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Development of multi-use platforms at sea: Barriers to realising Blue Growth

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ABSTRACT

The recent H2020 Blue Growth projects MARIBE and MUSES investigated the potential of a variety of different combinations of economic activities in co-location or integrated in multi-use platforms. Both projects identified barriers - including regulatory, financing, liability and insurance issues; environmental concerns; stakeholder perceptions; and lack of appropriate skills – that hamper the development of multi-use platforms. The H2020 MARIBE project concluded that further funding for multi-use demonstrations should be provided to increase investor confidence and bring multi-use through the so-called Valley of Death. The H2020 MUSES project concluded that multi-use needs to be proactively facilitated and incentivised through public regulatory bodies and respective support programmes. This paper combines and analyses results from both projects in order to identify key research gaps and actions required for the continued development of multi-use platforms, based on a structured critical review of available peer-reviewed literature on the topic as well as reports of both the MUSES and MARIBE projects. Research gaps and actions are analysed based on a multi-use platform typology to inform developers, policy makers, academia and investors for future development of multi-use at sea.

1. Introduction

Increasingly the World's seas and oceans are expected to play a role in addressing society's challenges. Aquaculture is expected to deliver an increasing supply of healthy food (Bene et al., 2016). Offshore energy generation (wind, wave and tidal) is contributing to the global energy transition (Weiss et al., 2018a,b). Protection of the marine ecosystem calls for establishment of Marine Protected Areas (Kirk and Liu, 2015). The seas mineral resources are sought for to meet increasing global demand (Petersen et al., 2016). Climate change is redefining the interface between seas and land, demanding new approach to coastal defence (Morris et al., 2018). Ambitions to mitigate the impacts of climate change drives research into offshore production of lower trophic species for carbon sequestration (Duarte et al., 2017).

The seas however are not empty unused areas. Traditional maritime sectors such as fisheries, transportation, tourism and gravel and sand mining use sea space. Concerns about competing claims for space, between new and traditional activities, have sparked investigations into the potential of multi-use. This includes both multi-use platforms (MUPs) - i.e. physical structures hosting multiple activities - and the multi-use of sea space (MUS) - i.e. different activities sharing sea space. The European Union was central to supporting early research into multi-use through its research programs (e.g. FP6 COEXIST, FP7 Projects included MERMAID, H2OCEAN and TROPOS, H2020 Space@Sea and Blue Growth Farm). Other sponsors have supported research into multi-use, including Lloyds Register Foundation (SOMOS). However, the EU continues to play a pivotal role with new research calls on multi-use published in 2017, 2018 and 2019.

In the period 2015–2018, two EU funded projects on multi-use were conducted. MARIBE (Marine Investment for the Blue Economy)[1]

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explored cooperation opportunities for companies that combine different blue growth and blue economy sectors.[1] The MUSES project (Multi-Use in European Seas) explored the opportunities and barriers for multi-use in European Seas across five EU sea basins (Baltic Sea, North Sea, Mediterranean Sea, Black Sea and Eastern Atlantic). Both projects analyse the opportunities and barriers to the implementation of multi-use.

The objective of this paper is to provide a synthesis of the MARIBE and MUSES results, with a focus on multi-use platforms. This will focus on (i) the potential contribution of MUPs to Blue Growth, and (ii) the main barriers that impede implementation of MUPs and identified solutions. Barriers are defined as the factors hindering MUPs development (Zaucha et al., 2017). Analysis of the projects can provide developers, policy makers, academia and investors with an overview of relevant barriers and guide future investigations into MUPs.

To this end, the following research questions are formulated:

- What different types of multi-use platforms can be identified? (see 3.1)
- What are multi-use platforms believed to contribute to Blue Growth? (see 3.2)
- What barriers have been identified to the implementation of multi-use platforms? (see 3.3)
- What is required for multi-use platforms to contribute to Blue Growth? (see 4)

2. Methodology

This research provides a state-of-the-art overview of barriers to MUPs at sea, based on a structured qualitative review of publications prepared in the multi-use projects MUSES and MARIBE. The approach taken falls apart into five steps, described in detail below.

2.1. Step 1: Identification of publications for review

The research data was collected by a literature search using Scopus, CORDIS as well as the MARIBE and MUSES project websites. The focus of this review lay on the results from the MARIBE and MUSES projects. This paper draws on information from three key sources: (i) the peer-reviewed outputs produced by both the MARIBE and MUSES projects; (ii) key project deliverables such as the MUSES Multi-Use Action Plan (Schultz-Zehden et al., 2018), and; (iii) a literature search which revealed a further 8 relevant publications (see Table 1).

2.2. Step 2: Method for design of a unifying classification

This step designed a unifying classification of MUPs. This was achieved by, uniting the different typologies developed in MUSES (Schupp et al., 2019) and MARIBE (Dalton et al., 2019). The two typologies have different foci, one focussing on the means of production with the other focussing on the overall connectivity of uses. To better serve the multi-use focus of this study, and extract project results for further analysis, the typologies were combined to create a non-overlapping classification scheme for MUPs. The results are presented in section 3.1.

2.3. Step 3: Assessing the contribution of multi-use platforms to Blue Growth

Step 3 assessed how MUPs are believed to contribute to achieving the European Commission's Blue Growth objectives. To this end, the objectives from the Blue Growth strategy were first identified, based on COM (2012) 494 and the European Commission's Working Staff document "Report on the Blue Growth Strategy. Towards a more sustainable growth and jobs in the blue economy". Subsequently, the literature retrieved was read and analysed to review how the multi-use combination studied are believed (by the authors of the reviewed publication) to contribute to the Blue Growth objectives, per sector. An Excel file was prepared to record which Blue Growth objectives were mentioned in each of the publications selected for review. The results are recorded in the evidence collection tables and are presented in section 3.2.

Table 1
Peer-reviewed literature and reports collected for review.

Project	Title	Reference
MUSES	Analysing the potentials and effect of multi-use between tidal energy development and environmental protection and monitoring: A case study of the inner sound of the Pentland Firth	Sangiuliano (2018)
	Multi-use of the sea: a wide array of opportunities from site-specific cases	Bocci et al. (2019)
	Towards a common understanding of ocean multi-use	Schupp et al. (2019)
	Exploring multi-use potentials in the Euro-Mediterranean sea space	Depellegrin et al. (2019)
	Multi-use of the sea: from research to practice	Przedrzymirska et al. (2018)
	Multi-uses in the Eastern Atlantic: Building bridges in maritime space	Calado et al. (2019)
	MUSES Action Plan	Schultz-Zehden et al. (2018)
MARIBE	Business case for mussel aquaculture in offshore wind farms in the Netherlands	van den Burg et al. (2017a)
	Mobilising investors for Blue Growth	van den Burg et al. (2017b)
	Multi-use maritime platforms – North Sea oil and offshore wind: opportunity and risk	Legorburu et al. (2018)
	Assessment of the geographical potential for co-use of marine space, based on operational boundaries for Blue Growth sectors	van den Burg et al. (2019)
	Feasibility of investment in Blue Growth multiple-use of space and multi-use platform projects; results of a novel assessment approach and case studies	Dalton et al. (2019)
	Multi Use Platforms (MUPs) and Multi Use of Space (MUS)	Johnson et al. (2018)
Other	Boosting blue growth in a mild sea: analysis of the synergies produced by a multi-purpose offshore installation in the Northern Adriatic, Italy	Zanuttigh et al. (2015)
	Co-location opportunities for renewable energies and aquaculture facilities in the Canary Archipelago	Weiss et al., 2018b
	Discussing and Analyzing "Maritime Cohesion" in MSP, to Achieve Sustainability in the Marine Realm	Kyvelou and Ierapetritis (2019)
	The feasibility of offshore aquaculture and its potential for multi-use in the North Sea	Jansen et al. (2016)
	A methodology for multi-criteria design of multi-use offshore platforms for marine renewable energy harvesting.	Zanuttigh et al. (2016)
	The Governance of multi-use platforms at sea for energy production and aquaculture: challenges for policy makers in European seas	Stuiver et al. (2016)
	Participatory design of multi-use platforms at sea	van den Burg et al., 2016)
	The mechanics of blue growth: Management of oceanic natural resource use with multiple, interacting sectors	Klinger et al. (2018)

2.4. Step 4: Preparation of evidence collection tables

Step 4 required the preparation of evidence collection tables to assist in the structured review of the publications identified. The parameters used in these evidence collection tables are presented in Table 2.

2.5. Step 5: Method for identifying and categorising barriers

The MUSES categorisation system was adopted to classify gaps/barriers and solutions/actions (Bocci et al., 2019; Depellegrin et al.,

Table 2
Overview of parameters used in evidence collection tables.

Parameter	Type of answer
Type of barrier	Select from the six different barrier types: Legal – factors related to the institutional and legal obstacles for the transition of research projects to commercial ones. Administrative – factors related to the bureaucratic, organizational and managerial obstacles Social – factors related to the human wellbeing and safety Economic – factors related to the profitability of the MU implementation Technical – factors related to the applied and industrial science requirements of a MU Environmental – factors affecting directly and indirectly the ecological status of the marine environment
Description	Free text
Relevance to types of MU	Type A, Type B, type C, not specified (multiple answers possible)
Other remarks	Free text, option to give more information om multi-use combinations concerned
Solutions/actions	Free text
Example/case-study	Free text, if possible identifying for which regions barriers are relevant
Reference	Author-year of publication
Related project	MARIBE, MUSES or other

2019). Each document was read for evidence of barriers and solutions. This can include both explicitly mentioned barriers (or synonyms such as obstacles and bottlenecks) and implicitly formulated barriers and solutions in relation to MUPs. Relevant examples were collated and grouped in evidence collection tables. The barriers were linked to the type of multi-use platform investigated in the publications where possible. Ancillary information of the existence, level of development, specific geographic references are also extracted from the literature for the combinations inventoried. The authors of this article did not estimate likelihood or importance of the barriers on a case-by-case level. The overview of barriers and solutions was used to analyse: (i) the frequency of occurrence of types of barriers; (ii) the main type of barriers; and (iii) solutions per type of multi-use platform (presented in section 3.3).

3. Results

3.1. Unifying classification of multi-use platforms

The last two decades has seen a proliferation of research into multi-use of ocean space (see Schupp et al., 2019 for a brief history). National and international projects have investigated many technological, environmental and socio-economic aspects of the combination and integration of multiple ocean uses. Despite this research effort a common understanding of the underlying conceptual nature of multi-use is only now beginning to form. A growing number of studies (e. g. Klinger et al., 2018; Schupp et al., 2019; Dalton et al., 2019), including the MARIBE and MUSES projects, have developed typologies of multi-use to explain the complex social, technological, economic and environmental interrelationships between multiple users of ocean space (Kluge, 2000).

Klinger et al. (2018), focus on interactions between sectors, using an ecology derived approach based on the concept of symbiosis. This approach yields an account of the trade-offs and benefits of various use combinations. However, this approach might struggle to fully represent the interrelationships between sectors in complex cases. Based on the results of the MUSES project, Schupp et al. (2019) focus on the degree of connectedness of the uses. This yielded four distinct types ranging from Type 1, “Encompassing” e.g. highly connected combinations such as bespoke MUPs, to Type 4, the “Re-use or re-purposing of offshore platforms”. To apply this typology, functional, provisioning, spatial and temporal dimensions are used to assess the ‘connectedness’ of uses. Dalton et al. (2019) focus explicitly on MUPs. Drawing upon MARIBE results they divide MUPs into three categories: Type 1, MUP service platform, servicing multiple uses; Type 2, MUP multiple production platform, hosting production facilities for multiple uses; and Type 3, MUP a combined multiple production and service platform. As this paper focuses on MUPs, other studies focussing solely on the co-use of space (with no synergetic or antagonistic relations or connections between the different sectors) were excluded. In support of the analysis of this paper, a unifying classification was developed, combining the concepts of both Dalton et al. (2019) and Schupp et al. (2019). This allows barriers and solutions to be ascribed to specific types of MUP. This approach identifies three broad types of MUP: A (shared production platform), B (shared auxiliary platform) and C (‘staggered’ use of the same platform) (see Fig. 1).

Type A includes all examples where the production facilities of multiple uses are fully, or largely, contained on the same platform, with high levels of synergy between uses. An example of Type A would be the platforms designed in the TROPOS Project, a floating modular multi-use platform system for use in deep waters combining transport, aquaculture, energy and leisure (Hernandez Brito, 2015; Quevedo et al., 2013). Type B examples include the sharing of common platforms for auxiliary services (e.g. energy storage, equipment testing, data services). Such a platform can also host the production facilities of one use while hosting auxiliary or supporting services for one or more other uses which may be external to the platform. One key example for this type of shared auxiliary platform includes the PLOCAN platform off the coast of the Canary Islands (Hernandez Brito, Delory, and Llinas, 2009). Type C refers to the ‘staggered’ use of the same platform i.e. repurposing of platforms after their original lifespan has ended. This can take multiple different forms including recreational locations, observatories, mooring points for other ocean industries, or as part of a rigs-to-reefs system (Depellegrin et al., 2019; Fowler et al., 2014).

This classification scheme served to guide the following review and is adapted to the content underlying the review. This approach may limit its immediate transferability; however, it may well serve as a starting point in future attempts at classifying MUPs.

3.2. Contribution to Blue Growth

3.2.1. The objectives of the Blue Growth strategy

In 2012 Blue Growth was launched as a strategy for economic growth in European seas. This policy initiative was set against a backdrop of climate change, increaset al.,ed scarcity of natural resources, the increased vulnerability of our ecosystems, growth in urbanization and the concentration of humans in coastal regions. Blue Growth refers to a subset of activities within the wider marine economy that exhibit potential for growth (Johnson et al., 2018). Blue Growth represents a new and ambitious vision and strategy for enhanced, and better targeted, investment in the ocean economy. Initially championed by the European Commission (European Commission, 2017), the concept has found its way into the international arena (see for example van den Burg et al., 2017a; Stuiver et al 2016; European Commission, 2019).

COM 494 (2012) argues that Blue Growth *“can contribute to the EU’s international competitiveness, resource efficiency, job creation and new sources of growth whilst safeguarding biodiversity and protecting the marine environment, thus preserving the services that healthy and resilient marine and coastal ecosystems provide*”. Five sectors were identified as Blue Growth Focus Areas, with potential to deliver both sustainable growth and job creation. These are: (1) blue energy, (2) aquaculture, (3) maritime, coastal and cruise tourism, (4) marine mineral resources, and (5) blue biotechnology.

3.2.2. How does MU contribute to achieving these objectives?

The reviewed publications consistently argued that MUPs, irrespective of the type, contribute to Blue Growth. However, the five sectors are not mentioned equally often. It is often argued that multi-use can contribute to sustainable growth, whereas multi-use potential

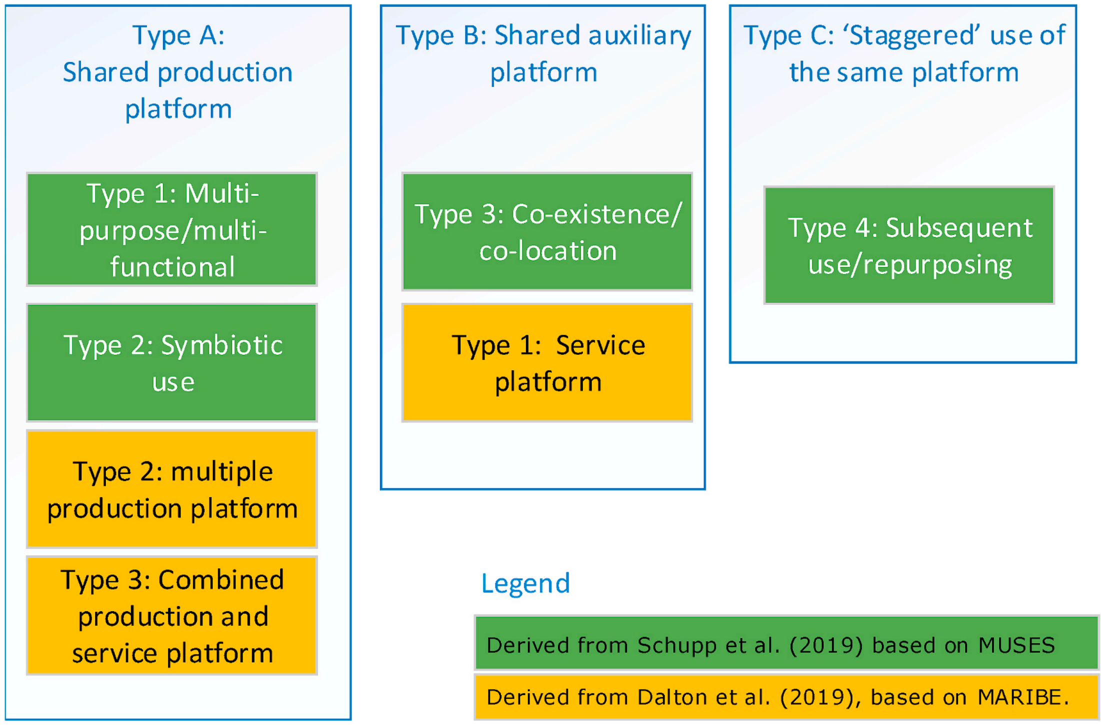

Fig. 1. Unifying classification for MUPs. Classifications in green are derived from Schupp et al. (2019) following the MUSES project. Classification in yellow boxes are derived from Dalton et al. (2019) and are based on the MARIBE project. The resultant three types and defined in Table 3 below, with an example provided. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 3
Definitions and examples of Types A, B & C MUPs.

	Type A: Shared production platform	Type B: Shared auxiliary platform	Type C: 'Staggered' used of the same platform
Definition	A platform hosting two or more production facilities (e.g. offshore Wind and aquaculture facilities)	A single or multiple use platform hosting supporting or auxiliary services for close by uses (e.g. power conversion coupled with charging for electric vessels and/or feed storage for aquaculture)	Repurposing of previously used platforms for new uses (e.g. 'Rigs-to-Reefs', turning offshore wind turbine foundations into mooring points for future offshore installations)
Example	Space@Sea[a]	The combination of wave energy and aquaculture developed in MARIBE[b]	Repurposing of oil and gas platforms[c]

[a] https://spaceatsea-project.eu/[April 01, 2020].
[b] https://maribe.eu/wave-aquaculture/[April 01, 2020].
[c] https://www.archdaily.com/931507/proximity-island-architectural-ideas-for-repurposing-oil-rigs [April 01, 2020].

contribution to job creation is less often mentioned (see Fig. 2 below). Blue energy in the form of wind, wave and tidal energy are identified as the most recurrent contribution of multi-use to Blue Growth (n = 20 manuscripts), followed by aquaculture (n = 19 manuscripts) and coastal tourism in form cruise tourism (n = 12 manuscripts).

Based on this analysis and reviewing the publications stemming from the MARIBE and MUSES projects, allows the following observations are be made.

There is a strong emphasis on the economic growth of blue growth. In both projects, the economic impact of MUPs is given significant attention. In various papers, the key questions addressed are whether there are economic synergies between sectors (Zanuttigh et al., 2015) and if there is a "business case" for multi-use (van den Burg et al., 2017a; Dalton et al., 2019). The emphasis is on the financial benefits of MUPs, expressed in financial terms. This is illustrated by van den van den Burg et al. (2019) who state that *"combining compatible industries allows for more efficient use of space, enables various sectors to cooperate in the same area and develop synergies, both of which can lead to cost savings"*.

Resource-efficiency is focused on efficient use of space. Achieving resource efficiency is one of the key objectives of Blue Growth but in publications reviewed this aspect is discussed in a simplistic manner. There is a tendency to reduce the multi-facetted issue of resource efficiency to one of efficient use of ocean space. This focus omits potentially important issues such as the material and energy inputs required to produce MUPs. Moreover, many publications focus on combining existing uses, e.g. offshore wind energy farms, and investigate feasibility of co-use (van den Burg et al., 2016; Jansen et al., 2016; Zanuttigh et al., 2015). Furthermore, proposals which simply add new function to marine space have potential to leave existing and historic users of ocean space out of the equation. Comparisons of foreseen and current use of ocean space are generally not undertaken.

Social and cultural aspects of multi-use receive little attention. The societal objectives of the European Blue Growth strategy receive significantly less attention in the papers reviewed. The potential of MUPs to contribute to job creation is discussed in some publications (Bocci et al., 2019; Depellegrin et al., 2019). Issues of distribution, if – and how-the economic benefits of multi-use end up with local and/or affected communities, remain understudied. Social inclusiveness is one of the objectives of Blue Growth but not an explicit objective of existing investigations into MUPs. Similarly, territorial cohesion and issues of property rights are not an issue in discussions on MUPs, albeit one of the topics discussed in relation to the Blue Growth strategy (Kyvelou and Ierapetritis, 2019). Blue Growth has the potential to accelerate the creation of private property and private spaces in the oceans (Legorburu et al. 2018; Weir and Kerr, 2019). Despite the potential of MUPs to accelerate this process, property rights are not yet a feature of current

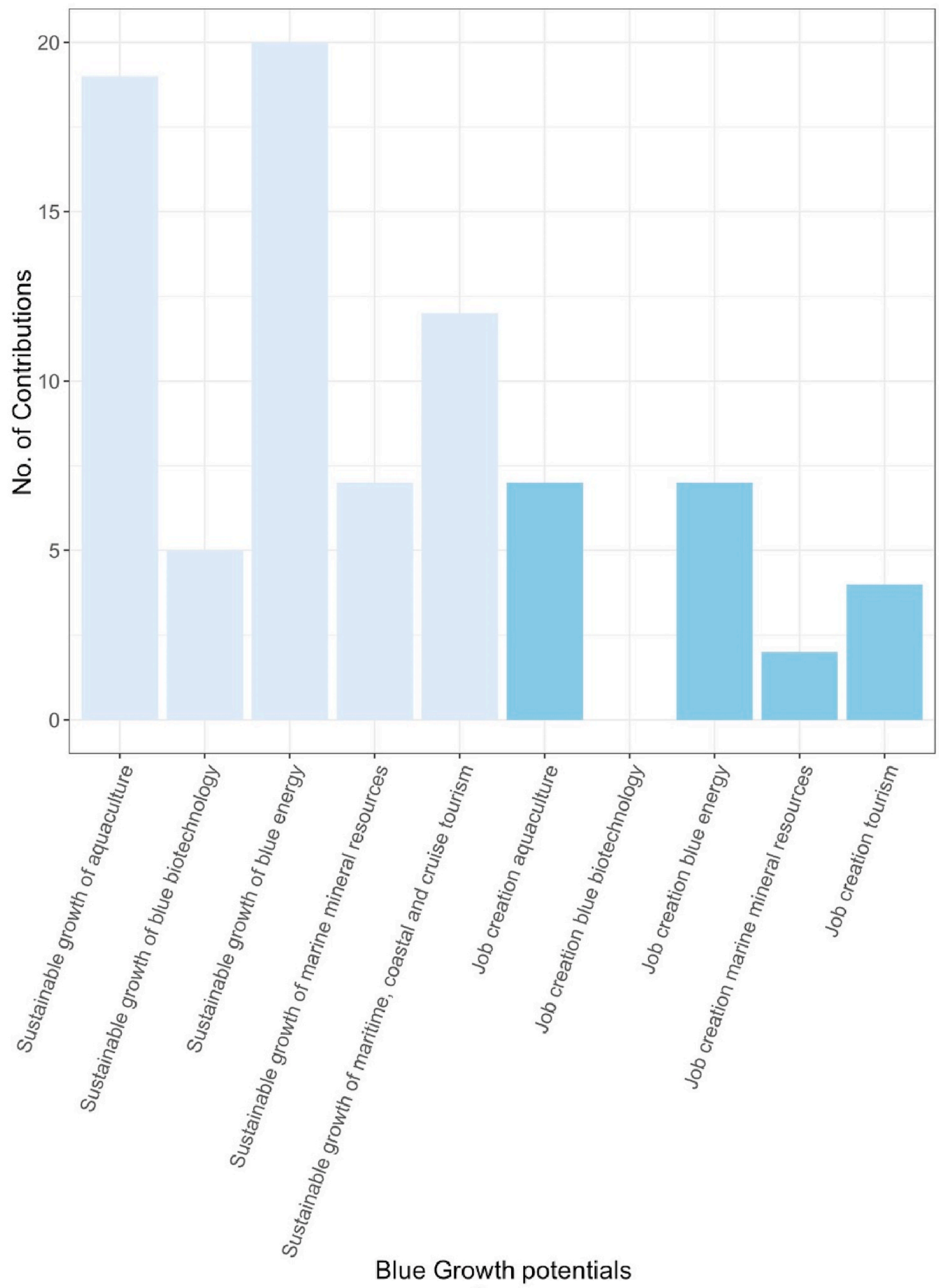

Fig. 2. MUPs contribution to Blue Growth, in terms of number of contributions derived from the 21 manuscripts reviewed. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

discourse.

3.3. Barriers to implementation and identified solutions

3.3.1. Quantitative analysis of identified barriers

The literature review resulted in the identification of a total of 120 barriers distributed among six barrier categories ((Fig. 3). Most barriers were of economic nature (n = 31; 26%), followed by social barriers (n = 257; 23%), technical barriers (n = 25, 21%) and administrative barriers (n = 17; 14%). Other barrier categories of relevance include legal (n = 14; 12%) and environmental barriers (n = 6; 5%).

Figs. 3 and 4 illustrates the total number of barriers for the six barrier categories distributed by MUP type. Most of the barriers are related to Type B MUPs (n = 47) in the category of economic barriers (n = 19) followed by social barriers (n = 12). In Type A MUPs (n = 26) most relevant barriers are of technical nature (n = 11), followed by economic barriers (n = 6). Type C MUPs (n = 9) register the lowest number of barriers. A further category of 'Not specified' barriers (n = 44) were identified, containing barriers that are not linked to any specific multi-use type. Social barriers were most significant (n = 9) in this generic group. The following section provides a detailed description of the solutions per barrier. It is important to note that this analysis identifies the barriers, and the types of MUP that are the focus of current research, in advance of significant deployment.

3.3.2. Economic barriers and identified solutions

Under the heading category economic barriers, a total of 31 barriers were identified. Of these, 15 barriers relate to high costs for MUPs and an overall lack of business cases that support the socio-economic viability of MUPs (Dalton et al., 2019). Uncertainty is another

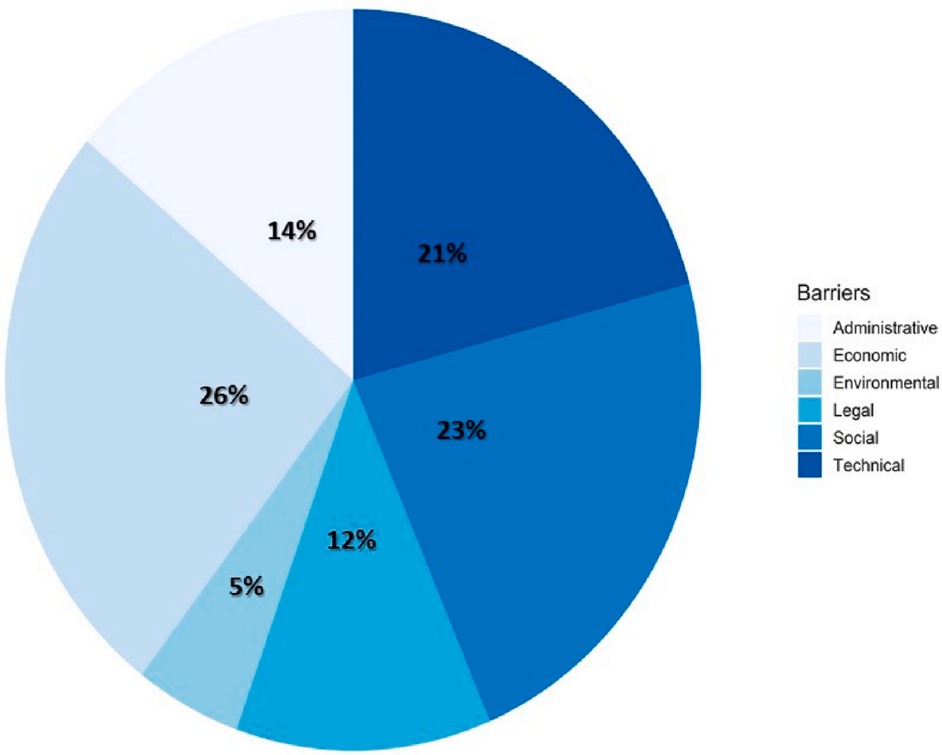

Fig. 3. Number of identified barriers per category, based on 21 reviewed publications.

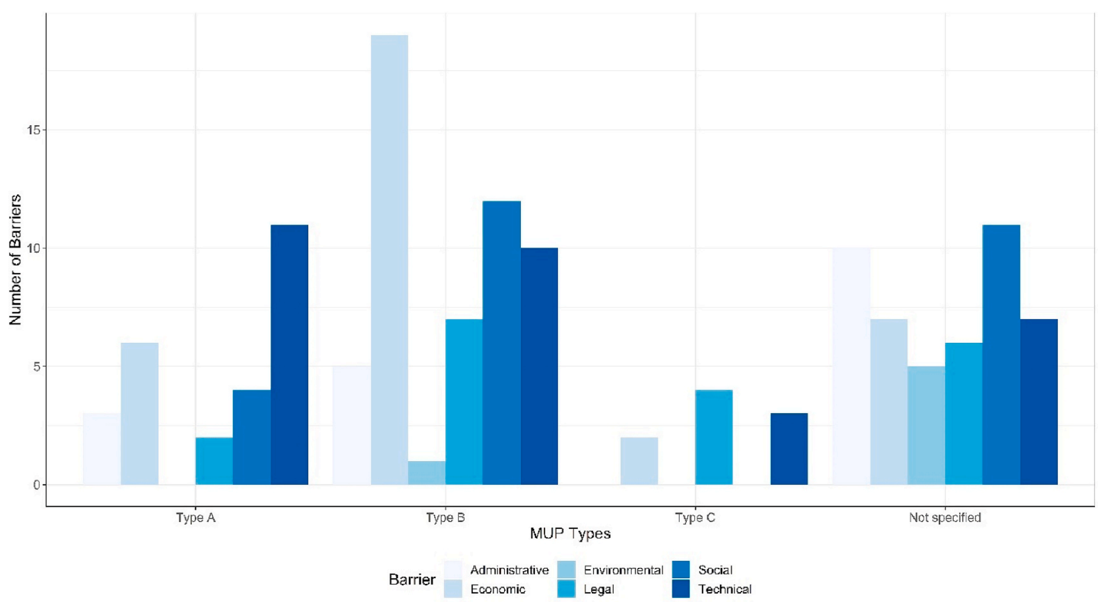

Fig. 4. Number of barriers per multi-use type. Note: Type A – shared production platform; Type B – shared auxiliary platform and Type C – staggered use of the same platform; Not specified refers to barriers not belonging to a specific multi-use type.

important category of barriers (n = 7), followed by the lack of tools and methods to assess economic performance (n = 5) and low attractiveness to investors (n = 3).

High maintenance costs were frequently stated as a significant barrier. For example, for offshore aquaculture cages when combined with renewable energy devices in MUPs (Type A and B) and in case of repurposed O&G platform combined with aquaculture and/or tourism facilities (Type C). Cages need to be continuously monitored especially when co-located with other uses in offshore areas (Zanuttigh et al., 2016). In case of MUPs combining multiple types of production (Type A), desalination plants combined with wind energy devices, maintenance costs of the structure are much higher compared to land (Depellegrin et al., 2019).

Solutions to overcome economic barriers refer to the development of new methodologies for selecting, filtering, developing and ranking business propositions (Type B and C). In case of Type C MUPs based on repurposing of O&G infrastructures (combined with aquaculture and tourism or offshore wind energy), one solution is the creation of pilot demonstrator sites that can disclose the economic feasibility and benefits of those multi-use constellations (Depellegrin et al., 2019). The upscaling of innovative practices to full commercial scale is essential to meet aspirations for Blue Growth. This requires know-how, stakeholder networks and, critically, sufficient financial capacity of investors (van den Burg et al., 2017a,b). Investor confidence may be increased (especially Type B) through a combination of: (i) the development of business cases that clarify financial the risks of multi-use development (van den Burg et al., 2019); and (ii) financial incentives and sureties for development of new technologies and combinations (Schupp et al., 2019). In the case of tidal energy subsidy mechanisms were identified as critical to attracting investors. This would allow pre-commercial tidal energy systems to be competitive in combination with more commercial forms of electricity generation (Type B) (Sangiuliano, 2018).

3.3.3. Technical barriers and identified solutions

A total of 25 technical barriers were identified. This includes: lack of technology (n = 6); lack of infrastructure to connect technologies to the grid (n = 3); and barriers stemming from higher risks under multi-use conditions (n = 5). Technical barriers for the implementation of MUPs combining renewable energy devices (wind or wave energy) with aquaculture production (Type A and B) are mainly related to the potential damage risks to the fixed offshore energy structures by aquaculture gear and vessels under adverse weather conditions (Depellegrin et al., 2019). Further constraints relate to anchoring and mooring technology to be implemented in case of MUPs. This challenge is a result of fixed and floating use combinations requiring specialized technology for mooring. Other barriers are related to insufficient infrastructure on adjacent land (e.g. electrical grid). Overcoming some barriers does not necessarily require new or improved technologies; instead these barriers relate uncertainty and lack of real-life experience and data on MUPs. This includes, uncertainty about the risk of collision between users and uncertainty about the reliability of technologies deployed (Zanuttigh et al., 2016).

Technical solutions to Type B MUPs barriers can include the integration of a telemetric system for environmental monitoring and feeding, ideally supported by alternative energy resources, e.g. solar panels. Another important technical solution is the development of anchoring systems capable of securing re-purposed platforms (Type C) in adverse weather and reducing collision risks with aquacultures sites in Type B MUPs.

3.3.4. Social barriers and identified solutions

The majority of the 25 social barriers identified are related to the acceptance of local communities (n = 9) of visually impacting devices in proximity of coastal areas resulting from the installation of renewable energy (wind and wave) in combination with aquaculture cages and a general lack of communication and trust-building between the sectors involved and other stakeholders (n = 7) (Bocci et al., 2019). Furthermore, 4 barriers point to conflicting claims for space occurring through the definition of navigation safety zones around MUPs or the restrictions for fishing activities in proximity of the MUPs (Calado et al., 2019; Depellegrin et al., 2019).

Social barriers need to be tackled through policy actions oriented to stakeholder engagement mechanisms that can sustain innovative social networks (Soma et al., 2018). Ideally, stakeholder engagement should occur in an early stage in MSP or sectoral plans and incorporate stakeholders' opinions on multi-use development. Specifically for Type B MUPs (e.g. tidal energy and environmental protection, offshore wind energy and tourism activities) it was stressed that key policy documents on EU and national level such as SEA, EIA, and MSP Directives should incorporate synergies and negative impacts specific to MUPs and other uses/users of marine space.

To tackle power imbalances among stakeholders in multi-use constellations, and amongst other of the sea operating in the same geographic area (e.g. Type B, offshore wind energy and fishery), policy makers should adapt clear regulatory guidelines and policy that promotes multi-use. For example, the fishing industry may need financial support to make the transition to vessels capable of working in a multi-use environment. The ability to share information from different countries on environmental impacts and safety risks etc. has potential to help accelerate development. However, this requires the establishment of effective cooperation mechanisms between representatives of different sectors (e.g. in topical working groups, stakeholder forums or sectoral planning channels) and the realization of real pilots and the experience exchange (Schultz-Zehden et al., 2018). In the case of multi-use based on offshore wind energy and shellfish aquaculture, priority should be given to the involvement of established businesses to increase investment capacity (van den Burg et al., 2017a).

3.3.5. Administrative barriers and identified solutions

A total of 17 regulatory and administrative barriers were identified. The lack of a policy framework to guide multi-use licensing procedures (Stuiver et al. (2016); van den Burg et al., 2019) is highlighted (n = 10). These administrative gaps are reflected in different MUPs cases. In the case of offshore wind energy & tourism, licensing procedures for boat tours are complicated within offshore wind farms. Combinations of tidal energy, environmental monitoring and aquaculture, appear to come with complex licensing procedures (Sangiuliano, 2018). Several barriers (n = 3) relate to the process of Marine Spatial Planning which, it is argued, has difficulty accommodating multi-use development. For Type C MUPs, regulatory barriers include OSPAR Decision 98/3, and Directive 2013/30/EU, on offshore oil and gas safety (Jørgensen, 2012). These enforce strict removal policies for offshore platforms after the end of their production cycle for all of OSPARs contracting parties as well as EU countries. These policies are increasingly being questioned in light of the apparent success of the rigs-to-reefs programme in the USA (Techera and Chandler, 2015). Decision support programmes have already been developed in order to assess so called "renewables-to-reefs" strategies for their costs and benefits to society and the environment (Smyth et al., 2015) and might offer potential for future Type C "staggered" MUPs cases to gain approval.

Administrative solutions require the recognition that combined uses need to have overlapping operational boundaries such as minimum or maximum water depth. Geographic information systems can be a powerful instrument to identify and communicate boundary conditions (van den Burg et al., 2019; Legorburu et al., 2018). Other solutions include facilitating knowledge exchange on the environmental impacts using an open process that can advise future EIA requirements.

3.3.6. Legal barriers and identified solutions

The 13 legal barriers identified fall into two main sub-categories: (i) legislation which hampers the development of MUPs (n = 6); and (ii) a lack of legislation to further develop MUPs (n = 5). Where legislation does exist, it is often fragmented and unclear (Depellegrin et al., 2019; Przedrzymirska et al., 2018). Other important legal barriers (especially pertaining to Type B) refer to the safety distance to other uses or the distance from shore of the MUPs infrastructure (Zanuttigh et al., 2016). The lack of national policies to encourage the development of MUPs is identified as a significant barrier (Jansen et al., 2016). A lack for pilot areas that can be used for testing is another constraint (Stuiver et al., 2016).

Legal barriers may be overcome by creating a clear regulatory framework for MUPs development that can facilitate private-public cooperation for example in oil & gas platform re-purposing (Depellegrin et al., 2019). This could be accompanied by assistance mechanisms based on the level of maturity of MUPs (Type B and C). In the recent years, some progress has been made. Most notably, Dutch and German governments exploring the potential for MUPs with offshore wind (Schultz-Zehden et al., 2018; Stuiver et al., 2016).

3.3.7. Environmental barriers and the identified solutions

Few environmental barriers are identified in the literature (n = 6), most of which reflect a concern about the negative environmental impact of the MU (n = 5). A key consideration in the analysis of environmental impacts exerted by a multi-use setting is that the combination of two or more sea uses may exert multiple environmental impacts to marine ecosystems. For example, this can include eutrophication events associated with the MUPs that includes finfish aquaculture (Depellegrin et al., 2019), increased navigation collision risks or an intensification of pollution phenomena related to underwater noise or realise of synthetic/non-synthetic compounds (Stuiver et al. (2016)).

The environmental barriers raised could be reasonably described as speculative or precautionary in nature. This reflects a lack of knowledge, or uncertainty, on the nature of potential environmental impacts of MUPs (Depellegrin et al., 2019) and the synergetic, antagonist or additive nature of their environmental interactions. In the absence of reliable insights, a precautionary approach should be taken. A proposed solution is the further development of methodologies for cumulative environmental impact assessment (Menegon et al., 2018) that take into consideration the multi-use perspective of environmental stressors. A guiding principle is the identification of the anthropogenic pressures using for instance the Marine Strategy Framework Directive (MSFD) pressure list (EC, 2017) that can provide standardized and replicable method for pressure accounting.

4. Discussion

Overlooking the results from the literature review and the analysis of the prepared evidence collected, the following observations can be made.

4.1. Multi-use platforms are more than a techno-economic challenge

Much research and political interest in MUPs is motivated by expected cost-savings, job creation and growth in value added through marine production. This includes both an expected absolute growth of the sectors (more aquaculture, more offshore wind energy, etc) and the potential cost-saving through MUPs (cheaper aquaculture, cheaper offshore wind, cheaper O&G decommissioning). At the same time, the lack of clear business cases, and poor understanding of the economic risks involved, is widely cited as an important barrier to development. Understanding if MUPs can live up to expectations is fast becoming a critical issue – will they really make marine production cheaper?

In the debate on MUPs and Blue Growth the rationale of developing technologies for improvement of economic performance dominates (Soma et al., 2018). Other potential benefits such as social cohesion, territorial cohesion, equity and coastal community development, lower environmental impacts – receive significantly less attention.

As a policy strategy, Blue Growth seeks: 1) Smart growth – developing an economy based on knowledge and innovation; 2) Sustainable growth – promoting a more resource efficient, greener and more competitive economy; and 3) Inclusive growth – fostering a high employment economy delivering economic, social and territorial cohesion (Soma et al., 2018). Despite this broad agenda, existing research into multi-use appears to take a narrow interpretation of Blue Growth, focussing predominantly on the economic benefits of MUPs. If multi-use is to achieve smart and inclusive Blue Growth, it is necessary to acknowledge that the development of multi-use impacts on vested interest and local communities. There is a distributive, equity dimension to MUPs development that currently is hardly studied.

4.2. An integrated approach to identifying barriers and solutions is needed

Development of MUPs is largely discussed as a technological-economic challenge, focussing on how to design cost efficient and reliable technologies. However, there is no hard line between these two challenges; technical uncertainties and unknowns translate into non-technical economic barriers. For example, the collision risks between different users can be framed as a technical risk, requiring improved navigation and signalling technologies. However, it also creates a financial risk if insurance premiums increase to the point where they impact on the economic viability of MUPs. In the same way social barriers are just as important as economical barriers. If a project's social license to operate (SLO) is lost it has the potential to halt any development. The loss of SLO can affect marine projects promoted by the most powerful organisation. This is famously demonstrated by Shell's failed disposal of the Brent Spar in 1995 (Side, 1997) and more recently Shell's Corrib Gas interconnector (Gilmartain, 2009). Loss of SLO can rapidly become an economic barrier through lost revenues, increased security costs, or court costs in the case of litigation. The solution to this conundrum is not a full focus on either type of barriers, but rather to devise holistic and integrated research initiatives that address all facets of the proposed MUPs development.

4.3. Past research paid little attention to the reuse of existing platforms

Much of the past research so far has focussed on type A and type B (see Fig. 1) of MUPs. Investigation in Type C MUPs ('staggered' use) are few this type of MUPs deserves more scrutiny. About 470 platforms will be decommissioned by 2035 in the North Sea alone (Bull and Love, 2019) and 8 platforms in the Italian North-Central Adriatic Sea within 2020–2021 (Depellegrin et al., 2019). In addition to this the first offshore wind farms, constructed largely in the early 2000s, will be repowered, or decommissioned, by the mid 2020's (Deign, 2019). Both represents significant opportunity to develop innovative MUPs.

4.4. More real-life experiences with multi-use platforms are needed

A recurrent issue is the lack of in-situ experience and data with MUPs. Although this is not surprising, given the early development stage of most MUPs concepts, it does raise some important questions. If some issues can only be addressed by in-situ, full-scale testing of MUPs, who will take the initiative and risk for such testing given the barriers and uncertainties that still exist? The development of real-life pilots – with an option of failure – is not an attractive business proposition and will require financial support and incentives from public resources.

In 2019 the European Commission approved two new Horizon 2020 projects on MUPs, titled UNITED and MUSICA. These projects are still in their early stages., However, analysis of their objectives sheds light on envisioned actions and the possible contribution to resolving some of the barriers identified.

UNITED, short for *multi-Use platforms and co-locatioN pilots boostIng cost-effecTive, and Ecofriendly and sustainable proDuction in marine environments*, is led by Deltares, in the Netherlands with a total of 26 participants. The objective is to develop pilots in a real environment to enable the large-scale adoption of the multi-use of marine space, including MUPs concepts and co-location activities. As such, the project explicitly uses a broad definition of multi-use. UNITED aims to elaborate on five pillars: technical, regulatory, economic, social and environmental, in five pilots across European regional seas in close cooperation with local stakeholders and industrial actors.

MUSICA, short for *Multiple use of Space for Island Clean Autonomy*, is led by University College Cork, Ireland with a total of 15 consortium partners. MUSICA has an explicit focus on small islands; MUSICA is to accelerate the roadmap to commercialisation of its Multi-Use Platform and Multi-use of Space combination for the small island market, and de-risk for future operators and investors. Similar to UNITED, MUSICA's interpretation of multi-use includes both the multi-use of space and MUPs. Sectors covered in MUSICA include renewable energy, energy storage, smart energy systems, and desalination.

5. Concluding remarks

The review of scientific publications on MUPs projects, including those prepared under the MARIBE and MUSES projects, sheds light on the development of MUPs. The potential of MUPs to contribute to economic growth – this being one of the objectives of Blue Growth – is heavily emphasized in the literature. However, increasing investor confidence in this potential remains a challenge. Uncertainty about the business case for MUPs is key amongst a number of barriers standing in the way of upscaling commercial development of MUPs. These include economic, legal, administrative, social, environmental, and technical barriers. Taking a step back and considering all objectives of the Blue Growth strategy, it is noticeable that the social and environmental benefits of MUPs are less often discussed.

To advance the development of MUPs, the following specific actions are proposed:

- The social dimension of MUPs development needs to be studied and understood. If the development of MUPs results in real, or anticipated, social problems progress will remain slow.
- Research on MUPs should identify multi-use concepts that deliver a positive impact for the economy, the environment and society.
- Further *in situ* trials are critical if technical challenges are to be overcome, investor confidence increased, and social acceptability achieved. These trials must be used to address both technical and non-technical barriers

CRediT authorship contribution statement

S.W.K. van den Burg: Investigation, Writing - original draft, Methodology, Formal analysis, Writing - review & editing. **Maximilian Felix Schupp:** Investigation, Writing - original draft, Methodology, Formal analysis. **Daniel Depellegrin:** Investigation, Writing - original draft, Methodology, Formal analysis, Visualization. **Andrea Barbanti:** Investigation, Writing - original draft, Methodology. **Sandy Kerr:** Investigation, Writing - original draft, Methodology, Formal analysis, Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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