of 31 W&TS devices, +other activities	£98m GVA 1653 FTE-years (Orkney), £285m GVA 4227 FTE-years (UK), for period 2003–2017.
Vivid Economics – Energy Innovation Needs Assessment sub-theme report: Tidal Stream [14].	2019	UK exports	Not stated	Export could add over £540m GVA and nearly 5,000 jobs/annum by 2050
ETIP Ocean – Potential economic value of wave and tidal in Europe [15].	2021	Europe, W/TS	24 GW (Europe) 93 GW (RoW)	€78bn between 2021 and 2050
Supergen ORE – What is the value of innovative offshore renewable energy to the UK economy? [16].	2021	UK, W/TS/ FOW	6.2 GW (UK) 77 GW (global)	£4.5bn (domestic) and £12.7bn (exports) between 2021 and 2050
ELEMENT Project - European Tidal Energy Impact Analysis Report [17].	2022	France, UK, Norway & Italy, TS	Per 1 MW	25–30 €m/MW & 53–119 FTE/MW (CAPEX) plus 1.5–1.9 €m/MW/y & 3.3–7.4 FTE/MW/y (OPEX)
ORE Catapult – Cost reduction pathway of tidal stream energy in the UK and France [18].	2022	TS project, Scotland	20 MW	46 FTE-years per MW
EMEC/BiGGAR Economics, Economic Impact of 20 years of EMEC [19]	2023	Orkney, Scotland, UK	Testing of W&TS devices, +other activities	£130m GVA 224 FTE jobs (Orkney), £370m GVA 540 FTE jobs (UK), for period 2003–2023.
IEA-OES – Roadmap to Develop 300 GW of Ocean Energy by 2050 [3].	2023	Global, W&TS	300 GW† (120 GW TS)	$340bn† to 2050, 680,000 jobs† by 2050
Bianchi & Fernandez – A systematic methodology to assess local economic impacts of ocean renewable energy projects: Application to a tidal energy farm [20].	2024	TS project, Scotland	34.5 MW	€158m and 965 FTE jobs, for a 23-turbine farm.
University of Edinburgh – Economic Review of Tidal Stream Energy in Scotland [21].	2025	Scotland, TS	6.2 GW (UK) 114 GW (RoW)	£4.5bn (UK) and £11.4bn (exports) between 2024 and 2050. Up to 22,500 FTE jobs in 2050.
Supergen ORE – What is the value of innovative offshore renewable energy to the UK economy? [22].	2025	UK, FOW/TS/W	6.2 GW (UK) 114 GW (RoW)	£6bn GVA, 100,000 jobs-years (UK) and £14bn GVA, 275,000 job-years (exports) between 2024 and 2050.

* W = Wave energy, TS = Tidal Stream, FOW = Floating Offshore Wind, RoW = Rest of World. † from both tidal stream and wave energy.

The remainder of the paper is structured as follows: background on the O2-X turbine and on quantifying economic benefits is given in section II, the methodology is outlined in section III, followed by results at a European level and Orkney case study in sections IV and V respectively, then finishing with sections VI discussion and VII conclusions.

II. BACKGROUND

A. The Orbital O2-X turbine

The O2-X, developed by Orbital Marine Power, is their next generation of floating tidal stream turbine. As shown in Fig. 1, the device has a pair of two bladed rotors mounted on adjustable legs either side of a tubular hull. The legs can be raised to the water surface for maintenance, or lowered below the device in operational mode. By refining its existing O2 turbine platform, Orbital draws parallels with the wind energy sector's evolution, focusing on optimising key components and processes to enhance performance and reduce costs. Enhancements in the O2-X include larger hull compartments for high flow speeds, increased hub and nacelle freeboard to facilitate O&M, stabilisers for improved roll stability, while pile anchors and a single-point mooring improve logistics and deployment flexibility. The rotor diameter has increased to accommodate up to 13 metre blades for better performance in lower-speed sites, these are coupled to drivetrains with a more powerful gearbox and generator, each rated at 1.2 MW to give a total of 2.4 MW per device.

Fig. 1. The Orbital O2-X turbine. Credit: Orbital Marine Power.

The subsea electrical architecture Orbital is currently developing is designed to connect up to 12 turbines to

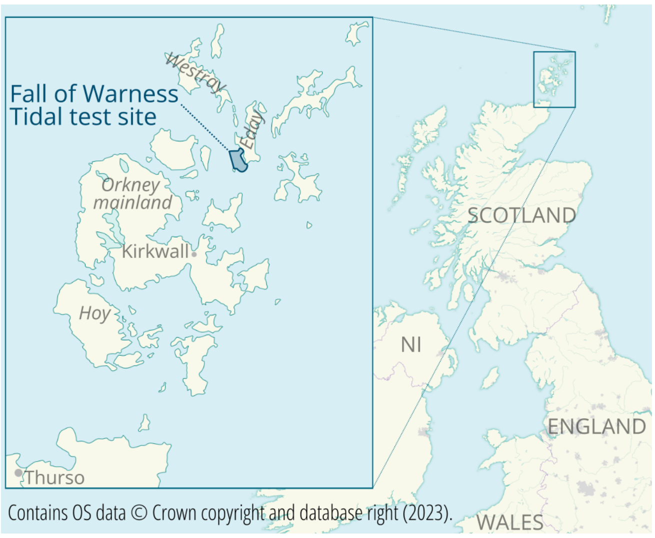

Fig. 2. Location of EMEC Fall of Warness test site.

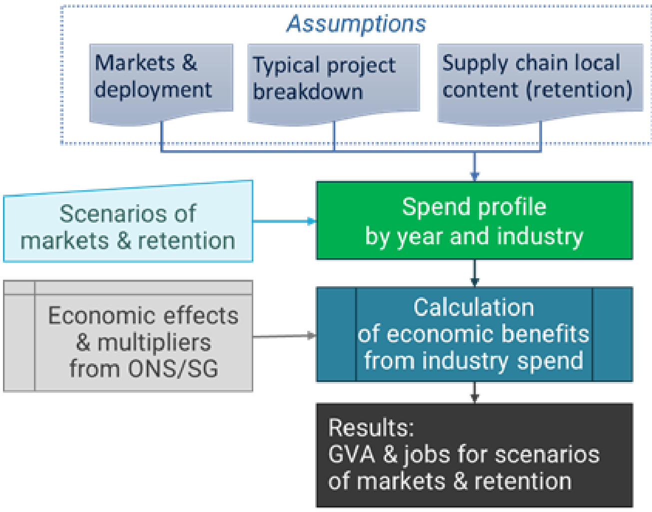

Fig. 3. Schematic of methodology

an export cable, developing projects in approximately 30 MW array blocks. Since the devices include a transformer onboard (either 11 kV or 33 kV) there is no need for a subsea transformer in the array.

By considering metocean data from tidal hotspots around the world, Orbital expect over half of the global theoretical resource for tidal stream energy will be accessible to the O2-X, making it viable for commercial exploitation. The O2-X thus enables scalability, commercial viability, and can contribute to decarbonisation efforts, positioning tidal stream energy as a significant player in the transition to a net-zero future.

Development of the O2-X turbine is partially supported by the FORWARD2030 project, and the first array of four O2-X turbines will be demonstrated within the EURO-TIDES project. These will both take place at the European Marine Energy Centre (EMEC) Fall of Warness tidal test site, where the Orbital O2 is currently being tested. EMEC is located in the Orkney Islands, in the north of Scotland, Fig. 2.

B. *Quantifying socio-economic benefits*

As outlined in [23], the economy of a country or region can be modelled using the European System of Accounts (ESA 2010) which consists of three types of "Input-Output" (IO) tables, namely Supply, Use and Symmetric Input-Output Tables. These illustrate the flows of goods and services within an economy in a given year, including the relationships between producers and consumers and the interdependencies of industries. The Supply Table shows products produced by each industry, while the Use Table shows the demand for products by industry. To analyse linkages between industries and economic impacts, the Use Table can be represented in a symmetrical Industry by Industry (I×I) format.

The Leontief inverse of the I×I table is used to derive a series of effects and multipliers for GVA and FTE jobs [23]. These are split into type I and type II effects, detailed by industry, and show the impact of an additional unit of final use. Type I effects include direct and indirect spend, while type II also includes induced impacts. Direct refers to the spend on the project, including Tier 1 suppliers for device manufacture and installation. Indirect then refers to the spend by these businesses in their supply chain, while induced effects correspond to the knock-on spend within the wider economy, such as staff spending their wages.

III. Methodology and Input Assumptions

In this work, the potential future socio-economic benefits are quantified in terms of Gross Value Added (GVA) and Full-Time-Equivalent (FTE) jobs, both in a specific year and cumulative job-years. The economic benefits quantified in this work come from the development, construction, and operation of tidal stream projects in various markets. There may be additional value resulting from sources including underpinning innovation and research on topics around tidal stream or other renewable energy, and from the exploitation of technical know-how in wider markets.

The benefits are quantified to Europe as a whole (EU27+UK), while also drilling down to look at UK, Scotland, and the Orkney Islands where the O2-X will first be deployed. While the case study is Orkney in Scotland, the methodology is applicable to any European country or region.

Details of the expected cost breakdown for the upcoming O2-X build were provided by Orbital. These were aggregated by main cost centres, and split by the expected region of the contract. A set of credible assumptions, consistent with previous work, have then been used to represent the wider market including global technology deployment and cost reduction pathways. The overall methodology is shown in Fig. 3, and is discussed further in the following subsections.

A. *Deployment and cost reduction pathway*

Rapid growth in renewable energy technologies has been observed in Europe and elsewhere. Fig. 4 shows the annual growth in onshore and offshore wind, which both increased from 10 MW to 10 GW installed

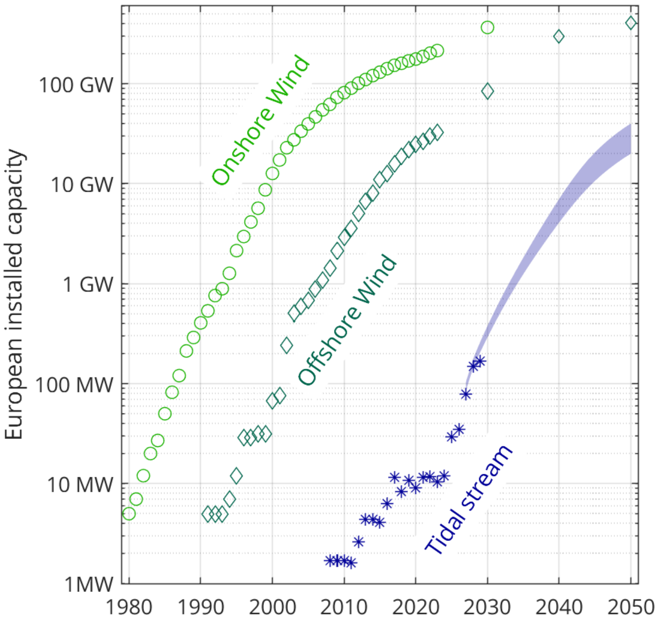

Fig. 4. Historical trends and future estimates of European deployment of renewable technologies (EU27+UK). Tidal stream shows historical deployments and known projects, plus a plausible growth scenario reaching 20–40 GW by 2050. Data sources [18], [25]–[29]. Adapted from [30], [31].

capacity in under two decades. A plausible scenario for 20–40 GW of tidal stream in Europe is also shown, based on tidal stream accounting for a smaller or larger share of the target for 40 GW of ocean energy in the EU Strategy on Offshore Renewable Energy [24] plus deployments in the UK. At a broader level, global deployment by 2050 of 80–120 GW is modelled, based on meeting most or all of the IEA-OES roadmap target [3], giving an export market of 60–80 GW.

Tidal stream is an emerging technology, and presently has higher levelised costs of electricity (LCOE) than other energy sources. However, cost reductions with increasing global deployment are expected, as have been observed for other renewable energy technologies. A global cost reduction pathway based on previous UK modelling has been used [31], [32]. This has an ambitious but achievable learning rate of almost 15%, which is consistent with what has been observed in other comparable technologies in recent decades and with previous work including the SET-Plan. Expected costs have also been informed by the CfD Strike Prices awarded to tidal projects in the UK over the past three years, to be commissioned by 2029.

The cost reduction trajectory includes learning from all factors, including research and innovation, knowledge transfer and collaboration, economies of volume manufacture and shared infrastructure, plus learning from experience. It is assumed to be consistent between markets, resulting from global supply chains and effective collaboration. While construction costs may be cheaper in some non-European markets, the focus of this study is on jobs and production in Europe.

B. Project spend profile and local content/retention

Depending on the level of analysis the spend profile can either be estimated 'top-down' using general industry assumptions, or can be developed 'bottom-up' using known or forecast project parameters. While the latter should be more accurate, it is only suitable for relatively small projects given the more onerous data requirements, and there may be confidentiality implications.

The aim from this work is to capture the value added in the supply chain from manufacturing and operating the device, however there will be material imports from other countries or regions which are not explicitly modelled.

1) Regional assessments: As in previous work investigating the economic benefits to a country or region, a top-down approach was used. As discussed above, a global technology cost reduction pathway for LCOE was developed consistent with previous work.

BVG Associates published a cost breakdown of components for a typical tidal stream project [33]. This has been refined using available information from the MeyGen project [17] and Magallanes Renovables [20] as well as internal assumptions. The costs were split into six main cost centres, namely:

- Development & project management (D&PM)
- Generating device supply (Device)
- Balance of plant supply (BoP)
- Installation & commissioning (I&C)
- Operations & maintenance (O&M)
- Decommissioning (Dec.)

Projects costs were allocated to supply chain sectors using standard industry classification (SIC) codes, which align with those used in the IO tables. A more granular breakdown of sectors has been assumed than in previous work at a country scale, with project costs split into six main cost centres using 18 SIC codes, as shown in Table II. This aims to capture the spread of key activities, but it cannot capture all aspects of the device build and project life cycle.

Project operational lifetime of 25-years is used in line with industry expectations. Installation and commissioning occur prior to this, i.e. in year 0. Decommissioning happens in year 26, so there is very limited activity by 2050. Construction of devices and balance of plant is assumed to take around two years, with the bulk of development and project management costs occurring over five years prior to installation.

The amount of local content is modelled using retention rates. These were developed building on previous

TABLE II
PROJECT STAGES WITH SHARE OF COST, STANDARD INDUSTRY CLASSIFICATION CODES AND TIMELINE USED FOR EACH

Stage	Share of cost	SIC codes used*	Timeline years
D&PM	8.0%	M691, M692, M70, M71, M72, M73, M74, K65	-4 to 0
Device	54.0%	C25, C27, C28	-1 and 0
BoP	19.5%	C25, C27, C28, C33, F41–43	-1 and 0
I&C	12.0%	H49, H50, H52, C33	0
O&M†	3.0%†	C27, C33, H50, K65, L68, M70	1 to 25
Dec.	6.5%	E38, H50, M70	26

* *See Table V for description of SIC codes, main text for stages.*
† *Annual O&M as a percentage of fixed costs.*

TABLE III
SUPPLY CHAIN RETENTION RATES BY COST CENTRE SHOWING INCREASE OVER TIME AS SUPPLY CHAIN DEVELOPS FOR SCENARIOS OF LOWER AND HIGHER AMBITION.

Cost centre	Lower	Higher
D&PM	42%–69%	75%–100%
Device	37%–63%	70%–96%
BoP	29%–59%	62%–92%
I&C	34%–67%	67%–100%
O&M	37%–65%	70%–98%

analyses of the tidal, ocean energy, and offshore wind sectors [10], [12], [16], [34]–[36]. There is a limited supply chain for tidal stream technology at present, and significant growth is forecast for other renewable energy technologies, stretching their supply chains. However, with suitable coordination of policy interventions and financial investment, a comprehensive European tidal power supply chain should develop, and retention rates could increase over time. For the global (export) market the retention rate has been assumed not to increase over time, as other countries are likely to also develop their supply chains. European involvement in 5–30% of projects worldwide is considered; this factor is considered separately for transparency, but could equally be modelled using lower retention rates for exports. Scenarios of lower and higher supply chain ambition are shown in Table III by project cost centre.

2) Orkney project case study: A hypothetical near-term project case study is also presented, based on the deployment of 12 O2-X turbines near the Fall of Warness in Orkney, Scotland. The timeline for this ≈30 MW array is to install the first device in 2026, two devices in 2027 and three devices per year in 2028–2030. A further simplification has been introduced for this case study, in that all development and build costs are assumed to occur in the year prior to the deployment for each turbine. The spend profile has been developed based on expected costs and contract locations for the upcoming build of the initial O2-X turbine. Cost reduction for subsequent turbines has been modelled consistently with the global trajectory and Orbital's expectations. The costs were again allocated to supply chain sectors by SIC codes; these are geographically split into Orkney, rest of Scotland, rest of UK, and rest of Europe. It is assumed in this work that all of the tier 1 supply chain is located in Europe, in line with Orbital's expectations for the upcoming O2-X build. Note that not all inputs have been disclosed for commercial sensitivity reasons.

C. Calculation

The GVA and jobs resulting from spend in each industry sector, and location if applicable, are then calculated using the published effects and multipliers. These depend on the geographical scope of the analysis, using data published by the Scottish Government and the UK Office for National Statistics (ONS) [37]–[39]. Data from 2019 has been used, as the latest year unaffected by the COVID–19 pandemic, following advice published by the Scottish Government [37].

Costs are presented in current (2024) values, but are deflated using the GDP Index to the year of the job effects (2019) for that calculation. The total GVA is calculated between 2025 and 2050, discounted using the UK Treasury Social Time Preference Rate of 3.5%, consistent with previous studies. The GVA includes direct, indirect, and induced effects, while only direct and indirect jobs have been counted in this work. The jobs are quantified as FTE since many of the roles, particularly in the supply chain, will spend only part of their time on tidal energy related tasks.

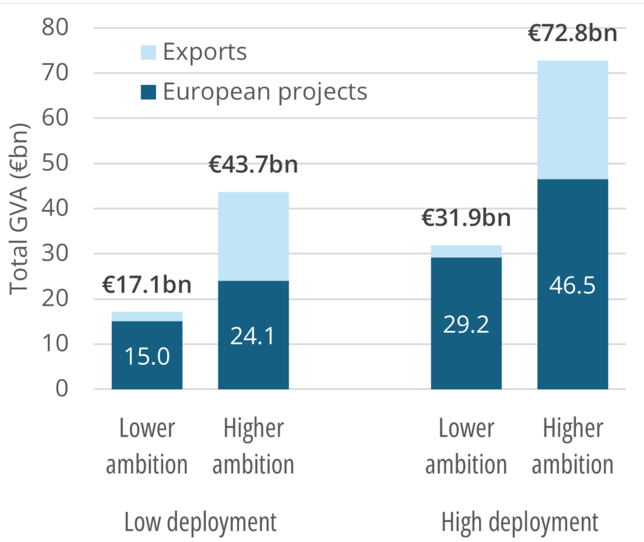

Fig. 5. Total GVA for European projects and international exports by scenario of deployment at supply chain ambition.

IV. EUROPEAN TIDAL MARKET RESULTS

Results are first presented for the whole European tidal stream market, including international exports. This is modelled using the sector cost-breakdown and retention rates described in section III-B1.

A. GVA by market and cost centre

The total GVA from developing, building and operating tidal stream farms in Europe from now until 2050 could be between €15bn and €46.5bn depending on deployment and supply chain ambition. This is shown in Fig. 5. The international export market could add a further €2bn to €26bn in GVA to the European economy. The benefits in striving for a higher ambition in supply chain retention are clearly visible, they are more than double the lower ambition scenario regardless of the total deployment assumptions. The lower deployment scenario only has 20 GW in Europe versus 40 GW in the higher, but it captures around 55% of the GVA for both supply chain ambition scenarios. This is a factor of the slower cost reduction resulting from lower deployment, discussed further in section VI-A. For all scenarios the split between direct, indirect, and induced GVA is approximately 46%, 30%, and 24%.

The breakdown of GVA from European projects for the higher deployment scenario is shown in Fig. 6

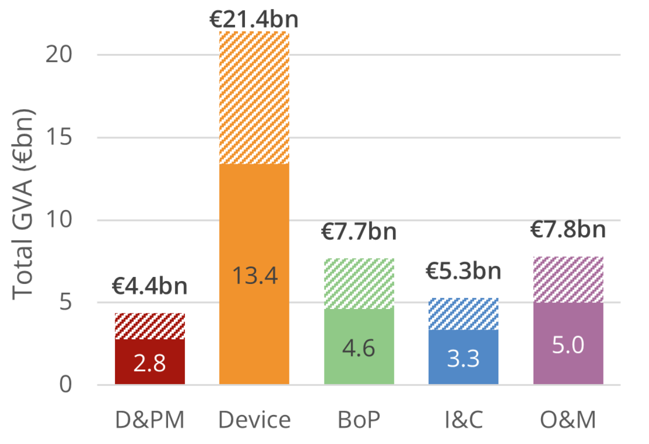

Fig. 6. Breakdown of GVA by project cost centre. Solid bars show lower ambition, hatched bars the increase with higher ambition.

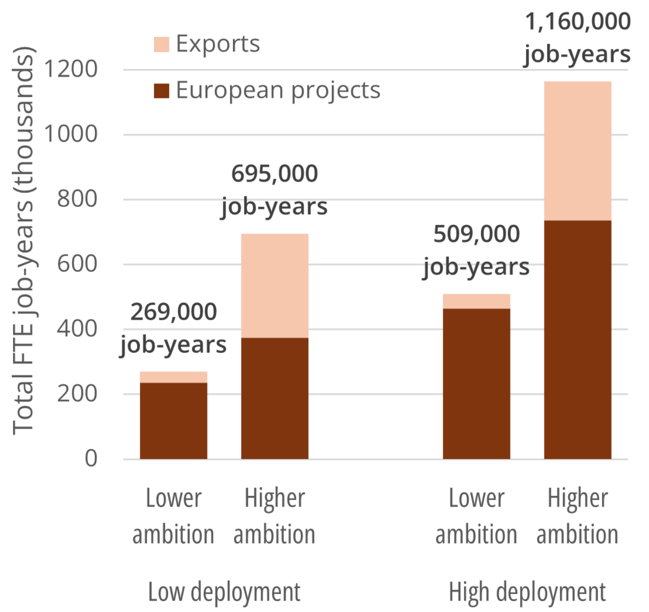

Fig. 7. Total FTE job-years for European projects and international exports by scenario of deployment at supply chain ambition.

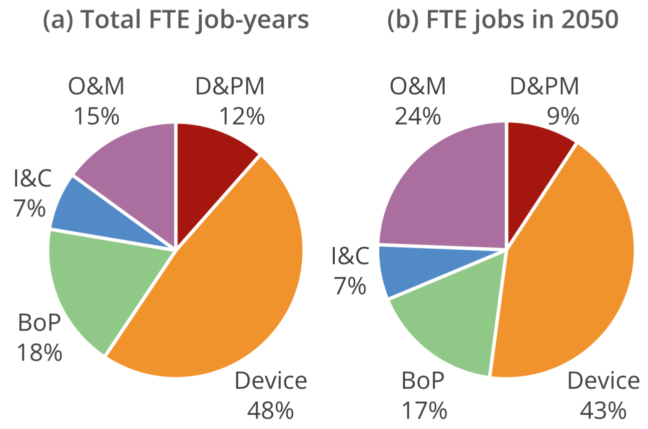

Fig. 8. Share of European jobs by project cost centre for (a) total FTE job-years employment, and (b) FTE jobs in 2050.

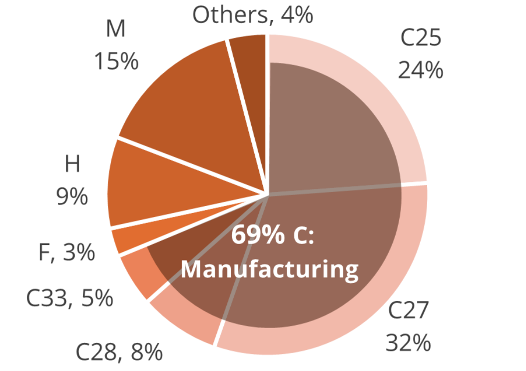

Fig. 9. Share of cumulative European job-years by SIC code.

split by cost centre and supply chain ambition. By far the largest share, almost half, comes from manufacturing of the generating device. Ongoing operation & maintenance over the lifetime is the next largest share, followed by supply of the balance of plant. Decommissioning is not shown, as given the project lifetime assumptions this is very limited by 2050, but would be a growing (albeit limited) market beyond.

B. *Jobs by market, cost centre and industry*

The total number of FTE job-years of employment supported by European projects and global exports is shown in Fig. 7. This corresponds to the GVA results in Fig. 5, and given the underlying assumptions, there is a clear link between GVA and job-years of employment over the same period. Approximately 59% of the employment is directly linked to the project, with the remaining 41% being indirect jobs in the supply chain. By 2050 there could be almost 70,000 FTE jobs supported by the tidal stream sector from projects in Europe (for the higher deployment and supply chain ambition scenario). Alongside this, there could be over 40,000 further FTE jobs from international exports.

Looking next at the breakdown of jobs, again focusing on European projects for the higher deployment and supply chain ambition scenario. The share of the cumulative job-years of employment is shown in Fig. 8(a) by project cost centre. As with the GVA, the manufacture of the device is again the largest share at almost 48%. Ongoing O&M is an increasing share of employment over time, seen by this growing from an average of 15% over the full period to over 24% of FTE jobs in the year 2050, shown in Fig. 8(b). This is a direct result of there being more projects and devices in the water over time.

The breakdown of cumulative job-years of employment by standard industry classification (SIC) codes is shown in Fig. 9, noting this represents direct jobs only and is a direct result of the input assumptions. Over two-thirds of the jobs are within SIC section C (manufacturing), with almost half in the manufacture of electrical equipment (C27), followed by almost a third in the manufacture of fabricated metal products (C25).

V. Orkney Project Case Study Results

To illustrate the potential economic benefits of a small project built over the near-term, results are next presented for the ≈30 MW Orkney project case study outlined in section III-B2. The results here relate to Orkney, the rest of Scotland and the UK, but could

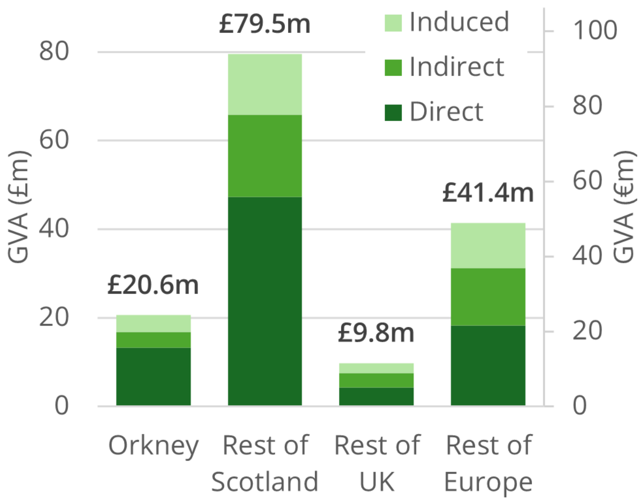

Fig. 10. Total Orkney project GVA by type and spend location.

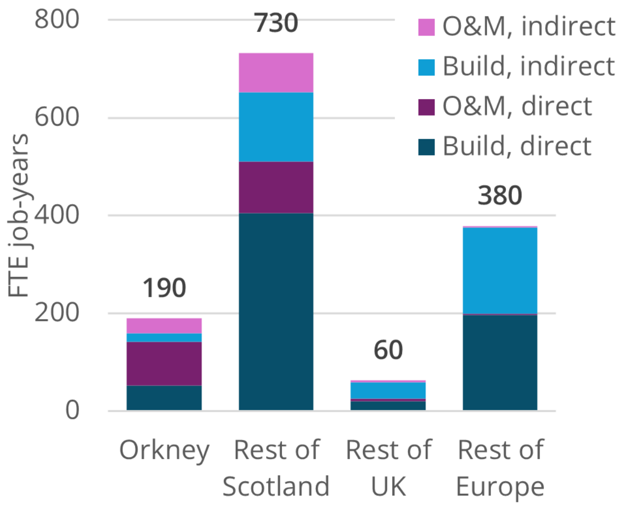

Fig. 11. Cumulative Orkney project job-years by type, spend location and project stage.

equally give an indication of the possible local share for any European country or region.

The total GVA resulting from the project over the lifetime is just over £151m (€179m). This is shown in Fig. 10, split by spend location (based on expected contracts for the initial O2-X turbine build). Almost two-thirds of the GVA is from spend within Orkney and the rest of Scotland, with the latter accounting for over half the total GVA. Slightly more than 25% of the GVA is within the rest of Europe, largely resulting from spend on selected components for the device and balance of plant supply.

The cumulative job-years resulting from the project are shown in Fig. 11, these are again split by location and type, but are also disaggregated by those relating to the turbine build (including D&PM, BoP and I&C) and those for ongoing O&M over the project lifetime. The build phase results in over 1000 job-years of employment, plus over 300 job-years from the ongoing O&M over the lifetime until 2050. As with the wider European results, the overall employment closely mirrors the split of GVA, with the largest share

TABLE IV
AVERAGE FTE JOBS/YEAR BY LOCATION AND PROJECT STAGE.

Stage	Years (inclusive)	Orkney	Rest of Scotland	Rest of UK	Rest of Europe
Build	2025–2030	12	90	8	60
O&M	2027–2055	5	9	<1	

Note: results are rounded.

in the rest of Scotland followed by the rest of Europe. When considering the the O&M phase, however, a larger share of the jobs result from spend in Orkney. This is more clearly shown by the average number of FTE jobs expected in each phase of the project in Table IV. The build phase for the project lasts six years while the O&M is counted until 2055, i.e. 25 years after the last deployment.

VI. DISCUSSION

It should be stressed the results in this paper are not predictions of what *will* happen, merely informed scenarios of what *could* happen to illustrate the potential economic benefits.

The commercialisation of the tidal stream sector will be highly contingent on the development of a modernised and competitive supply chain. This supply chain needs to be capable of volume manufacture of tidal turbines, both in the vicinity of tidal stream project sites but also across Europe more widely. These results will not be achieved through a business-as-usual approach; significant effort and funding will be required to achieve them. A framework is required to guide prospective policymakers to ensure that the decisions they make to develop the tidal stream sector maximise the competitive performance of the supply chain and streamline the technology cost reduction pathway [40].

Investment in skills and training will also be required, to facilitate an adequate workforce for the considerable jobs outlined. Additionally, there needs to be investment in upgrading infrastructure, including electrical grids, port and harbours, to facilitate tidal stream projects alongside the continued roll-out of other renewable energy technologies.

Tidal stream provides a predictable source of renewable electricity contributing to both energy security and Net Zero targets. It also offers a source of economic growth as illustrated by the economic benefits outlined in this work. Finally, the sector offers a source of high-value jobs, both in coastal communities and throughout the manufacturing supply chain, contributing to the Just Transition across Europe.

A. Sensitivity to inputs

Sensitivity of the results to the input parameters has been explored through a range of scenarios. Credible lower and higher ranges of retention rates are used to illustrate varying ambition regarding supply chain competitiveness and sophistication.

For the lower deployment scenarios, the cost-reduction pathway is slower, assuming the same global learning rate. This leads to higher technology costs in later years, with correspondingly more GVA and jobs projected in the analysis—for European projects, 50% of the deployment leads to around 55% of the GVA and jobs, given the higher LCOE over time for the lower deployment scenario. However, it should be stressed that commercial projects with higher costs are less likely to go ahead, although this is not something explicitly captured in this analysis.

Results are also shown for a smaller near-term project in Orkney. Although using the same methodology, the results are not directly comparable. The Orkney case study is for early-stage technology costs, while the European results are dominated by the long-term cost reduction. The European results show the GVA retained by the European economy, whereas the Orkney case study shows where the spend is expected, although both show the jobs directly and indirectly associated with the deployments. Nevertheless, these complimentary results highlight the significant potential socio-economic benefits from tidal stream power, both across Europe and to a country and region within.

B. Limitations and further work

As with all numerical modelling, certain assumptions and other simplifications need to be made. These are discussed further below for completeness and transparency.

The cost reduction pathway implicitly assumes that CAPEX and OPEX decrease at the same rate as the overall LCOE; however, this may not be the case for various reasons. Some items, such as raw material costs or leasing costs, may not reduce (significantly) over time. Others, such as insurance, might reduce rapidly as the industry matures and investor confidence improves.

Cost reductions are modelled using a single-factor learning rate, and are assumed to occur annually at the point of deployment. In the calculation, operations and maintenance costs decrease with each turbine build year, but are assumed constant over the lifetime of the project, which is an unavoidable simplification in the absence of data. In reality, cost reductions will come from a variety of sources at different points in time, including:

- focused improvements in the technology design, prior to construction,
- benefits of automated and volume manufacturing, during construction,
- lessons learnt from building and operating farms of turbines over multiple years, plus
- improved operating procedures over time, which could also be retrospectively applied to previously deployed turbines.

There may also be changes in the legislative landscape, such as environmental risks being “retired” once sufficient evidence is collected [41], reducing their burden.

A related simplification required is that technology costs are assumed to decrease worldwide, annually, in a smooth manner proportional to increasing global deployment. Again, reality will be more complex, e.g. step-change cost reductions occurring from breakthrough innovations, and technology costs may vary between markets around the world.

However, the learning rate used models all factors and is applied generally over the 25-year timescale considered in this work. This is therefore considered to be an acceptable approach to illustrate the scale of the potential economic benefits from tidal stream turbines.

Analytical IO tables with GVA and jobs effects are only published for the UK and Scotland. There is no public data available specifically covering Orkney, so the Scottish tables have been used as a proxy. Similarly, GVA and jobs multipliers are not readily available for the wider European economy, so ONS UK values have been used, on the assumption that the main economies developing tidal technology (including the UK) will be broadly similar to the UK. However, more ambitious supply chain retention rates have been used in this work than in previous work covering the UK, given the larger share of the spend (up to 100% in some cases) expected in Europe. Finally, the regional breakdown of indirect and induced results is based solely on location of the primary spend, when in reality it is likely to be more diverse and widespread, especially for the induced effects.

Some details for the upcoming O2-X turbine build are commercially sensitive, so not all details and results can be published. It is also worth noting that the Fall of Warness is a pre-consented site with aspects of the required infrastructure already in place. The case-study results presented here are based on currently expected contract values and locations, not the final build of the O2-X turbine. The Orkney project case study therefore cannot fully align with the commercial plans being developed by Orbital.

Further work, including refinement of the assumptions and aiming to address some limitations, will be undertaken within the FORWARD2030 project over the coming year.

VII. Conclusions

This paper shows the substantial potential socio-economic benefits to the European economy, and sets out how they can be quantified, both at the wider scale and a regional case study. These benefits come from building and operating tidal stream devices and projects, and are additional to the predictable renewable electricity these tidal farms can generate.

Depending on supply chain competitiveness and on deployment, the economic benefit to the European economy from building and operating tidal stream projects in Europe could be €15bn to €46.5bn, with exports worth €2bn to €26bn. By 2050 there could be almost 70,000 FTE jobs supported by the tidal stream sector from projects in Europe, and a further 40,000 from international exports, totalling nearly 1.2 million job-years of employment between now and 2050. Almost half of the GVA and jobs relates to the construction of tidal turbine devices. Ongoing O&M is the next largest share, and will grow with increasing deployment, reaching almost a quarter of sector jobs in the year 2050. Over two-thirds of the European jobs modelled are in the manufacturing sector and its supply chain.

It is important to note that these socio-economic benefits will not be achieved through business-as-usual. Significant investment and policy support is required to develop the manufacturing capability, supply chain, and skilled workforce in Europe. This will ensure the jobs outlined in this work are based in Europe, thus capturing the significant added value to the European economy.

APPENDIX A

TABLE V
STANDARD INDUSTRY CLASSIFICATION (SIC) CODES USED

SIC	Short description
C	*Manufacturing*
C25	Manufacture of fabricated metal
C27	Manufacture of electrical equipment
C28	Manufacture of machinery and equipment NEC
C33	Repair and installation of machinery and equipment
E	*Water supply; sewerage, waste management and remediation activities*
E38	Waste collection, treatment and disposal activities; materials recovery
F	*Construction*
F41–43	Construction, including civil engineering and specialist activities
H	*Transportation and storage*
H49	Land transport and transport via pipelines
H50	Water transport
H52	Warehousing and support activities for transportation
K	*Financial and insurance activities*
K65	Insurance, reinsurance and pension funding, except compulsory social security
L	*Real estate activities*
L68	Real estate activities
M	*Professional, scientific and technical activities*
M691	Legal activities
M692	Accounting, bookkeeping & auditing services; tax consulting services
M70	Activities of head offices; management consultancy activities
M71	Architectural and engineering activities; technical testing and analysis
M72	Scientific research and development
M73	Advertising and market research
M74	Other professional, scientific and technical activities

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