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European Technology & Innovation Platform for Ocean Energy

Deliverable 3.3

A study into the potential economic value offered to Europe from the development and deployment of wave and tidal energy to 2050

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1. Executive Summary

This report, Deliverable 3.3 GVA Study ('A study into the potential economic value offered to Europe from the development and deployment of wave and tidal energy to 2050'), presents results, analysis, and high-level policy recommendations concluding from the study quantifying the potential economic benefit, in terms of Gross Value Added (GVA), to the European economy of the development of ocean energy electricity generation technologies in Europe and their deployment globally to 2050. Furthermore, this study investigates the impact on the economic benefit of the overall domestic (European) supply chain strength for European and international deployments.

This GVA benefit has been calculated for three deployment scenarios based on and beyond the achievement of the Strategic Energy Technology Ocean Energy Implementation Plan (SET Plan) targets of €100/MWh for tidal and €150/MWh for wave by 2030[1]. The three scenarios are described below and the comparative deployment is illustrated in Figure i. More detail on these scenarios can be found in Section 6.6 of this report.

- **Scenario 1 – Achievement of the SET Plan**
  This scenario is based solely on the achievements of the SET Plan targets for LCOE in Europe and globally, reaching net zero in Europe by 2050 and globally by 2070. 61GW of ocean energy is deployed in Europe by 2050 and 192GW globally. The tidal stream/wave energy proportional split is based on modelling from the EC Joint Research Council for Europe, and assumed to be 40%/60% for the rest of the world. The European supply chain is assumed to be strong, with Europe as a market leader for ocean energy, retaining a high proportion of the economic activity required for this deployment.
- **Scenario 2 – Europe follows the global market**
  This scenario is based on the achievements of the SET Plan targets, but reaching net zero in globally by 2050 rather than by 2070. 60GW of ocean energy is deployed in Europe by 2050 and 293GW globally, with the tidal stream/wave energy proportional split assumed to be 40%/60% in all regions for this deployed capacity. The European supply chain is assumed to be less strong, with Europe as a market follower for ocean energy, retaining a lower proportion of the economic activity required for this deployment.
- **Scenario 3 – Europe leads the global market**
  This scenario also assumes net zero is reached globally by 2050 and has more ambitious European deployment, assuming Europe leads the global market for ocean energy in this time. 100GW of ocean energy is deployed in Europe by 2050 and 293GW globally, with the tidal stream/wave energy proportional split assumed to be 40%/60% in all regions for this deployed capacity. The European supply chain is assumed to be strong, with Europe as a market leader for ocean energy, retaining a high proportion of the economic activity required for this deployment.

These scenarios have been informed by TIMES energy system modelling from the European Commission's Joint Research Centre (JRC) and the International Energy Agency (IEA), in which ocean energy cost inputs are based on the SET Plan targets. The JRC SET Plan scenario

[1] SET Plan temporary working group for ocean energy, "*SET Plan Ocean Energy Implementation Plan*", 2018.

results in 61GW of marine energy deployed by 2050[2]. The IEA sustainable development scenario in the 2020 Energy Technology Perspectives results in 192GW of ocean energy globally[3] and the IEA Further Innovation scenario results in 293GW of ocean energy globally[4]. All scenarios have pre-2030 deployment consistent with Ocean Energy Europe's 2030 vision[5].

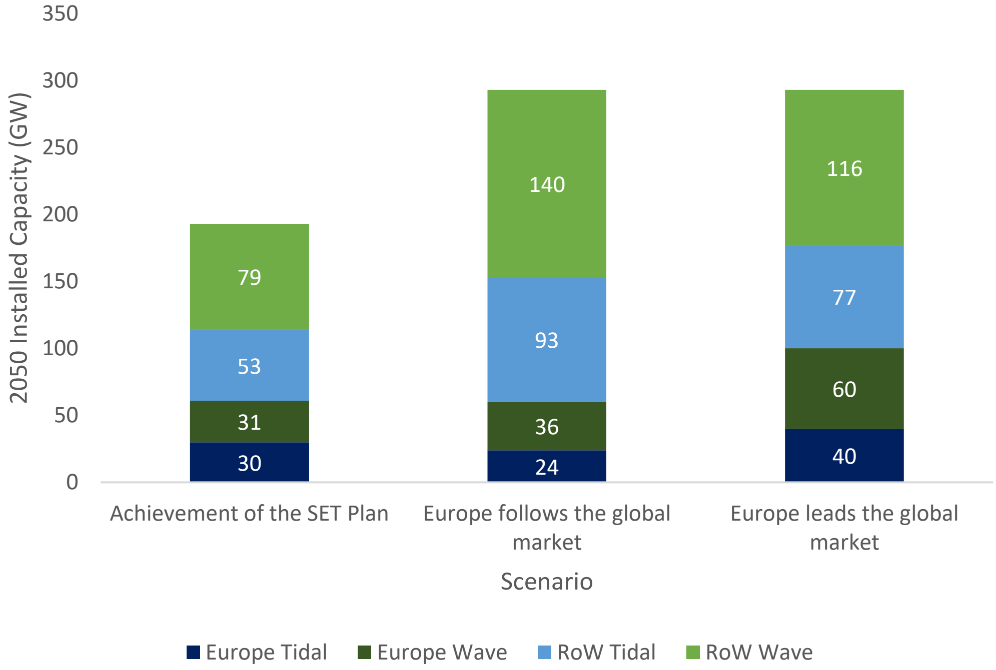

Figure i – 2050 installed capacity of wave and tidal stream generation for the three scenarios considered

A comprehensive GVA model built in-house at the University of Edinburgh incorporates TIMES-derived deployment data and Leontief inverse-derived economic effects to produce rigorous results, as illustrated in the flow diagram in Figure ii. More detail on the GVA calculation methodology can be found in Section 6 of this report.

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[2] European Commission Joint Research Centre, *"LCOE Ocean Energy Technology Development Report"*, 2018.
[3] International Energy Agency, *"Energy Technology Perspectives 2020"*, 2020.
[4] International Energy Agency, "*Special Report on Clean Energy Innovation*", 2020.
[5] Ocean Energy Europe, *"2030 Ocean Energy Vision"*, ETIP Ocean, 2020.

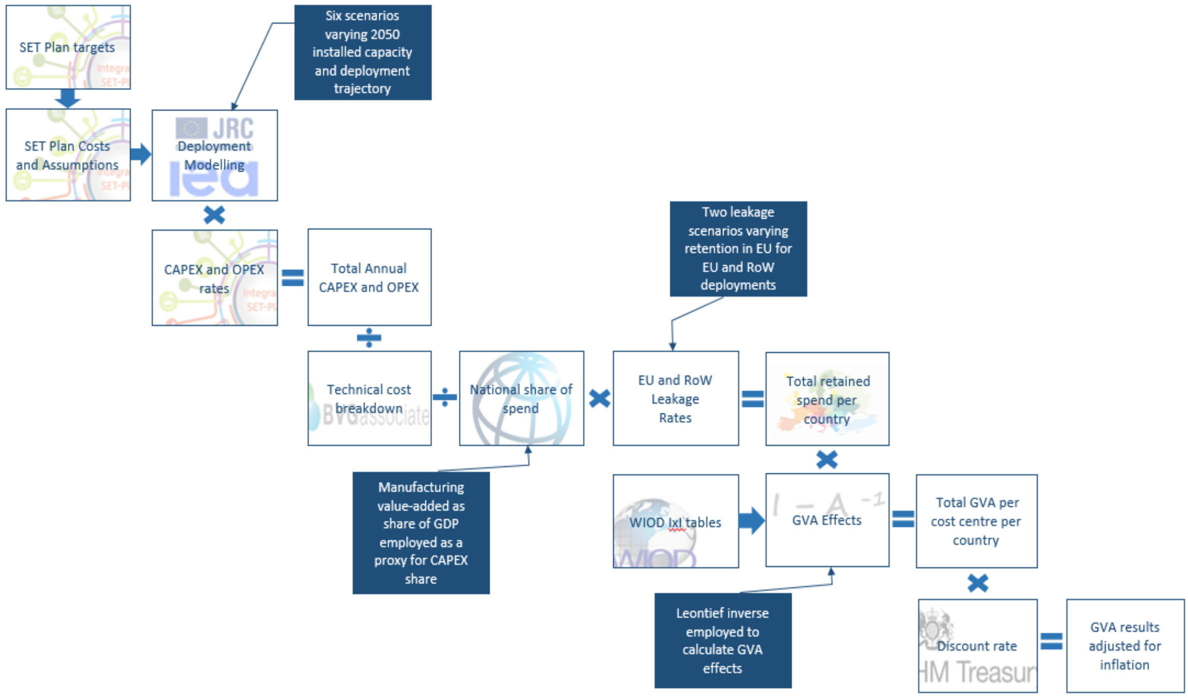

Figure ii – flow diagram of methodology used to calculate GVA in this study

The results from this study conclude that there is significant GVA benefit to be generated by supply chain activity servicing global (European and non-European) deployments of ocean energy to 2050. The total GVA benefit to the European economy these deployments has a potential range of €59bn to €140bn across the three scenarios presented here, shown in Figure iii. These GVA results are presented in detail in Section 7 of this report.

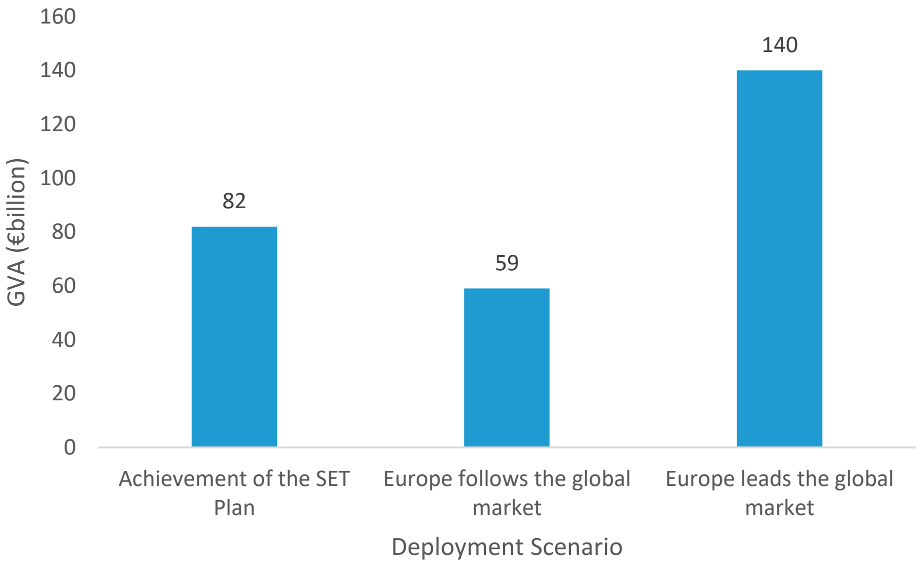

Figure iii – GVA results for the three scenarios considered (€ billion)

These results are presented as the proportional GVA per cost centre in Figure iv and the sensitivity of GVA results to leakage assumptions (i.e. the percentage of spend which is not retained by the European supply chain) is shown in Figure v. More detail on the sensitivity of these results to supply chain input assumptions can be found in Section 8 of this report. The analysis indicates that the strength of the domestic supply chain has a significant impact on the proportion of this economic benefit reaped by the European economy. That is to say, there is significant opportunity offered to Europe, provided policy is enacted to reduce costs to or beyond the SET Plan targets, prioritise local content for domestic deployments and exports alike, and attract deployment to European waters.

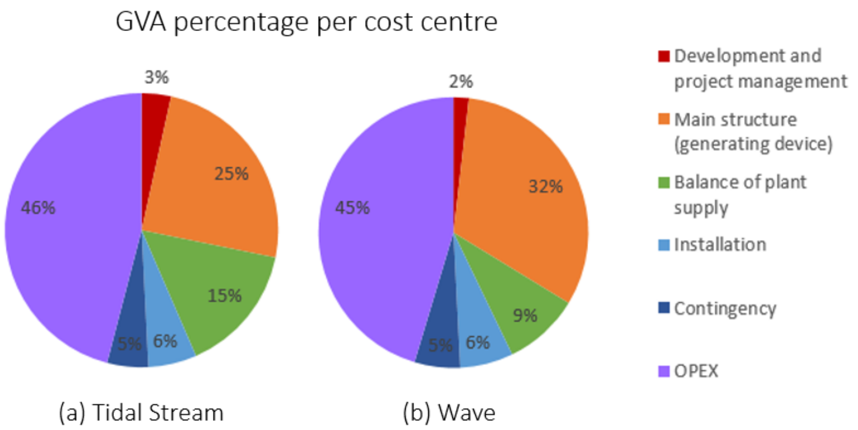

Figure iv – GVA percentage per cost centre for (a) tidal stream and (b) wave energy

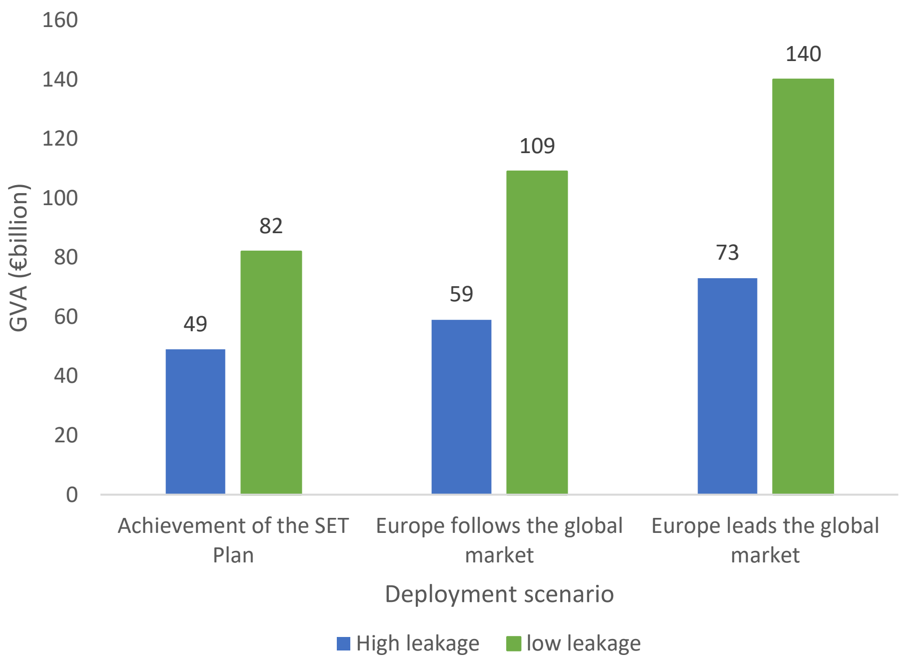

Figure v – sensitivity of GVA results to leakage assumptions for three scenarios considered (€billion)

The results of this study will feed into a corresponding socioeconomic study identifying key quantitative results in terms of job losses and gains, impact on the value chain, impact on occupational distribution and impact on educational requirements as well as a qualitative discussion of the social impacts that cannot be expressed in monetary terms.

This study has produced three evidence-based deployment scenarios for ocean energy in Europe and globally up to 2050, and the economic returns resulting from these deployments in terms of Gross Value Added (GVA). The results show a significant economic opportunity to Europe if current and future policies support ocean energy development. The results from this study are intended to inform energy and economic policymaking at a member state and European Commission (EC) level. The results are also highly relevant to technology developers, research institutions, and renewable energy project developers and investors.

2. Acronyms

CAPEX	Capital Expenditure
DG-MARE	Directorate-General for Maritime Affairs and Fisheries
EC	European Commission
ETIP Ocean	European Technology and Innovation Platform for Ocean Energy
ETP	Energy Technology Perspectives
EU	European Union
FIC	Faster Innovation Case
GDP	Gross Domestic Product
GVA	Gross Value Added
GW	Gigawatt
IEA	International Energy Agency
IEA-OES	International Energy Agency – Ocean Energy Systems
IO	Input-Output
IxI	Industry-by-Industry
JRC	Joint Research Centre
LCOE	Levelised Cost of Energy
MW	Megawatt
NPV	Net Present Value
OEE	Ocean Energy Europe
OPEX	Operating Expenditure
OPIN	Ocean Power Innovation Network
RoW	Rest of World
SCOE	Socialised Cost of Energy
SDS	Sustainable Development Scenario
SE	Socioeconomic
SEA	Socio-Economic Accounting
SET	Strategic Energy Technology

SIC	Standard Industrial Classification
SRIA	Strategic Research and Innovation Agenda
TIMES	The Integrated MARKAL-EFOM1 System
TRL	Technology Readiness Level
UN	United Nations
WIOD	World Input Output Database

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5. Introduction

Economic benefit is at the forefront of current decarbonisation policy. The European Commission (EC) Offshore Renewable Energy Strategy states that investment, growth and export opportunities are priorities for European industry, and that up to €800 billion in investment will be required to effectively develop offshore renewable energy technologies. With that investment comes the potential for substantial value added for the European economy, with appropriate policy intervention [1].

The objective of this study is to quantify the value to the European economy of the development of ocean energy electricity generation technologies in Europe and their deployment globally to 2050. This document presents the results of this study, based on a range of possibilities through policy interventions at varying levels of ambition. The resultant potential economic benefit is presented here in terms of Gross Value Added (GVA).

The study is based on consistent modelling at a European and global scale carried out by the JRC and IEA, respectively. Thanks to liaison across these teams organised by this study, there is alignment for the first time across projections for wave and tidal at multiple geographical scopes. Deployment outputs from JRC-TIMES-EU model and IEA-ETP-TIMES meeting and exceeding the Strategic Energy Technology Ocean Energy Implementation Plan (SET Plan) target costs serve as inputs to the GVA calculations.

A purpose-built GVA model incorporates economic multipliers obtained through Leontief inverse of the World Input Output Database (WIOD) Industry-by-Industry (IxI) input-output tables. Thanks to the rigorous compilation of these tables, GVA results yielded through this method have a high level of accuracy. In addition to this, results are obtained at an economic industrial sector level, which will feed into ETIP Ocean 2's subsequent work, Task 3.3 Socioeconomic Study, which is led by Tecnalia.

Further analysis is carried out on the GVA results to assess the influence of European supply chain strength on the economic benefit results. To do this, domestic supply chain capability is modelled through variance in the proportion of global deployment occurring in Europe and the application of variable leakage rates.

Observations from this body of data and analysis shall serve as guidance for future economic and energy policy at the Member State and EC level.

5.1 ETIP Ocean

The ETIP Ocean 2 project carries out a range of research, stakeholder engagement and knowledge sharing activities to fulfil its three strategic objectives, which are:

- Ensure the optimal use of existing resources for the sector and streamline sectoral activities
- Support and accelerate European and global deployment of ocean energy
- Ensure that the potential benefits for European industry and society are maximised.

The work in this study fulfils these objectives as it aims to demonstrate the potential value of future sectoral activity to Europe, illustrating and reinforcing in doing so the need for applied support mechanisms at a governmental level.

This study sits within the Economics and Social Impact work package of the project (WP3). The objectives of this work package are to conduct analysis at the macro- and micro-economic level, to identify the macro- and socio-economic fundamentals of the ocean energy sector.

As illustrated in Figure 1, WP3 is informed by sectoral stakeholders and will feed into the Ocean Energy Roadmap to be produced at the conclusion of the project.

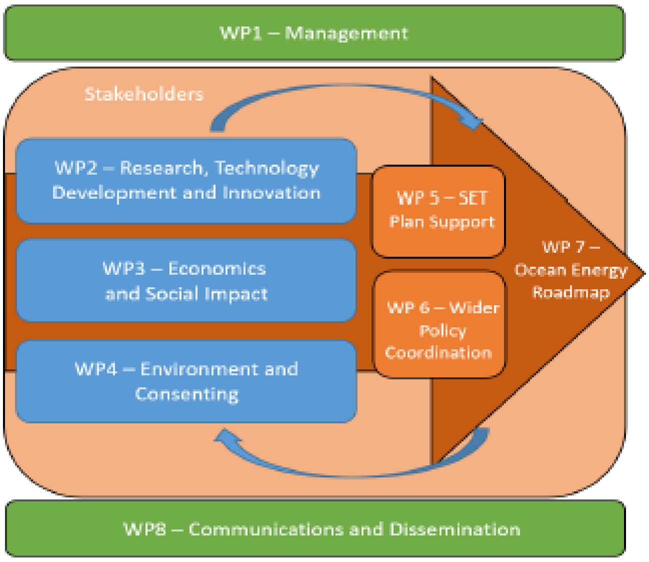


Figure 1 Work package interaction within the ETIP Ocean project

The results presented in this report will feed into a socioeconomic study to be conducted by Tecnalia, also within WP3 of ETIP Ocean 2. This subsequent study will follow a two-pronged approach, with top-down and bottom-up investigation into the qualitative impact on jobs across Europe of this activity.

The following subsection describes the current state of the technology. The results from this study will inform the policy defining governmental support, targeted at further progressing the technology beyond the stages described in the following section.

5.2 Technology

Tidal stream has achieved a relatively high TRL of between 6 and 8, depending on device type [2]. The technology, both at device and component level, is anticipated to achieve competitive commercialisation by 2030, provided dedicated research, development and deployments in the real-sea environment occurs in the interim period. With the application of appropriate support mechanisms, array-scale deployment in Europe is feasible today. Turbines in existing smaller scale tidal stream devices have rated power of between 0.1 and 0.25 MW, and between 1 and 2 MW in larger scale devices. There is scope to increase existing larger devices by at least 50% in the near future [3]. Tidal stream's operating hours, capacity deployed and electricity generated in recent years demonstrates its promising progress. For instance, in the last ten years, over 27.7 MW of tidal stream deployment has occurred in Europe, 10.4 MW of which is currently operating. 17.3 MW has been successfully decommissioned following the successful conclusion of testing programmes [4]. To service this deployment, an industrial supply chain is growing in Europe and globally, adapting expertise from other sectors and creating new goods and services specific to technological need [5]. The system balancing benefits of tidal stream and its role in future energy systems is being demonstrated; the predictability of electricity supply generated from tidal stream has significant grid-balancing properties, placing the technology in a strong position relative to alternative, intermittent, renewable energy sources. Because the periods between tides are consistently short, the addition of small storage volumes can deliver round-the-clock power, and the associated flexibility, to electricity systems [6].

Wave technology has reached a TRL of around 7. Onshore designs, such as the OWC Mutriku Wave Power plant in the Basque country, have demonstrated consistent power production and so have reached TRL 8 [7]. In the last decade, 11.8 MW of wave energy has been installed in Europe, 1.5 MW of which is currently in the water and 10.3 MW of which has been decommissioned due to the successful completion of testing programmes [6]. Ongoing research is investigating geographical resource and identifying potential markets [5]. An industrial supply chain continues to grow, with suppliers focused both on wave-specific requirements and adapting existing services [5]. For example, knowledge and experience of survivable materials can potentially be found in other sectors such as offshore wind, or oil and gas. Development of wave energy device prototypes has gained a sustainable pace; phased development mitigates the risk associated with large-scale prototype testing [6] [5].

Please refer to ETIP Ocean's Strategic Research and Innovation Agenda (SRIA) for further information about the challenges and opportunities associated with wave and tidal deployment today [6].

5.2.1 The SET Plan

Cost targets on which the deployment modelling component of this study is based centre around the Strategic Energy Technology Ocean Energy Implementation Plan (SET Plan). The SET Plan was laid out in 2017 in an effort to lead the clean energy transition in Europe. Coordinated by the SET Plan Working Group, the SET Plan outlines a structured approach that aids the progression of wave and tidal technologies to commercialisation. As part of this, the SET Plan sets quantitative targets to be achieved. Specifically, tidal stream should reach a Levelised Cost of Energy (LCOE) of 10ct€/kWh and wave of 15ct€/kWh by 2030 [8].

5.3 Gross Value Added

This work can be described as a Socioeconomic Cost of Energy (SCOE) study, as it quantifies one externality excluded by LCOE as a defining metric of the deployment of energy generating devices. For this SCOE analysis, GVA is employed as the metric calculating the external economic effects of the deployment of tidal stream and wave energy devices at grid scale. Deployment is a grid-scale level (as opposed to device level), and so takes into account the impact that will occur at an international, economy-wide scale. GVA is an economic performance metric employed to measure the impact of an activity on a particular economy.

The geographical scope of this study is the pre-Brexit European Union (EU-28)[6]. In this instance, the activity in question is the 'demand shock' associated with the additional activity involved in developing and deploying wave and tidal devices. The term 'demand shock' describes the additional spend entering the European economy in exchange for direct supply chain activity (goods and services) associated with enabling the modelled deployment investigated in this study. Section 6 details the approach taken to calculate this GVA.

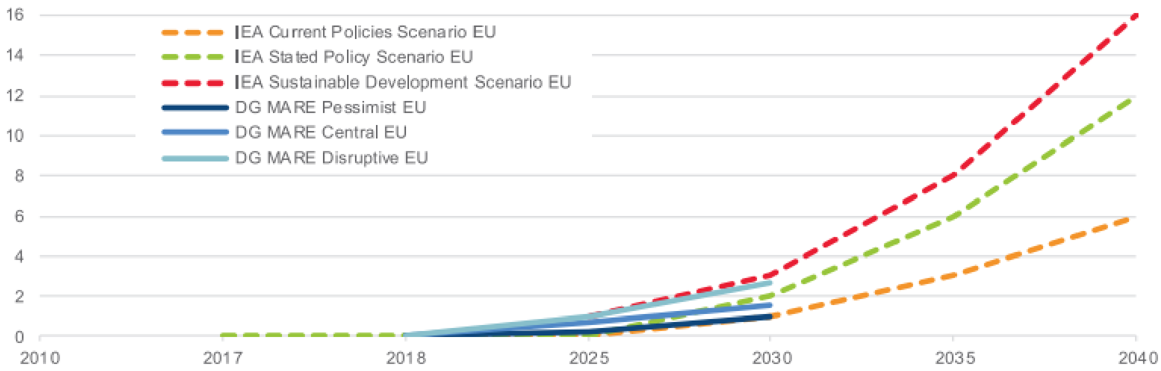
5.3.1 Previous studies

This work builds on a number of existing studies which have produced deployment scenario and GVA results for ocean energy in Europe. Figure 2 compares European ocean energy deployment trajectories from studies produced by the Directorate-General for Maritime Affairs and Fisheries (DG MARE) in 2018 and the IEA in 2019 [9].

DG MARE commissioned a market study on ocean energy in 2018 [10]. Their optimistic scenario, in which all projects in the pipeline are able to deploy and start at the proposed date, results in 3.9GW of cumulative ocean energy installed capacity by 2030. Their medium and pessimistic scenarios, which account for some delays and cancellations suggest this global capacity could be 2.8 GW and 1.3 GW by 2030 respectively.

The IEA produced a number of market scenario assessments as part of their 2019 World Energy Outlook [11]. Their results indicate that the total European ocean energy installed capacity by 2030 could range between 0.5GW and 2.6GW, depending on the level of cost reduction achieved and supporting policies introduced.

A Blue Economy report produced by DG MARE and the JRC for the European Commission (EC) in 2020 used these deployment trajectories as the basis of calculating the GVA to Europe due to these ocean energy deployments [12]. They found that the cumulative GVA from these scenarios to range between €500 million and €5.8 billion, and between 50000 and 200000 FTE over the ten year period of 2020-2030.



Source: JRC, DG MARE, IEA World Energy Outlook 2019

Figure 2 Modelled European wave and tidal capacity deployments in GW, IEA (2019) and DG MARE (2018)

[6] Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, United Kingdom

Ocean Energy Europe have undertaken a bottom-up approach to develop ocean energy deployment trajectories to 2030 [13]. Extensive consultation with technology developers has led OEE to produce predicted cost reduction pathways in line with the SET Plan targets (€100/MWh for tidal stream by 2030, €150/MWh for wave), resulting in 0.2GW of wave energy and 1.3GW of tidal stream globally by 2030. In addition to this, a Faster Innovation Case has been developed in which the SET Plan targets are reached by 2030, followed by rapid cost reduction, resulting in 0.5 GW of wave energy and 2.4GW of tidal stream globally by 2030. Details of these scenarios are depicted in Figure 3 and Figure 4, below.

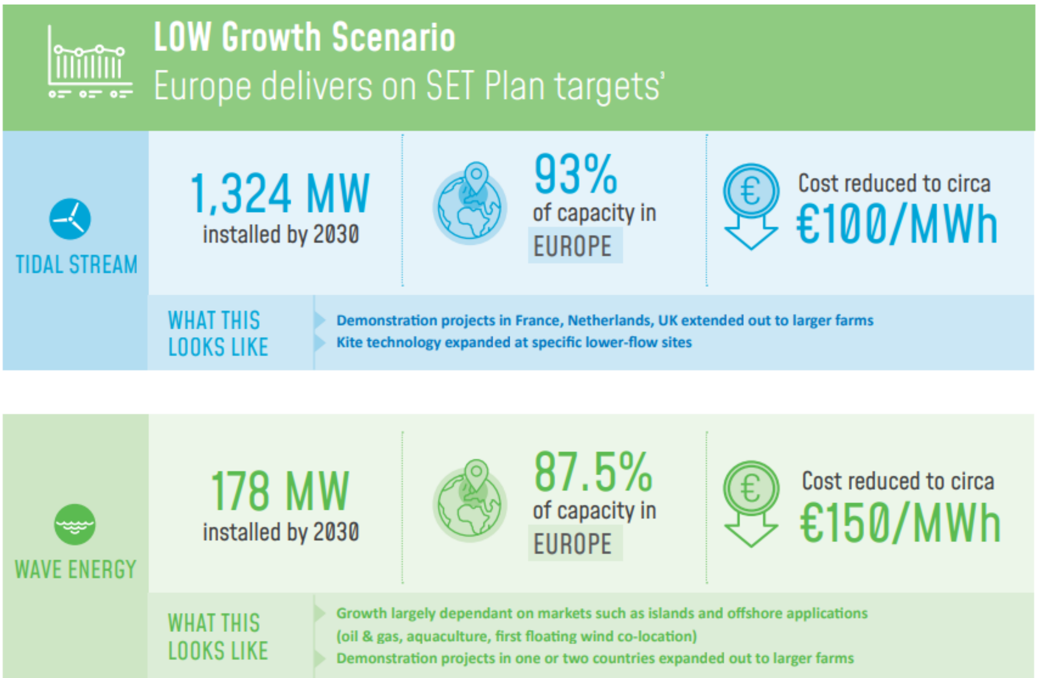


Figure 3 Ocean Energy Europe 2030 Vision Low Growth Scenario [13]

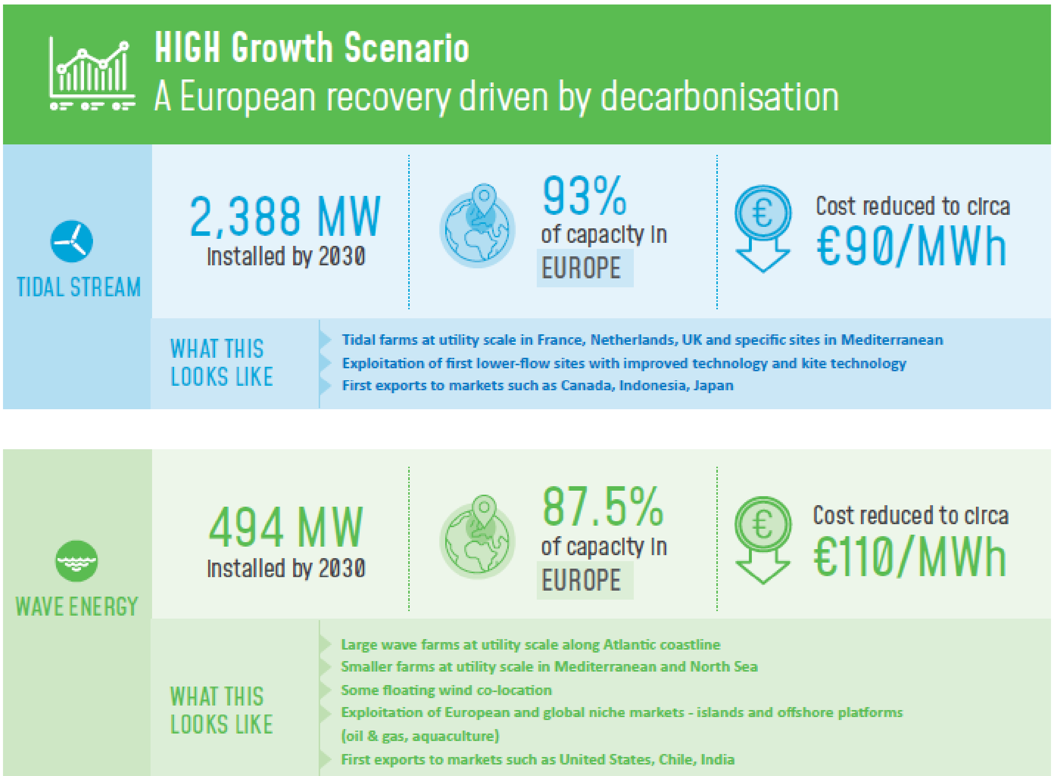


Figure 4 Ocean Energy Europe 2030 Vision High Growth Scenario [13]

6. Methodology

6.1 Summary

- Deployment scenarios based on and around the SET Plan targets were designed and modelled by the TIMES modelling teams at the JRC and the IEA.
- Capital expenditure (CAPEX) and Operational expenditure (OPEX) values were derived from the cost to deploy associated with the SET Plan targets from 2030 to 2050 and the deployment modelling outputs.
- These expenditure values were split across individual technical cost breakdowns for tidal stream and wave devices. Different breakdowns were employed to reflect not only the different technological requirements between the two, but their varying stages of development.
- National share of spend was distributed according to data obtained from the World Bank using manufacturing share of Gross Domestic Product (GDP) as a proxy for CAPEX share [14]. Manufacturing is the majority cost centre to incur CAPEX.
- GVA effects obtained through the Leontief inverse of IxI Input Output (IO) tables from the WIOD enabled the calculation of GVA benefit associated with the development and deployment of each scenario [15].
- The impact on the GVA results of the strength of the European supply chain was assessed through the application of variable leakage rates and the proportional global deployment occurring in Europe.

6.2 GVA Model

The GVA model used in this study was developed based on a model built by the University of Edinburgh [16]. The GVA model is structured as such:

1) Type 1 and Type 2 GVA effects[7] are obtained through the Leontief inverse of WIOD IxI tables

- GVA effects are employed in lieu of multipliers because the calculation inputs (spend) are different in nature from the outputs (GVA generated).

- The Leontief inverse method is employed in favour of a singular multiplier, to incorporate the relative value of each specific sector into the calculation, thereby yielding a high level of accuracy in the results. The supply and use tables on which the IxI tables are based are assembled through rigorous data collection and are accepted as a close reflection of the relative economic value of every industry active in the economy in question [17].

- Type I and Type II Leontief matrices are created from the intact IxI table, and GVA effects yielded from Equation 3, where I is an identity matrix and A_I is the direct

[7] The Scottish Government defines Type I Leontief matrices as how much of each industry's output is needed, in terms of direct, indirect and, in type II Leontief matrices, induced requirements, to produce one unit of a given industry's output [13]

requirements matrix. This process is described in more detail in the Appendix 1: GVA Effects Appendix

Equation 1

$$L_I = (I - A_I)^{-1}$$

- It is widely accepted that Type II effects overstate income through wages as it doesn't distinguish between wages and income from other sources, such as pensions [18]. For this reason, a *Total Household Income from All Sources* value is endogenised to serve as the corresponding output of the additional Compensation of Employees 'industry' in the Type II matrix [17]. This value is obtained for each country from the Compensation for Employees data from the WIOD Socio-Economic Accounting (SEA) dataset [19].

- Once the Leontief matrices have been obtained, irrelevant industries and countries are subsequently removed. Specifically, the extra-European element of demand for output is eliminated from the calculations to ensure only activity within the domestic supply chain is accounted for. Similarly, industries out-with the requisite supply chain – and therefore receiving no spend – are removed for ease of use.

2) Spend is calculated and allocated to national, technical and industrial cost centres

- Total CAPEX and OPEX associated with the development and deployment of a single scenario is calculated based on that scenario's annual deployment (Section 6.6) and cost inputs associated with the TIMES modelling outputs (see Section 6.3.4). A 20 year project lifetime is assumed, with CAPEX incurred in Year 0.

- Given the multilateral direction of this spend, CAPEX and OPEX is proportionally allocated to each EU country. Given the domination of CAPEX by manufacturing spend (around 40%), national manufacturing power (*Manufacturing value added as percentage share of GDP* [14]) is used as a proxy for national share of overall CAPEX. While it was considered to apply a variable OPEX share based on national offshore activity, it was decided to allocate OPEX share at the same proportion as CAPEX. The assumption was made that the firms involved in upfront manufacturing activity will also be recruited in post-deployment activities such as repair and maintenance. This breakdown of national expenditure is presented in Table 1

Table 1 Share of CAPEX and OPEX incurred by each country [14]

Country in EU-28	*Share of CAPEX and OPEX*
Austria	2.8%
Belgium	2.6%

Bulgaria	0.3%
Cyprus	0.0%
Czech Republic	1.9%
Germany	30.8%
Denmark	1.6%
Spain	6.6%
Estonia	0.1%
Finland	1.5%
France	11.3%
United Kingdom	10.3%
Greece	0.8%
Croatia	0.3%
Hungary	1.1%
Ireland	2.0%
Italy	11.5%
Lithuania	0.3%
Luxembourg	0.1%
Latvia	0.1%
Malta	0.0%
Netherlands	3.5%
Poland	3.5%
Portugal	1.0%
Romania	1.6%
Slovakia	0.8%
Slovenia	0.4%
Sweden	3.2%

- This spend is allocated across wave and tidal technical cost breakdowns from a BVG Associates and Ocean Power Innovation Network (OPIN) value chain study for Scottish Enterprise [20]. These cost centres are assigned to economic sectors of the WIOT - those of the Leontief matrices - in order for relevant GVA effects to be identified.

- The technical cost centre breakdown and WIOD code allocation for wave and tidal technologies are presented in Table 2 and Table 3. Please note, the wave Generating Device high-level cost centre has been further broken down using a secondary source to enable allocation of spend to component-specific sectors; the original source designated 100% of spend towards the generating device, without splitting it into separate components.
- In this instance, a flat leakage rate is applied to each scenario, with the same proportion of spend leaked for every industry across the sectoral spend breakdown. Please refer to Section 6.4.2 for more detail.

Table 2 Technical cost breakdown with corresponding WIOD industrial cost centres for tidal devices at current TRL levels [20]

Technical cost centre and WIOD Sector Code	Sector	Technical Cost Centre	CAPEX Share
Development and project management			**6%**
M69_70	Legal and accounting services; activities of head offices; management consultancy activities	Development and consenting services and expenditure incurred by lost projects	5%
		Professional and enabling services	1%
Generating device			**46%**
C25	Manufacture of fabricated metal products, except machinery and equipment	Rotor Tower	11% 28%
C27	Manufacture of electrical equipment	Nacelle	28%
Balance of plant			**28%**
C25	Manufacture of fabricated metal products, except machinery and equipment	Support structure Sea bed connection Subsea cables Onshore electrical	36% 40% 20% 12%
Installation			**11%**
H50	Water transport	Turbine installation Support structure installation Cable installation Professional and enabling services	5% 4% 2% 1%
Contingency			**9%**
K65	Insurance, reinsurance and pension funding, except compulsory social security	Contingency	9%

Table 3 Technical cost breakdown with corresponding WIOD industrial cost centres for wave devices at current TRL levels [20]*, unless otherwise stated*

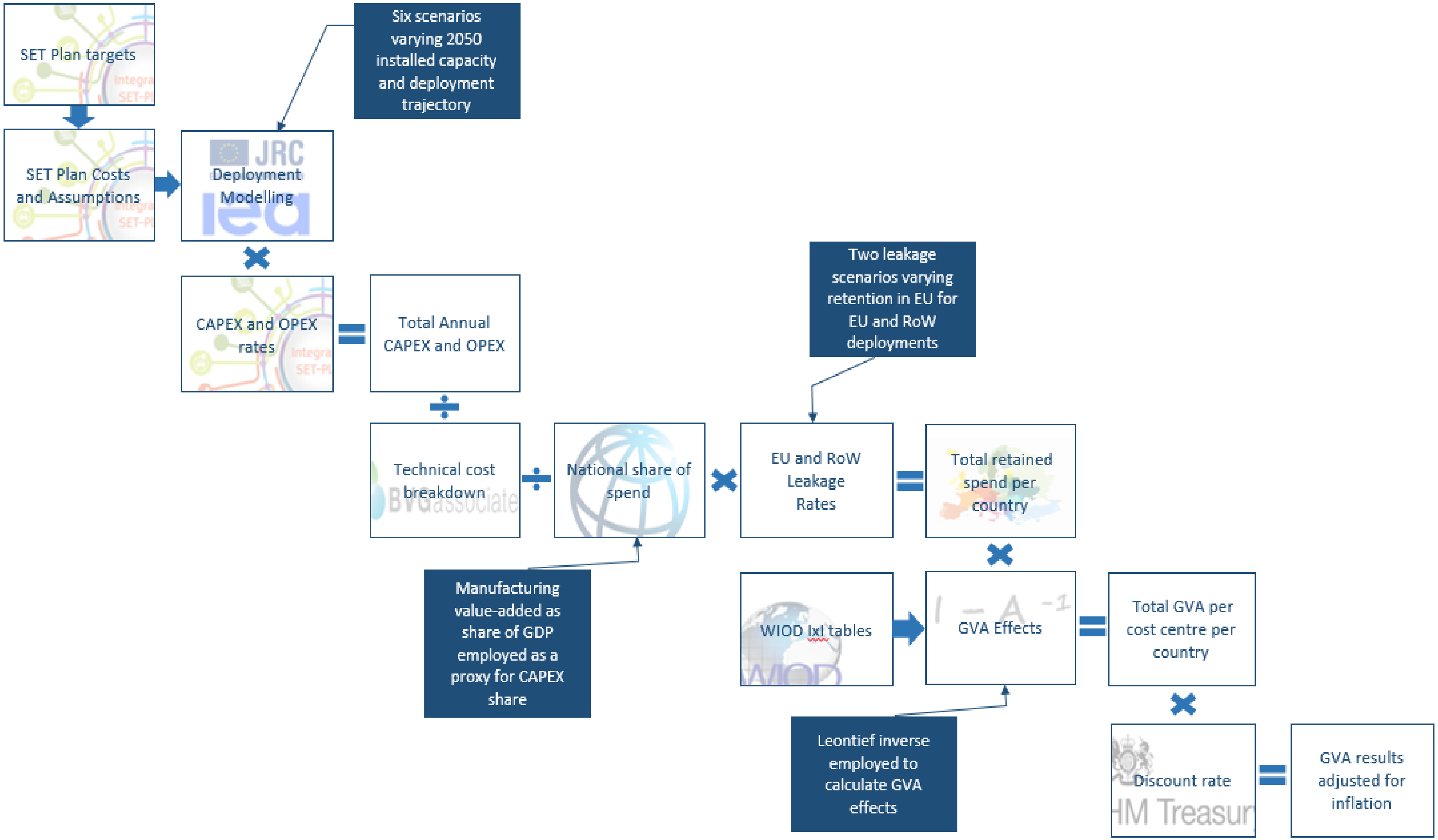
Technical cost centre and WIOD Sector Code	Sector	Technical Cost Centre	CAPEX Share
Development and project management			**3%**
M69_70	Legal and accounting services; activities of head offices; management consultancy activities	Development and consenting services and expenditure incurred by lost projects	2%
		Professional and enabling services	1%
Main structure (generating device)			**58%**
C25	Manufacture of fabricated metal products, except machinery and equipment	Hydrodynamic system [21]	22%
		Reaction system [21]	19%
C27	Manufacture of electrical equipment	Power Take-Off system [21]	14%
C26	Manufacture of computer, electronic and optical products	Control system [21]	3%
Balance of plant supply			**17%**
C25	Manufacture of fabricated metal products, except machinery and equipment	Support structure and mooring system	13%
		Subsea cables	3%
C33	Repair and installation of machinery and equipment	Onshore electrical	1%
Installation			**11%**
H50	Water transport	Main structure installation	5%
		Support structure and mooring system installation	5%
		Cable installation	1%
M69_M70	Legal and accounting services; activities of head offices; management consultancy activities	Professional and enabling services	1%
Contingency			**11%**
K65	Insurance, reinsurance and pension funding, except compulsory social security	Contingency	11%

3) GVA effects are applied to annual national, industrial spend in the equivalent industries to obtain disaggregated GVA results for each scenario geographical component (Europe and Rest of World)

- Results are obtained in the form of direct, indirect and induced effects for each country's industry, on an annual basis. The process for calculating these effects is described in Appendix 11.1 Appendix 1: GVA Effects.
- Results are aggregated for each sector to obtain total spend and GVA per industry, in addition to being divided by total capacity for each scenario to obtain GVA offered per MW of deployment. Because the leakage rates are constant across the industries, and the GVA effects are constant across scenarios, the distribution profile of GVA generated by each industry for the European economy is therefore constant across all scenarios. This profile can be seen in Section 41.
- GVA results for European industries servicing wave and tidal deployments are summed and coupled with the equivalent for the Rest of World to produce the global GVA result per scenario.
- Type 2 results for each scenario are tabulated and presented in 7 GVA Results. Type 1 results are contained in the Appendix.
- To account for inflation, a constant discount rate of 3.5% is incorporated into the calculation to obtain the Net Present Value (NPV) of the annual GVA results across all years [22].

A high-level flowchart illustrating the steps taken (white boxes) and inputs required (blue boxes) to obtain the results contained within this report is shown in Figure 5.

Figure 5 Flowchart of study inputs, outputs, processes and overall structure



6.3 Deployment modelling

The economic calculations within this report are based on externally-commissioned deployment modelling from TIMES.

TIMES is a linear optimisation tool used to model whole energy systems over a range of geographical distributions [23]. TIMES models represent the full energy lifecycle, from mining primary resources to processing, transforming, transporting, distributing and converting energy supply. Inputs include prices, resource and emissions associated with the current and candidate energy system technologies, commodities and flows and the energy demand requirements over a future time period. The model produces a solution for a least-cost energy system, subject to constraints representing resource and supply chain limitations and political targets, such as long-term carbon reduction. For this work, existing TIMES models at a European and global[8] scale have been run over the period of 2020-2050, with ocean energy costs assumed to meet the SET Plan targets by 2030 [23] [24].

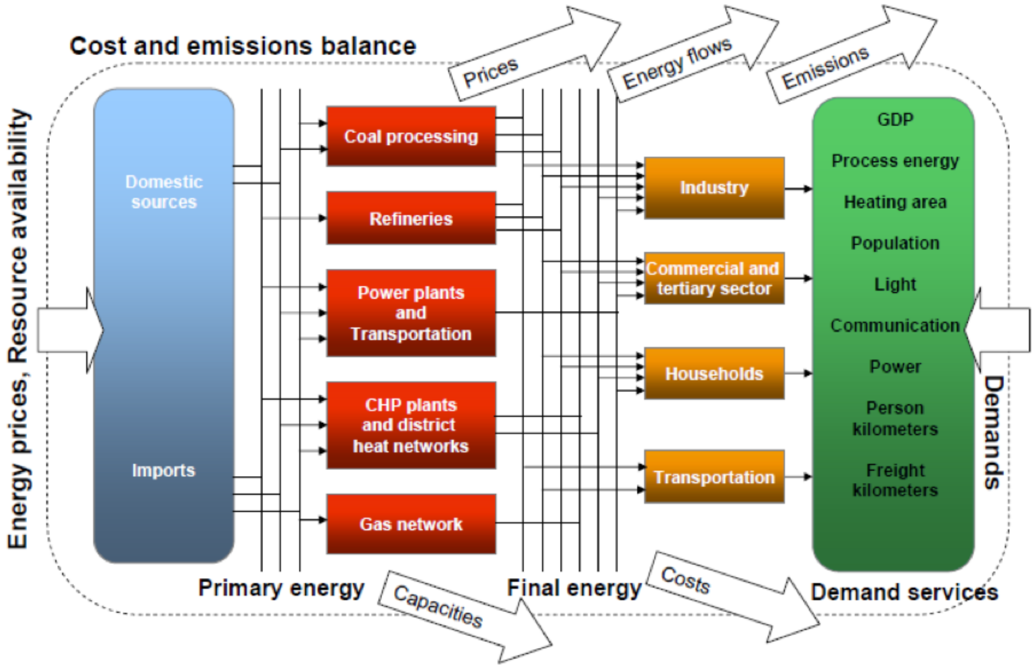


Figure 6 Diagram of TIMES inputs and outputs [25]

Energy system optimisation models such as TIMES include constraints within their objective function to ensure that the least cost solutions produced are realistic in terms of limiting factors such as the available resources and which meet long term carbon reduction targets. Three types of modelling constraints are of particular interest to this work, those representing: 1) renewable energy resource, 2) technology build rates and 3) carbon reduction targets.

6.3.1 TIMES model constraints

Renewable energy resource constraints are included within these models as a maximum annual energy production by a single technology. This means that the maximum amount of technology deployed at any point in the model time horizon will be limited to represent the renewable resource available in each model region. The regions correspond to European countries within the JRC European TIMES model, and larger aggregated regions within the IEA global TIMES model. Each region will have a technology specific maximum annual energy production constraint for all forms of energy generation, including wave and tidal energy. This means that generation cannot be deployed beyond the existing renewable resource.

Carbon reduction targets are a key constraint for energy system planners, allowing a modeller to constrain the model to meet explicit long-term carbon reduction targets within legislation. In the JRC European TIMES model runs, the explicit constraint on carbon production reaches an 80% reduction on 1990 levels in Europe by 2050. In the IEA TIMES model runs, results are produced which constrain carbon production to zero by 2070 and by 2050 for the Sustainable Development Scenario (SDS) and Faster Innovation Case (FIC) respectively (see Sections 6.3.3 and 6.3.2 for descriptions). This limits the amount of carbon-producing generation which is able to be installed within deployment scenario results, even if such generation has cheaper lifetime costs than generation which does not produce carbon emissions.

Introducing these three types of modelling constraints within energy system optimisation models can produce deployment results which differ from the unconstrained least cost solution, but allows modellers to produce a range of scenarios to better represent technology, resource and policy considerations which will impact on the future energy mix. The use of these modelling constraints is thus very important to this work, which focuses on deployment trajectories for ocean energy within high-renewable low-carbon future scenarios.

6.3.2 JRC

The European component of the SET Plan scenarios is founded on the 2050 installed capacity outputs from the JRC-TIMES-EU SET Plan model run. For this, the JRC ran the JRC-TIMES-EU model with current cost assumptions, and under the assumption that technology innovation enable the SET Plan to be accomplished not just for ocean energy but for all technologies [26].

6.3.3 IEA

The IEA ETP Sustainable Development Scenario (SDS) and the Faster Innovation Case (FIC) are two of four scenarios depicting possible energy futures that may be achieved through a range of policy mechanisms at various levels of ambition. The SDS has historically been presented as part of the regular ETP research package alongside the less ambitious Current Policies and Stated Policies scenarios, and is supplemented with the FIC from 2020 going forward. The assumptions on which the SDS is based are as follows:

- The net zero carbon emissions target would be attained globally by 2070
- That the major changes that would be required to reach the key energy-related goals of the United Nations (UN) Sustainable Development Agenda are achieved. These include emissions reductions in line with the Paris Agreement, as well as rapid deployment of renewable technologies, universal access to fit-for-purpose energy and dramatic increase in air quality [27].

The FIC is an additional scenario run by the IEA in the 2020 edition of their ETP publication. The FIC was presented in the IEA's Special Report on Clean Innovation and investigates the potential outlook if Net Zero is to be achieved globally by 2050 [28]. In comparison to the IEA's SDS, which examines the possibility of achieving this target 20 years later, by 2070, this would require relatively steeper cost reduction between 2030 and 2050. The assumptions on which the FIC is based are as follows:

- The net zero carbon emissions target would be attained globally by 2050 – 20 years earlier than in the SDS
- Clean energy technology innovation progresses at a much faster rate. For example, deployment of technologies currently only at laboratory or small prototype stage is widespread [29].

6.3.4 Inputs and Assumptions

Cost reduction within the TIMES model occurs through a learning rate once a target deployment has been achieved, via a 'learning by doing' mechanism. Until that target is reached – in this instance by 2030 – cost reduction is assumed to be achieved through learning by research. A constant learning rate of 10% is assumed. The capacity factors for tidal stream and wave are assumed as 39% and 33%, respectively [30].

The CAPEX and OPEX cost assumptions – consistent across the SET Plan runs by the two models – are presented in Table 4, Table 5 and Table 5.

Coupled with annual deployment values, these same rates function as inputs for the calculation of annual CAPEX and OPEX.

Table 4 CAPEX inputs for European and Global SET Plan scenario modelling for tidal and wave deployments (€/kW) [31]

	2020	2025	2030	2035	2040	2045	2050
Tidal	5300	2750	1850	1580	1460	1360	1260
Wave	5630	3350	2500	1650	1530	1420	1310

Table 5 CAPEX inputs for FIC scenario modelling for global deployments (€/kW) (Exchange rate of 1.18 from USD 2018 to EUR 2018) [32]

	2030	2035	2040	2045	2050
Tidal	1848	1590	1289	1117	988
Wave	2497	2167	1790	1508	1366

Table 6 OPEX inputs for European and Global SET Plan and FIC modelling, (€/kW) and as a percentage of CAPEX [33]

	2020	2025	2030	2035	2040	2045	2050
Europe and Global	6.0%	5.0%	4.5%	4.5%	4.5%	4.0%	4.0%

6.3.5 Deployment Inputs

Deployment modelling obtained from these models to serve as inputs to this study are presented in tabular format in Table 7.

Table 7 Cumulative installed capacity outputs from JRC-TIMES-EU and IEA-ETP-TIMES 2020 (GW)

Source	Scope	Scenario	Technology	2050 Installed Capacity (GW)
JRC-TIMES-EU [26]	Europe	SET Plan	Tidal	28.6
			Wave	30.9
IEA-ETP-TIMES 2020 [27]	Europe	SDS	Ocean	50.0
	Global	SDS	Ocean	192.0
	Europe	FIC	Ocean	50.0
	Global	FIC	Ocean	293.0

Deployment between 2020 and 2050 was interpolated, from the five-yearly time steps of the JRC-TIMES-EU model and the final output of the IEA-ETP-TIMES model, into an exponential curve for each. The need to do this highlights a limitation of the TIMES model, which is explored further in Section 27.

6.4 European Market Share

6.4.1 Ready Reckoners

To obtain the *net spend* – CAPEX and OPEX – incurred by each country's industrial cost centre, a leakage ready reckoner is used. In this case, *net spend* is the cost attributable to a specific industrial cost centre, which is spend within the area in question.

Equation 2 describes the calculation to eliminate the exogenous spend, through which *gross spend* is converted to *net spend*.

Equation 2

$$NS_{CC} = GS_{CC}\left[(1 - L)(1 - D_w)(1 - D_p)(1 - S)\right]$$

The Ready Reckoners in Equation 2 are:

- Leakage *(L)*, which indicates the proportion of spend not retained within the economy in question, the benefits of which are not seen domestically. A high leakage rate indicates that a significant proportion of spend is invested outside the region in question, for example due to reliance on imports. Conversely, a low leakage rate implies a high proportion of domestic investment.
- Deadweight (D_w), Displacement (D_p) and Substitution *(S)* [17].

Due to the international scope and scale of this study, Leakage is the only Ready Reckoner in the equation to be assigned a value; Deadweight, Displacement and Substitution are all kept as zero. As such, all economic impact described is purely additional, in that the activity pertains to a demand shock in lieu of replacing existing activity. Similarly, a flat leakage rate has been applied to all CAPEX and OPEX cost centres across all countries. Further study into the application of variable leakage rates per national cost centre would add value for the sector.

6.4.2 Leakage

An assessment is made of the impact on the potential economic benefit offered to Europe through this deployment of changes in the strength of the domestic supply chain. As such, two levels of leakage rates were applied to the calculation; one – low leakage - based on European independence from imports and a relatively strong export market; the other – high leakage - Europe relies more heavily on imports and attains a less significant share of the global market. These are modelled using leakage factors, which represent the share of spend not spent within the economy in question (i.e. 'leaked' to a foreign economy through imports). A low leakage rate indicates high retention of spend within the economy in question, thanks to strong domestic supply chain and little need for imports. Conversely, a high leakage rate implies weakness in the domestic supply chain and consequent reliance on imports to deliver the service in question. Leakage is an important element to the GVA calculation because, while significant activity dedicated to delivering the deployment can be taking place domestically, minimal economic benefit will be generated within the domestic economy if the goods and services are imported from foreign firms.

Leakage from EU for EU deployments is comparatively lower than leakage from the EU for deployments elsewhere. Generally speaking, the smaller a territorial unit (country, region or county,) relative to another, the greater its dependence on external territories through trade, and therefore higher leakage rate [34]. In this case, the smaller economy in question is Europe and the greater is the Rest of the World. As such, leakage rates from Europe for extra-European deployments will generally be higher than those for European deployments. Reasons for this include the increased competition the EU would face within the global market, and local content regulation encouraging domestic supply chain development.

Furthermore, constant leakage rates are applied to spend in all industries within each scenario. This is because this study assesses the impact on the overall supply chain strength for European and international deployments – rather than identifying the relative strength of specific national supply chains within Europe. This has the additional and deliberate benefit of not assigning strength or weakness to any one national industry in particular.

Leakage is incorporated into the calculation through the multiplication of national spend into each cost centre by the retention rate (leakage's counterpart). Leakage and corresponding retention rates are displayed in

Table 8.

Table 8 Rates of leakage from the European economy for domestic and international deployments

	Low leakage		*High leakage*	
	Leakage (%)	Retention (%)	Leakage (%)	Retention (%)
European deployments	10	90	30	70
Global deployments	75	25	95	5

6.4.3 European Proportion of the Global Energy Mix

In addition to leakage rates, the proportion of global installed capacity deployed in Europe was varied to assess the importance of a high market share in the generation of domestic GVA. The 293 GW total ocean deployment in 2050 under the FIC scenario is split across deployment occurring inside and out-with European waters. A medium proportion sees 60 GW of ocean deployed in Europe by 2050; a high equivalent increases this share to 100 GW.

Table 9 outlines the capacity (GW) of wave and tidal deployed under the medium and high proportion variations of the FIC.

Table 9 Medium and high European proportions of the FIC's 293 GW 2050 global installed capacity

	2050 Installed Capacity (GW)			
	Europe follows the global market		Europe leads the global market	
	Europe	RoW	Europe	RoW
Tidal stream	24	93	40	72
Wave	36	140	60	116
Ocean	**60**	**233**	**100**	**193**

6.5 The linear relationship between year of deployment and GVA generated

The linear relationship between timeliness of deployment and GVA generated has been explored by varying deployment trajectory taken by the SET Plan scenario and the discount rates applied to all scenarios.

Findings confirm that, when cost reduction is linked to the passage of time, as per the TIMES model structure, earlier deployments generate higher GVA than later deployments. Similarly, due the unavoidable impact of inflation, the application of a discount rate has a more significant impact on later deployment than earlier.

The results of this assessment are presented in Appendix 2: Deployment Trajectory.

6.6 Deployment Scenarios

Given the uncertainties associated with predicting future deployment, a range of deployment scenarios were modelled and assessed. Three scenarios were developed, based around and beyond the achievement of the SET Plan 2030 target LCOEs for wave and tidal [8].

The SET Plan Scenario is based on the achievement of the SET Plan targets for LCOE in Europe and globally, reaching Net Zero in Europe by 2050 and globally by 2070. This scenario assumes:

- 2030 LCOE values of €100/MWh for tidal and €150/MWh for wave;
- 2050 European deployment of 60 GW and global deployment of 192 GW; and
- Modelling at a European level from the JRC-TIMES-EU SET Plan outputs and at a global level from the IEA SDS [26] [27]. The SDS is based on the same cost assumptions as the JRC SET Plan run, and so can be considered a global equivalent.

Two additional scenarios based on the IEA's FIC modelling at a global level (described in more detail in Section 6.3.3) also see the achievement of the SET Plan targets for LCOE in Europe and globally, followed by steep cost reduction and enabling Net Zero globally Europe by 2050. The parameter varied across these two deployment cases is the proportion of global deployment occurring in Europe. These scenarios assume:

- 2030 LCOE values of €100/MWh for tidal and €150/MWh for wave, with costs reducing from 2030 to 2050 at a steeper rate;
- 2050 global deployment of 293 GW and a range of European deployment of 60 GW, to account for alignment of the JRC-TIMES-EU SET Plan output, and 100 GW, to quantify the impact of achieving the IEA-OES mission statement's stated target of 300 GW of ocean deployment globally by 2050 [35]; and
- Modelling at a global level from the IEA's ETP 2020 FIC, from the Special Report on Clean Energy Innovation (2020), with European share extracted proportionally.

These two FIC scenarios investigate two market possibilities:

Europe follows the global market

This variation of the FIC sees Europe capture 60 GW of 293 GW global deployment, and a lower share of the domestic and export markets servicing this deployment. While the overall 2050 global deployment is higher in this scenario than the SET Plan (293 GW compared with 192 GW), Europe's gross share of it is consistent at 60 GW, meaning Europe captures a relatively smaller proportion. In other words, Europe hasn't taken the action to invest in ocean energy and incorporate it into its energy mix. Similarly, Europe doesn't capitalise on opportunity to stake a claim of the global export market, instead losing out to competitors elsewhere in the world. Finally, a high leakage rate signifies Europe's neglect of local content for domestic deployments and consequent reliance on imports to service domestic deployments.

Europe leads the global market

Also based on the FIC, Europe captures 100 GW of the 293 GW global deployment and fosters strong domestic and export markets servicing this deployment. While this scenario sees higher global deployment consistent with the less-ambitious FIC scenario, conversely, Europe invests in ocean energy to incorporate it into energy mix and encourages a relatively higher proportion of global deployment to occur in Europe. Europe makes itself an attractive place to deploy ocean energy technologies, capitalising on its blue economy opportunity and thereby encouraging developers to deploy in its waters instead of elsewhere. Capitalising on opportunities to stake a claim of the global export market, Europe wins global contracts for components or at device-level, beating out competition elsewhere in the world. The low leakage rate applied symbolises Europe's prioritisation of local content for domestic deployments and encourage the development of strong European supply chain

Deployment shares across these scenarios are tabulated in Table 10 and plotted in Figure 7. Note the consistency in European deployment, but difference in global deployment, under the SET Plan and Follower scenarios, and the consistency in global deployment, but difference in European deployment under both the Follower and Leader scenarios.

Note the overall increase in deployment between the SET Plan and both market scenarios, and the increase in European share between the Follower and Leader scenarios. In other words, note the consistency in European deployment, but difference in global deployment, under the SET Plan and market scenarios, and the consistency in global deployment, but difference in European deployment under the two market scenarios.

One additional market scenario was assessed, where Europe takes a 50 GW proportion of the global 293 GW, in alignment with the geographical breakdown of the IEA FIC output [29]. The results of this scenario are included in Appendix 3: Faster Innovation Case with 50 GW in Europe.

Table 10 LCOE and 2050 installed capacity across the three scenarios

Scenario	2030 LCOE target (€/MWh)		2050 Installed Capacity (GW) Europe			Rest of the World			Global Total
	Tidal stream	Wave	Tidal stream	Wave	**Ocean**	Tidal stream	Wave	**Ocean**	**Ocean**
Achievement of the SET Plan			30	31	**61**	53	79	**132**	**192**
Europe follows the global market	100	150	24	36	**60**	93	140	**233**	**293**
Europe leads the global market			40	60	**100**	77	116	**193**	**293**

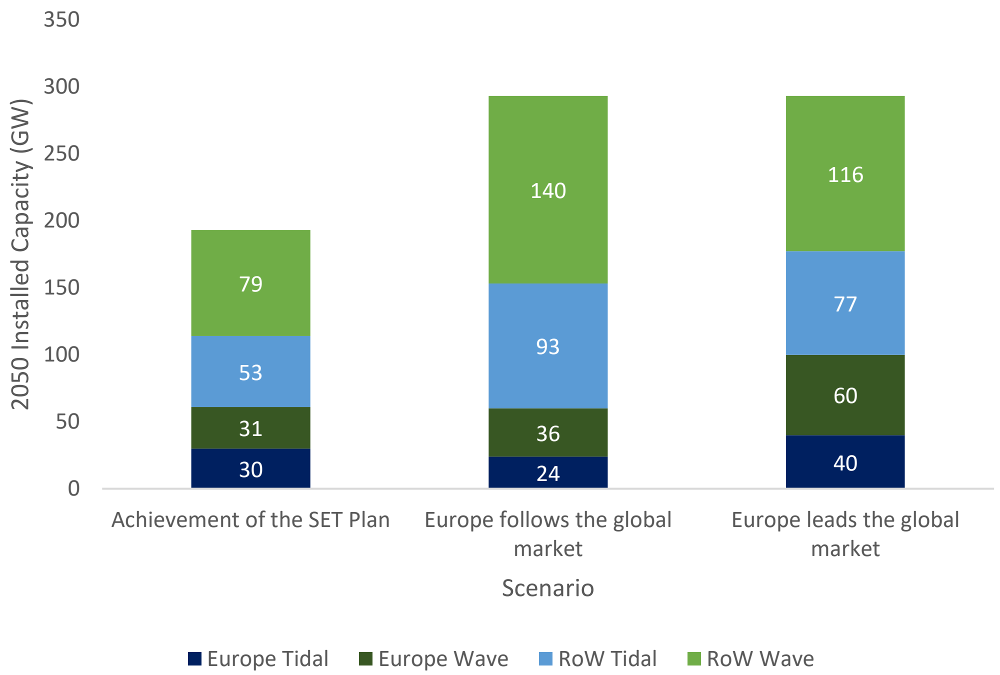


Figure 7 Technological and geographical breakdown of 2050 installed capacity under each scenario

7. Results

The potential economic benefit associated with the three deployment scenarios is presented in the form of direct spend and the resultant indirect and induced GVA.

GVA results are aggregated within the following sections and presented by deployment scenario. Each scenario has variation in the parameters of global and European deployment, and leakage rates. All results presented have been discounted to account for inflation at a rate of 3.5% [22]. Further discussion around discounting can be found in Section 6.5.

The total GVA benefit to the European economy from ocean energy deployments up to 2050 has a potential range of €59bn to €140bn across the three scenarios presented here.

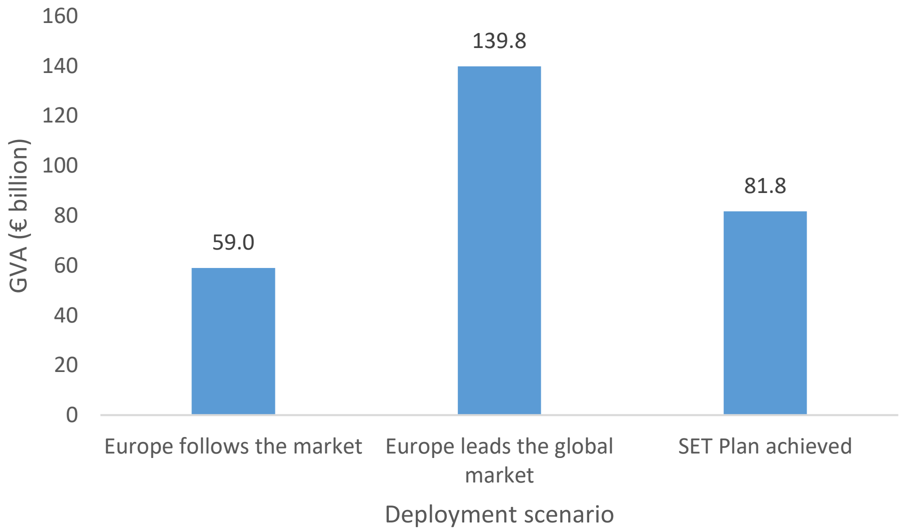


Figure 8 GVA results for each deployment scenario (€ billion)

7.1.1 SET Plan Scenario: Achievement of the SET Plan targets

As summarised in Section 6.6, this scenario would see both wave and tidal stream achieving their respective SET Plan targets. With the lowest overall global ocean deployment of the three scenarios, Europe does still achieve a higher proportion of the global deployment. In other words, Europe invests in ocean energy to incorporate it into energy mix. Similarly, Europe makes itself an attractive place to deploy ocean energy technologies, capitalising on its blue economy opportunity and thereby encouraging developers to deploy in its waters in lieu of elsewhere. Furthermore, Europe prioritises local content for all deployments and therefore has relatively low reliance on imports to support the domestic supply chain.

Both wave and tidal deployment under this scenario follow an exponential trajectory, passing through OEE Low and DG-MARE Central scenario of just under 1.5 GW by 2030 globally, of which around 90% occurs in Europe [13] [36]. This trajectory allows for relatively organic advancement of the wave and tidal supply chain within European industries. Global (Europe plus Rest of the World) deployment under this scenario is charted in Figure 9. The 2050 installed capacity for tidal and wave in Europe is 30 GW and 31 GW, respectively, and 53 GW and 79 GW in the Rest of the World, respectively. Deployment follows a less aggressive trajectory than that followed by historical offshore wind in its early stages of commercialisation [37].

Results for the SET Plan Scenario

- With low leakage rates applied, this scenario would generate €69bn in GVA for the European economy.
- To develop and deploy this scenario, direct spend of €82bn would be incurred.
- Therefore, this scenario yields an overall economic benefit of €151bn to the European economy, less any subsidy awarded by Member States at the national level.
- The discounted results from this scenario are presented in Table 11 below.

Table 11 Low leakage economic benefit results for SET Plan Scenario

Deployment Scope	Technology	2050 Installed Capacity (GW)	Leakage Rate	Direct Spend (€ billion)	Indirect GVA (€ billion)	Induced GVA (€ billion)	GVA (€)/ MW
Europe	Tidal	30	10%	25.55	21.32	4.75	€ 870,515.53
	Wave	31	10%	25.42	21.21	4.71	€ 838,662.27
Rest of World	Tidal	53	75%	12.73	10.69	2.41	€ 248,014.79
	Wave	79	75%	16.37	13.64	3.04	€ 210,659.91
Global	Tidal	83	-	38.28	32.01	7.15	€ 473,318.68
	Wave	110	-	41.79	34.85	7.75	€ 386,911.25
Global total	**Ocean**	**193**	**-**	80.07	66.86	14.91	€ 423,987.81

7.1.2 Europe follows the global market

Both market scenarios follow an exponential trajectory passing through OEE Low and DG-MARE Central scenario of just under 3 GW by 2030 globally, of which around 90% occurs in Europe [13] [36]. In this variation of the two FIC scenarios, the EU achieves 60 GW of 293 GW global ocean total by 2050. This scenario aligns with the JRC-TIMES-EU SET Plan output, which suggests 60 GW of European ocean deployment by 2050. Please see Section 6.3.2 for further details of this modelling. Global (European and non-European) deployment under this scenario is charted in Figure 10. 2050 installed capacity for tidal and wave in Europe is 24 GW and 36 GW, respectively, and 93 GW and 139 GW in the Rest of the World, respectively.

Results when Europe follows the global market

- Given the high leakage rates applied, this scenario would generate €59bn in GVA for the European economy.
- To develop and deploy this scenario, direct spend of €58bn would be incurred.
- Therefore, this scenario yields a net economic benefit of €117bn to the European economy, less any subsidy awarded by Member States at the national level.
- The discounted results from this scenario are presented in Table 12 below.

Table 12 High leakage economic benefit results when Europe follows the global market

Deployment Scope	Technology	2050 Installed Capacity (GW)	Leakage Rate	Direct Spend (€ billion)	Indirect GVA (€ billion)	Induced GVA (€ billion)	GVA (€)/ MW
Europe	Tidal	24	30%	17.72	14.80	3.30	€ 754,100.47
	Wave	36	30%	26.51	22.12	4.92	€ 751,129.41
Rest of World	Tidal	93	95%	7.18	6.04	1.51	€ 80,950.40
	Wave	140	95%	6.23	5.20	1.16	€ 45,404.30
Global	Tidal	117	-	24.90	20.83	4.81	€ 218,796.83
	Wave	176	-	32.73	27.31	6.08	€ 189,921.39
Global total	**Ocean**	**293**	**-**	57.63	48.14	10.89	€ 201,471.57

7.1.3 Europe leads the global market

In this market scenario, Europe achieves 100 GW of the 293 GW global ocean total, by 2050 - the highest proportion of the three scenarios analysed. This deployment is plotted on an exponential trajectory aligning with the IEA-OES sector target of 300 GW of wave and tidal deployed globally (with 100 GW in Europe) by 2050 [35]. Global deployment under this scenario is charted in Figure 11. The 2050 installed capacity for tidal and wave in Europe is 40 GW and 60 GW, respectively, and 77 GW and 116 GW in the Rest of the World, respectively.

Results when Europe leads the global market

- With low leakage rates applied, this scenario would generate €140bn in GVA for the European economy.
- To develop and deploy this scenario, direct spend of €138bn would be incurred.
- Therefore, this scenario yields a net economic benefit of €278bn to the European economy, less any subsidy awarded by Member States at the national level.
- The discounted results from this scenario are presented in Table 13 below.

Table 13 Low leakage economic benefit results when Europe leads the global market

Deployment Scope	Technology	2050 Installed Capacity (GW)	Leakage Rate	Direct Spend (€ billion)	Indirect GVA (€ billion)	Induced GVA (€ billion)	GVA (€)/ MW
Europe	Tidal	40	10%	38.70	32.31	7.18	€ 987,312.97
	Wave	60	10%	57.77	48.21	10.73	€ 982,192.60
Rest of World	Tidal	77	75%	15.94	13.34	3.07	€ 212,527.51
	Wave	116	75%	25.94	21.63	4.81	€ 228,316.23
Global	Tidal	117	-	54.65	45.65	10.25	€ 476,959.41
	Wave	176	-	83.70	69.83	15.54	€ 485,611.92
Global total	**Ocean**	**293**	**-**	138.35	115.48	25.79	€ 482,150.91

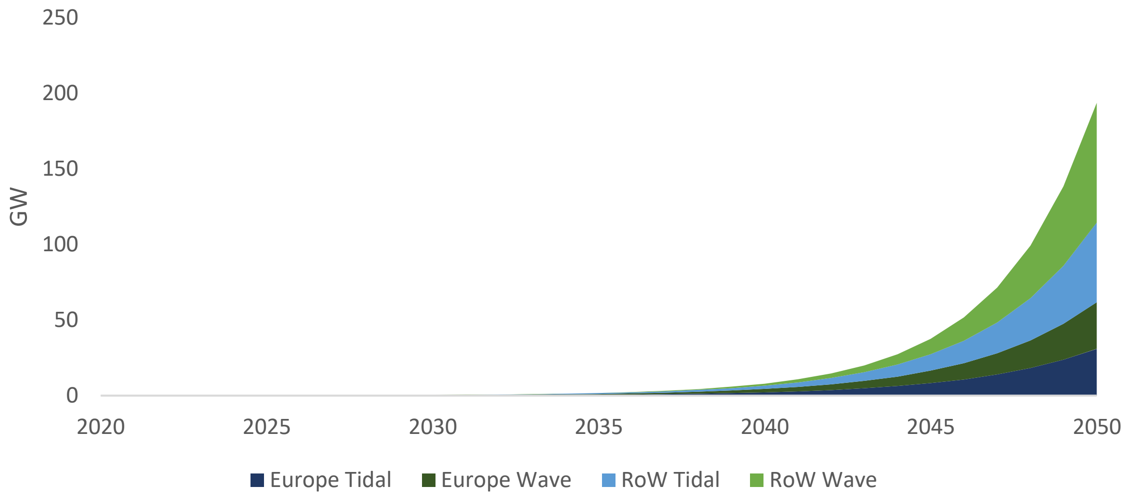


Figure 9 Cumulative installed capacity (GW) to 2050 when the SET Plan targets are achieved

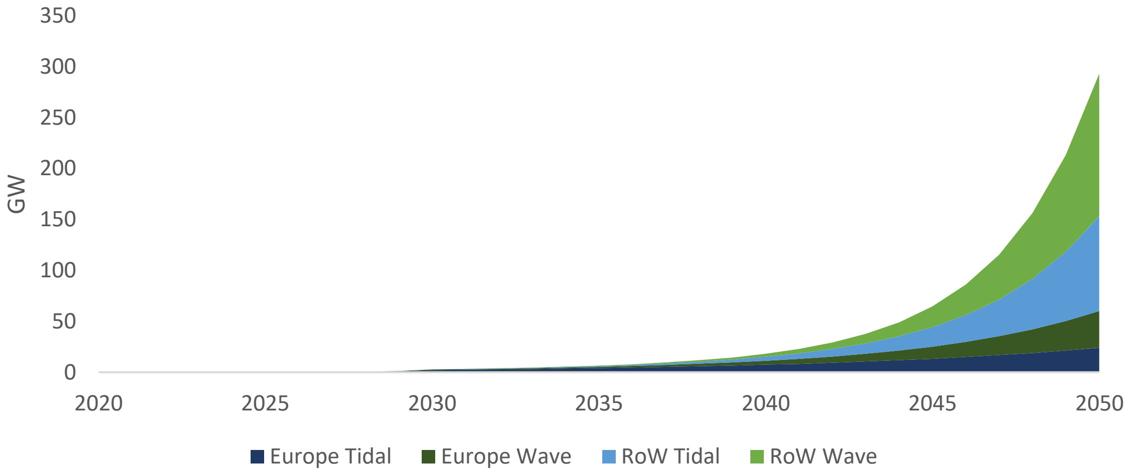


Figure 10 Cumulative global installed capacity (GW) when Europe follows the global market

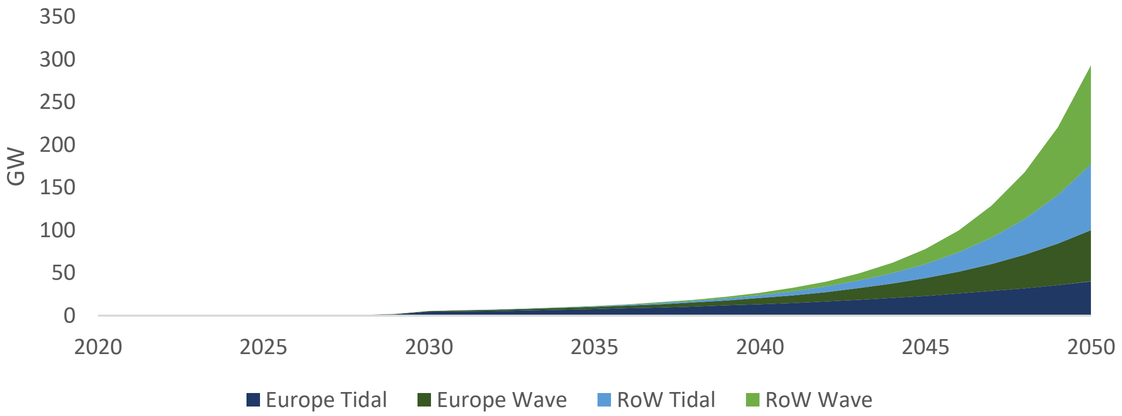


Figure 11 Cumulative global installed capacity (GW) when Europe leads the global market

7.2 GVA per economic sector

Because the leakage rates are constant across the industries, and the GVA effects are constant across scenarios, the distribution profile of spend and GVA generated by each national industry for the European economy is therefore constant for wave and for tidal across all scenarios. An example of such a tidal profile is presented in Figure 12, and for wave in .

Where OPEX alone contributes to just under half of the overall GVA – which is to be expected, given it comprises an equivalent share of spend – development and production of the main structure (the generating device) generates the most GVA of the CAPEX technical cost centres, for both tidal stream and wave.

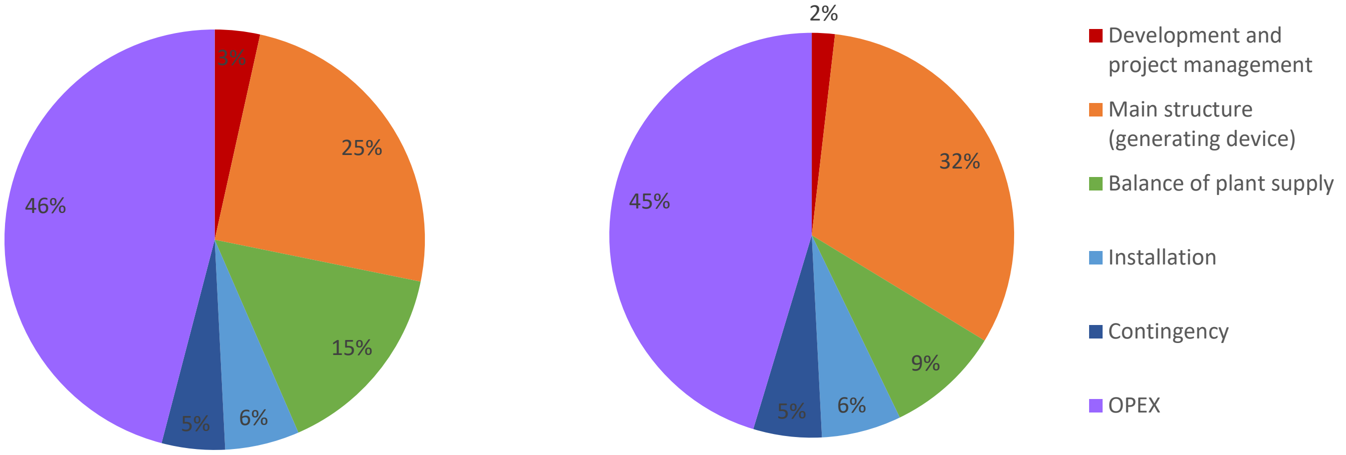


Figure 12 and Figure 13 Percentage share of GVA generated by technical cost centre for tidal stream (left, 24 GW by 2050) and wave (right, 36 GW by 2050) deployment

8. Discussion

Analysis is carried out on the GVA results presented in Section 7 to assess the impact of leakage and share of global deployment occurring in Europe on the GVA benefit generated and retained by the European economy. The primary conclusion drawn from this analysis is that capture of high market share both domestically and through exports is critical for maximising the economic benefit seen by Europe, regardless of the level of deployment achieved globally.

This section sets out the evidence behind the assertion that capture of market share is equally as – if not more - important for maximising the economic benefit seen by Europe as the level of deployment achieved in Europe and elsewhere. To do this, the two parameters of leakage rate and European share of the global total were varied to assess the impact of a changing market share on GVA results.

8.1.1 Leakage

Sensitivity of the GVA results to domestic supply chain strength is assessed by varying the rate at which CAPEX and OPEX is leaked from the European to the Rest of the World economy. Please see Section 6.4.2 for details on the leakage rates applied.

Results (Figure 14) demonstrate that the market share captured by Europe servicing European and international deployments has a significant impact on the resultant economic benefit. A higher share of less deployment in Europe (i.e. low leakage for deployment within the EU) is worth more than a lower share of greater deployment elsewhere (i.e. high leakage for deployment elsewhere). This conclusion is emphasised by the margin of difference between low and high leakage results for exports relative to those in Europe.

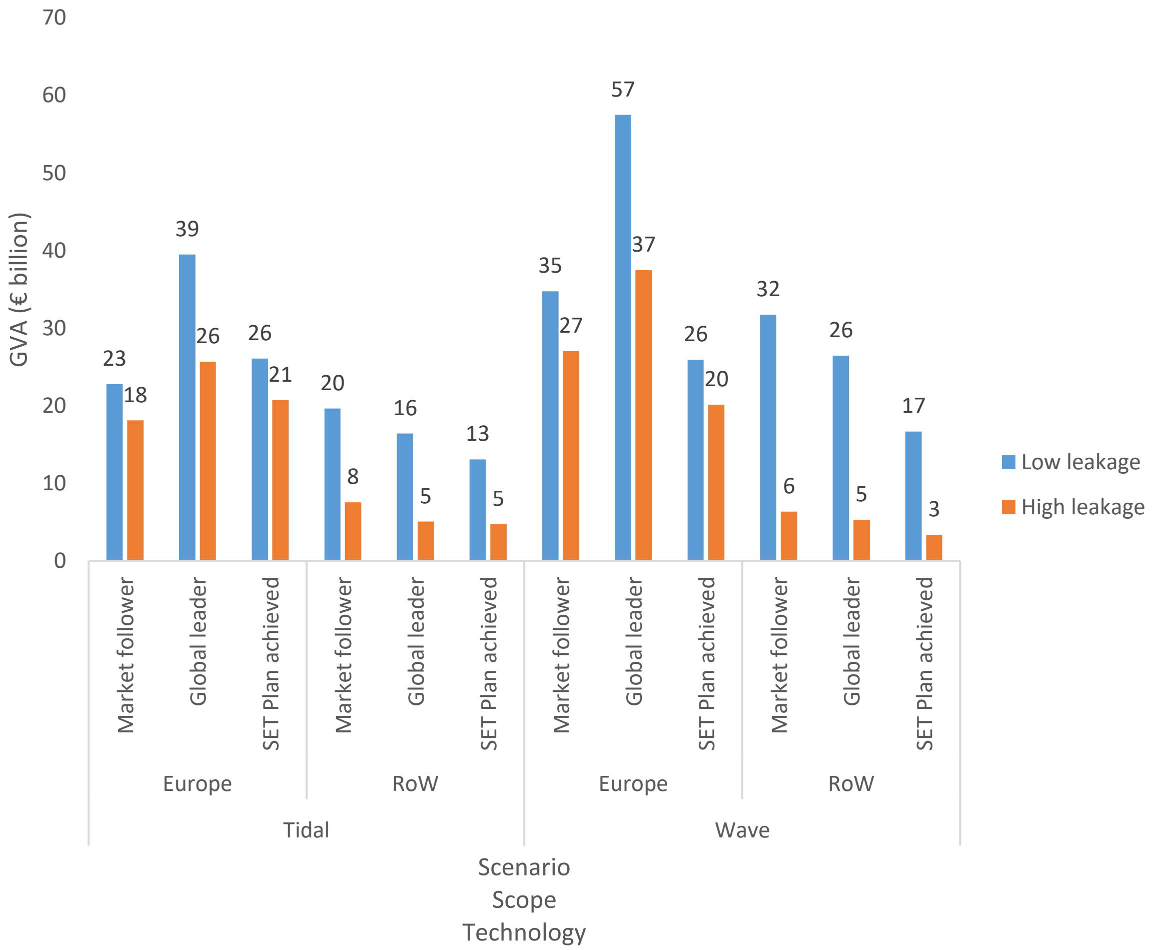


Figure 14 Impact on GVA results of leakage rate variance

8.1.2 EU share of global deployment

The share of global installed capacity occupied by European deployment is varied to assess the influence that this variable has on benefit to the EU-28 economy. To facilitate direct comparison, the two FIC market scenarios serve as the foundations for this analysis. This means that the total global deployment is consistent between the two (293 GW by 2050), and only the European component is varied; the SET Plan scenario has been omitted from this particular analysis because the total global deployment is lower, at 192 GW by 2050. For more details on the variation across these scenarios please see Section 7. Pie charts illustrating the changing global distribution of each technology are presented in Figure 15 and Figure 16. Note the increase in the European proportion (dark blue and dark green) to 100 GW in the Leader scenario, relative to the 60 GW in the Follower scenario. This is enabled by a corresponding reduction in the Rest of World deployment (light blue and light green).

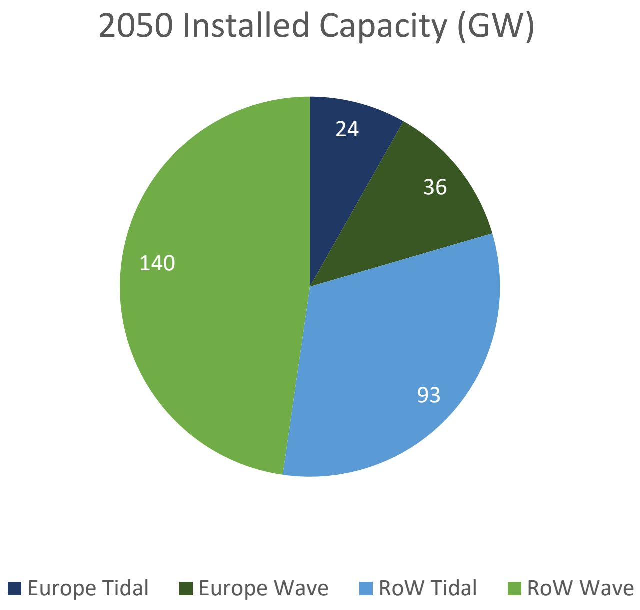


Figure 15 2050 installed capacity (GW) of wave and tidal in Europe and the rest of the world, when Europe follows the global market

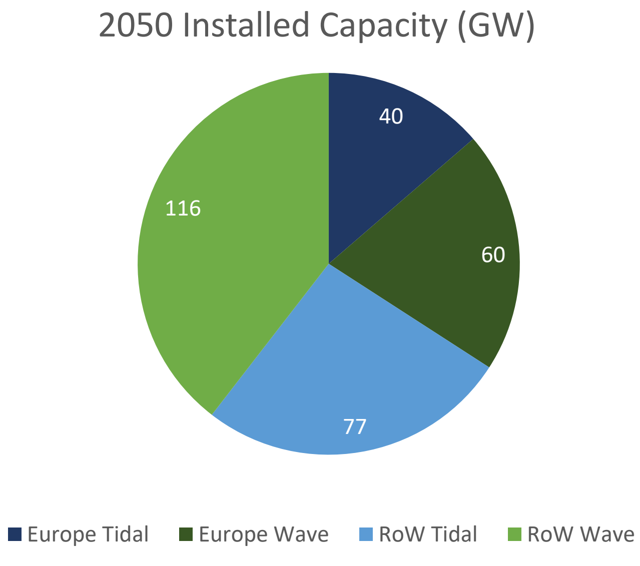


Figure 16 2050 installed capacity (GW) of wave and tidal in Europe and the rest of the world, when Europe leads the global market

The potential GVA benefit associated with the delivery of the above scenarios are presented in Figure 17 and Table 14.

Due to the relatively higher leakage rates from the export market, accounting for increased global competition (see Section 8.1.1 for more details), the proportion of GVA generated from European deployments is greater than the proportion of deployment occurring in Europe.

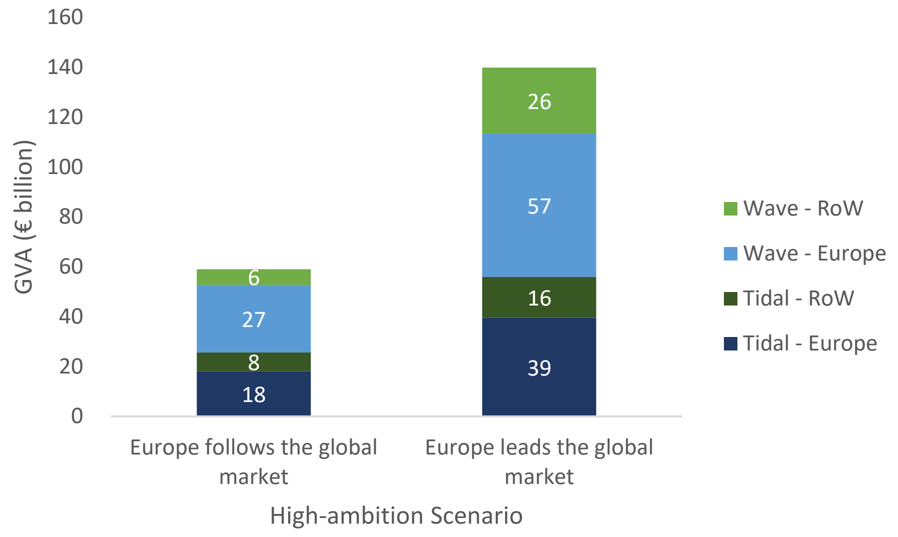


Figure 17 GVA results for the FIC scenario when Europe follows and leads the global market, with 293 GW in total deployed globally for each

Table 14 Comparison of low leakage Type II GVA results when Europe follows and leads the global market

	Domestic deployments		*Exports*		*Total*
Scenario	Spend (excluding subsidy)	Total GVA	Spend (excluding subsidy)	Total GVA	Overall economic benefit
Europe follows the global market	€44.2bn	€45.1bn	€13.4bn	€13.9bn	€116.7bn
Europe leads the global market	€96.5bn	€97.0bn	€41.9bn	€39.8bn	€275.1bn

Direct comparisons of equivalent technology and geographical scope, presented in Figure 18, demonstrate that the higher the GVA from European proportion of deployment, the lower the GVA from the equivalent proportion deployed in the rest of the world – see the Global Leader bars for the most pronounced example of this. In GVA terms, lower leakage from Europe for European deployments than for rest of world deployments means that increasing the EU share has a greater impact than increasing RoW share (by decreasing EU share).

EU-derived GVA increases by 80% when the 2050 deployment is increased by 80%, and it would change linearly as such with any other increase or decrease in deployment. However, the overall GVA doesn't increase by 80%, because exports-derived decreases in direct proportion to the increase in European stake. This is evident by the RoW bars, where the GVA is higher when only 60 GW of the 293 GW is deployed in Europe. When that proportion increases to 100 GW, GVA from exports falls. This difference is less pronounced when a high leakage rate is applied. In general, GVA associated with wave is higher than with tidal, primarily due to the higher LCOE SET Plan target of €150/MWh by 2030, compared with the tidal target of €100/MWh, and associated cost curve.

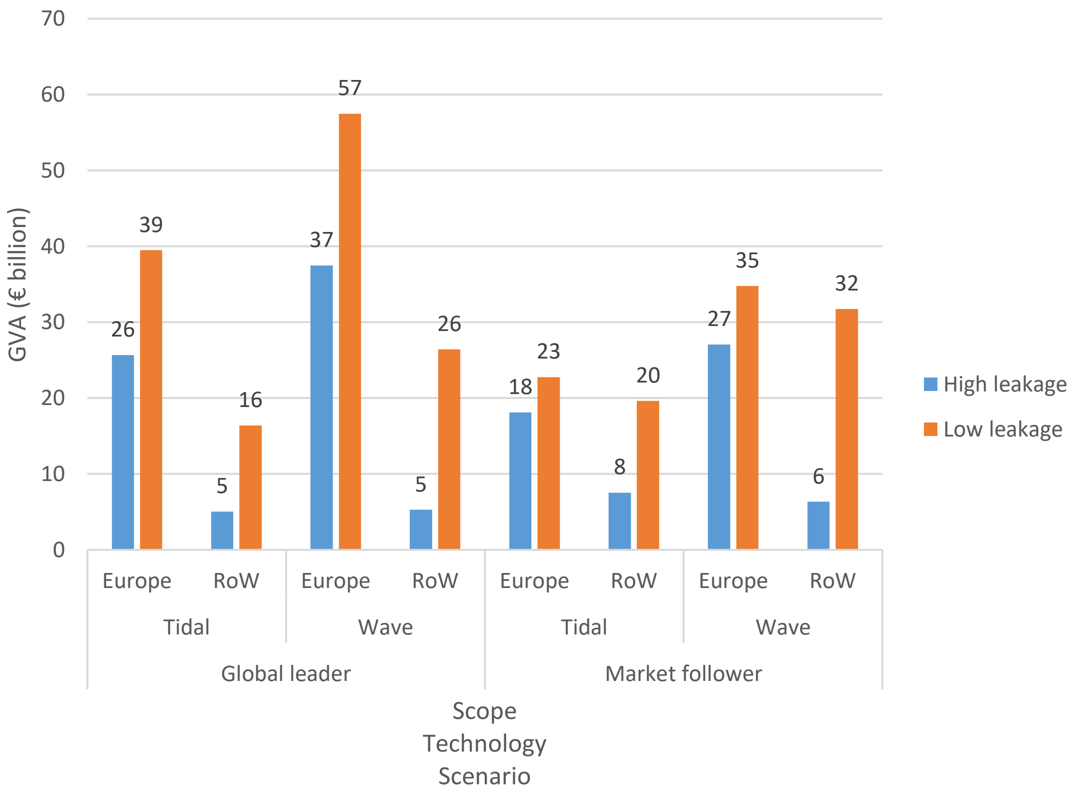


Figure 18 Sensitivity of GVA results to variance in EU share of global deployment and leakage rate

These results emphasise the importance of capturing not only a high domestic and export market share of technological development, but of attracting a large proportion of global deployment to European waters.

Prioritising local content in the supply chain through policies strengthening local (i.e. European) industry are critical in minimising leakage, thereby maximising the GVA generated for Europe through whatever deployment does occur in future. Such policies include tax exemptions, elimination of barriers to market entry and those which support the building of capacity in Europe.

9. Conclusions

The primary conclusion drawn from this analysis is that capture of high market share is critical for maximising the economic benefit seen by Europe. The potential economic benefit is significant, ranging from €59bn to €140bn depending on the deployment and leakage conditions. This benefit is only achievable through significant cost reduction and performance improvement, requiring appropriate policy intervention at EC and member state level. The business-as-usual policy landscape will not facilitate the achievement of any scenario presented in this report.

Capturing a high market share of the supply chain servicing the deployment achieved is more important than the level of deployment achieved globally. Alongside member states, on behalf of Europe as a whole, the EC can take action to maximise the benefit offered.

Facilitate cost reduction to – and beyond - the SET Plan targets

Build policy supporting the sector to bring costs down to, and beyond, the SET Plan targets. Policy support to enable this could include: market pull mechanisms to enable deployment of innovative technologies, encouraging volume production and economies of scale; and technology push funding to bring down costs and achieve – or surpass - the SET Plan targets.

Maximise the retention of value by the European economy

Decrease leakage from the European economy by minimising reliance on imported supply and strengthening Europe's global export position.

To promote Europe's independence from foreign supply, prioritise local content in the supply chain for all deployments and projects by supporting European and national industrial activity. Furthermore, recognising and enabling the potentially great wider benefits at the community level is critical to engendering strong local content[9].

For deployments outside Europe, strengthen the European export position. Nurture and maintain areas of existing strength, where Europe is already a market leader, where global supply relies on European expertise. Cultivate a strong export market servicing deployments outside Europe: seize the opportunity to develop nascent supply chain for exports where there is currently little competition. Similarly, identify areas where Europe can become global market leaders at component level, if not in the design and production of entire devices.

Attract deployment in Europe by global developers

Building policy that presents European waters as attractive deployment locations to both domestic and international developers will maximise the proportion of global deployment occurring in Europe.

10. References

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11. Appendices

11.1 Appendix 1: GVA Effects

Multipliers and *effects* indicate the wider impact of spending in an industry on the economy in a certain region [38] in this case the EU-28. Where GVA *multipliers* indicate the impact on GVA of a €1 change of GVA in each industry, a GVA *effect* indicates the impact on GVA from a €1 change (or expansion) in output of an industry. In this instance, the demand shock can be taken as an expansion in output, thus GVA effects are used. These *effects* can be categorised by *direct*, *indirect,* and *induced effects*. The *direct effect* is the impact of spending in one industry *i* on that same industry *i*. The *indirect effect* represents the impact of spending in one industry *i* on another industries *j*. The *induced effect* considers the increase in household spending on the economy due to the *direct* and *indirect effects*. The *direct, indirect,* and *induced effects* are presented through Type I and Type II *effects*. Type I *effects* include the *direct* and *indirect effects* of spend in a sector. Type II *effects* include the *direct*, *indirect* and *induced effects* of spend. To obtain the Type II *multiplier*, household spend is incorporated into the intermediate demand table as additional industry in the form of 'total household income from all sources' (earned and unearned) and compensation for employees. Equation 3 describes the calculation yielding GVA effects, where I is an identity matrix and A_I is the direct requirements matrix.

Equation 3

$$L_I = (I - A_I)^{-1}$$

The process for calculating GVA effects is described in detail in [39].

11.2 Appendix 3: Type 1 GVA results

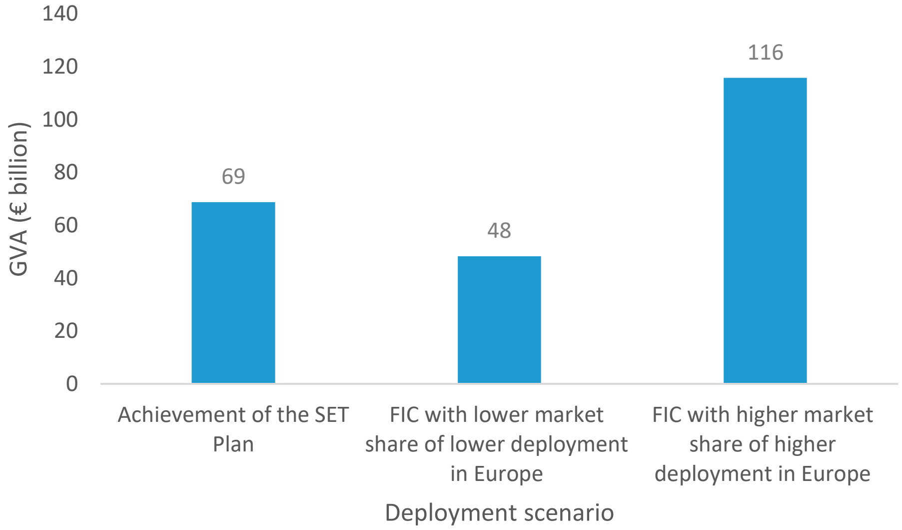

Figure 19 Type I GVA results for each deployment scenario (€ billion)

11.3 Appendix 2: Deployment Trajectory

Sensitivity of the GVA results to deployment trajectory is assessed by varying the deployment pathway taken to achieve the 2050 JRC-TIMES-EU model outputs. Given the linear relationship between GVA generation and spend incurred, as costs reduce through the application of learning rates, the GVA generated decreases. In spite of this negative implication in terms of economic benefit, the reduction in costs is overall positive for funders, technology developer and deployment objectives.

As described in Section 6.6, the SET Plan Scenario achieves the final installed capacity output by the model, but follows an exponential trajectory passing through just under 1.5 GW in 2030, aligning with Ocean Energy Europe's Low and DG MARE's Central targets for Europe [13] [36]. SET Plan Scenario 2 follows the JRC-TIMES-EU deployment trajectory at each time step for both wave and tidal; wave deploys the entire 30 GW between 2040 and 2050, while tidal deploys in sharp increments, with 50% of 2050 capacity deployed by 2030, the remaining 50% by 2040, with no further deployment between 2040 and 2050. This trajectory was omitted from the primary analysis due to the unrealistic supply chain and cost reduction requirements it would necessitate. The deployable tidal resource within JRC-TIMES-EU is within a set range; this is the reason only 30 GW of tidal stream capacity is installed to 2050. Similarly, the global deployments follow this same trajectory, passing through 1.5 GW, which these two sources state as the RoW deployment target.

Figure 20 and Figure 21, illustrate the variation in deployment trajectory between SET Plan Scenarios 1 and 2. Note the consistency of RoW deployment across both; deployment outside Europe achieves the IEA-ETP 2020 SDS scenario and follows an exponential trajectory through OEE and DG-MARE's 2030 low target of 1.5 GW. The primary difference lies in the path taken by European tidal: SET Plan Scenario 1 follows an exponential trajectory so sees maximal deployment of all technologies in the latter years. In SET Plan Scenario 2, tidal stream reaches the limitation of its European resource potential by 2040 and plateaus to 2050,

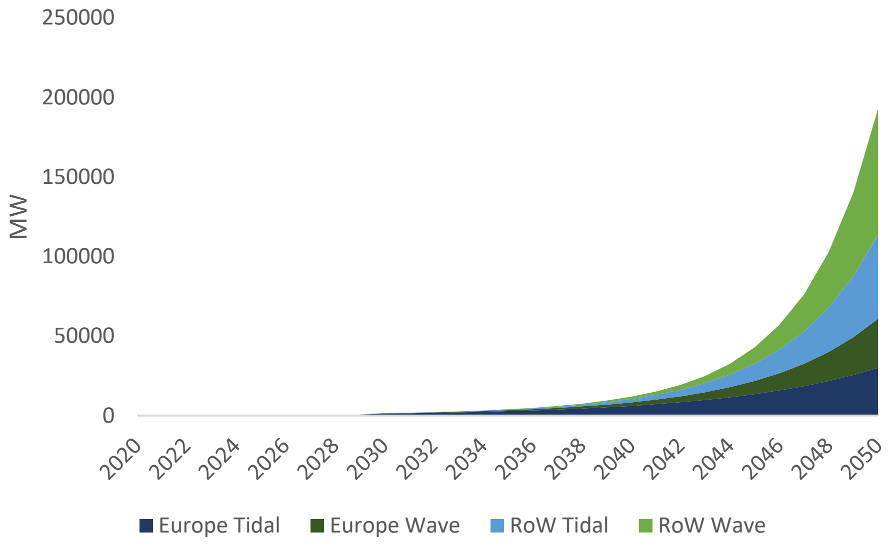

Figure 20 Global deployment (MW) to 2050 under the SET Plan scenario, following an exponential trajectory

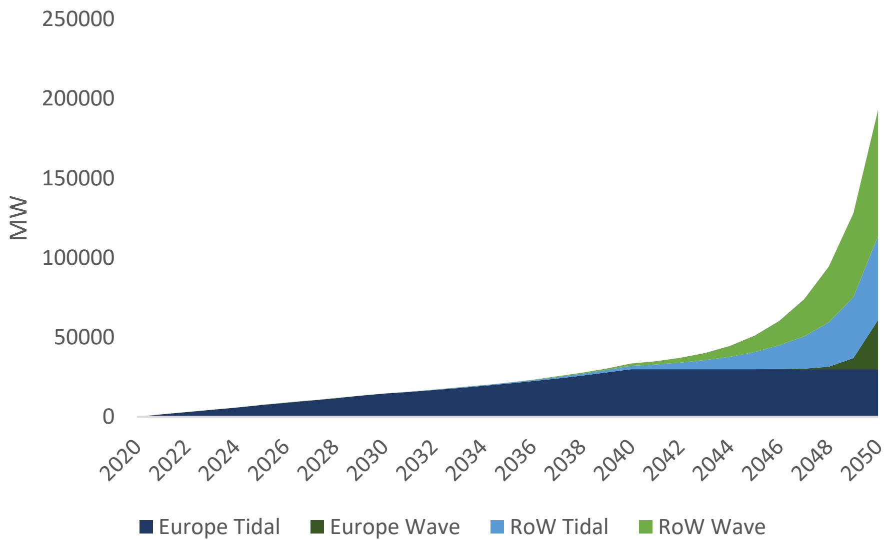

Figure 21 Global deployment (MW) to 2050 under SET Plan 2 Scenario, which adheres to the JRC-TIMES-EU time-step model outputs for European deployment

Results - presented in Figure 22 and Table 15 below - show that trajectory followed by the deployment has a significant impact on economic benefit in the sense that earlier deployments cost more than later ones and therefore incur greater GVA. In this sense, the impact is great when deployment is front- or back-loaded; the GVA associated with later deployment is lower than GVA associated with earlier deployments.

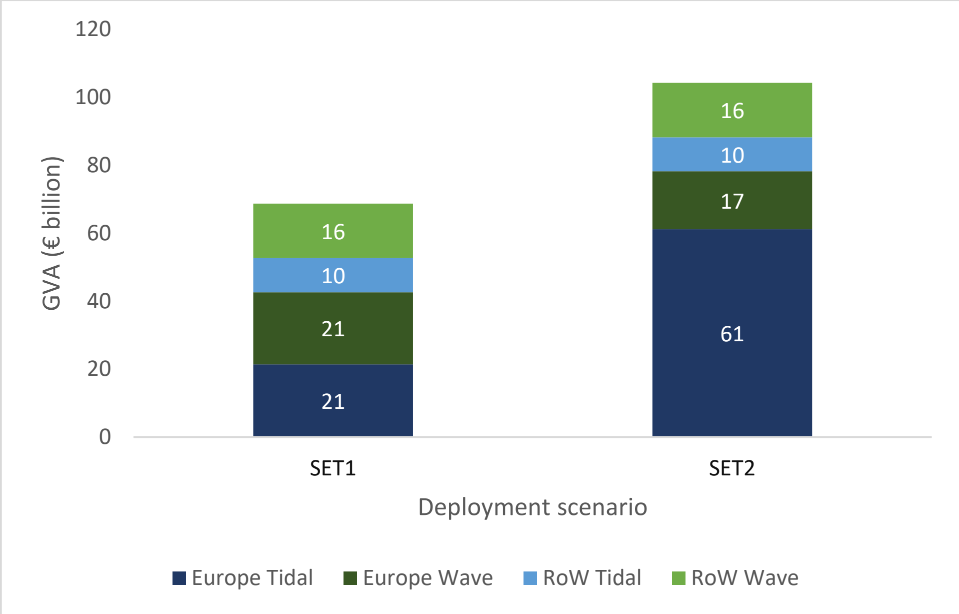

Figure 22 Sensitivity of GVA results to deployment trajectory, assessed across the two SET Plan Scenarios

Table 15 Difference in GVA results across SET Plan scenarios 1 and 2

	Europe		*Rest of the World*		*Global*
Scenario	Spend (excluding subsidy)	Total GVA	Spend (excluding subsidy)	Total GVA	Overall economic benefit
SET Plan 1	€51bn	€43bn	€31bn	€26bn	€151bn
SET Plan 2	€94bn	€78bn	€31bn	€26bn	€229bn

Comparison of results for the two trajectories

- Both wave and tidal follow an exponential trajectory, passing through OEE and DG-MARE's 2030 low target of 1.3 GW and 0.1 GW of tidal and wave, respectively, of which around 90% is deployed in Europe.
- Of the two, this scenario reflects the most probable - and feasible - pathway for both technologies. The gradual and exponential increase in deployment would allow for the development of specialised supply chains with minimal governmental support.
- Relative to SET Plan 2, the overall GVA results are lower. This is because the European deployment occurs much later, and at a similar rate as the rest of the world, when costs are lower.

Discounting for inflation also impacts on the total GVA results, such that deployments further in the future will have a lower impact on the final figure, and that this will be discussed more fully in the next subsection.

11.3.1 Discounting

For the sole purpose of assessing the impact of discounting on the economic benefit, undiscounted results were calculated in addition to the primary discounted results.

Given the compound impact of inflation on currency value over time, the analysis of sensitivity around discounting relates closely to deployment trajectory sensitivity analysis presented in Section 6.6. As such, early deployment minimises inflation's effect. This further emphasises the trade-off between economic benefit and costs incurred discussed in the same section. The results of this sensitivity analysis are presented at low leakage in Figure 23.

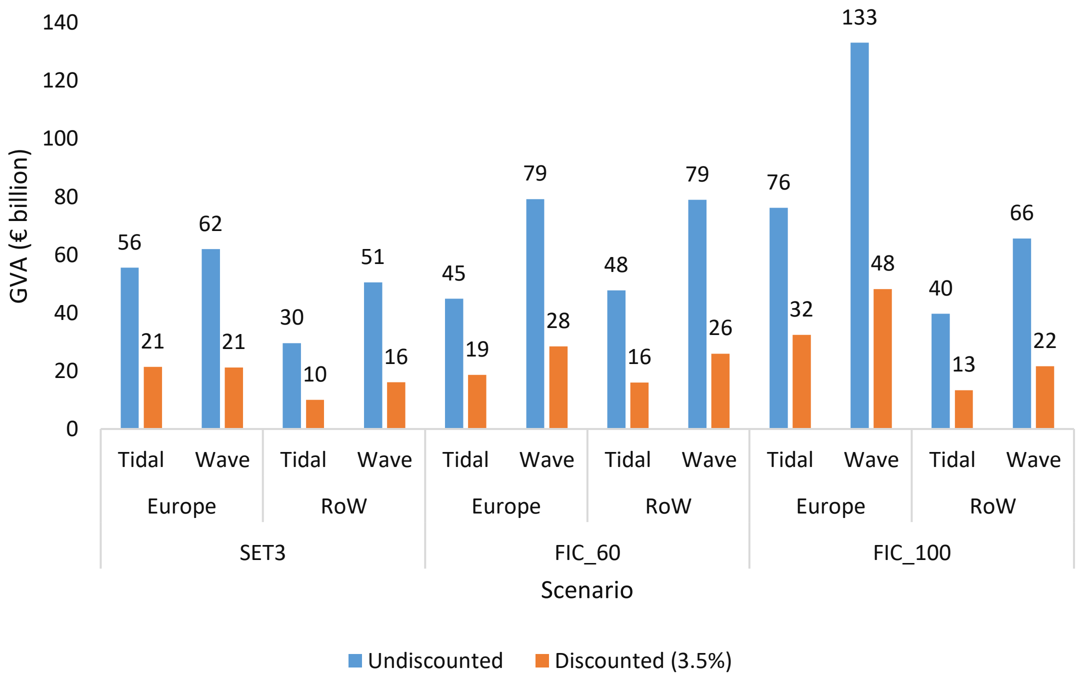

Figure 23 Sensitivity of GVA results to discounting (low leakage rates applied)

The biggest impact is on benefits generated by spend outside Europe for both wave and tidal technologies. This is due to the exponential, and therefore later, trajectory more than any particular characteristics of domestic/international deployments.

Furthermore, discounting significantly impacts on the final result. Care should be taken when comparing GVA results between studies to make sure that time frames and discount rates are taken into account.

With costs falling over time, earlier deployment costs more in terms of subsidy than later deployments. With time, the domestic supply chain can develop organically – to an extent – with less need for governmental intervention. Non-subsidy governmental support could include deployment and cost reduction targets, financial incentives, and research and development grants.

11.4 Appendix 3: Faster Innovation Case with 50 GW in Europe

The IEA-ETP-TIMES 2020 output for the FIC posits that 50 GW of the 293 GW global total could occur in Europe. Deployment of wave and tidal in and out-with Europe is presented in *Figure 24* and Table 9.

In acknowledgement of this output, this study calculated the GVA associated with this 50 GW share of total FIC deployment. The result is presented in *Table 19*, alongside the two primary results by way of comparison.

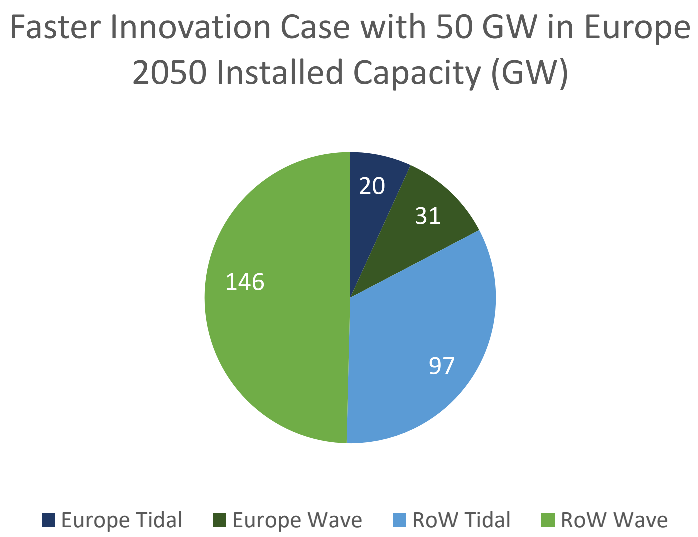

Figure 24 2050 installed capacity (GW) of wave and tidal in Europe and the rest of the world, when Europe takes a 50 GW share of the FIC

Table 16 Low European shares of the FIC's 293 GW 2050 installed capacity (GW)

	Low share	
	Europe	RoW
Tidal stream	20	97
Wave	30	146

Ocean	**50**	**243**

11.4.1 FIC with low European share

In this variation of the three Faster Innovation Case scenarios, the EU achieves 50 GW, the lowest share of 293 GW global total, by 2050. This scenario aligns with the IEA-ETP-TIMES FIC output in terms of global deployment and its European component. Please see Section 6.3.3 for details of this modelling. Global deployment under this scenario is charted in Figure 25.

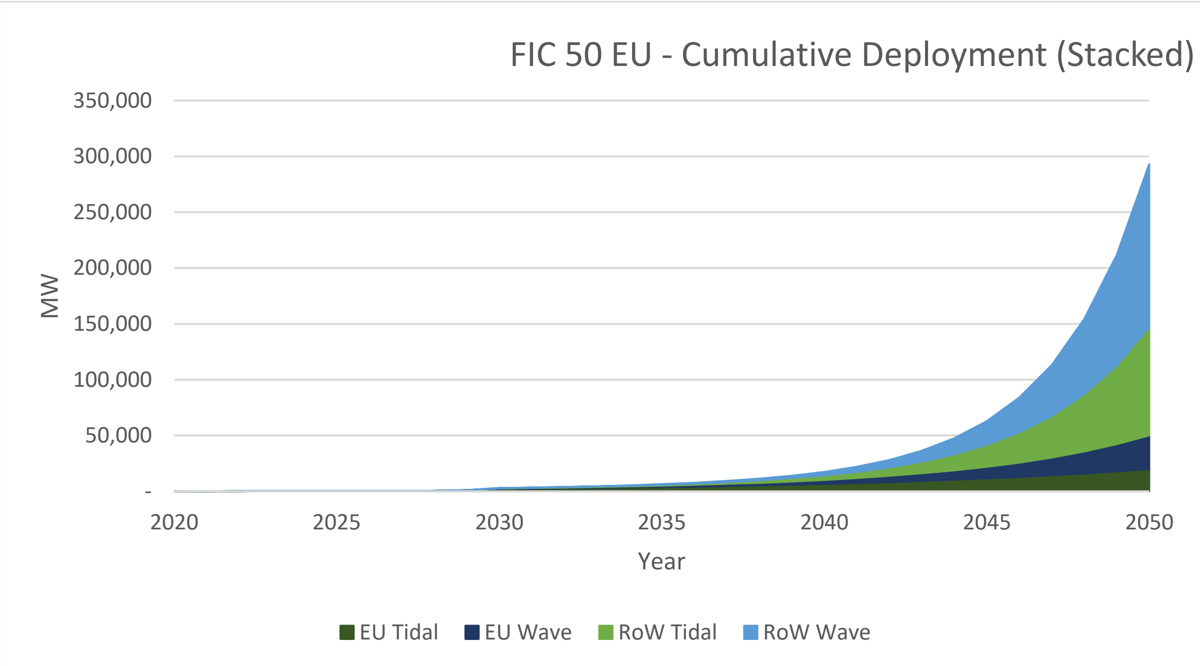

Figure 25 Cumulative installed capacity under the FIC with 50 GW deployed in Europe

Low leakage

- This scenario would generate €84bn in Type I GVA for the European economy.
- To develop and deploy this scenario, a total direct spend of €101bn would be required.
- Therefore, this scenario yields a net economic benefit of €185bn to the European economy, less any subsidy awarded by Member States at the national level.
- The discounted results from this scenario are presented in Table 17 below.

Table 17 Low leakage economic benefit results for the Faster Innovation Case with low EU share

		2050 Installed Capacity (GW)	Leakage Rate	Direct Spend (€ billion)	Indirect GVA (€ billion)	GVA (€)/ MW
European Deployment	Tidal	20	10%	€ 19	€ 16	€ 811,081
	Wave	30	10%	€ 29	€ 24	€ 803,991
Rest of World Deployment	Tidal	97	75%	€ 20	€ 17	€ 171,650
	Wave	146	75%	€ 32	€ 27	€ 185,588
Global Deployment	Tidal	117	-	€ 39	€ 33	€ 280,768
	Wave	176	-	€ 61	€ 51	€ 291,117
Global total	**Ocean**	**293**	**-**	**€ 101**	**€ 84**	**€ 286,978**

High leakage

- This scenario would generate €43bn in Type I GVA for the European economy.
- To develop and deploy this scenario, a total direct spend of €52bn would be incurred.
- Therefore, this scenario yields a net economic benefit of €95bn to the European economy, less any subsidy awarded by Member States at the national level.
- The discounted results from this scenario are presented in Table 18 below.

Table 18 High leakage economic benefit results for the Faster Innovation Case with low EU share

		2050 Installed Capacity (GW)	Leakage Rate	Direct Spend (€ billion)	Indirect GVA (€ billion)	GVA (€)/ MW
European Deployments	Tidal	20	30%	€ 15	€ 13	€ 644,158
	Wave	30	30%	€ 22	€ 19	€ 625,326
Rest of World Deployments	Tidal	97	95%	€ 8	€ 6	€ 64,960
	Wave	146	95%	€ 6	€ 5	€ 37,118
Global Deployments	Tidal	117	-	€ 23	€ 19	€ 163,799
	Wave	176	-	€ 29	€ 24	€ 137,494
Global total	**Ocean**	**293**	**-**	**€ 52**	**€ 43**	**€ 148,016**

Table 19 Difference in low leakage Type I GVA results when Europe takes a 50 GW, 60 GW and 100 GW share of the Faster Innovation Case

	Europe		*Rest of the World*		*Global*
Scenario	Spend (excluding subsidy)	Total GVA	Spend (excluding subsidy)	Total GVA	Overall economic benefit

FIC with 50 GW in Europe	€48 bn	€40 bn	€52 bn	€44 bn	€185 bn
FIC with 60 GW in Europe	€57 bn	€47 bn	€50 bn	€42 bn	€196 bn
FIC with 100 GW in Europe	€97 bn	€81 bn	€42 bn	€35 bn	€254 bn