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Assessing Mission-Oriented Government Strategies' Contribution to Wave Energy Implementation: A Comparative Study of Pioneering Countries Using Mariana Mazzucato's Framework

Author: Paula Patrīcija Avotiņa
1408976

Supervisor: Prof. Dr. Dave Huitema

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Abstract

Wave energy is one of the emerging ocean renewable energy sectors. Although wave energy has the potential to provide clean energy, wave energy technologies are in the pre-commercial stage, facing barriers such as a lack of public and private investments and policy documents for wave energy development at the national level. This thesis analyses whether and how five pioneering countries - Australia, Canada, Ireland, Portugal and Scotland - are using Mariana Mazzucato's key pillars for a mission-oriented approach in wave energy development. Mariana Mazzucato's book "Mission Economy: A Moonshot Guide to Changing Capitalism" is used as a theoretical basis, as well as document analysis and interviews to obtain results. The results show that Ireland, Portugal and Scotland are more proactive in developing wave energy, taking advantage of R&D funding opportunities and improving the available infrastructure for testing wave energy technologies. Australia and Canada are more reactive, highlighting a lack of national-level policy coordination and long-term support. The main challenges that emerged in all countries are sufficient and long-term financial support for wave energy, wave energy policies and development strategies, as well as infrastructure development. On the basis of using the mission-oriented approach to promote the commercialisation of wave energy technologies, this thesis concludes that wave energy could be made as one of the puzzle pieces in the transition to renewable energy sources.

Keywords: wave energy, mission-oriented innovation, Mariana Mazzucato, offshore renewable energy, government policy, funding mechanisms, public-private partnerships

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Liels paldies par atbalstu!

List of Abbreviations

AUD	Australian dollar
AMETS	Atlantic Marine Energy Test Site
AORES	Australian Ocean Renewable Energy Symposium
ARENA	Australian Renewable Energy Agency
CAN	Canadian dollar
CEFC	Clean Energy Finance Cooperation
CET	European Clean Energy Transition Partnership
CER Act	Canadian Energy Regulator Act
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DCCEEW	Department of Climate Change, Energy, the Environment and Water
DECC	Department of Environment, Climate and Communications
DFO	Fisheries and Oceans Department of Canada
DGEG	Directorate-General for Energy and Geology of Portugal
EMEC	European Marine Energy Centre
EMFAF	European Maritime, Fisheries and Aquaculture Fund
EPSRC	Engineering and Physical Sciences Research Council
EVE	Ente Vasco de la Energía, Basque Country
FCT	Foundation for Science and Technology
FEUP – CIIMAR	Marine Energy and Hydraulic Structures Research Group
GHG	Greenhouse gas emissions
GHw	Gigawatt hours
H2020	Horizon 2020 research and innovation funding programme of the EU
ICE Fund	Innovative Clean Energy Fund
kW	Kilowatt
MAC	Maritime Area Consent
MaREI	Research Ireland Centre for Energy, Climate and Marine
MIS	Mission-oriented Innovation System
MOIP	Mission-oriented Innovation Policy
MW	Megawatt
NOTF	National Ocean Test Facility
NRC	Natural Resources Department of Canada
OCEANERA-NET	Ocean Energy European Research Area Network

ORE Catapult	Offshore Renewable Energy Catapult
ORER	Offshore Renewable Energy Regulation of Canada
PDF	Prototype Development Fund
PPA	Power Purchase Agreement
PRIMED	Pacific Regional Institute for Marine Energy Discovery
RO	Renewables Obligation
R&D	Research and Development
RD&D	Research Development and Demonstration
SEAI	Sustainable Energy Authority Ireland
SME	Small and medium enterprise
SREPs	Smart Renewables and Electrification Pathways Program of Canada
TRL	Technology Readiness Level
UCC	University College Cork
UMACK	Universal Mooring, Anchor & Connectivity Kit
WCWI	West Coast Wave Initiative
WEC	Wave Energy Converter
WES	Wave Energy Scotland
ZLT	Technological Free Zones in Portugal

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1. Introduction

To reach net zero by 2050, the transition to renewable energy must be encouraged while meeting the growing needs of energy consumption. Current renewable energy research is shifted towards the exploitation of ocean energy, as oceans cover ¾ of Earth's surface (Wilberforce, et al., 2019). With the development of the blue economy, which includes ocean-based industries, social, environmental and economic challenges in the future could potentially be addressed (OECD, The Ocean Economy in 2030, 2016). Ocean energy is anticipated to contribute significantly to the diversification of renewable energy sources in the future (OECD, The Ocean Economy in 2030, 2016). However, the historic COP21 accord and its support for renewable energy should eventually help both offshore wind and ocean energy capabilities. For this research, focus will be put on one of the ocean renewables – wave energy.

Despite being relatively new and not yet economically competitive with more established technologies like wind energy, governments, and private sectors are becoming more and more interested in wave energy technology (Clément, et al., 2002). In addition, wave energy has the highest energy density, compared to other renewables, meaning that wave energy can provide 15-20 times the amount of energy that is accessible per square meter compared to solar or wind (Vining & Muetze, 2007). Ocean waves' constant ebb and flow offer a limitless supply of renewable energy that might far surpass the current energy demand (Lewis A. , et al., 2011). However, the International Energy Agency has concluded that before 2030 it is unlikely that wave energy converters (hereinafter WEC) will have a significant impact due to the necessity of scaling up the technology to withstand the high commercial risk and offshore conditions (Dalton & Gallachóir, 2010). Accelerating the development and application of WEC requires the creation of suitable wave energy policies and practical procedures.

The kinetic energy of wind, transferred to the ocean's upper surface, creates wave energy, which is consistent enough to generate base load energy (Arvizu, et al., 2011). The energy from ocean waves is captured by WEC. WEC is recommended to be installed between latitudes 30° and 60°, where the largest yearly wave power occurs (Arvizu, et al., 2011). WEC can be classified into three categories: oscillating body converters, which are floating or submerged devices that use wave motion (up/down, forwards/backwards, side to side) to generate electricity; oscillating water columns, which use trapped air pockets in a water column to drive a turbine; and overtopping converters, which use reservoirs to create a head before driving turbines (Kempener & Neumann, 2014). WEC, vessels, and other equipment must be installed at one of the three sites—shoreline, nearshore, or offshore—where power generation is anticipated to take place (Wilberforce, et al., 2019). It is predicted that the total theoretical wave energy potential is 32,000 TWh/yr (115 EJ/yr), which is about double the amount of electricity produced worldwide in 2008 (Lewis, et al., 2011). Although the first WEC started to develop after the first oil crisis in 1973, most of the WEC are still in the pre-commercial phase (Lewis, et al., 2011). Due to being still in the pre-commercial phase, compared to other renewable energy sources like offshore wind and tidal current technologies, wave energy farms (10 MW) are expected to have levelized costs of between EUR 330 and EUR 630/MWh (Kempener & Neumann, 2014). Wave energy has rather high costs, given its early development however, there is a significant chance that costs could be lowered.

On one hand, when looking at the environmental impact of WEC, wave energy does not directly emit CO2, however, greenhouse gas emissions (hereinafter GHG) can be generated during the life cycle of these technologies, such as raw material extraction, construction, maintenance and decommissioning (Lewis, et al., 2011). Other potential impacts on the environment are noise pollution, mainly during construction and decommissioning, disruption to marine life, and competition for limited space in the ocean (Lewis, et al., 2011). On the other hand, WEC can attract new marine life. In addition, it is unclear whether electromagnetic fields from sea cables impact migration patterns.

Besides being in the pre-commercial stage, wave energy faces similar barriers as offshore wind energy, such as the need for both public and private investments, lack of sufficient infrastructure for offshore grid connections, e.g., port facilities, licensing procedures for WEC deployment to avoid potential conflict between maritime users, e.g., trade, fishing, tourism. To connect the arrays, wave energy farms placed farther offshore and in deeper waters will need specialised substation designs, unique undersea power, and cost-effective long-distance grid connections (Kempener & Neumann, 2014). In addition, coastal communities engaged in marine activities might not be supportive towards wave energy farm installation, therefore licensing and planning procedures need to be comprehensive enough to consider all possible activities in the planned deployment area. These challenges that wave energy faces can be resolved with governments taking the lead role in wave energy development, such as government investments, setting ambitious targets, as well as creating networks to ensure collaboration with industry and researchers.

1.1. Research question and objectives

This research aims to analyse using Mariana Mazzucato's book "Mission Economy: A Moonshot Guide to Changing Capitalism" key pillars, such as governments' co-creating and distributing market value for inclusive growth, implementing public-private partnerships, having a vision that has societal relevance, and taking financial risks, as a normative standard of wave energy implementation in countries. Through an analysis of case studies of wave energy implementation in leading nations, this study aims to highlight whether pioneering nations are implementing wave energy following the main tenets outlined in Mariana Mazzucato's book or not, and what lessons can be drawn from their experiences. Assessing the role of governments in wave energy development, analysing how Mariana Mazzucato's fundamental principles are applied in wave energy policies, and evaluating (mostly ex-ante) the success of mission-oriented strategies in wave energy policies and outlining lessons learned are some of the research objectives.

For this research project following research question was put forward: *How are governments taking up their role in the development of creation and commercialisation of wave energy, and how much of Mariana Mazzucato's mission-economy approach is being used in wave energy policy frameworks?*

To answer the research question, multiple subquestions were formulated:

1. Which interventions are leading countries making in order to realize the potential of wave energy?
2. To which degree are these interventions (seen as) promising or successful in accelerating the adoption of wave energy, and which interventions are having (or expected to have) the most impact (so far)?
3. To which extent do the identified successful interventions align with the ideas propagated by Mariana Mazzucato on how to stimulate innovations towards sustainable development?
4. To which degree do the conclusions of this study give rise to amending the model that Mazzucato developed?
5. What lessons can be learned from the experiences of pioneering countries in using mission-oriented strategies to support the development of wave energy?

This research project is divided into six chapters, counting this introduction. The second chapter of this work is dedicated to the theoretical framework, describing mission-oriented innovation policies and the seven key pillars outlined in Mariana Mazzucato's book " Mission Economy: A Moonshot Guide to Changing Capitalism " that are necessary for a mission-oriented economy. The third chapter will be devoted to the methodology that will be used during this research, namely the qualitative case study approach using document analysis, comparative analysis, and semi-structured interviews. The fourth chapter is dedicated to the results of case studies, namely, the wave energy policies of five pioneering countries - Australia, Canada, Ireland, Portugal and Scotland - will be analysed, as well as comparing the implementation of Mariana Mazzucato's key pillar between countries in wave energy development policies. The fifth chapter – discussion - focuses on the role of governments in implementing wave energy and the alignment of their actions with the use of Mariana Mazzucato's key pillars, and the sixth chapter will be devoted to conclusions.

2. Theoretical Framework

2.1. Introduction

Once, missions were associated with large-scale technology and research policy initiatives driven by the Cold War superpower competition and national pride, while now missions are being presented more and more as a promising strategy for bringing together a variety of innovative skills to tackle challenging societal issues (Janssen, et al., 2023). Missions can be understood as emerging governance mechanisms which allow for the involvement of a wider range of stakeholders, implementing innovative activities of the parties around an objective of societal significance (Janssen, Torrens, Wesseling, & Wanzenböck, 2021). Missions can also emerge from negotiations and their outcomes between interested parties, their imperatives and concerns, which are neither neutral nor apolitical (Janssen, Torrens, Wesseling, & Wanzenböck, 2021). Missions are found where two systems converge - the socio-economic system and the innovation system - which both create and subject changes that address societal problems (Janssen, Torrens, Wesseling, & Wanzenböck, 2021). To regularly evaluate progress toward the mission, missions should be both broad enough to spark a wide range of industries and detailed enough to convert into tangible issues that need to be resolved (Mazzucato, 2016). Missions have the power to steer change, which is necessary to solve societal issues.

Innovation policies focus on addressing societal challenges, thus changing socio-economic systems. The previous two generations of innovation policies mainly focused on fixing market failures by focusing on market failure strengthening national innovation systems and repairing the private sector’s underinvestment in Research and Development (hereinafter R&D) (Hekkert, Janssen, Wesseling, & Negro, 2020). For the third-generation innovation policy, the concept mission is used to address societal problems. Therefore, societal challenge-based missions are used as an urgent strategic goal that requires a transformative change to overcome wicked societal problems (Hekkert, Janssen, Wesseling, & Negro, 2020). The term “transformation failures” legitimises government intervention intending to influence the direction of the innovation system towards solving societal problems (Kattel & Mazzucato, 2018). One of the most noticable drivers of this third-generation innovation policy is the European Commission’s R&D framework “Horizon 2020” (hereinafter H2020).

To understand how wave energy has developed in Australia, Canada, Ireland, Portugal and Scotland, a theoretical framework for this thesis is built on three theoretical frameworks: 1) Mariana Mazzucato’s framework for mission-oriented economy, 2) the comparable Utrecht

University’s Mission-oriented Innovation Policy Observatory’s, and 3) OECD’s designs for mission-oriented innovation policy. Besides using Mariana Mazzucato’s theoretical framework, which is the main theory used to see whether Mariana Mazzucato’s theory for mission-oriented innovations is applied in wave energy development, Utrecht University’s Mission-oriented Innovation Policy Observatory and OECD’s frameworks for mission-oriented innovations are used to better understand how missions work and how policymakers can shape mission-oriented innovations. As Mariana Mazzucato focuses on the seven principles of how to achieve mission-oriented innovations, Utrecht University and OECD offer in-depth on how policy coordination and implementation of the missions should be created and how the mission-innovation systems work, which complements Mariana Mazzucato’s framework. In the introductory part of this chapter, missions and innovation policies are described, followed by the first section, which focuses on Mariana Mazzucato’s book “Mission Economy: A Moonshot Guide to Changing Capitalism” and the seven key pillars used in this research. The second section focuses on Utrecht University’s and OECD’s frameworks to give more insights into how missions work in policy coordination and implementation stages, which covers policy implementation and stakeholder collaboration more in depth.

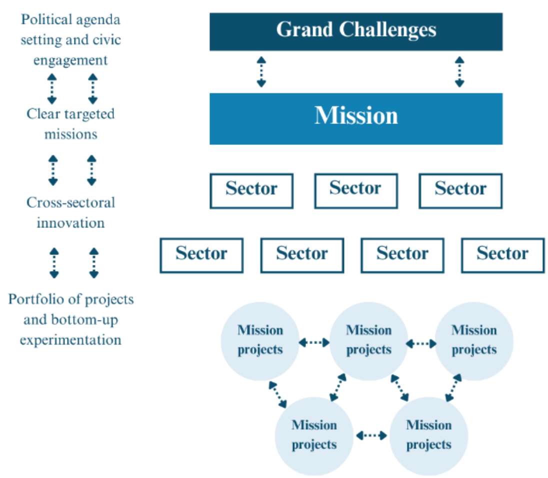
2.2. Mariana Mazzucato’s “Mission Economy: A Moonshot Guide to Changing Capitalism” – key pillars for mission-oriented economy

Mariana Mazzucato's book "Mission Economy: A Moonshot Guide to Changing Capitalism" highlights the necessity of transitioning to a mission-oriented economy to tackle social issues with governments being risk takers and developing long-term thinking (Mazzucato, 2021). In addition, more citizen engagement in the mission’s vision is required. The idea for a mission-oriented approach comes from the Apollo 13 mission and its success. Key features highlighted in the Apollo 13 success are the government’s leadership with vision and purpose, which involved behavioural, social and political factors with wide citizen engagement; risk-taking and experimentation in the innovation sector; organisational change ensuring flexibility; effect of spillovers as innovations are characterised by unpredictable spillovers; ensuring outcome-based financing; by common purpose created partnerships (Mazzucato, 2021). All these components are vital also nowadays for ensuring a mission-oriented approach to tackle societal problems, such as climate crisis.

For guiding mission-oriented organisations, Mariana Mazzucato suggested using the acronym ROAR – routes and directions; organisations; assessment; risks and rewards (Mazzucato, 2021). Routes and directions emphasise setting the direction of change motivation innovation (Mazzucato, 2021). Organisations focus on building dynamic partnerships with private and third-sector partners, while assessment elaborates on evaluating the dynamic effects of investments that create markets (Mazzucato, 2021). Risks and rewards highlight the need for establishing mutually beneficial agreements between the public and private sectors to share risks and benefits (Mazzucato, 2021). These four components allow for successfully guiding mission-oriented organisations.

For mapping the mission-oriented approach, Mariana Mazzucato offers a mission map (see Figure 1). The idea behind the mission map begins by trying to answer the question of what problem it wants to solve (Mazzucato, 2021). Depending on the response, the problem is presented as an objective to stimulate new partnerships and stimulate investments and ideas across various industries.

Figure 1: Mission map



Source: (Mazzucato, Mission Economy: A Moonshot Guide to Changing Capitalism, 2021)

2.2.1. Seven principles for mission economy

Mariana Mazzucato, in her book, highlighted seven key principles for a mission-oriented economy that focuses on addressing societal challenges with the government's taking the leadership position. These seven principles are collective value creation, market shaping, dynamic capabilities for public and private organisations, outcome-based financing, value distribution, public-private partnership with stakeholder value, and participation in co-creating the value (Mazzucato, 2021).

Collective value creation: collective value creation is the first step for defining objectives for the mission and achieving them. Investments that are focused on problem-solving require a renewed understanding of public purpose, therefore creating policies that are driven by public and not private interests and value, as well as a framework for market co-creation (Mazzucato, 2021). Public interest and public goods should be seen as common objectives, not market failures, which require adequate capabilities and knowledge for planning and managing public goods implementation involving different interest groups (Mazzucato, 2021). Public value creation should follow the question of whether public values endorsed by society have been provided or guaranteed (Mazzucato, 2021).

Market shaping: collectively co-created value requires a policy that creates and shapes markets, not just fixes them by allowing the private sector to create the markets, therefore putting in the centre the question of what kind of market the public wants (Mazzucato, 2021). Market shaping is the government's proactive action for building a new market and associated ecosystem with it, therefore pushing technological market frontiers (Mazzucato, 2021). Market shaping requires mission-oriented investments, market creation and governance mechanisms, e.g., patents. Therefore, governments are the ones creating and shaping new markets with innovations and policies to inspire various actors who are able to identify investment opportunities, not leaving the market only to the private sector and providing public funding only when the market has problems and governments need to fix them (Mazzucato, 2021).

Dynamic capabilities for public and private organisations: market shaping and co-creation of value require both public and private organisations' dynamic capabilities for learning and experimentation (Mazzucato, 2021). Some of the capabilities for the government to use to achieve mission-oriented goals are leadership and engagement for market shaping and co-creation of the value, as well as encouraging bottom-up engagement; coordination and ability to find coherent policy mixes; administrative capabilities; risk-taking and experimentation; evaluation capabilities, including putting citizens in the centre (Mazzucato, 2021). Dynamic capabilities, part of core competencies, help organisations develop and improve resources.

Outcome-based financing: spending and investment are given the exact directionality they need by missions to increase productive capacity in the intended direction (Mazzucato, 2021). A system of public organisations investing in long-term growth areas, such as the primary drivers of productivity (research and education), attracts private sector investment when public investment is done strategically (Mazzucato, 2021). When creating an outcome-based approach, finances will serve the economy, not vice versa, therefore creating an economy that works for societal goals.

Value distribution: creating collective value and shaping the market, it makes sure to ensure equal predistribution and redistribution. The allocation of this value should be based on the premise that value creation is a team effort (value) that calls for experimentation and risk-taking (capabilities) as well as suitable and organised funding (finance) (Mazzucato, 2021). This can be achieved by rewarding the entire set of value creators, finding the opportunity to restore this value by investing in creativity and replenishing sources of funding (Mazzucato, 2021). If the value is created collectively, it needs to be distributed equitably, therefore not only rewarding stakeholders but also communities, workers and the environment.

Public-private partnership with stakeholder value: the emphasis here is put on how the collaboration with stakeholders is designed, meaning moving away from parasitic partnerships to symbiotic ones. In essence, stakeholder value should be viewed as a means of producing differently. It gives various economic actors a reason to interact and create value for the common good, which means that the value produced is reinvested into the larger group of actors, including society (Mazzucato, 2021). One of the examples mentioned was patent pools, which are agreements between patent owners to allow different parties to use and manage intellectual property jointly.

Participation in co-creating the value: new forms of participation in the value creation process should be implemented for revitalising debate, discussion and consensus building (Mazzucato, 2021). New, decentralised forums are needed to facilitate discussion, debate, and consensus. The participatory system must be open to change, and adaptation based on feedback, thus preventing tokenistic participation (Mazzucato, 2021). The understanding that value is jointly created by several parties, such as companies, workers, and local and federal governments, must be the first step in a stakeholder approach to value (Mazzucato, 2021). It is vital to provide a mission statement for diverse stakeholders to collectively envision the future.

2.3. Mission-oriented innovation policy

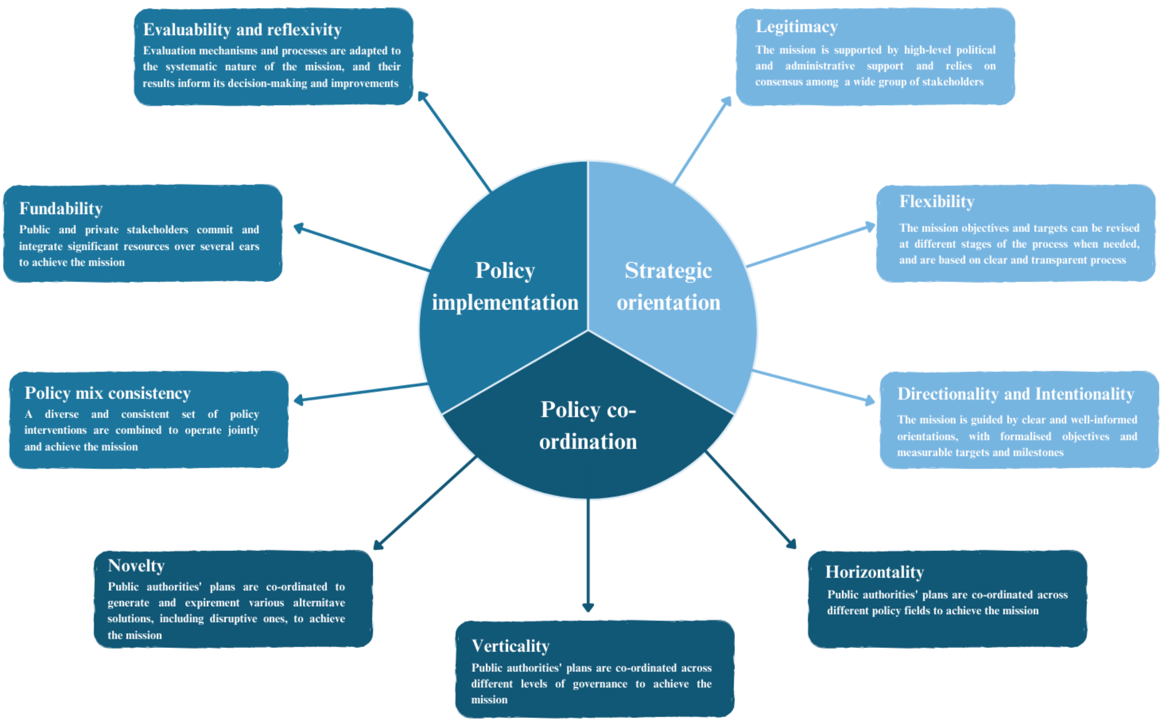
Policy missions are about direction and, therefore, about concrete problems to be solved (Kattel & Mazzucato, 2018). The concept of mission-oriented policies originated from military and space areas, e.g., the Apollo 13 programme, therefore, historically, military-driven innovations were characterised as mission-oriented, as they sought to accomplish well-defined technological objectives (Larrue, 2021). For supporting transitions, mission-oriented policies require a wide range of participants and systematic policy with complementary instruments, such as public investments, that could attract private investments.

While Mariana Mazzucato invites to rethink the current economic system with governments taking the lead in the market and investments focusing on missions following seven key pillars, the OECD has defined its own mission-oriented innovation policy that follows three dimensions of strategic coordination, policy coordination and policy implementation, that complements Mariana Mazzucato's seven key pillars (Larrue, 2021). According to the OECD, which also builds upon other Mariana Mazzucato's works besides her "Mission Economy" book, mission-oriented innovation policy (hereinafter MOIP) is a coordinated set of legislative and regulatory actions designed to mobilise innovation, technology, and science to fulfil clearly stated goals associated with a societal challenge within a certain timeframe (Larrue, 2021). MOIP relies on setting the purpose or having a mission for public investment, e.g., science meets problems and creates conditions for new markets, e.g., spillover effect from science to new demand and supply (Kattel & Mazzucato, 2018). A market-shaping framework for public investment and policy, MOIP seeks to change the course of innovation systems (Kattel & Mazzucato, 2018). Therefore, MOIP is a deliberate choice not to base public sector operations on the market failure approach, therefore indicating that governments should take a leadership position for creating policies and ensuring public investments that address societal challenges and attract private investments, similarly highlighted in Mariana Mazzucato's "Mission Economy" books. Public agencies have been compelled by mission-driven innovation to not only "de-risk" the private sector but also take the lead in directly developing new market environments and technical prospects (Mazzucato, 2016). A policy framework provided by MOIP enables the public sector to get past persistent issues with policy coordination (Kattel & Mazzucato, 2018). In addition, Utrecht University offers to divide MOIP into three aspects: policy focus to address societal challenges with innovations and innovative solutions; legitimacy of policy intervention for overcoming "transformative failures", such as market failures and government failures and describes how such policies can affect other forms of science, technology, and innovation policy (Janssen M. , 2022). MOIP is characterised as a policy aimed at meeting measurable and ambitious societal goals. To complement the Marina Mazzucato framework, which includes seven key pillars, and the vision of all three - Mariana Mazzucato, OECD, and Utrecht University - on MOIP, the following sections will focus on the OECD approach to MOIP, namely the three main MOIP dimensions - strategic orientation, policy coordination, policy implementation, and the Utrecht University approach to MOIP, namely the creation of mission-oriented innovation systems and their recommendations for implementing mission-oriented goals.

2.3.1. Main dimensions: strategic orientation, policy coordination, policy implementation

Since 2019, the OECD has worked to develop its own analytical framework for MOIPs, which are built on three main dimensions: strategic orientation, policy coordination and policy implementation, which is implemented by collective action (see Figure 2) (OECD, 2024). MOIP includes a collectively developed agenda, a governance structure that monitors and accepts the impact of joint decisions, and a deliberately designed "joined-up" policy mix (OECD, 2024). MOIP maintains a close two-way flow of decisions and information between these three building blocks.

Figure 2: Mission-oriented innovation policy design principles



Source: (OECD, Mission-Oriented Innovation Policies for Net Zero: How Can Countries Implement Missions to Achieve Climate Targets?, 2024)

The first function of the MOIP is to provide an institutional space for private and public stakeholders to ensure the creation of common objectives and a strategic agenda for solving problems (OECD, 2024). According to the OECD, defining missions begins with broad challenges, so most mission work relies on creating a consensus and precise strategic agenda that will guide the collective work (OECD, 2024). Missions are chosen and developed together with all relevant parties during the strategic orientation phase, and specific goals are established with anticipated outcomes (OECD, 2024). State institutions mainly acquire a moderating role in strategic agenda-setting, but they retain the ability to intervene in the actual direction of decisions.

In the policy coordination phase plans from various government actors in control of various elements, like finance and technologies, are coordinated to accomplish goals that have been agreed upon by all (OECD, 2024). The MOIP brings together policy structures responsible for different stages of the innovation chain from research to deployment across various components of innovation systems, such as infrastructure, regulations, R&D, and skills (OECD, 2024). To establish shared objectives, track and enhance them, match their plans with these objectives, and determine whether investments and actions are necessary, this diverse group of mission partners uses a variety of committees (OECD, 2024). They can vary in terms of mandate, composition, status, and level of decision-making, such as operational or strategic.

In the policy implementation phase, the needed interventions are designed to achieve the policy's objectives, which include employing a wide range of programs and policy measures to assist a variety of activities, from market launch and capacity building (OECD, 2024). Varied missions have varied levels of integration: some missions function as a "single initiative", combining several interventions, while others only offer routine operational coordination and information exchange between different policy bodies.

OECD provides a methodology, namely three dimensions, to examine whether national governments are implementing MOIP. The OECD framework draws similarities to Mariana Mazzucato's theoretical lens on mission implementation in policymaking: shared agenda-setting with the private sector, NGOs and academia, policy coordination and implementation to promote policy change in creating market incentives. While Mariana Mazzucato provides a more detailed framework with seven key pillars that underpin MOIP implementation, the OECD provides a methodological framework that partially covers Mariana Mazzucato's framework, focusing specifically on shared agenda-setting and the role of governments in mission implementation, with less focus on the role of other stakeholders in achieving the mission.

2.3.2. Mission-oriented innovation systems

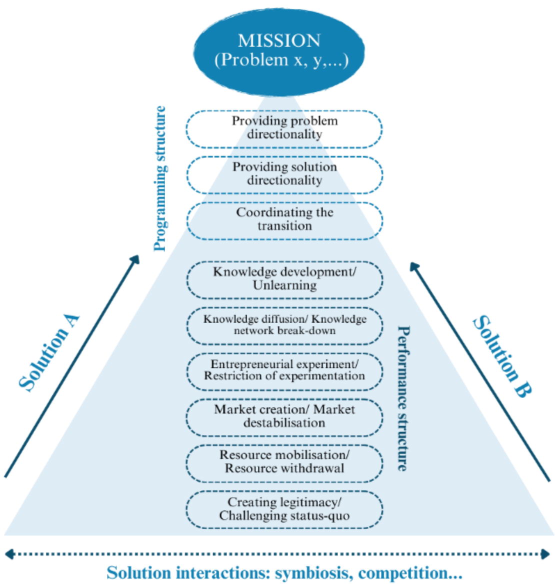
"Missions" for innovation policies can be characterised as the new buzzword for policymakers and policy analysts; however, policy departments are still struggling to implement mission-oriented innovation policies (Hekkert, Janssen, Wesseling, & Negro, 2020). Therefore, for policymakers and policy analysts to understand how to implement mission-oriented innovation policies, mission-oriented innovation systems (hereinafter MIS) were developed by Utrecht University's Mission-oriented Innovation Policy Observatory. To identify, pursue, and accomplish a societal goal, MIS is a network of agents and a collection of organisations that facilitate the development and dissemination of creative solutions (Hekkert, Janssen, Wesseling, & Negro, 2020). The main difference between MIS and other conceptual lenses of innovation is its interaction, such as demand-pull versus supply-push, as well as the final result of this system, which can be new behavioural and technological solutions instead of, for example, the OECD's MOIP framework (Hekkert, Janssen, Wesseling, & Negro, 2020). For example, in the Netherlands, the MIS is composed of civil servants, representatives of NGOs, science and industry, which increases the ability of each party involved to determine the scope of the mission.

Missions ask for combining several technology and non-technological breakthroughs. According to the authors, MIS arises to solve problems, but it will not be immediately clear which actors play a key role in mission execution, thus, depending on which issue is prioritised and how the linked mission is developed, the promotion of the mission may involve actors from various public and private sectors (Hekkert, Janssen, Wesseling, & Negro, 2020). The MIS can currently be considered as a temporary innovation system, recognising its novelty and complexity, in which policymakers and other stakeholders seek to collaborate in innovation coordination to develop a coherent set of technological, behavioural solutions, and institutional solutions (Hekkert, Janssen, Wesseling, & Negro, 2020). MIS actors contribute to mission development for various reasons, such as economic benefits that would accrue to the private sector.

Firstly, MIS also arises from the involvement of various actors in mission formulation, recognising that determining priorities and urgent societal problems is a complex process that requires the involvement of multiple actors (Hekkert, Janssen, Wesseling, & Negro, 2020). It is important to highlight that the actors engaged attempt to sway the mission formation process, for instance, by lobbying or participating in intentional agenda-setting actions, therefore, to manage the scope of innovation activities, the actors involved need to be familiar with how policymakers organise mission formulation processes. Secondly, MIS is associated with the influence of strong direction. Ambitious goals, ongoing monitoring, and milestone evaluation are likely to be the hallmarks of MIS, which should ideally be defined by perpetual urgency and determination (Hekkert, Janssen, Wesseling, & Negro, 2020). Thirdly, strict guidelines may also have an impact on the degree of technological variety in the innovation system. As a result, potential winners may be chosen early on, which lowers technological diversity, to guarantee that innovation is motivated by immediate outcomes (Hekkert, Janssen, Wesseling, & Negro, 2020).

MIS can be thought of as an analytical tool for examining how actors interact to define and carry out the objective (Elzinga, Janssen, Wesseling, Negro, & Hekkert, 2023). A MIS may include groups of actors involved in different potential solutions to societal challenges that could compete with or complement each other (Elzinga, Janssen, Wesseling, Negro, & Hekkert, 2023). Elzinga, Janssen, Wesseling, Negro and Hekkert (2023) have developed an analytical framework for assessing mission-specific innovation systems (see Figure 3). The framework comprises structural analysis for institutions and actors in the performance and programming structure examination; functional analysis for key process influence to speed up solutions assessment; and problem-solution diagnosis-analysis for the mission's problem framings, solution directions, and interactions (Elzinga, Janssen, Wesseling, Negro, & Hekkert, 2023).

Figure 3: MIS framework, containing a problem-solution diagnosis, a structural analysis and a functional analysis



Source: (Elzinga, Janssen, Wesseling, Negro, & Hekkert, 2023)

Compared to the OECD and Mariana Mazzucato frameworks, Utrecht University's frameworks provide a detailed description of how stakeholders need to collaborate to achieve the mission by working on problem-solution diagnosis. While Mariana Mazzucato's pillars mention collaboration based on symbiotic partnerships, MIS provides a more detailed insight into how stakeholders should interact in developing MOIPs, thus complementing Mariana

Mazzucato's pillars. Both the OECD and MIS frameworks complement the Mariana Mazzucato framework. However, these visions are in some cases utopian, especially in terms of achieving the objectives of all stakeholders equally and including all stakeholders in agenda-setting equally, knowing that Mariana Mazzucato's vision with seven key pillars is more realistic, specifically from the value-distribution perspective, that everyone gains some benefit, but, of course, it also requires some sacrifices.

3. Methodology

3.1. Case studies: Australia, Canada, Ireland, Portugal, Scotland

For this research, Australia, Canada, Ireland, Portugal and Scotland have been chosen as pioneering countries based on the information previously obtained at the beginning of the study. The strategies of all countries that have signed the Paris Agreement for the extraction of wave energy were analysed from October to November 2024. Using the United Nations Nationally Determined Contributions database, 195 countries' reports were analysed using the keywords wave energy, ocean energy, offshore energy and renewable energy.

In total, out of the 195 countries analysed, 64 countries have shown interest, meaning countries have either indicated in Nationally Determined Contributions reports the possibility of exploring wave energy in their renewable energy resources or have research institutes or universities exploring wave energy potential. Countries were divided into five groups, ranging from just research activities in wave energy development to policy development and project implementation. In Group 1, 26 countries out of 64 have researched developing wave energy opportunities in their country, but no further action has been taken. The research has been mainly conducted by universities and research institutes, mainly self-interest driven, seeing the potential for wave energy and presenting reports to the authorities indicating the route of developing wave energy. Group 2 consists of 18 countries that have tested WEC in their territorial waters at least once, but yet no policy development in wave energy has taken place at the national or sub-national level. In Group 3, 8 out of 64 countries, WEC developer companies exist, and national strategies highlight the potential of wave energy as a renewable energy source. Ambitions for the creation of wave energy farms are also highlighted, but there is no consistent state support for the development of wave energy. In 7 countries, which are part of Group 4, there is a significant development of wave energy at the policy level, including the involvement of research institutes, universities and the private sector in international projects for the development of wave energy and getting funds for WEC testing and research, therefore showing the development of wave energy commitment on the international scale, as well as interest in the creation of wave energy farms or even already established ones, however, in some cases, wave energy is indicated in policy documents more as an option than a specific solution for achieving net zero. It should be noted that the previous group can also be included in the list of pioneer countries, however, when analysing how the five pioneer countries were indicated in this master's thesis, Australia, Canada, precisely province of British Colombia, Ireland, Portugal and the UK, more precisely, Scotland, taking into account the number of national test sites, scientific institutes, national agencies in the development of ocean renewable energy resources and the activity of industry and research institutes in the development of wave energy. Table 1 indicates all the countries in all five groups.

Table 1: Wave energy development in the World

Level of development	Countries
Group 1	Antigua and Barbuda, Argentina, Azerbaijan, Bangladesh, Brazil, Cabo Verde, Cuba, Cyprus, Fiji, Greece, Honduras, Italy, Kenya, Kuwait, Malaysia, Maldives, Mauritania, Monaco, Montenegro, Morocco, Oman, Peru, Seychelles, Sri Lanka, United Arab Emirates, Vanuatu **In total: 26**
Group 2	Bahamas, Belgium, Chile, Ecuador, India, Indonesia, Malta, Mexico, Namibia, Netherlands, New Zealand, Russia, Saudi Arabia, Singapore, South Africa, Thailand, Tonga, Vietnam **In total: 18**
Group 3	Barbados, Finland, Ghana, Israel, Japan, Mauritius, Norway, Türkiye **In total: 8**
Group 4	China, Denmark, France, South Korea, Spain, Sweden, USA **In total: 7**
Group 5	Australia, Canada, Ireland, Portugal, United Kingdom **In total: 5**

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3.2. Research design

To address the research question: *How are governments taking up their role in the development of creation and commercialisation of wave energy, and how much of Mariana Mazzucato's mission-economy approach is being used in wave energy policy frameworks?* and subquestions regarding wave energy development in pioneering countries using Mariana Mazzucato's approach, qualitative research methods were used: document analysis, and semi-structured interviews. Qualitative research collects the views, behaviours, and experiences of people, rather than addressing how many or how much, it addresses hows and whys (Tenny, Brannan, & Brannan, 2022). Using these methods has allowed to gain insights into how and why these five pioneering countries have developed wave energy. In addition, comparative analysis was used for analysing and comparing best practices between these five pioneering countries. These countries – Australia, Canada, specifically the province of British Colombia, Ireland, Portugal and the UK, specifically Scotland were chosen based on their investments in wave energy research and development, such as existing test sites, amount of WEC developers, as well as country's provided financial support for wave energy projects, as well as created policies for supporting wave energy development. Table 2 elaborates on the methods used for each research subquestion and for researching wave energy development in five pioneering countries.

Table 2: Subquestions and methods

Subquestions	Methods
Which interventions are leading countries making in order to realize the potential of wave energy?	Document analysis, semi-structured interviews
To which degree are these interventions (seen as) promising or successful in accelerating the adoption of wave energy, and which interventions are having (or expected to have) the most impact (so far)?	Semi-structured interviews
To which extent do the identified successful interventions align with the ideas propagated by Mariana Mazzucato on how to stimulate innovations towards sustainable development?	Document analysis, semi-structured interviews
To which degree do the conclusions of this study give rise to amending the model that Mazzucato developed?	Document analysis, semi-structured interviews
What lessons can be learned from the experiences of pioneering countries in using mission-oriented strategies to support the development of wave energy?	Document analysis, semi-structured interviews, comparative analysis

Before starting the data collection, the theoretical framework was used as a basis for researching how pioneering countries are implementing Mariana Mazzucato's suggested frameworks in developing wave energy. The theoretical framework was used for creating interview questions.

3.3. Data collection

In this research's framework, document analysis and interviews were used to collect data. The following two subsections will describe each of the two data collection methods.

3.3.1. Document analysis

This thesis analysed the laws, strategies, available government program implementation and funding conditions, reports on implemented wave energy projects, discussion papers, action plans for achieving climate goals, and policy briefs of Australia, Canada, Ireland, Portugal, and the United Kingdom, more specifically, Scotland. In total, 75 documents were analysed, which can be viewed in Appendix 1. In addition to documents, the websites of governments and government agencies involved in the development of renewable energy resources in the countries were also analysed to obtain an overall view of the development of wave energy. It should be noted that some of the websites provided additional information on government strategies, funding programs for renewable energy projects, including wave energy, as well as the development of already implemented projects. Document analysis is needed to understand how pioneering countries are developing wave energy through regulations and public funding and whether countries are following Mariana Mazzucato's seven key pillars for mission-oriented innovation policy development.

3.3.2. Semi-structured interviews

To better understand how national regulations and support mechanisms for wave energy development are implemented in pioneering countries, interviews with experts were conducted. The semi-structured interview questions can be found in Appendix 2.

A total of 52 emails were sent out inviting participants to participate in semi-structured interviews. Potential interview participants were selected from government, arm's length institutes, and the private and research sectors. 18 emails were sent to representatives of Australia, 10 to representatives of Canada, 9 to representatives of Ireland, 5 to representatives of Portugal, and 10 to representatives of Scotland. In total, only three interviews were conducted. The list of interviewees can be found in Appendix 3. Interviews took place via Microsoft Teams from December 2024 to January 2025. For data analysis, interviews were recorded and then transcribed.

3.4. Data analysis

A coding method using Atlas.ti software was used to analyse documents and interviews. All available documents in PDF format were uploaded to Atlas.ti, grouped by country folders, as well as interview transcripts. Seven codes were created, corresponding to the seven pillars of Mariana Mazzucato. A codebook with the total number of codes can be found in Appendix

4. The coding was used to group the information according to all seven pillars of mission-oriented innovation, which were used to conduct the comparative analysis.

Using comparative analysis, the fourth chapter compared the involvement of pioneering countries in the development of wave energy in each of the seven pillars, thus investigating which of the pillars each country promotes the development of wave energy more and which does not. The comparative analysis also allows us to highlight the best examples from each country in each of the pillars for wave energy development.

3.5. Ethical considerations

Before interviews, participants received a standard prior informed consent form, which they and the thesis author needed to sign. The informed consent form covered the confidentiality of participants and their consent to the use of data in this study. The obtained data was stored on the author's computer, which can only be accessed by the author.

3.6. Limitations

During the research, limitations were identified as access to documents, lack of time, as well as the responsiveness of stakeholders to interviews. Some of the government documents were not available to the public, thus limiting the possibility of analysing all the documents necessary for this study. Lack of time was identified in organising the interviews, considering that invitations to interviews were sent in late November and early December, which is one of the busiest times at the end of the year. Considering that out of 52 emails sent, only three interviewees responded, the small number of interviews is another limitation, for example, representatives from Canada and Portugal did not participate in the interviews. A larger number of interviews would provide a more accurate analysis of the reality of wave energy implementation in countries.

4. Case studies of pioneering countries in wave energy development

4.1. Overview of selected countries

After the analysis, indicated in Chapter 3, Australia, Canada, Ireland, Portugal and Scotland were identified as pioneer countries in implementing wave energy, recognising the policies developed in the field of renewable energy resources, focusing on offshore renewables, projects, researchers and wave energy developers' activity. This subsection will outline the overall activities of all five countries in the development of wave energy.

4.1.1. Australia

Australia has the world's largest wave energy resources, with the majority located in the Western and Southern parts of Australia, including Tasmania and the Victorian coastlines (Gaudin & Wolgamot, 2024). This region is estimated to produce wave energy resources that can make up as much as 11% of 2050 Australia's wave energy needs (Australia's Offshore Energy Regulator, 2022). Currently, Australia's Department of Climate Change, Energy, and the Environment (hereinafter DCCEEW) is writing a national Sustainable Ocean Plan for future ocean management, that will unite government, research, industry, communities and conservation for a sustainable ocean economy (Kurniawan, Sergiienko, & Marsh, 2024).

With interim targets of a 43% emission reduction by 2030, Australia's climate strategy aims to achieve net zero emissions by 2050 (Gaudin & Wolgamot, 2024). Included in this strategy is Powering Australia's objective to boost the use of renewable energy sources and create employment (Gaudin & Wolgamot, 2024). In addition, it is estimated that particularly in coastal areas, Australia has the chance to use wave energy to boost the expansion of its AUD 118 billion blue economy (Gaudin & Wolgamot, 2024). Some of the additional benefits of wave energy development mentioned in the Blue Economy Cooperative Research Centre's report are the possibility of ensuring coastal protection from WEC, as well as being led by best practices of environmental impact assessments and social engagements.

In 2012, the Australian Renewable Energy Agency (hereinafter ARENA), which is a Commonwealth corporate entity under the Public Governance, Performance and Accountability Act 2013, was created with investing approximately AUD 44 million for ocean energy (wave and tidal) projects out of AUD 2.25 billion in 663 projects (Gaudin & Wolgamot, 2024). ARENA's budget over the years for the ocean energy projects makes out only less than 2% of the total allocated money. The most notable projects are the Perth Wave Energy Project, UniWave200 King Island Project and Australian Wave Energy Atlas. More of the projects can be found in the Appendix 5. The Australian Renewable Energy Agency Regulation 2016 supports the ARENA Act by expanding ARENA's purview to encompass electrification and energy efficiency technologies in addition to renewable energy technologies (Australian Renewable Energy Agency, ARENA Corporate Plan 2024 - 25 - 2027 - 28). ARENA’s overall goal is to support the Australian government in achieving climate and energy targets, ensuring meaningful First Nations engagement through the ARENA’s Advisory Panel, and providing financial assistance following ARENA’s General Funding Strategy. ARENA cooperates with industry, cooperative research centres, Clean Energy Finance Corporation (hereinafter CEFC), Clean Energy Regulator and other actors to provide financial assistance for R&D, as well as pre-commercial deployment of technologies (Australian Renewable Energy Agency, ARENA Corporate Plan 2024 - 25 - 2027 - 28). ARENA has not indicated wave energy as a strategic priority for their latest Corporate Plan 2024-25 - 2027-28 but mainly focuses on low-cost solar energy and renewable hydrogen commercialisation.

Besides ARENA, financial support is provided by the CEFC for renewable energy projects and the Blue Economy Cooperative Research Centre, which was established in 2019 under the Australian Government’s Cooperative Research Centre programme. Several research institutions are working in Australia for wave energy development, such as the Commonwealth Scientific and Industrial Research Organisation (hereinafter CSIRO), University of New South Wales, Australian Maritime College, University of Adelaide, University of Queensland, University of Western Australia and Swinburne University of Technology (Kurniawan, Sergiienko, & Marsh, 2024). The leading wave energy developers in Australia include Wave Swell Energy with UniWave200, AMOG with Sea-Saw WEC, and Carnegie Clean Energy Limited with CETO systems' WEC. Australia has the Mutriku wave energy farm, which has been operating since 2011, having generated 3 GHw since 2011, as well as the Eco Wave Power Plant, which completed its pilot trial in 2022 (Osman, Manasseh, & Sergiienko, 2024).

For Australia to reach its climate targets, it should increase investments in diverse renewable energy technologies, including ocean energy renewable technologies, as well as strengthen public funding for energy R&D (Kurniawan, Sergiienko, & Marsh, 2024). In 2020, public funding for energy R&D was only 0.019% of GDP (Kurniawan, Sergiienko, & Marsh, 2024). Mainly, initiatives for wave energy development come from WEC developers and the research sector. On the national level, Australia lacks focused strategies for wave energy development. Wave energy is not specifically included in the nation's roadmaps or in the most recent Integrated System Plan (Gaudin & Wolgamot, 2024). In addition, Australia lacks national grid-connected test sites (Kurniawan, Sergiienko, & Marsh, 2024). Although ARENA focuses on supporting renewable energy technology research and development, little attention has been focused on wave energy, making a 1.94% share of the total allocated money amount for all ARENA’s projects (Australian Renewable Energy Agency, ARENA Corporate Plan 2024 - 25 - 2027 - 28). Besides allocating less than 2% to ocean energy projects, ARENA’s engagement in ocean energy has significantly decreased (Kurniawan, Sergiienko, & Marsh, 2024).

4.1.2. Canada

Wave energy resources are abundant in the oceans along the Atlantic and Pacific coastlines of Canada. While the theoretical capacity off Canada's Atlantic coast is the largest with over 146,500 MW, the theoretical capacity off Canada's Pacific coast is assessed at around 42,000 MW (Natural Resources Canada, Ocean Energy, 2024).

A Blue Economy Regulatory Roadmap was developed by Fisheries and Oceans Canada (hereinafter DFO) together with other governmental departments created Blue Economy Regulatory Roadmap (Fisheries and Oceans Canada, Blue Economy: Targeted Regulatory Review – Regulatory Roadmap, 2024). It is intended to handle operational and regulatory issues and investigate creative strategies to benefit from new opportunities in the blue economy. The roadmap is built on the consultation process in five thematic areas, one of which was focused on marine renewable energy (Fisheries and Oceans Canada, Blue Economy: Targeted Regulatory Review – Regulatory Roadmap, 2024). The consultation process involved a comprehensive amount of partners and stakeholders in the ocean sector, as well as Indigenous communities and other governmental agencies. A focus was put on regulations and regulatory practices that concern the review and authorisation process of marine renewable energy, mainly focusing on tidal energy with the creation of the Task Force on Sustainable Tidal Energy Development in the Bay of Fundy in 2023 (Fisheries and Oceans Canada, Blue Economy: Targeted Regulatory Review – Regulatory Roadmap, 2024). Wave energy was mentioned in this roadmap for its potential to generate electricity, but additional attention was not paid specifically to wave energy in this roadmap.

Another theme for these consultations was ocean technologies, with the Canadian government focusing on leveraging already-existing infrastructure, namely ocean-focused test facilities with an ocean focus, to assist businesses in testing and certifying ocean innovations in a real-world environment (Fisheries and Oceans Canada, Blue Economy: Targeted Regulatory Review – Regulatory Roadmap, 2024). In addition, the National Research Council’s Ocean program is investing around CAN 10 million (2021–2027) in cooperative research initiatives to encourage technical innovation and test locations that are focused on the ocean (Fisheries and Oceans Canada, Blue Economy: Targeted Regulatory Review – Regulatory Roadmap, 2024). Ocean program's four blocks are coastal resilience, such as flood prediction and resilient marine infrastructure; intelligent marine assets, such as marine renewables in harsh environments; pollution remediation and bio assets (National Research Council Canada, 2024). The National Research Council's program does not focus strictly on ocean energy development.

The Offshore Renewable Energy Regulations (hereinafter ORER) Initiative is the ongoing effort of the Government of Canada to draft its offshore renewable energy regulations concentrating on the safety and environmental protection regulations that will be relevant to the investigation, construction, operation, and decommissioning of renewable energy projects (Ocean Energy Systems, 2025). Canada Energy Regulator reviews and authorises offshore renewable energy-related operations in Canada's offshore regions including site characterisation tasks and the development, approval, use, and decommissioning of energy and technology facilities (Canadian Energy Regulator Act, 2024).

In 2021, the Canadian Government introduced the Smart Renewables and Electrification Pathways Program (hereinafter SREPs). To guarantee a dependable, reasonably priced, and decarbonised electrical system, the CAN 4.5 billion SREPs encourage the construction of sustainable power infrastructure and seek to update and fortify the electrical grid (Natural Resources Canada, Smart Renewables and Electrification Pathways Program, 2024). This programme collaborates with Indigenous Peoples (First Nations), provinces, and territories to promote important regional priority projects that will lessen reliance on the production of fossil fuels, therefore wave energy projects can also be supported by this programme.

British Colombia is the pioneering province in Canada for wave energy development. Accumulated Ocean Energy and Neptune Wave Power are two of the active Canadian wave energy technology developers in British Columbia (Marine Renewables Canada, Wave Energy, 2025). In addition, the province has funded two wave energy projects on the west coast of Vancouver Island - the Pacific Coastal Wave Energy Corp and SyncWave Energy Systems (Marine Renewables Canada, Wave Energy, 2025). More projects can be found in Appendix 6. In addition, Mowachaht/Muchalaht First Nation is leading the feasibility study for the project that will demonstrate wave energy technology. The project's goal is to carry out a front-end engineering and design study of a 200-kW wave energy plant that will replace the Mowachaht/Muchalaht First Nation members' existing use of diesel fuel in the isolated reserve community of Yuquot (Natural Resources Canada, Yuquot Wave Energy Demonstration Project – FEED Study, 2024). For this project, Mowachaht/Muchalaht First Nation works with the Pacific Regional Institute for Marine Energy Discovery (hereinafter PRIMED), Barkley Project Group, CalWave Power Technologies, Canpac Marine Services, and Environmental Dynamics Inc (Natural Resources Canada, Yuquot Wave Energy Demonstration Project – FEED Study, 2024).

Some of the key organisations involved in wave energy development are the West Coast Wave Initiative (hereinafter WCWI) and Wave Environment Research Centre. The WCWI is an academic and industrial multidisciplinary team dedicated to statistically assessing the viability, effects, and potential structure of wave energy conversion on Canada's West Coast (University of Victoria, 2025). To produce the most accurate evaluation of the viability of wave energy conversion in British Columbia, the team is creating numerical grid integration toolboxes, numerical simulation tools for WEC, and industry-leading wave energy resource assessment techniques (University of Victoria, 2025). Wave Environment Research Centre was founded to research the utilisation of ocean wave energy to deliver seawater to land-based aquaculture (Marine Renewables Canada, Wave Energy, 2025). The research centre is located at the College of the North Atlantic in Burin Bay Arm.

The leading national organisation for tidal, offshore wind, wave, and river current energy is Marine Renewables Canada, which represents a membership of technology and project developers, suppliers, utilities, Indigenous organisations, researchers, and communities (Marine Renewables Canada, About Us, 2025). By working with governments, businesses, and researchers to develop a roadmap for the sector in 2011, Marine Renewables Canada was able to influence the development of enabling legislation and promote the inclusion of marine renewable energy in financing and programs (Marine Renewables Canada, About Us, 2025). Marine Renewables Canada has been issuing yearly reports since 2013, and wave energy for the first time was mentioned in these reports in 2015, showcasing wave energy development initiatives mainly on the West Coast.

4.1.3. Ireland

Ireland has pledged to achieve net zero emissions by 2050 and cut greenhouse gas emissions in half by 2030 under the Programme for Government and the Climate Act 2021 (Mak & Dennehy, 2024). Ireland has 31,100 MW of theoretical wave energy development potential that may be harvested without likely causing any environmental harm, according to the Offshore Renewable Energy Development Plan, which was released in 2014 (Sustainable

Energy Authority of Ireland, Ocean Energy Technologies, 2025). In addition, Ireland has a coordinated government effort to use Ireland's offshore renewable energy potential, which the Offshore Renewable Energy Technology Roadmap supports (Sustainable Energy Authority of Ireland, The Offshore Renewable Energy Technology Roadmap, 2024). Ireland has set offshore wind to be the driver for achieving 2030 renewable energy goals, therefore there are no set goals for wave, tidal, or other ocean energy technology in the country.

In 2021, the Irish government created the National Marine Planning Framework following EU Directive 2014/89/EU, which unifies all human activities based on the sea and describes the goals, vision, and marine planning policies of the government for marine activity, including offshore energy (Mak & Dennehy, 2024). In addition, the Maritime Area Planning Act 2021 was created by the Department of Housing, Local Government, and Heritage, which established a new maritime planning system that is governed by the National Marine Planning Framework and supported by a legislative Marine Planning Statement (Mak & Dennehy, 2024). The Act also established the Maritime Area Regulatory Authority, which grants Maritime Area Consent and Maritime Usage licences for offshore developers. For market incentives, Ireland is using the Renewable Electricity Support Scheme to fund renewable electricity projects. Renewable energy projects compete with one another in an auction-based procedure, offering their lowest price in hopes of winning contracts to supply power at the twenty-year term's bid price (Mak & Dennehy, 2024). The main institutions for providing financial support for wave energy development are the Sustainable Energy Authority Ireland (hereinafter SEAI), the Irish Marine Institute, the Environmental Protection Agency, Climate Action Ireland, and the Geological Survey Ireland.

One of the SEAI’s funds for sustainable and secure energy is the SEAI National Energy Research Development and Demonstration (hereinafter RD&D) Funding Programme (Sustainable Energy Authority Ireland, 2025). Over the past five years, the SEAI RD&D program has provided funding for eleven maritime energy initiatives totalling €4.4 million (Mak & Dennehy, 2024). In order to facilitate the testing and advancement of ocean renewable energy technologies through the early phases of development before open sea testing, SEAI and Lir National Ocean Test Facility (hereinafter NOTF) at University College Cork (hereinafter UCC) Research Ireland Centre for Energy, Climate and Marine (hereinafter MaREI) created and provided funding for a pilot initiative (Mak & Dennehy, 2024). Lir has supported thirteen wave energy projects for their test sites.

Ireland has received support from the EU for wave energy development. One of the examples is the Saoirse Project. The CorPack, a pre-commercial wave energy array that employs CorPower Ocean WEC in a 5 MW array, will be demonstrated off the west coast of Ireland by the pre-commercial wave energy project Saoirse (Mak & Dennehy, 2024). The European Commission's Innovation Fund program approved €39.475 million in financing for the Saoirse wave energy project in 2023 (Mak & Dennehy, 2024). In addition, Irish ocean energy research institutes and developers are partners for ocean energy projects, mainly through Horizon, Interreg, and European Maritime, Fisheries and Aquaculture Fund (hereinafter EMFAF) programmes. A list of those projects is indicated in Appendix 7.

Ireland has test locations that support the development and testing of offshore wind, wave, and tidal energy technologies at all stages of technological readiness. The UCC Beaufort Building in Ringaskiddy is home to the world-renowned Lir NOFT a centre for marine research and renewable energy (Ireland Ocean Energy Expertise, 2025). With a technology readiness level (hereinafter TRL) ranging from 1 to 4, Lir is a specially constructed test facility with extended and enhanced tanks and equipment for evaluating small-scale Ocean Energy sustainable devices (Ireland Ocean Energy Expertise, 2025). The TRL explanation table can be found in Appendix 10. Another test site is the Smartbay Marine and Renewable Energy Test Site. WEC prototypes that are quarter to half-sized and have a TRL of four to six can be deployed openly at the test site (Mak & Dennehy, 2024). The third test site is the Atlantic Marine Energy Test Site (AMETS), which is being constructed by the SEAI to allow full-scale wave energy converters and floating offshore wind technology to be tested in a harsh maritime environment (Ireland Ocean Energy Expertise, 2025). A complete list of wave energy test sites can be found in Appendix 11.

4.1.4. Portugal

Portugal's extensive coastline and marine expertise make it one of the best places to deploy wave energy projects. To decarbonise the energy sector, Portugal seeks to improve energy efficiency and ensure the growth of renewable power generation (Brito e Melo, Gato, & Taveira Pinto, 2024). The Directorate-General for Energy and Geology (hereinafter DGEG) is the main climate and energy coordination and implementation department.

Portugal has multiple documents and strategies for renewable energy development. The National Energy and Climate Plan 2030 aims to reduce GHG by 85–90% by 2050 compared to 2005 levels (Brito e Melo, Gato, & Taveira Pinto, 2024). Portugal established Technological Free Zones (hereinafter ZLT) for offshore renewable energy technology deployment and testing. These zones function as designated areas for testing and showcasing innovative technology in an actual setting. Furthermore, the goal of Portugal's National Strategy for the

Sea 2021–2030 is to increase the ocean's economic value to the country and promote a healthy ocean that enhances Portuguese residents' quality of life (Brito e Melo, Gato, & Taveira Pinto, 2024). For the Maritime Spatial Planning Policy, Portugal has established the National Maritime Spatial Plan. The Plan specifies areas of exclusion as well as current and prospective uses and activities. Additionally, this plan permits the issuance of a Permit for Private Use of the National Maritime Space (Brito e Melo, Gato, & Taveira Pinto, 2024).

WavEC is one of the leading organisations in Portugal for marine energy research and development. The organisation focuses on research, innovations, as well as engineering solutions for ocean renewable energy development, which includes accounting for social, legal, economic, environmental, and technological factors (Brito e Melo, Gato, & Taveira Pinto, 2024). Since 2003, WavEC has been participating in 60 R&D projects on marine renewable energy (Brito e Melo, Gato, & Taveira Pinto, 2024). Additionally, two institutes at the University of Lisbon's Higher Technical Institute are working on ocean energy. One institute with decades of experience in wave energy conversion research, the Institute of Mechanical Engineering, has focused its efforts in recent years on wave energy conversion, particularly the creation of novel oscillating water column converters and self-rectifying air turbines (Brito e Melo, Gato, & Taveira Pinto, 2024). The second institute, the Centre for Marine Technology and Engineering, conducts research on ocean energy conversion, with a primary focus on wave energy converters. It does this by conducting numerical theoretical and modelling studies and testing various arrays and devices (Brito e Melo, Gato, & Taveira Pinto, 2024). In addition, Marine Energy and Hydraulic Structures Research Group (hereinafter FEUP – CIIMAR) primary areas of study include the engineering design of marine structures to address marine environmental activities, using either numerical modelling or other methods, and the creation, design, and optimisation of technology to exploit marine renewable energy resources (Brito e Melo, Gato, & Taveira Pinto, 2024).

Portuguese developers have received public funding from the EU H2020 programme, the European Maritime and Fisheries Fund, Interreg, the European ERA-NET- European Research Area Network, National Foundation for Science and Technology (hereinafter FCT), and Ente Vasco de la Energía Basque Country (hereinafter EVE) for developing wave energy and testing WEC. Some of those projects can be found in Appendix 8.

For wave energy development, innovative concepts may be researched and shown in a designated test facility in Aguçadoura that is 3.3 km2 in size and located at a water depth of 45 meters (Brito e Melo, Gato, & Taveira Pinto, 2024). Within this allotted region, the Swedish company CorPower has been making rapid progress on Hi-Wave-5, their flagship wave energy project (Brito e Melo, Gato, & Taveira Pinto, 2024). The CorPower C4 in Aguçadoura wave energy farm was linked to the Portuguese national grid via a subsea export cable after being attached to a Universal Mooring, Anchor & Connectivity Kit (hereinafter UMACK) anchor that had already been placed on the seabed (Brito e Melo, Gato, & Taveira Pinto, 2024). A complete list of wave energy test sites can be found in Appendix 11.

4.1.5. Scotland

Several academic institutions and technology developers work to create the next generation of WEC, mostly in Scotland. The Scottish Government is dedicated to reaching net zero of GHG by 2045, making Scotland the country with the most ambitious climate ambitions in the UK (Grattan, Noble, & Jeffrey, UK, 2024). The Scottish Government's energy sector future vision supports Scotland's move to net zero and calls for 50% of the country's power and heat transportation energy to originate from renewable sources by 2030 (Grattan, Noble, & Jeffrey, UK, 2024).

On the UK level, the country has developed the UK Marine Energy Council. The UK Marine Energy Council was established in 2018 to represent the country's wave and tidal Stream Energy sectors (Grattan, Noble, & Jeffrey, UK, 2024). To improve information exchange and pinpoint areas where the groups may collaborate, the UK Marine Energy Council and Marine Renewables Canada signed Memorandums of Understanding in 2023 (Grattan, Noble, & Jeffrey, UK, 2024). The Marine Energy Council addressed the Sustainable Industry Reward, changes to Allocation Round 6, and significant devolved administration consultations, including the Just Transition strategy consultation for the Welsh Government and the Draft Energy Strategy and Just Transition Plan for the Scottish Government (Grattan, Noble, & Jeffrey, UK, 2024). In addition, the UK has the Offshore Renewable Energy Catapult (hereinafter ORE Catapult), which is the leading offshore energy technology and innovation research centre and a major contributor to the UK's net zero goals (Grattan, Noble, & Jeffrey, UK, 2024). Crown Estate Scotland hired ORE Catapult to carry out a comprehensive survey of tidal and wave technology developers, project developers, and important stakeholders in order to get their input on how to improve the current leasing arrangement for projects ranging from 3 to 30 MW in order to maximise commercialisation potential (Grattan, Noble, & Jeffrey, UK, 2024). In 2024, ORE Catapult created the Marine Energy Partnership.

The Scottish wave energy industry has benefited from ongoing assistance and direction through the Wave Energy Scotland (hereinafter WES) initiative. Through a competitive stage-gate process, WES has been directing breakthrough technology initiatives into commercialisation since 2014 by applying Scottish Government finances to the technical issues in the wave energy industry (Grattan, Noble, & Jeffrey, UK, 2024). This has led to the completion of the control system development projects, the demonstration of three mechanical and electrical fast connections, the support for the re-deployment of Mocean's Blue-X device, and the completion of the AWS Waveswing device demonstration in the Scottish seas (Grattan, Noble, & Jeffrey, UK, 2024). Additionally, WES is delivering the EuropeWave device development program in collaboration with the European Commission, EVE, and Ocean Energy Europe (Grattan, Noble, & Jeffrey, UK, 2024). Besides that, WES started the Direct Generation initiative to enable more drastic cost-cutting measures, and it is now developing concepts for flexible wave energy devices based on electrostatic power conversion technology (Grattan, Noble, & Jeffrey, UK, 2024). Early in 2023, the Scottish Government unveiled its draft energy plan, which calls for ongoing assistance for WES and allocates £18.25 million for investments to promote the industry's long-term growth (Grattan, Noble, & Jeffrey, UK, 2024). The development programs, which employ a three-stage pre-commercial procurement method to facilitate competitive design evolution to solve major obstacles to commercialising the wave energy industry, are the fundamental operations of WES (Wave Energy Scotland, 2025). Some of the programmes are Power Take Off, Novel WEC, Quick Connection Systems, Structural Materials, Control Systems and Direct Generation (Wave Energy Scotland, 2025).

Besides the WES initiative, Scotland has Scottish Enterprise, which supports businesses with innovation and investment and boosts their global competitiveness to enable ambitious enterprises throughout Scotland to expand (Grattan, Noble, & Jeffrey, UK, 2024). The European Clean Energy Transition Partnership (hereinafter CET), a Horizon Europe collaboration with more than 30 financing agencies from Europe and beyond, was delivered in 2023 under the direction of Scottish Enterprise (Grattan, Noble, & Jeffrey, UK, 2024). Support for maritime energy projects is part of the €5 million Scottish funding for the Joint Call 2023 (Grattan, Noble, & Jeffrey, UK, 2024).

Scotland has several wave energy projects mainly funded by the Engineering and Physical Sciences Research Council (hereinafter EPSRC). Additionally, Scotland has a strong presence in cooperative European initiatives that are mostly supported by H2020 and Horizon Europe. Scottish wave energy projects are indicated in Appendix 9.

One of the main test sites in Scotland is the European Marine Energy Centre (hereinafter EMEC). EMEC, the world's leading facility for testing and demonstrating tidal and wave stream technologies in the ocean, celebrated its 20th anniversary in 2023 (Grattan, Noble, & Jeffrey, UK, 2024). EMEC provides pre-consented grid-connected demonstration sites in difficult wave and tidal regimes in addition to scale test sites in gentler conditions for testing smaller-scale innovations, subsystems, and components. (Grattan, Noble, & Jeffrey, UK, 2024). A complete list of wave energy test sites can be found in Appendix 11.

4.2. Mariana Mazzucato’s seven principles in wave energy implementation

In this subchapter, Australia’s, Canada’s, Ireland’s, Portugal’s, and Scotland’s wave energy implementation through Mariana Mazzucato’s seven principles for mission-oriented innovation policy results will be addressed. The analysis of the results will be discussed in Chapter 5.

4.2.1. Collective value creation

For MOIP, the first step is to set a common strategic agenda and create common objectives for solving societal problems. Based on Mariana Mazzucato’s framework, this step requires improved comprehension of the public purpose, resulting in the development of public interest-driven policies (Mazzucato, 2021).

All five countries have the same mission to which they aspire – to transition away from fossil fuels, thereby transforming the energy system towards renewable energy resources, which coincides with the goal of the Paris Agreement. As a result, countries have developed their strategies and plans to achieve net zero. Each country has its guiding principles for renewable energy, namely Scotland’s plans to become an international hub for ocean renewable energy, specifically wave and tidal energy to develop the Scottish economy and achieve the Just Transition plan. In contrast, Portugal's plans go more hand in hand with achieving the UN Sustainable Development Goals, mainly connected to investors, which are increasingly seeking to align their portfolios with Sustainable Development Goals ambitions, as well as changes in the employment market for newer generation (20-29) prioritising those workplaces, which align with the UN goals (General Directorate of Maritime Policy, 2021). Ireland primarily plans to gain greater energy independence, recognising the country's dependency on fossil fuel imports. However, only 17% of Irish people support the phase out of fossil fuels and using only renewable energy, while 30% of the population supports having an energy mix that prioritises renewable energy development and keeping low-emission fossil fuels (Glesson, 2025). Canada explores the possibility of developing a blue economy based on Blue Economy Regulatory Review Engagement consultations with Canadians (Fisheries and Oceans Canada, Engaging on Canada’s Blue Economy Strategy: What We Heard, 2022). Australia reduces emissions in the energy sector as it creates the most greenhouse gas emissions.

In order to enhance competitiveness and accelerate the pre-commercial innovation phase of renewable energy technologies, boost the supply of renewable energy, and assist Australia in reaching net zero by 2050, the country established the ARENA to create public interest-driven policies that will help shape the market (Australian Renewable Energy Agency, ARENA General Funding Strategy 2024-25 - 2026-27). Besides ARENA, the Australian government's National Energy Performance Strategy highlighted the need to establish an energy performance governance framework to promote collaboration between communities, businesses, and governments (DCCEEW, The National Energy Performance Strategy, 2024). For common agenda-setting for clean energy transformation, the Australian government and First Nations developed First Nations Clean Energy Guidelines involving First Nations in energy transformation.

Canada has worked together with industry and researchers to implement ocean energy. Although Canada mainly focuses on tidal energy, leaving wave energy more in the background, there has been some development in the wave energy sector. For creating Canada's Blue Economy Strategy, stakeholder consultations were held, after which the Canadian government is planning to support ocean energy industries for research, development, demonstration and commercialisation of ocean energy technologies, as well as encouraging collaboration between ocean energy sectors and developers (Fisheries and Oceans Canada, Engaging on Canada's Blue Economy Strategy: What We Heard, 2022). For establishing the ORER Initiative, which focuses on developing security, safety and environmental protection, stakeholder consultations were held for regulation and technical requirements for the project (Natural Resources Canada, 2024). In addition, in British Colombia, First Nation is involved in all the consultations for renewable energy project deployment and development (Government of British Colombia, Clean Energy Production in B.C. An Inter-Agency Guidebook for Project Development, 2016).

Ireland has highlighted that it is important to have public support for developing further wave energy and analysing what role wave energy could play in Ireland's energy mix (Sustainable Energy Authority of Ireland, 2024). Public support and engagement are mainly linked to supporting technology development in the country, as well as community benefits mechanisms from these technology developments (Sustainable Energy Authority of Ireland, 2024). For industry representation and creating a collective agenda, the Marine Renewable Industry Association is the main organisation representing ocean energy industry developers. In addition, for wave energy development, the Irish Marine Institute and SEAI are involved. To keep an eye on advancements in the most pertinent technologies, SEAI and the Department of Environment, Climate and Communications (hereinafter DECC) regularly assess whether other technologies—particularly wave energy—should be a major part of Ireland's energy mix (Sustainable Energy Authority of Ireland, 2024). These two organisations are also involved in offshore renewables development for Ireland's Research and Innovation Strategy "Impact 2030". The Irish government organised a public consultation process to set specific goals for Marine Protection Areas (Department of the Taoiseach, 2021).

Portugal has held a prominent position in marine technologies, namely wave energy (Foundation for Science and Technology, 2019). Under National Ocean Strategy 2021-2030, Portugal is aspiring to diversify local and renewable power sources via investments in Renewable Ocean Energy would lessen reliance on fossil fuels and, therefore, greenhouse gas emissions (General Directorate of Maritime Policy, 2021). In addition, Portugal has an underlying idea with the European Strategic Energy Technology Plan for applying clean technologies with lower costs, which is also in line with Portugal's multi-level strategy, which encourages brainstorming among stakeholders in fields like energy efficiency using renewable energy to address the many societal concerns (Directorate-General for Communication, 2019). By developing new specialisations in the Portuguese naval industry and reaffirming the national port network as the engine of the new maritime economy, the primary strategic goal is to establish a competitive and innovative industrial cluster that exports renewable ocean energy, such as floating offshore wind energy and wave energy (Foundation for Science and Technology, 2019).

By releasing and implementing a new Energy Strategy and Just Transition Plan, the Scottish government intends to set a clear course for the country's energy sector's future and outline the measures it will take to maximize the economic and social advantages of our shift to a future energy system and to guarantee our energy security (First Minister & Director of Performance, Delivery and Resilience, 2023). This will give consumers, workers, businesses, and investors policy certainty. Energy Strategy and Just Transition Plan vision discuss an innovative goal for marine deployment and outline the industry's prospects as well as possible steps to support the sustained expansion of tidal and wave energy (Energy and Climate Change Directorate, Draft Energy Strategy and Just Transition Plan – delivering a fair and secure zero carbon energy system for Scotland, 2023).

4.2.2. Market shaping

Market shaping aims to shift the direction of innovation systems to focus on mission-oriented investments, and new governance mechanisms, e.g., patents, therefore pushing technological market frontiers and avoiding building public sector operations on a market failure approach (Mazzucato, 2021). Market shaping characterises goal-oriented investments as a supply and market creation as a demand, led by governance mechanisms, such as patents, for achieving innovation-led and inclusive growth (Mazzucato, 2021).

Some countries, such as Australia, Ireland and Scotland, have established national agencies for the development of ocean renewable energy. Most countries have policy documents and strategies dedicated to the development of offshore renewable energy, but none of the countries have developed documents dedicated only to wave energy development. The focus is currently on offshore wind energy in Canada, Ireland and the UK to achieve legally binding climate goals as quickly as possible.

In Australia, for market shaping and pushing technological market frontiers, the responsible agency is ARENA, as its functions are offering financial assistance for research, development, deployment, demonstration, commercialisation and knowledge storage of renewable energy technologies (Australian Renewable Energy Agency Act 2011, 2024). To achieve this, ARENA has funded 735 renewable energy technology projects as of 30th June 2024, but less than 2% of these funds have reached ocean renewable energy technologies, such as tidal and wave. Some of the wave energy projects were cost reduction through location and configuration optimisation for WEC, Australian Wave Energy Atlas Project. The Australian government's commitment to the development of renewable energy technologies was also mentioned in the National Energy Performance Strategy, where the government committed to facilitating research and development into these technologies (DCCEEW, The National Energy Performance Strategy, 2024). Except for ARENA’s provided funding, Australia does not have enabling wave energy policies (Interview 3). Since there are no special rules in place for wave energy, the main issue in Australia is essentially a lack of policy and a lack of awareness of the potential of wave energy (Interview 3).

For market shaping, Canada has come up with multiple regulations. TC114 regulation, for which Marine Renewables Canada is involved in the consultation process, is supplemented with a draft for the standard on guidance for wave energy prototype development (Marine Renewables Canada, 2017 Annual Report, 2017). Offshore Renewable Energy Projects and Offshore Power Lines, Part 5 of the Canadian Energy Regulator Act (hereinafter CER Act), went into effect in 2019 (Natural Resources Canada, Canada Offshore Renewable Energy Regulations, 2024). The legislative basis for monitoring an offshore renewable energy project's entire life cycle is provided by Part 5, which also gives the CER the authority to examine and approve actions of offshore renewable energy projects in Canada's federal offshore regions (Natural Resources Canada, Canada Offshore Renewable Energy Regulations, 2024). Canada’s

Blue Economy Strategy serves as a guide for developing ocean renewable energy with the government's aim to encourage the private sector to engage in research and development by providing additional funding sources to reduce the risk of private sector investments (Fisheries and Oceans Canada, Engaging on Canada's Blue Economy Strategy: What We Heard, 2022).

Ireland is dedicated to moving away from fossil fuels and using renewable energy, which was outlined in Energy Security Ireland in 2030 (DECC, Energy Security in Ireland to 2030, 2023). Wave energy has been highlighted as one of the untapped potentials for Ireland to reach net zero by 2050. Ireland established the Maritime Area Regulatory Authority in 2023, which oversees evaluating Maritime Area Consent (hereinafter MAC) applications (DECC, Climate Action Plan 2024, 2024). Subject to obtaining planning clearance, a MAC grants the right to inhabit the marine area, as it is necessary before submitting a planning approval application (DECC, Climate Action Plan 2024, 2024). However, it should be noted that Ireland, in its Transition to Low Carbon Energy Future strategy, does not anticipate wave energy technologies making large contributions to renewable energy development in a short time, but in the medium to long term, the Irish government anticipates that wave energy will contribute to our energy transformation (DCENr, 2021). Ireland's long-term focus on ocean energy and stimulation of industry-led projects for developing and deployment of ocean energy technologies was also highlighted in its Offshore Renewable Energy Development Plan (DECC, National Energy & Climate Plan 2021-2030, 2021). Fostering R&D in wave energy was accented in Ireland's Transition to Low Carbon Energy Future strategy. However, the Sustainable Energy Authority of Ireland took a bold step in 2009 by establishing the Prototype Development Fund (hereinafter PDF) and a supporting team to promote Ocean Energy (Marine Renewables Industry Association, 2023). Over time, several government energy policy documents have reaffirmed their support for ocean energy. The Offshore Renewable Energy Development Plan, released in 2014, provided significant policy support for ocean energy by aiming for the local apex of Ocean Energy financing through a planned revenue support program for pilot devices (Marine Renewables Industry Association, 2023). Although Ocean Energy projects have been eligible to apply to the SEAI National Energy Research RD&D financing program scheme, which is not typically ideal for smaller wave energy converter companies, the PDF has not been reopened since (Marine Renewables Industry Association, 2023). Maritime test sites like the Galway Bay Maritime & Renewable Energy Test Site do not allow for the creation of engineering designs, manufacture, installation, and testing of prototypes under real-world environmental circumstances (Marine Renewables Industry Association, 2023). Marine renewable energy has been identified as one of the fourteen Irish government's priority research areas defined in the Government's Research Prioritisation Exercise. For SEAI's RD&D fund, industry-led projects to develop and test wave energy capture devices are emphasised (Sustainable Energy Authority of Ireland, Ocean Energy Prototype Research and Development Programme Application Guide, 2015). In addition, Ireland established the Marine Wave and Tidal Research Programme (hereinafter UKRI). The National Offshore Renewable Energy Development Plan, introduced by the Irish government in 2014, outlined the course for the development of offshore renewable energy across the nation. Offshore wind, wave, and tidal energy were examined there, but after seven years the focus shifted to offshore wind energy to achieve legally binding carbon emission reduction goals set by the EU (Interview 2). In 2023, the government subsequently changed its approach from a sector-led to a state-led framework, designating areas for offshore renewable energy, primarily offshore wind, through marine spatial planning, therefore leaving wave energy behind (Interview 2).

Portugal has set the path toward the gradual adoption of affordable ocean renewable technology that will increase the nation's capacity to utilise its renewable resources to achieve objectives set in the Roadmap for Carbon Neutrality 2050 (General Directorate of Maritime Policy, 2021). Portugal is committed to establishing both inshore and offshore national infrastructures in the ocean for testing and scaling up in a natural setting. This will allow for synergies with existing infrastructures, especially those about offshore aquaculture, underwater connections, and renewable energy production (General Directorate of Maritime Policy, 2021). The two primary objectives of Portugal's Industrial Strategy for Ocean Renewable Energies, which was released in 2017, are to help the industry lower risks and to encourage export and value-added investment (Brito E Melo & Falcão, 2018). According to the action plan that goes with it, Portugal's wave energy business prospects should be centred on creating the ideal environment for luring R&D investment in terms of funding and infrastructure (Brito E Melo & Falcão, 2018). Portugal is committed to its Industrial Strategy for Ocean Renewables Energies to provide funding for wave energy R&D projects (TRL 1-5) through the Blue Fund, as well as attract more investments to develop wave energy (Council of Ministers, 2017).

Scotland plays a crucial part in helping the UK to achieve its climate targets. The necessity of developing Scotland's future energy system for their economy is outlined in the proposed Energy Strategy and Just Transition Plan, which Scotland consulted on (Energy and Climate Change Directorate, Draft Energy Strategy and Just Transition Plan – delivering a fair and secure zero carbon energy system for Scotland, 2023). Scotland is supporting this by investing around £5 billion in the country's net-zero energy economy during this legislative term (First Minister & Director of Performance, Delivery and Resilience, 2023). The Scottish Government's policies, particularly their spatial plan, to guide the development of offshore renewable energy on a commercial scale are included in Sectoral Marine Plans (Scottish Government, Scotland's National Marine Plan, 2015). In recent years, Scotland has taken the lead in the UK and the world by adding more support for wave and tidal stream generating to the Renewables Obligation. Through the Renewables Obligation, which was created by the UK's government to create supportive market mechanism for developing renewable energy, and its potential successor, the Scottish Government will continue to provide marine renewables technologies with effective market support (Scottish Government, 2020 Routemap for Renewable Energy in Scotland , 2011). With the creation of WES, the Scottish government has started to include wave energy in their policy plans for enhancing wave energy development (Interview 1). On the UK level mainly focus has shifted to offshore wind and tidal energy development.

4.2.3. Dynamic capabilities for public and private organisations

The government can use a variety of capabilities to accomplish mission-oriented goals, such as coordination and the ability to find coherent policy mixes; administrative capabilities; risk-taking and experimentation; evaluation capabilities; leadership and engagement for market shaping and co-creation of the value, as well as encouraging bottom-up engagement (Mazzucato, 2021).

In Australia, Ireland and Scotland, the leadership role is mainly dedicated to national agencies - ARENA, SEAI and WES, which offer support mechanisms to WEC developers and wave energy researchers. In Canada, the leadership role has been mainly taken by the province of British Columbia - its government and research institutes in the province. In Portugal, no specific leadership actors were identified. For coherent mixes, it is mainly the local governments of Scotland, British Columbia, and Western Australia that are creating more accessible policies for demonstrating wave energy. Companies like Wave Swell, another Australian firm that has a project in Tasmania and is currently working on a project in the US, and Carnegie, which is likely to be extremely successful in Europe, are seen as positive examples of increasing its capacities (Interview 3).

In the case of Australia, the leadership and engagement role are dedicated to ARENA for ensuring funding opportunities for emerging renewable energy technologies, including wave energy. Through ARENA-funded wave energy projects, the result is published on ARENA's website as reports and lessons learned, which serve as recommendations for policymakers and, of course, new knowledge gained from wave energy development, wave farm construction and WEC testing projects. ARENA prioritises knowledge sharing by gathering, storing, analysing, curating, and disseminating data, and expertise(Australian Renewable Energy Agency (General Funding Strategy) Determination 2021, 2021).

To improve capabilities and knowledge in the wave energy sector in Canada, the WCWI gathers information on waves, winds, and currents and maintains and runs four offshore wave-measuring buoys (Marine Renewables Canada, Annual Report 2015, 2015). To assist future wave energy development off the coast of British Columbia, it has been carrying out several resource assessments, technology modelling, and grid integration efforts, which the grid integration is also linked to market shaping (Marine Renewables Canada, Annual Report 2015, 2015). For projects under the Canadian Energy Regulatory Act, the Canadian government requires information about environmental effects, health, social and economic effects, as well as interests of Indigenous people for deployment of ocean renewable energy projects (Canadian Energy Regulator Act, 2022).

In Ireland, the leadership role from the government’s side is mainly dedicated to SEAI, which mainly supports and funds research and WEC development and deployments. Academic research on early-stage offshore renewable energy technology has found success with the SEAI RD&D funds (Marine Renewables Industry Association, 2023). In addition to providing academic currency for the associated institution's standing through the publication of papers on innovative ocean renewable energy technologies, the current RD&D program maximises value for academic partners by offering fully funded tank testing programs and funding for the hiring of Post Doctoral Research Associates (Marine Renewables Industry Association, 2023). For knowledge dissemination, SEAI is creating a National Energy Research Database to promote cooperation and communication among researchers and to give further details on ongoing and completed Energy Research initiatives. For Irish companies, the biggest obstacle is the lack of human resources. In terms of finance, procurement, project management, engineering design, manufacture, sign-off, and certification, few local Irish firms and developers have the personnel with the necessary skills and knowledge to do it (Interview 2).

Over the past 17 years, Portugal has made significant investments and national efforts in the renewable energy industry, increasing the percentage of power generated from renewable sources from 3% in 2000 to 27% in 2012 (Foundation for Science and Technology, 2019). Portugal has acknowledged that more technological development in the areas of solar and wave energy as well as the creation of an extensive portfolio of cost-effective renewable technologies, will be required to attain greater success, which will be essential to advance beyond the current technology (Directorate-General for Communication, 2019). In terms of participation and leadership in European R&D projects, national public and private institutions hold prominent positions throughout Europe (in Portugal, there were 43 European R&D projects, 24 national and four prototype testing projects at sea) (Foundation for Science and Technology, 2019).

In Scotland, WES was created to provide leadership and develop further wave energy. WES is stimulating innovation in wave energy's primary systems and subsystems, which are still in the early stages of technological and economic development compared to tidal energy (Energy and Climate Change Directorate, 2023). For instance, WES is co-leading EuropeWave, a pan-European initiative that supports the advancement of the most promising wave energy concepts by replicating and expanding upon the WES pre-commercial procurement approach (Energy and Climate Change Directorate, 2023). On the UK level, the EPSRC supports research with the goal of generating knowledge and funding innovation that may benefit society and the economy (Grattan, Noble, & Jeffrey, UK Ocean Energy Review 2023, 2023). Scotland's Draft Energy Strategy and Just Transition plan, as well as WES, which receives financial support from the Scottish Government, indicate a change in policy that facilitates WEC testing and wave energy development, however, energy matters are a UK government competence, as a result of which Scotland's policy for wave energy development may still remain in the shadows, given the UK's energy policy, which is currently focused on wind energy.

4.2.4. Outcome-based financing

Expenditures and investments are directed towards increasing production capacity to achieve the required mission (Mazzucato, 2021). Risk-based public investments by the government in emerging technologies will also attract private sector investments.

Funding for wave energy development is provided through available project programmes offered by national agencies as well as local governments. European countries receive additional funding from EU programmes such as Horizon and EMFAF. Although financial support mechanisms have been established in all five countries, they are insufficient for wave energy due to the countries' shift in focus to offshore wind energy and, in some cases, tidal energy, as in Canada and the UK (Interview 1) (Interview 2). For example, wave energy projects previously received more financial support in Australia than in the past five years (Gaudin & Wolgamot, 2024). Similarly, in Ireland, wave energy projects previously received more financial support from SEAI, and wave energy appeared as a keyword in more Irish energy documents (Interview 3). At the UK and Canadian levels, the focus through CfD and Marine Renewables Canada and other funding projects from the Canadian side is on tidal energy, as its technology offers cheaper electricity generation costs than wave energy currently does. For Portugal, no change in the focus on wave energy was observed. In all five countries, outcome-based financing is mainly expressed through the financing of wave energy projects, provided by national agencies, such as ARENA, SEAI, and WES. Projects range from research into the potential of waves in coastal areas to testing WEC devices at existing test sites or finding new test sites, such as the Albany project in Australia. In some cases, supply-demand is provided for WEC to produce electricity, such as the Aguçadoura wave energy farm in Portugal or the Scottish wave energy projects in Orkney.

To encourage and facilitate private investment, the Australian government has taken steps. By actively funding projects and promoting private investment, the CEFC and the ARENA have been instrumental in assisting developers in securing funding (DCCEEW, Electricity and Energy Sector Plan Discussion Paper, 2024). For example, Carnegie Clean Energy Limited received an AUS 20 million five-year financing facility from CEFC to help expedite the last phase of development for its CETO wave power technology (Clean Energy Finance Corporation, 2014). In November 2015, Carnegie Clean Energy Limited obtained alternative private sector financing for their CETO 6 technology from Commonwealth Bank, repaying the CEFC's debt (Clean Energy Finance Corporation, 2014). Compared to CEFC, which has funded only one wave energy project, ARENA has funded eleven wave energy projects since 2012, including also CETO 6 technology. Through the 2024-25 Federal Budget record funds were allocated to ARENA, increasing the entity's budget from AUS 7 billion to AUS 14 billion (Australian Renewable Energy Agency, ARENA Corporate Plan 2024 - 25 - 2027 - 28). In total, ARENA has invested AUS 44 million in wave and tidal energy of the total allocated 2.61 billion to renewable energy projects since 2012 (Australian Renewable Energy Agency, ARENA Corporate Plan 2024 - 25 - 2027 - 28). Financial assistance in the form of grants is provided for wave energy research, development, demonstration of feasibility and deployment of WEC as one of the renewable energy sources for reaching Australia's net zero. In addition, ARENA's funding has a commercial focus on advancing technologies towards commercial readiness (Australian Renewable Energy Agency, ARENA General Funding Strategy 2024-25 - 2026-27). Another project example is in Albany, south of Perth, where Carnegie Clean Energy Limited has set up a full-scale prototype. In Western Australia, the state government at the time provided backing for the AUD 3 million project for Albany's project to test the wave energy resource potential, ensure data availability to researchers and explore the possibility of Albany becoming a test site for WEC (Interview 3). The development required some logistical and scientific assistance, which resulted in the establishment of the Wave Energy Scientific Centre, a research facility also supported by the Western Australian state government (Interview 3).

Canada has made some investments in ocean energy development. For instance, the government of British Columbia operates the Innovative Clean Energy (hereinafter ICE) Fund, which is intended to promote the province's clean energy industry (Government of British Colombia, Innovative Clean Energy (ICE) Fund, 2024). Over CAN 114 million has been allocated by the ICE Fund since 2008 to research and development, energy efficiency initiatives, clean energy vehicles, and pre-commercial clean energy technology projects collaborating with universities, municipalities, First Nations and clean energy technologies developers (Government of British Colombia, Innovative Clean Energy (ICE) Fund, 2024). ICE Fund has supported two projects, which include wave energy development – the development of the PRIMED and Blind Channel Test Sites developed by PRIMED. The project "Supporting for the Continuing Development of the Pacific Regional Institute for Marine Energy Discovery (PRIMED)" has received CAN 300,000 used by the University of Victoria in collaboration with province's Ministry of Energy, Mines and Low Carbon Innovation to increase the capacity of PRIMED to employ its financial, computational, and human resources in order to: advance understanding of offshore wind, wave, and tidal resources for energy conversion; create the foundation for a marine energy sector in the province; attract federal funding and encourage the creation of jobs (Ministry of Energy, Mines, Low Carbon Innovation, 2023). The Blind Channel Test Centre project has received CAN 2 million, with funding partners being PacifiCan and Natural Resources Canada (hereinafter NRC) (Ministry of Energy, Mines, Low Carbon Innovation, 2023). Although this project was mainly focused on the deployment of tidal turbines, wave energy technologies were also considered for testing how resilient these technologies are on the West Coast of Canada. Besides the ICE Fund, the WCWI, which is also under the University of Victoria's supervision, received CAN 1.4 million for PRIMED development from Western Economic Diversification (Marine Renewables Canada, 2017 Annual Report, 2017). In addition, British Columbia and the government of Canada have created a partnership to invest CAN 40 million in the advancement of sustainable energy initiatives and technologies that are not yet commercially viable (Marine Renewables Canada, 2017 Annual Report, 2017).

In Ireland, the 2024 SEAI National Energy RD&D Funding Program provides about €75M in research funding for 240 creative projects that were awarded between 2018 and 2023

(Sustainable Energy Authority of Ireland, 2024 SEAI National Energy Research, Development & Demonstration Funding Programme, 2024). Since 2003, SEAI has helped Ocean Energy's R&D by providing more than €20 million in government-funded grant funding to Irish SMEs so they may advance their innovations (Sustainable Energy Authority of Ireland, Review of funding supports to the Ocean Energy Sector, 2020). SEAI's dedication to supporting this cutting-edge technology expanded along with the sector's demands, and in 2009 it established the PDF. Moving ocean energy technologies closer to commercialisation was the goal of this programme and through the development and implementation of test wave and tidal energy capture systems, devices, and locations, the fund has contributed to the sector's improvement (Sustainable Energy Authority of Ireland, Review of funding supports to the Ocean Energy Sector, 2020). PDF funded 125 projects of which wave energy technologies accounted for over half (61) of the initiatives. with obtaining more than €10 million (51%) in funding from grants (Sustainable Energy Authority of Ireland, Review of funding supports to the Ocean Energy Sector, 2020). The Irish Marine Institute is making sure that there is a test site for wave energy developers and other cutting-edge marine technology. The number of projects that the Marine Institute supports and the number of proposals that are successful in obtaining financial returns are used as indicators of success (Interview 2). Additional funding comes from Interreg, Horizon, and Atlantic Arc funds.

Portugal has implemented an ocean programme to ensure financial support for wave energy development. Through the Ocean Energy European Research Area Network (hereinafter OCEANERA-NET) initiative, FCT has been providing financing for ocean energy research (Brito E Melo & Falcão, 2018). Out of the 10 projects that OCEANERA-NET authorized, FCT supported Portugal's involvement in the following 8 projects, the first three of which were coordinated by Portugal (WavEC, IST, and INEGI) and concluded in 2018 (Brito E Melo & Falcão, 2018).

On the UK’s level, the country gives 15 years of support, while CfD generators receive a top-up payment between the market price and a competitively established "strike price," in contrast to the RO, which offers a fixed payment per MWh (Reid, 2017). In March 2017, the CfD held its second auction, raising £290 million for technologies like wave and tidal stream, anaerobic digestion, and offshore wind (Reid, 2017). Wave energy developers have difficulties competing in CfD with offshore wind energy due to higher technological costs (Interview 1). The WES technology programme has invested £50 million, sponsored 120 contracts, and worked with 300 organisations in 18 different nations. These initiatives are setting the standard for sophisticated control systems and creating wave devices, subsystems, and components

(Energy and Climate Change Directorate, 2023). In addition, early in 2023, the Scottish Government unveiled their draft energy policy, which calls for ongoing assistance for WES and allocates £18.25 million for long-term growth in the industry (Grattan, Noble, & Jeffrey, UK Ocean Energy Review 2023, 2023). The development of innovative wave energy devices, power take-off systems, control systems, rapid connection systems, and materials has been aided by several funding streams under the WES program (Grattan, Noble, & Jeffrey, UK Ocean Energy Review 2023, 2023). With a total funding of €18.8 million, the Scottish Government is the second largest funder for ocean renewables after EPSRC. Most of this funding goes to the wave sector, with €0.5 million coming from Scottish Enterprise through OCEANERA-NET and €18.3 million coming from Wave Energy Scotland through its programs and EuropeWave (Grattan, Noble, & Jeffrey, UK Ocean Energy Review 2023, 2023).

4.2.5. Value distribution

Value distribution’s essence is to shape the market and create communal value while ensuring equal redistribution and predistribution. This can be accomplished by compensating all value creators, identifying opportunities to restore value through creative investment, and reviving financial sources (Mazzucato, 2021).

For value distribution, pioneer countries are mainly focused on open-source projects for knowledge dissemination and data availability gained from projects, which operate in all countries, and the establishment of test sites for testing and development of WEC, which operate in Ireland, Portugal, and Scotland.

Adherence to a Knowledge Sharing Plan regarding the funded project or measure is a requirement of ARENA program funding to inform the industry and the public of the progress (Australian Renewable Energy Agency, Emerging Renewables Program Guidelines, 2013). For risk-sharing, the Australian Commonwealth Bank is one of the private sectors that invests in wave energy projects, such as the Garden Island Microgrid project, which also received ARENA’s grant, and Carnegie Clean Energy Limited CETO 6 technology development, which at first received financial support from CEFC. ARENA is focused on maximising the value of projects through knowledge sharing (Australian Renewable Energy Agency, ARENA Corporate Plan 2024 - 25 - 2027 - 28).

Like Australia, Canadian projects also require knowledge dissemination, as it is one of the conditions for receiving funding for projects. As mainly all the wave energy development activities happen in British Columbia, the wave energy potential reports on the West Coast of Canada. Some of the WEC has been deployed, for example, Neptune 3A was installed in early

September 2016 after Mermaid Power Corporation's Neptune 3 wave energy device was launched at Keats Island in December 2015 (Marine Renewables Canada, Annual Report 2016, 2016). In addition, the WCWI maintains four offshore wave energy measurement buoys carrying out several grid integration, technology modelling, and resource assessment tasks that will aid in the development of wave energy in the future in British Columbia (Marine Renewables Canada, Annual Report 2015, 2015). The Canadian government is issuing licenses for test sites to private developers for ocean energy projects, with the following regulations as environmental protections, societal and economic gain, as well as consulting First Nations before deploying projects. Power Purchase Agreements (hereinafter PPA) in British Columbia can also be offered to developers for their ocean renewable energy technology deployment and energy production (Ministry of Water, Land and Resource Stewardship, 2024).

In Ireland, SEAI established a national energy research database for disseminating knowledge. In the form of a brief, publishable project report, project outcomes—that is, information gained, scientific output, research results, and lessons learned—should be made public (Sustainable Energy Authority of Ireland, Ocean Energy Prototype Research and Development Programme Application Guide, 2015). In addition, Ireland has three test sites for developers to test WEC. SEAI funds aim to bring the technology of ocean energy closer to commercialisation. Through the development and implementation of test wave energy capture systems, devices, and locations, the fund has contributed to the sector's improvement (Sustainable Energy Authority of Ireland, Review of funding supports to the Ocean Energy Sector, 2020).

In Portugal, in terms of producing wave energy, national efforts in recent years have concentrated on creating floating systems that can be installed in waters as deep as about 80 meters and on creating new kinds of air turbines and controlling them so that they can be installed in different kinds of oscillating water column converters (Foundation for Science and Technology, 2019). Portugal operates ZLT, which allows testing wave energy technologies in the sea. ZLT also ensures knowledge dissemination from the WEC projects carried out, as well as energy production (Foundation for Science and Technology, 2019).

In Scotland, value distribution goes through knowledge dissemination and energy production. WES uses a competitive procurement process to support a range of projects focused on the primary systems and subsystems of WEC (Grattan, Noble, & Jeffrey, UK Ocean Energy Review 2023, 2023). The goal is to develop dependable technology that will enable wave energy production at a reasonable cost. For instance, Mocean Energy finished sea testing of a 10kW ½ scale prototype in 2021 and is working on a 250kW pre-commercial prototype design as part of the EuropeWave initiative (Wong & Jeffrey, 2023). Crown Estate Scotland hired ORE Catapult to carry out a comprehensive survey of tidal and wave technology and project developers, and stakeholders to get their input on how to improve the current leasing arrangement for projects ranging from 3 to 30 MW to maximise commercialisation potential (Grattan, Noble, & Jeffrey, UK Ocean Energy Review 2023, 2023).

4.2.6. Public-private partnership with stakeholder value

Public-private partnership is aimed at shifting from parasitic to symbiotic partnerships, therefore encouraging different economic players to collaborate and generate value for the benefit of everybody, which implies that the wealth generated is then reinvested in society and other actors (Mazzucato, 2021).

Pioneering countries have engaged in symbiotic partnerships for developing wave energy. These relationships are manifested within the framework of program implementation, granting public funding to projects, requesting reports and knowledge dissemination. In WEC projects, the funding of which is provided by one of the national agencies or EU funds, there is an opportunity to apply for both ownership of the acquired knowledge and data and a patent for WEC. Reviewing industry feedback and obtaining information from interviews, industry representatives highlight the insufficient support from the public sector for wave energy development, while the public sector signals that it is doing enough.

In Australia, ARENA-funded projects ensure symbiotic value rather than parasitic with involved stakeholders. While ARENA provides funding through grants, it also encourages collaboration between different stakeholders and disseminates gained knowledge from projects to the public. One of the examples is ARENA's funded Garden Islands Microgrid project – a collaborative project between the University of Western Australia and the Carnegie Clean Energy Limited. Several students who are interested in utilising Garden Island as a case study for university courses have contacted Carnegie Clean Energy Limited, which encourages these endeavours wherever it can (Carnegie Clean Energy Limited, 2021).

In Canada, the ICE Fund by British Columbia ensures a symbiotic partnership rather than a parasitic one. Involved stakeholders have worked together to develop new test sites on British Columbia's coast. In addition, The Canadian government awarded the University of Victoria CAN 83.6 million in 2023 to begin the Accelerating Community Energy Transformation initiative to bring together partners from academia, the private sector, and First Nations in energy system transformation (Marine Renewables Canada, Annual Report 2023, 2023).

In Ireland, SEAI-provided funds ensure symbiotic partnerships. For example, SEAI evaluated the 125 projects' return applications. A large percentage of candidates returning to the program is anticipated since SEAI advocates a step-by-step approach with all technologies up the technology readiness level scale and encourages applicants to reapply after completing a technology readiness level step. 94 out of the 125 projects, or 75 per cent, were returning applications (Sustainable Energy Authority of Ireland, Review of funding supports to the Ocean Energy Sector, 2020). The Irish government is dedicated to maximising supply chain and business potential via the study, development, and demonstration of floating wind, tidal, and wave technologies (DECC, National Energy & Climate Plan 2021-2030, 2021). Some of the problems arise from SEAI's side. Firstly, at maritime test facilities like the Galway Bay Maritime & Renewable Energy Test Site, engineering design creation, fabrication, installation, and testing of prototypes under real-world environmental circumstances are not made possible by the way the RD&D budget is set up (Marine Renewables Industry Association, 2023). Secondly, because SEAI has not been helpful with comments or suggestions on how to structure a proposal, applicants are taking a more cautious approach to making sure their proposals are "fundable" (Marine Renewables Industry Association, 2023). For the funding, collaborations in the project are highly valued.

In Portugal, the Finnish company AWEnergy, in collaboration with Portuguese R&D and industrial entities, designed and successfully tested a 300 kW prototype over the course of four years, delivering electricity to the national grid during the Waveroller wave energy technology test on the Peniche coast (Foundation for Science and Technology, 2019). With two foreign scientists (AW Energy and Bombora) creating technical development projects in this area, Peniche Shipyards has actively engaged in offshore renewable energy initiatives, namely wave energy. Investments are required to improve port conditions (Foundation for Science and Technology, 2019).

In Scotland, multiple cooperations with symbiotic partnerships have been made. WES's mission is to help the private sector in developing wave technologies while ensuring that Scotland continues to play a leadership position in the development of marine energy (Grattan, Noble, & Jeffrey, UK Ocean Energy Review 2023, 2023). To assist the advancement of the most promising wave energy concepts, WES and the Basque Energy Agency are co-leading EuropeWave, a pan-European program that replicates and expands upon the WES pre-commercial procurement methodology (Energy and Climate Change Directorate, 2023).

4.2.7. Participation in co-creating the value

To revitalise conversation, debate, and consensus building, new ways of participating in the value-creation process should be introduced with a focus on avoiding tokenistic involvement, the participatory system needs to be flexible enough to adjust in response to feedback (Mazzucato, 2021).

In all countries, collaboration between industry, researchers and government agencies is encouraged, especially to obtain funding for wave energy projects. After the projects are completed, feedback is provided on how to improve the wave energy development system, however, this feedback is not always taken into account, as is the case in Ireland. Industry representatives are also increasingly trying to encourage collaboration and jointly develop projects to obtain more accurate results.

Australia has good examples of participation in co-creating value. For developing the First Nations Clean Energy Strategy, the Australian government collaborated with First Nations peoples and organisations. In addition, in 2023, the First Nations Clean Energy and Climate Change Committee was established to provide advice to the DCCEEW (Australian Government 2024, 2024). In some ARENA-funded projects for wave energy, such as the Australian Wave Energy Atlas project, Garden Island Microgrid project, and Perth Wave Energy Project, stakeholder round-table discussions and workshops were held to gather feedback for project improvements. For example, for the Australian Wave Energy Atlas project, two workshops were held with Ocean Renewable Energy Stakeholder engagement. CSIRO, the University of Tasmania and the Swinburne University of Technology collaborated to organise the first Australian Ocean Renewable Energy Symposium (hereinafter AORES), which served as the second workshop (Hemer, Pitman, McInnes, & Rosebrock, 2018). In addition, the White Paper “Perspectives on a Way Forward for Ocean Energy in Australia” was developed based on the conclusions of the AORES "Way Forward" full-day workshop and is meant to reflect the opinions of numerous industry representatives and invited international guests (Hemer, Pitman, McInnes, & Rosebrock, 2018). The feedback was necessary for the project team to improve Wave Energy Atlas. Both workshops served for the formation of the Australian Marine Energy Taskforce as a new Australian ocean energy industry body (Hemer, Pitman, McInnes, & Rosebrock, 2018). Besides that, Australia also has a National Energy Transformation Partnership which links the Australian government with state and territory governments. In Albany’s project, project developers engaged with the local community to raise awareness of wave energy’s role in the renewable energy sector as well as counter disinformation (Interview 3). The local community had an opportunity to give Indigenous names to the device, therefore reflecting Indigenous history via this project (Interview 3).

Canada has some good participation in co-creating value examples. For developing the ORER initiative, the Canadian government engaged stakeholders to discuss regulatory and technical requirements related to this initiative (Natural Resources Canada, Canada Offshore Renewable Energy Regulations, 2024). In addition, for Canada's Blue Economy Strategy, multiple ocean energy-related stakeholders were consulted for also ocean energy and ocean technologies. In British Columbia, for all clean energy projects, including wave energy, First Nations are consulted as it is a regulatory requirement for it (Government of British Colombia, Clean Energy Production in B.C. An Inter-Agency Guidebook for Project Development, 2016). Established commercialisation centre, PRIMED has collaborated with four wave energy technology developers to bring wave energy innovations to the market and coastal off-grid communities (Marine Renewables Canada, 2017-2018 Annual Report, 2018). The development of the Accelerating Community Energy Transformation initiative is one of the prime examples in British Columbia. Over 40 partners, including Indigenous knowledge keepers and community leaders, are collaborating under the direction of the University of Victoria to create innovative place-based solutions for the energy system's transformation, which is being funded by the Canadian government (Marine Renewables Canada, Annual Report 2023, 2023).

In Ireland, the government's focus has mainly shifted to offshore wind energy development, for example, creating the Offshore Wind Delivery Task Force (DECC, Energy Security in Ireland to 2030, 2023). Although the government has been focused on offshore wind energy, national agencies continue providing some support for wave energy. In SEAI's strategy for 2022 – 2025, the agency has highlighted the need for collaboration to set a common ground for further renewable energy, including wave energy development. To further expand or strengthen Ireland's sustainable energy expertise base, SEAI plans to create a strategic cooperation strategy to promote the growth of collaborations and ties with regional, national, and worldwide industry experts and professionals (Sustainable Energy Authority of Ireland, Delivering Ireland's Energy Revolution Statement of Strategy 2022-2025, 2022). However, the industry has highlighted limited engagement from SEAI for RD&D project proposals. Due to the limited timeframe and formality of the process, SEAI has not been generous with suggestions or comments on how to create a proposal (Marine Renewables Industry Association, 2023).

In Portugal, the government aims to support national R&D initiatives to promote technological advancement, including wave energy development (Directorate-General for Communication, 2019). Portugal possesses substantial industrial, scientific, and technological capabilities for the development and building of wave energy harvesting devices. In addition to the National Laboratory of Energy and Geology, the WavEC Offshore Renewables, the company Kymaner, the University of Porto's Faculty of Engineering, and the Institute of Mechanical Engineering and Industrial Management, this activity started at the Higher Technical Institute (Foundation for Science and Technology, 2019). Businesses conducted more than half of the country's involvement in national or local R&D initiatives (Foundation for Science and Technology, 2019).

In Scotland, it is very common, similarly to the rest of the countries, to have collaborative projects. For example, the University of Strathclyde and the University of Edinburgh collaborate on the wave energy research project HAPiWEC, which is backed by industry partners Renewable Dynamics, WES, the National Renewable Energy Laboratory, and the West Atlantic Marine Energy Community (Grattan, Noble, & Jeffrey, UK Ocean Energy Review 2023, 2023). The Scottish government has indicated that to guarantee that development is sustainable and takes into consideration community and public opinions, public involvement in planning and consenting is essential. This is related to the discussion around the administration of The Crown Estate and its earnings (Scottish Government, 2020 Routemap for Renewable Energy in Scotland , 2011). In addition, the Scottish government is determining the objectives for ensuring the sector's future growth in light of the UK government's energy policy changes and the EU's withdrawal from the EU by collaborating with the marine energy industry working group (Energy and Climate Change Directorate, The future of energy in Scotland: Scottish energy strategy, 2017).

5. Discussion

This chapter aims to discuss the results described in Chapter 4 and develop recommendations for enhancing mission-oriented wave energy development in pioneering countries and any other country interested in developing wave energy.

5.1. Government's role in wave energy development

This thesis research question is "How are governments taking up their role in the development of creation and commercialisation of wave energy, and how much of Mariana Mazzucato's mission-economy approach is being used in wave energy policy frameworks?" which resulted in the aim of finding out whether governments are involved in the development and commercialisation of wave energy or not. Additionally, if countries are involved in the development of wave energy, then whether Mariana Mazzucato's frameworks are being used.

Wave energy development is an emerging field, and as a result, a mission-oriented approach from national governments is required to develop it. Mariana Mazzucato proposes seven key pillars that need to be implemented to realize the development of wave energy, which will be discussed in the next section. Overall, compared to the other 64 countries that have shown interest in wave energy and its potential in the diversification of renewable energy resources, Australia, Canada, more precisely British Columbia, Ireland, Portugal and Scotland are the countries that can be considered pioneers in the progress of wave energy development.

When comparing what is similar in all five countries, it is certainly the sponsorship of wave energy development projects by governments, for example, funding from national agencies ARENA, SEAI, WES and open tenders for project implementation, as well as support from local governments in financing projects, for example, British Columbia and Western Australia. Focusing on policy papers, nothing specific to wave energy and its development has been developed in all five countries, therefore lacking policy that would promote the development of wave energy, thus not realising its full potential in the policy implementation phase and market shaping to incentivise the wave energy market. While countries such as Ireland, Portugal and Scotland have made significant progress in developing marine planning and policy frameworks, that can increase the potential for wave energy development, such as the Irish National Marine Planning System and the Portuguese ZLT, there is still a lack of clear, consistent and long-term policies specifically targeting wave energy. In most countries, developers rely on project-specific short-term funding and lack certainty about long-term contracts or PPAs that would secure market demand for wave energy.

As already mentioned, in addition to creating binding policies for wave energy development, outcome-based financing is another vital element for government engagement. To develop renewable energy resources, including wave energy, Australia, Ireland, Portugal and Scotland have established national agencies that finance renewable energy projects. ARENA has invested around AUD 44 million in ocean energy projects since 2012, which accounts for less than 2% of total funding for renewable energy projects (Gaudin & Wolgamot, 2024). Although ARENA has supported some wave energy projects, wave energy development is not a priority, which was highlighted in ARENA's latest Corporate Plan (Australian Renewable Energy Agency, ARENA Corporate Plan 2024 - 25 - 2027 - 28). Ireland has several national agencies supporting wave energy development, such as SEAI, the Irish Marine Institute, and the Environmental Protection Agency. SEAI also runs the RD&D Funding Programme, which has allocated over €4.4 million to maritime energy projects in the past five years (Sustainable Energy Authority of Ireland, 2024 SEAI National Energy Research, Development & Demonstration Funding Programme, 2024). For WEC testing in Portugal, the FCT is the main agency providing funding. A key initiative driving wave energy development in Scotland is WES, which has been supporting breakthrough technology projects since 2014. In addition to WES, Scottish Enterprise plays a significant role in supporting innovation and investment for Scottish businesses.

One of the gaps in wave energy development is the lack of adequate funding. Although all five countries offer funding opportunities for wave energy development (see above), the funding is often fragmented and may not be sufficient to support the high-risk, capital-intensive nature of wave energy development. The lack of funding can be linked to national priorities for renewable energy development as the main focus now is on offshore wind energy (Australia, Canada, Ireland, Portugal, UK), tidal energy (Canada, UK), as well as the strong oil and mining lobby (Australia). Wave energy has been sidelined mainly to meet 2030 climate targets, as well as due to the TRL of WEC technology. The wave energy sector needs more stable, large-scale financial backing for commercialisation and integration into the grid. It should be noted that in the case of Scotland, the state also does not have sufficient jurisdiction to decide on energy policy, which is essentially the responsibility of the UK.

Focusing on government leadership, none of the countries has a clear leader. In Australia, although ARENA could be classified as a leader, the main impetus for wave energy development comes from the private sector and academia, who indicate that Australia is not doing enough in wave energy development. In Canada, specifically in the case of the British Province, the provincial government is showing leadership by offering funding projects to address some societal challenges. The British Province emphasises the need to involve Indigenous groups in project implementation, which is a mandatory requirement for project implementation. In Ireland, the main impetus for wave energy development also comes from the sector and academia, although the Irish government has provided test sites for WEC testing. The Portuguese government is more reluctant to provide support, namely, the Portuguese government relies more on the EU and other international projects than initiating its own projects. The Scottish Government is taking a more prominent lead in this regard, including wave energy in policy documents and providing increased funding for WEC and working with EMEC to test WEC.

5.2. Mariana Mazzucato's seven key pillars in pioneering countries

Mariana Mazzucato's **collective value creation** pillar highlights how public policy may help communities, corporations, and the government work together to create benefits for society and ensure that policies have societal relevance (Mazzucato, 2021).

Australia and Canada emphasise the role of cooperation between government agencies and industry in fostering innovation and WEC development. While both countries are making progress in engaging local communities, such as First Nations, in the energy transition, they are still mainly focusing on the technological aspects of the energy transition. Australia emphasises an energy efficiency management system for cooperation between communities, industries, researchers, and government. During the public consultation, the Government of Canada has worked closely with industry and research organisations to support the research, development, demonstration and commercialisation of ocean energy technologies. The ORER initiative and the involvement of First Nations communities in consultation processes on wave energy projects reflect a commitment to stakeholder engagement.

Ireland and Portugal, on the other hand, have adopted a more holistic approach, involving state support, industry cooperation and strategic investments in wave energy technologies. Important components of Ireland's policy include stakeholder participation and public consultation, such as discussions on offshore renewable energy development and marine protected zones. Particularly in the wave energy industry, Portugal's strategy aligns with a framework for creating shared value, giving long-term sustainability a top priority, encouraging technical innovation, and promoting stakeholder engagement. Portugal's focus on exportable ocean energy technologies and Ireland's public consultation processes are clear examples of how shared value can be created by harnessing shared public interests.

This thesis finds that Scotland is perhaps the most ambitious in combining economic and social objectives, as it has a clear focus on maximising both the social and economic benefits of the transition to renewable energy. Mazzucato's ideas of producing shared public value by including various stakeholders in the co-design of policies and guaranteeing fair results are embodied in Scotland's policy through its Energy Strategy and Just Transition Plan. Scotland’s approach is a prime example of Mazzucato’s collective value creation, as it seeks to strike a balance between economic growth and social justice, ensuring that all stakeholders are part of the process.

Market shaping emphasises the active role of governments in directing innovation systems and shaping markets to align with strategic societal missions. Mazzucato contends that rather than only correcting market flaws, governments need to actively advance innovation in technology using finances and laws (Mazzucato, 2021).

Australia and Canada show a more reactive market shaping approach. While both countries provide some support for wave energy, they are less focused on actively pushing the market frontier. Canada's concentration on offshore wind and tidal energy, along with Australia's lack of enabling regulations and restricted financing, represents a more passive kind of market shaping that is not consistent with Mazzucato's focus on mission-oriented innovation. Australia has not developed enabling wave energy legislation and lacks awareness of wave energy’s potential (Interview 3).

In the context of wave energy, this thesis finds that countries like Ireland, Portugal, and Scotland have demonstrated a more aligned approach with Mazzucato’s vision by prioritising long-term missions, providing funding for R&D, and establishing infrastructure that supports ocean renewable energy development. Ireland’s commitment to long-term strategies, such as the Climate Action Plan and Offshore Renewable Energy Development Plan, demonstrates an understanding of the need for a coordinated approach, but the immediate focus on offshore wind shows a practical shift that might delay the full potential of wave energy in the short term (Interview 2). Scotland, on the other hand, shows greater market support for wave energy through its integration into policy frameworks, funding schemes, and dedicated initiatives such as WES, aligning closer with Mazzucato’s approach. The creation of a Blue Fund for wave energy R&D projects and the country's long-term goals in its Roadmap for Carbon Neutrality 2050 position Portugal as a leader in fostering an environment for wave energy development.

Mariana Mazzucato's framework for **dynamic capabilities in public and private organisations** highlights the importance of governments acting as active drivers of innovation and participating in market-shaping efforts. Mazzucato asserts that governments need to be able to coordinate policies, take risks and encourage bottom-up engagement to encourage co-creation and facilitate learning and assessment (Mazzucato, 2021).

Australia and Canada exhibit somewhat reactive, fragmented, and regionally focused approaches. While ARENA in Australia provides financial support and knowledge dissemination, it lacks the coherent policy mix and long-term strategy that could allow it to foster dynamic capabilities more effectively. Canada similarly has strong regional leadership from British Columbia, but the lack of a unified national framework and a more coordinated approach limits the country's ability to accelerate wave energy development. In both countries, private sector innovation, such as the work done by companies like Wave Swell and Carnegie, demonstrates potential, but public support remains inadequate to scale these efforts.

In contrast, Ireland and Scotland show stronger efforts to develop dynamic capabilities at the national level. SEAI in Ireland plays a crucial leadership role, particularly through its RD&D programs that support innovation in wave energy, however, the industry's challenges in human resources still need to be addressed (Interview 2). Scotland, with its WES initiative, exhibits a robust market-shaping approach, coordinating technological advancements and facilitating cross-country collaboration (Interview 1). WES's leadership in the EuropeWave project, combined with the Scottish government's active investment in wave energy, showcases a dynamic and forward-thinking approach to accelerating innovation.

Despite lacking a centralised leadership figure for wave energy, Portugal has shown a high level of commitment to renewable energy innovation and R&D, both at the national and European levels. Its participation in numerous European projects demonstrates strong collaboration and technology development capabilities, although its wave energy efforts would benefit from a clearer strategic direction and stronger leadership.

Outcome-based financing emphasises government-led investments in innovation that drive economic growth and attract private sector funding. Mazzucato argues that public investment should not merely fill funding gaps but actively shape markets (Mazzucato, 2021). The challenge that remains in wave energy development the shift towards offshore wind in several countries has reduced the financial resources available for wave energy.

Australia demonstrates a strong outcome-based financing approach, as ARENA's funding structure facilitates commercial scalability for emerging technologies, as well as fosters R&D. Although, with funding ARENA, Australia showcases an outcome-based financing pillar, the funding provided for wave energy is not adequate to truly facilitate WEC commercial scalability. Scotland employs a blended approach, with long-term revenue support through CfD and targeted R&D funding via WES (Grattan, Noble, & Jeffrey, 2023). However, competition with offshore wind and high initial costs pose barriers to widespread commercialisation (Interview 1). Scotland's substantial funding allocation highlights a commitment to long-term industry development. With the funding schemes in place, Australia and Scotland are pioneers in ensuring outcome-based financing.

In contrast, Canada and Portugal exhibit a more research-oriented approach, focusing on test sites and feasibility studies rather than commercialisation. Canada's investment in wave energy development is primarily regional, with British Columbia playing a key role through the ICE Fund, but the national-scale strategic financing remains limited. Portugal has primarily relied on FCT and the OCEANERA-NET initiative to finance wave energy research. While Portugal has been involved in numerous European projects, its national funding is not as extensive as in the UK.

Ireland, with its PDF program and SEAI investments, balances both aspects by funding R&D while simultaneously advancing commercialisation efforts. The establishment of the PDF in 2009 marked a significant shift towards commercialising wave energy, as seen in its funding of 61 wave energy projects (Sustainable Energy Authority of Ireland, Review of funding supports to the Ocean Energy Sector, 2020). In addition to national-level investments, EU investments, such as Interreg and H2020, provide additional funding for wave energy development.

Mariana Mazzucato's **value distribution** pillar emphasises equitable benefit redistribution, ensuring that all stakeholders—researchers, developers, communities, and investors— are compensated and that financial and knowledge resources are reinvested in the system (Mazzucato, 2021). Effective value distribution in wave energy requires a balance between knowledge sharing, infrastructure support, and commercial incentives.

This thesis finds that Australia and Scotland have structured their value distribution effectively by embedding knowledge-sharing requirements into funding mechanisms. ARENA's funding mandates public dissemination of findings, while Scotland's approach through WES ensures that value is reinvested in cost reduction and commercialisation efforts. These models align well with Mazzucato's principle of predistribution, where value is created and distributed equitably from the outset rather than merely redistributed later. Canada follows a regulated value-sharing model, ensuring environmental and social benefits alongside economic gains. The integration of First Nations consultations indicates an effort to balance commercialisation with social equity. However, its funding mechanisms for wave energy remain more limited. Ireland and Portugal focus on infrastructure-driven value distribution, particularly through dedicated test sites and research initiatives. Portugal operates ZLT, a marine test site for wave energy technologies, ensuring that developers have access to real-world testing environments. Ireland has developed a national energy research database under SEAI, ensuring project insights are widely accessible. Ireland also stands out with three dedicated test sites for wave energy technologies, actively contributing to commercialisation efforts.

The **public-private partnership with stakeholder value** pillar advocates for shifting from parasitic to symbiotic partnerships, ensuring that generated wealth is reinvested into society rather than extracted for private gain (Mazzucato, 2021). This requires PPPs to be structured around long-term societal and economic benefits rather than short-term profit motives. All countries should move towards more proactive public sector involvement—not only funding projects but also ensuring long-term reinvestment, infrastructure development, and knowledge-sharing mechanisms that maximise stakeholder value.

Australia and Scotland have established the most structured public-private partnership frameworks, with clear mandates for collaboration, funding, and knowledge dissemination. ARENA and WES actively shape the market rather than react to existing trends, aligning with Mazzucato’s argument that the public sector should take an entrepreneurial role in driving innovation. Canada’s model is socially inclusive, particularly with First Nations engagement, ensuring broader societal value distribution. However, its focus on test sites rather than full-scale commercialisation suggests a need for stronger industry incentives. Ireland faces challenges in ensuring full stakeholder value creation, as test site infrastructure limitations and funding proposal issues hinder innovation. While SEAI supports long-term development through returning applicants, a more structured approach to feedback and engineering support could enhance Ireland’s role in wave energy commercialisation (Marine Renewables Industry Association, 2023). Portugal’s reliance on international partners highlights the importance of foreign investment in technology development. However, for true stakeholder value creation, domestic infrastructure improvements, such as port enhancements, are necessary.

Participation in co-creating value emphasises the need for meaningful collaboration rather than tokenistic involvement. It advocates for flexible, participatory systems that evolve in response to stakeholder feedback, ensuring genuine engagement rather than mere consultation (Mazzucato, 2021).

Australia and Canada demonstrate high levels of participatory engagement, particularly through Indigenous inclusion and industry-academia partnerships. Australia’s First Nations Clean Energy Strategy and Canada’s regulatory requirement for First Nations consultation reflect genuine efforts in inclusive value co-creation. In Canada, PRIMED's collaboration with four wave energy developers for commercialising wave energy technology is another strong example of co-creation.

In Ireland, SEAI's formalised and rigid approach limits meaningful engagement. While the SEAI 2022-2025 Strategy recognises the importance of collaboration, the sector feels that its feedback is not fully integrated into policy and funding decisions (Marine Renewables Industry Association, 2023). Portugal has a strong research community, with institutions such as WavEC and the National Laboratory of Energy and Geology promoting the development of wave energy. Although industry and research institutes are involved in Portugal's wave energy R&D initiatives, the government’s role in integrating feedback into national policies remains unclear. Scotland integrates academic, industry, and governmental collaboration through projects such as HAPiWEC. The Scottish Government explicitly acknowledges the need for public participation in planning and consenting processes, ensuring that community perspectives shape development.

5.3. Policy recommendations

The policy recommendations were developed based on Mariana Mazzucato’s framework and may also be influenced by my position in this work. First, the entire research process was influenced by my location in the Netherlands and Latvia rather than in any of the study countries, thus reducing the number of potential interviews. Second, the research recommendations stem from my perspective as a student of International Development with a specialisation in policy and management rather than as an expert in WEC technologies, which may result in the recommendations lacking the technical aspect necessary to develop wave energy. Third, recognising that each country has its own specific renewable energy policy and realising that I would not be able to obtain an overall picture of wave energy development in a particular country within five months of conducting research using available online resources, these recommendations are general and may not be appropriate for the development of wave energy in a particular country. The research has resulted in seven recommendations for wave energy policy and government leadership.

1. **Establish long-term wave energy policies and targets.** Governments should introduce dedicated wave energy policies within broader renewable energy frameworks to provide clarity and long-term direction. Policies should include long-term market support mechanisms, such as CfD or feed-in tariffs, to de-risk investments.

2. **Increase financial support for wave energy.** Governments should shift from fragmented, short-term funding to long-term, outcome-based financing mechanisms and introduce public-private co-financing mechanisms to de-risk early-stage wave energy projects.
3. **Develop national grid-connected test sites and infrastructure.** Countries without grid-connected test sites (e.g., Australia, Canada) should establish national wave energy test centres like EMEC in Scotland. Expand existing test sites (e.g., Ireland's AMETS, Portugal's Aguçadoura) to allow larger-scale demonstrations and commercial testing.
4. **Strengthen government leadership in market shaping.** Create dedicated wave energy roadmaps with clear industrial strategies, ensuring coordination across ministries and national agencies. Establish regulatory sandboxes to accelerate technology testing and deployment, following Portugal's ZLT model.
5. **Foster collaboration and public-private partnerships.** Ensure stakeholder-driven policymaking, integrating feedback from developers, local communities, and Indigenous groups.
6. **Improve access to commercialisation and market entry pathways.** Introduce PPAs and revenue support mechanisms to incentivise private investment in wave energy projects.
7. **Ensure inclusive value distribution and community engagement.** Implement value-sharing models where benefits from wave energy development are reinvested into research, workforce training, and local communities.

6. Conclusions

This thesis focused on the development of wave energy in five pioneering countries - Australia, Canada, Ireland, Portugal and Scotland. Although wave energy has great potential for diversifying renewable energy, WEC technologies have not reached the level of commercialisation. As a result, not many countries are using wave energy technologies for energy production, however, five of these countries - Australia, Canada specifically British Colombia, Ireland, Portugal and Scotland - are developing wave energy production potential. While these countries have recognised wave energy as a viable renewable energy source, its development has been hindered by fragmented funding, policy inconsistencies, and a lack of long-term strategic planning. The main objective of this study was to investigate the role of governments in the development of the creation and commercialisation of wave energy, as well as whether countries are using Mariana Mazzucato's mission-economy approach to the development of wave energy.

Document analysis and interviews outlined each country's different approaches to wave energy development that both promote and hinder wave energy implementation. Wave energy development is mainly driven by industry and the research sector, although countries are also trying to create the necessary environment for wave energy deployment, for example, by establishing national agencies such as ARENA, SEAI and WES to promote wave energy projects. A critical challenge in wave energy development has been the sidelining of the sector in favour of offshore wind and tidal energy, along with the absence of clear, long-term policies specific to wave energy. Establishing dedicated policies and long-term targets is essential to provide stability and direction for investors and developers. In addition, increasing financial support through performance-based financing mechanisms and public-private co-financing models can help de-risk early-stage projects and accelerate commercialisation.

Infrastructure development is another fundamental requirement for advancing wave energy. Countries such as Australia and Canada, which lack national grid-connected test sites, should establish dedicated wave energy test centres while existing sites in Ireland, Portugal, and Scotland should be expanded to support large-scale demonstrations. Furthermore, encouraging cooperation between local communities, businesses, government agencies, and research institutes is essential for advancing technical advancements and guaranteeing equitable value distribution.

Although this thesis investigated the wave energy development and policymaking of five pioneering countries, certain limitations existed. Given the low response rate to the interviews, in the cases of Canada and Portugal, it was not possible to find out the reality of wave energy development in the countries, and the unavailability of some documents made it difficult to see the full picture of wave energy development. This study and its limitations also highlighted future research directions. One of them is the role of the European Commission in promoting wave energy development in EU member states, recognising that Ireland, Portugal and Scotland have relied on EU grants for wave energy development, thus leaving Australia and Canada at the forefront of project development and funding. The second direction of future research is the impact of offshore wind energy as one of the obstacles to the development of wave energy.

Pioneering nations must enact laws with a long-term plan for wave energy development, increase funding, and improve infrastructure to make commercialisation and grid integration easier to unlock wave energy's full potential. Governments may promote innovation, guarantee equitable value distribution, and propel sustainable economic growth through wave energy development by coordinating with Mariana Mazzucato's seven pillars. A coordinated, mission-oriented approach will be key for driving wave energy as a vital piece of the puzzle to the global renewable energy transition, securing both environmental and economic benefits for future generations.

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Appendix 1. List of coded and analysed documents

Australia

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Appendix 2. Interview Guiding Questions

Background information:

- What is your position and role?
- What is your involvement regarding wave energy development in Australia/Canada/Ireland/Portugal/Scotland?

Policy interventions of leading countries:

- What are the key policies or interventions your country has implemented to support wave energy development?
- How is your government fostering collaboration between the public and private sectors in wave energy projects?
- How would you say the mission (transition to renewable energy) is defined, and what is the role of wave energy in Australia/Canada/Ireland/Portugal/Scotland and were multiple stakeholders engaged in the mission definition?

How promising are these interventions?

- How do you measure the success or impact of these interventions in driving wave energy adoption?
- How does the government coordinate involved stakeholders to produce innovative solutions?
- What factors have contributed to the success of these interventions, and are there any limitations or challenges associated with them?

Mariana Mazzucato's framework:

- How do the most successful wave energy interventions in your country reflect principles of co-creation and value distribution as outlined by Mazzucato?
- To what extent do these interventions incorporate a clear mission with societal relevance?

Appendix 3. List of Interviewees

No.	Name	Institution	Topic	Country	Date
1.	Lara Santos Ayllón	The University of Edinburgh	Wave energy development in Scotland	United Kingdom (Scotland)	11.12.2024.
2.	Alan Berry	Irish Marine Institute	Wave energy development in Ireland	Ireland	07.01.2025.
3.	Christophe Gaudin	University of Western Australia Oceans Institute	Wave energy development in Australia	Australia	15.01.2025.

Appendix 4. Codebook

This table portrays code names and the number of codes from all documents analysed. Code names are the same as Mariana Mazzucato's seven key pillars.

Code name	Number of codes
Collective value creation	60
Market shaping	149
Dynamic capabilities for public and private organisations	51
Outcome-based financing	115
Value distribution	76
Public-private partnership with stakeholder value	70
Participation in co-creating the value	74

Appendix 5. Wave Energy Projects in Australia

Name of the project	Involved institutions	Project description
Perth Wave Energy Project	Carnegie Clean Energy Ltd. Partially funded by ARENA	The first commercial-scale wave energy array in the world with grid connectivity and desalination capabilities. The CETO wave energy technology, which Carnegie owns 100% of, is used in the Perth Wave Energy Project.
UniWave200 King Island Project – Wave Swell	Wave Swell Energy Partially Funded by ARENA	The UniWave200 King Island Project included the design, construction, deployment, installation, and operation of the UniWave200, a 200KW wave energy converter in Grassy Harbour on King Island, Tasmania.
Ocean Energy Systems Technology Collaboration Program	CSIRO Climate-KIC University of Adelaide Swinburne University of Technology UNSW University of Tasmania University of Western Australia Partially Funded by ARENA	To increase Australia's voice, influence, and expertise in ocean energy advancements and research, CSIRO spearhead Australia's involvement in the International Energy Agency's Ocean Energy Systems initiative.
Garden Island Microgrid Project	Carnegie Clean Energy Ltd. Partially Funded by ARENA	The Garden Island Microgrid Project will generate power and desalinated water, making it the first wave energy integrated microgrid in the world. A 2MW/0.5MWh battery storage system, 2MW of photovoltaic solar capacity, and a control system with the ability to integrate wave energy producing technologies are all part of the project.
Wave Energy Cost Reduction	University of Western Australia Carnegie Clean Energy Ltd. Partially Funded by ARENA	To maximize power production while minimizing installation and infrastructure costs, the Wave Energy Cost Reduction project looks at the ideal number, size, configuration, and placement of wave energy device arrays.

Energy Cost Study for Bombora Wave Energy Converter	Bombora Wave Power Partially Funded by ARENA	The "cost of electricity" for energy generated by a 60MW mWave™ wave farm was described in detail in the Bombora "Cost of Energy Study," which also validated the mWave wave energy converter technology's possible commercial feasibility as a renewable energy source.
Ocean Wave-Power Machines	Swinburne University of Technology University of Tasmania Partially Funded by ARENA	The performance of wave energy farms has been modelled by Swinburne University of Technology. The study determined the effects of current flows in these arrays as well as the interactions between Wave Energy Converters in an array.
Australian Wave Energy Atlas	Australian Maritime College - The University of Tasmania Bureau of Meteorology BioPower Systems Carnegie Clean Energy Ltd. Swinburne University of Technology Partially Funded by ARENA	This research has created an atlas that facilitates the evaluation of wave power projects' viability.
Carnegie CETO 6 Technology	State Government of Western Australia Partially Funded by ARENA	The project consists of designing, building, deploying, and demonstrating a grid-connected wave energy demonstration plant with a maximum installed capacity of 1.5 MW at a location in State seas near Albany, Western Australia.
BPS bioWAVE Ocean Pilot at Port Fairy	BPS Partially Funded by ARENA	This study attempted to demonstrate a fresh new method for converting wave energy into electricity using the patented bioWAVE technology in order to efficiently convert wave energy to mechanical energy using a specialized mechanical-to-electrical energy converter.
Oceanlinx 1MW Commercial Wave Energy Demonstrator	OEC Pty Ltd, Strategic formwork Techport COOE Pty Ltd ACOR ABB	A 3,000-ton structure, the Oceanlinx commercial wave energy demonstration is around 21 meters wide by 24 meters long. The apparatus, which uses oscillating water column technology to

	VACON Power & Drive Solutions Broens Ltd Partially Funded by ARENA	produce a 1MW peak output, was made to sit in shallow water.
Carnegie Clean Energy's MoorPower	Carnegie Clean Energy Ltd. Blue Economy CRC	The MoorPower Scaled Demonstrator project finished its first operating phase in 2024 after being set up at an offshore test site in North Fremantle, Western Australia. The Demonstrator's initial objectives of verifying the efficiency of the power take-off architecture for offshore applications and validating the MoorPower modules' design and operation were accomplished.
M4 Albany Wave Energy Demonstration Project	University of Western Australia Blue Economy CRC	The goals of this research and innovation project are to identify an emerging supply chain, maximize local procurement (at least 60%, with the goal of 80% of project value), and show how wave energy may be used to decarbonize local aquaculture businesses.
Ocean Wave Energy in Australia	Blue Economy CRC University of Western Australia BMT Carnegie Clean Energy Ltd. CSIRO Griffith University University of Tasmania	This project aims to provide a thorough assessment of the state, opportunities, and challenges of wave energy in Australia by closely examining domestic resources, market dynamics, integration potentials, environmental considerations, regulatory frameworks, and social acceptance factors.

Source: (IEA-OES, 2024), (Australian Renewable Energy Agency, Ocean Energy Projects, 2025), (Gaudin & Wolgamot, 2024).

Appendix 6. Wave Energy Projects in Canada

Name of the project	Involved institutions	Project description
Yuquot Wave Energy Demonstration Project	Mowachaht/Muchalaht First Nation PRIMED Barkley Project group	A Front-end engineering design (FEED) study that supports and de-risks a future planned demonstration of the wave energy

	CalWave Power Technologies Canpac Marine Services Environmental Dynamics Inc. Funded by Natural Resources Canada	converter at Yuquot will be the project's output.
SyncWave Energy Systems	SyncWave Energy Inc. of Pemberton, B.C. Marinus Power LLC of Houston Used funds: Sustainable Development Technology Canada; BC Innovative Clean Energy Fund; NRCan Clean Energy Fund	A U.S. Ocean energy company and a Canadian wave energy developer have partnered to create a wave energy demonstration device that will be tested off the west coast of British Columbia's Vancouver Island.
Accelerating Community Energy Transformation	University of Victoria	Under the direction of University of Victoria, this cooperative project unites more than 40 partners, including community leaders and Indigenous knowledge keepers, to develop creative place-based solutions for the transformation of the energy system. In November 2023, University of Victoria had a kick-off event that gathered more than 100 community, government, and academic partners eager to interact and promote Accelerating Community Energy Transformation.

Source: (IEA-OES, 2024), (Marine Renewables Canada, Wave Energy, 2025), (Buckham, 2019) (Buckham, 2019), (Natural Resources Canada, Yuquot Wave Energy Demonstration Project – FEED Study, 2024).

Appendix 7. Wave Energy Projects in Ireland

Name of the project	Involved institutions	Project description
Multiple Use of Space for Island Clean Autonomy	MaREI-UCC (collaborative Irish partner) H2020 MUSICA project	Aims to provide Blue Growth solutions for small islands for renewable energy implementation, including wave energy.
Innovative Methods for Wave Energy Pathways	MaREI-UCC (collaborative Irish partner) H2020 IMPACT project	Creates and illustrates a next generation testing methodology for WEC.

Acceleration through Novel Criteria and Test Rigs		
Verification through Accelerated Testing Leading to Improved Wave Energy Designs	Ireland Ltd H2020 VALID project	Intends to enhance the dependability and durability of the constituent parts and subsystems that make up wave energy systems by creating and validating a new test rig platform and protocols for expedited hybrid testing.
Lift based Wave Energy Converter	National University of Ireland Maynooth University College Cork H2020 LiftWEC project	The lift forces produced by wave-induced water velocities are investigated in this project.
INTERREG Ireland-Wales Selkie project	MaREI-UCC GDG ltd DP Energy	Addresses gaps, which are slowing down wave and tidal energy progression, as well as helps Welsh and Irish small and medium enterprises go further on the commercialisation route.
Wave Energy Demonstration at Utility Scale to Enable Arrays	Ocean Energy University Cork College HORIZON Europe WEDUSEA	At the EMEC European Marine Energy Test Site, showcase the OE Buoy, a grid-connected 1MW OE35 floating wave energy converter.
Streamlining the Assessment of environmental efFEcts of WAVE energy	MaREI-UCC EMFAF SAFE Wave project	Focuses on the environmental monitoring of ocean energy systems, particularly those that utilize wave energy.
Strategic Environmental Assessment of Wave energy technologies	New Wave Technologies Limited EMFAF SAFE Wave project	One of SEA Wave's key goals is to conduct one of the first focused multi-WEC ecological sampling programs using a thorough experimental methodology to answer some of the lingering questions regarding WECs in offshore habitats.

Source: (IEA-OES, 2024).

Appendix 8. Wave Energy Projects in Portugal

Name of the project	Involved institutions	Project description
EU-SCORES	WavEC INESC TEC EDP Labelec	Development of wave energy array in Portugal co-located with a floating wind farm.

Lift based Wave Energy Converter	WavEC H2020 LiftWEC project	This study examines the lift forces generated by wave-induced water velocities.
SAFEWAVE	WavEC Hidromod	Addresses the long-term environmental issues associated with the installation of tidal and wave energy converters in the maritime environment.
ATLANTIDA	UPORTO UTAD UMINHO	Intends to provide a platform for North Atlantic Ocean promoting wave energy exploitation.
WEC4PORTS	FEUP INEGI	Seeking to create a new hybrid wave energy converter specifically for ports.
POSEIDON	CIIMAR	Focus on WEC expansion combined with offshore wind energy.
Ente Vasco de la Energía (EVE)	NOVATUM	Create a substitute for the Mutriku Wave Power Plant's aging air turbine technology.
ONDEP	WavEC Queen’s University of Belfast Horzion Europe funding	With the help of four WaveRoller units that have benefited from more than ten years of developmental insights, including two years of full-scale demonstrations, ONDEP plans to build a 2MW wave energy farm near Peniche, Portugal.
MEGA WAVE PTO	WavEC Horizon Europe and UKRI funding	The goal of the MEGA WAVE PTO project is to develop the necessary technology to convert ocean waves into sustainable, renewable energy. This project will develop a scalable, intelligent system that can adjust to changing circumstances and continue to function even in the event that a component fails.

Source: (IEA-OES, 2024), (WavEC, 2025).

Appendix 9. Wave Energy Projects in Scotland

Name of the project	Involved institutions	Project description
Bionic Adaptive Stretchable Materials for Wave Energy Converters (BASM-WEC)	University of Strathclyde	Creating and evaluating innovative wave energy technologies to achieve UK’s net zero targets with fund of £1 million.

Holistic Advanced Prototyping & Interfacing for Wave Energy Control (HAPiWEC)	University of Strathclyde University of Edinburgh	Intends to address the pressing problem of bringing wave energy's LCOE down to a level that is similar to other commercially available renewable energy sources.
MU-EDRIVE	Newcastle University University of Edinburgh Mocean energy	Aims to demonstrate the benefits of wave energy converters utilizing electric power technology.
SEETIP Ocean	University of Edinburgh Wave Energy Scotland	Supports the European Technology & Innovation Platform's maritime energy activities.
EUROPEWAVE	Wave Energy Scotland	Carrying out the EuropeWave wave device development initiative.

Source: (IEA-OES, 2024).

Appendix 10. Technology Readiness Level Table

To better understand the government's support for WEC development in different readiness levels, this technology readiness level table was used.

STAGE	DESCRIPTION	TRL
Stage 0	Concept creation	1
Stage 1	Concept development	2 3
Stage 2	Design optimisation	4
Stage 3	Scaled demonstration	5 6
Stage 4	Commercial-scale single device demonstration	7 8
Stage 5	Commercial-scale array demonstration	9

Early (1-3)
Analytical and numerical models

Mid (4-6)
Experimental tests in controlled environment

Late (6-9)
Experimental tests in representative environment

Source: (Marine Renewables Industry Association, 2023).

Appendix 11. Wave Energy Test Sites

For wave technology to be tested and developed at all technological maturity levels, test sites are required.

COUNTRY	WAVE ENERGY TEST SITES
Australia	Australia has no designated test sites for wave energy.
Canada	Canada has no designated test sites for wave energy.
Ireland	1. **Lir National Ocean Test Facility.** Lir is a specially constructed testing facility with extended and improved tanks and apparatus for evaluating small-scale Ocean Energy renewable devices with TRLs between 1 and 4. 2. **SmartBay Marine and Renewable Energy Test Site in Galway.** A quarter to half-sized prototype of Wave Energy Converters (WECs) with a TRL of 4 to 6 can be deployed openly at the test site. 3. **Atlantic Marine Energy Test Site (AMETS).** The SEAI is developing the Atlantic Marine Energy Test Site (AMETS) to enable testing of floating offshore wind technology devices and full-scale wave energy converters in an open ocean setting. TRL 7 to 9.
Portugal	1. **Aguçadoura.** Innovative concepts may be researched and shown on a specialised test site that is 3.3 km2 in size and located at a water depth of 45 meters. Within this allocated region, the Swedish company CorPower has been making rapid progress on their flagship wave energy project, Hi-Wave-5. TRL 6 to 8.
Scotland	1. **European Marine Energy Centre (EMEC).** For testing smaller-scale technologies, subsystems, and components, EMEC offers pre-consented grid-connected demonstration sites in challenging wave and tidal regimes in addition to scale test sites in milder circumstances. EMEC has two test sites for wave energy: Billia Croo wave test site and Scapa Flow scale test site.

Source: (Gaudin & Wolgamot, 2024), (Sustainable Energy Authority of Ireland, Offshore Renewable Energy test sites in Ireland, 2025), (EMEC, 2023), (IEA-OES, 2024).