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Spatial compatibility between emerging marine economies and existing uses in the exclusive economic zone of southern Brazil

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A R T I C L E I N F O

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A B S T R A C T

Blue Growth highlights the need for integrated management approaches and strategic planning to minimize conflicts and optimize the use of space. This study analyzes the spatial compatibility between existing uses and potential zones for emerging activities in the Exclusive Economic Zone of Southern Brazil. The proposed methodology was based on a three-step approach: (i) spatial analysis to identify possible zones of overlap between emerging activities (i.e., wind energy, wave energy, aquaculture and mining) and existing uses. (ii) Consultation with MSP experts and key stakeholders through an online survey based on the Delphi method. (iii) Application of the survey responses, using the Analytic Hierarchy Process, to generate a Spatial Compatibility Index. The combination of wind and wave energy was the most compatible interaction found. Aquaculture shows low compatibility with other uses, due to the sensitivity of farming live species. Mining also showed low compatibility, mainly due to the risks involved in its operation. This contribution shows the possible spatial conflicts and synergies from a stakeholder perspective. This methodological approach aims to boost sustainable development in the marine environment, driving multi-use and reducing the impact associated to the exploitation of different activities.

1. Introduction

The concept of blue growth has gained attention in recent years as efforts are made to balance economic expansion with the sustainable use and conservation of marine resources (Reimer et al., 2023; Spaniol and Hansen, 2021). This balance is a commitment of Marine Spatial Planning (MSP, Gacutan et al., 2022; Rezaei et al., 2024). MSP has emerged as a tool for the sustainable development of the blue economy, addressing environmental, economic and social aspects in an integrated manner (Douvere and Ehler, 2009). Therefore, MSP aims to achieve different sustainable development agendas (e.g., Sustainable Development Goals, European Green Deal) through ecosystem-based management (IOC-UNESCO/European Commission, 2022; Galparsoro et al., 2021).

The potential expansion of existing activities and the emergence of new ones will intensify competition for space (Guerreiro, 2021; Hoerterer et al., 2020). This development towards maritime space is determined by: (i) rapid blue growth to meet the demands of a growing world population (Weiss et al., 2018a, b) and; (ii) climate change, overexploitation and conservation needs (Reimer et al., 2023; Santos et al., 2020). Therefore, the increasing and often conflicting use of marine resources requires the application of spatial planning approaches (Boussarie et al., 2023). In this sense, approaches have emerged to assist the MSP process, such as multi-use, which consists of taking advantage of synergies between uses and activities to optimize the use of space (Stancheva et al., 2022). From an MSP perspective, multi-use can provide solutions to conflicts that arise or grow with the increasing exploitation of the oceans (Bocci et al., 2019). The multi-use approach can be defined by the joint use of resources in close geographical proximity by one or more users (Schupp et al., 2019).

Several studies addressing suitable areas for the development of emerging activities (e.g., Tavares et al., 2020; Vinhoza and Schaeffer, 2021) and their multi-use possibilities (e.g., Weiss et al., 2018c, 2023) have been conducted. In these studies, potential zones are identified according to technical, economic and operational criteria for each

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activity. Assessments of possible conflicts have also been carried out, such as the study considering offshore wind farms and protected areas by Boussarie et al. (2023). Muñoz et al. (2018) conducted a study on the high risk and conflict potential between human activities and ecosystem services in the Alboran Sea. However, spatial conflicts and multi-use possibilities are evaluated individually and separately from the actual situation of the zone studied.

Despite these efforts, there is still a lack of integrated approaches to assessing spatial compatibility between emerging and existing activities on a standardized basis. Studies and methodological approaches of this nature are essential in developing countries, where pressure from the marine economies comes before spatial planning (Weiss et al., 2023). An integral approach to analyze the compatibility between uses and emerging activities can be an alternative to speed up the MSP process. Therefore, the aim of this work is to analyze the compatibility between emerging sectors (*i.e.,* renewable energy, aquaculture, and mining) and existing uses from a spatial perspective. The proposed approach aims to identify the possible spatial conflicts and synergies for the Blue Growth. The case study is the Exclusive Economic Zone of Southern Brazil (EEZSB).

2. The current context of the EEZSB

Concrete initiatives for MSP in Brazil emerged in 2022, through a public call from the National Development Bank with the Secretariat of the Interministerial Commission for the Resources of the Sea. Until now, there have only been specific initiatives, mainly in the academic sphere (Gerhardinger et al., 2019). The 2022 call is supporting the pilot case study to characterize and map the current and potential uses of the marine environment. The zone selected was the EEZSB, covering 410, 000 km^2 (12.5 % of the Brazilian EEZ). Activities such as industrial fishing, mining and shipping predominate in this zone (Gandra et al., 2020). Moreover, the development potential of emerging marine economies has also been reported in this region (e.g., renewable energies, aquaculture and mining; ANM, 2022; Weiss et al., 2023).

This zone hosts four of Brazil's main ports, among other smaller ones (Fig. 1). This makes the EEZ a zone with high shipping traffic. Pipelines for transporting oil products from ships to storage facilities are also found in the study area. Gillnet, trawl, and seine fisheries play a significant role in capturing marine and estuarine fish (Castello et al., 2009). With regard to marine protected areas, the region has different environmental protection levels linked to Law 9.985/2000, which establishes the country's National System of Conservation Units (Lima et al., 2021). Furthermore, the Brazilian Ministry of Environment and Climate Change has established priority areas for biodiversity conservation, including initiatives such as the expansion and creation of protected areas and ecological corridors (MMA, 2018).

On the other hand, the potential of emerging marine economies is beginning to be exploited in this zone. Extensive heavy minerals and calcareous deposits were mapped by the National Department of Mineral Production. Mining activities in EEZSB are currently in the licensing phase. Meanwhile, the exploitation of wind energy is advancing very quickly, and there are currently 25 wind farms with a cumulative power of ~68 GW in the licensing phase in the study area (IBAMA, 2023). In addition, potential zones for the development of offshore renewable energies (i.e., wind and wave energy) have been identified in the region (Weiss et al., 2023). According to Weiss et al. (2018a), the country has the highest estimated extractable power for wave exploitation. Although offshore aquaculture has not yet established itself as a consolidated commercial activity, the EEZSB has a high potential for farming different fish species (Valenti et al., 2021; Weiss et al., 2023).

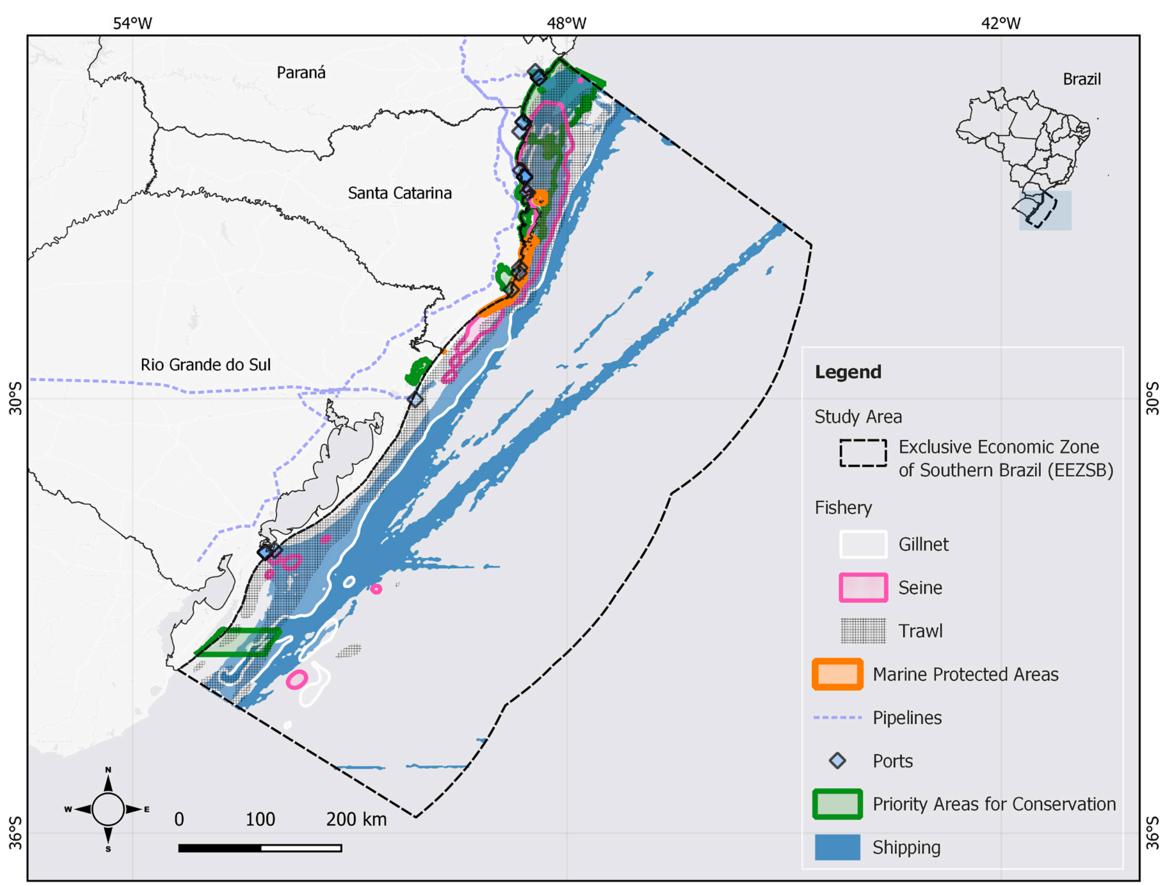

Fig. 1. Study area with the main existing uses in the EEZSB.

3. Material and methods

This study analyzed the spatial compatibility between emerging marine economies (i.e., wind energy, wave energy, aquaculture and mining) and existing uses in the EEZSB. The proposed methodology was based on a three-step approach (Fig. 2), comprised of: (i) spatial analysis to identify possible zones of overlap between emerging activities and existing uses. (ii) Consultation with MSP experts and key stakeholders through an online survey based on the Delphi method (Linstone and Turoff, 1975). (iii) Application of the survey responses, using the Analytic Hierarchy Process (AHP, Saaty, 2005), to generate a Spatial Compatibility Index (SCI).

3.1. Data

Zones corresponding to existing uses in the EEZSB were obtained mainly from government sources. The potential zones, corresponding to emerging activities, were obtained from the National Mining Agency (NMA, 2022) for mining and, from the study of Weiss et al. (2023) for renewable energies and aquaculture (Fig. A1 of the Supplementary Material). In the case of aquaculture, the potential zones were related to 6 fish species: European seabass (*Dicentrarchus labrax*), Gilthead seabream (*Sparus aurata*), Atlantic Bluefin tuna *(Thunnus thynnus*), Meagre (*Argyrosomus regius*), Greater amberjack (*Seriola dumerili*) and, Cobia (*Rachycentron canadum*). Table 1 provides a list of all the existing uses and potential zones for emerging activities considered in this case study.

3.2. Spatial analysis

The spatial analysis was based on the overlaps among existing uses and emerging activities. In the case of potential zones for wind energy, wave energy and aquaculture, only zones with a suitability index higher than 0.6 were considered (cf. Fig. A1 of the supplementary material). The suitability index (1 for maximum suitability, 0 for minimum suitability) developed by Weiss et al. (2023), https://i-mubrsea.glitch.me/) refers to the probability of meeting favorable conditions for the different aspects evaluated (e.g., species requirements for aquaculture; energy resource for wind and wave exploitation; energy evacuation for wind and wave exploitation; O&M activities for both activities, structural survivability for both activities). In a Geographic Information System (GIS) environment, the polygons referring to the zones of each use and potential development zone (emerging activities) were overlaid using the intersection tool.

Table 1
Existing uses and emerging activities (potential zones) considered in the case study, with their respective source of information.

Existing uses	Sources of information
Marine Protected Areas	MMA (2018)
Priority Zones for Biodiversity Conservation	MMA (2018)
Gillnet Fishery	PREPS (2020) ; Gandra (2020)
Seine Fishery	PREPS (2020); Gandra (2020)
Trawl Fishery	PREPS (2020); Gandra (2020)
Shipping	Marine Traffic (2021); Gandra (2020)
Pipelines	PREPS (2020)
Ports	ANTAQ (2022)
Emerging activities (Potential zones)	**Sources of information**
Aquaculture	Weiss et al. (2023)
Mining	NMA (2022)
Wave energy	Weiss et al. (2023)
Wind energy	Weiss et al. (2023)

3.3. Stakeholder's participation

To assess stakeholders' perceptions of the spatial compatibility between existing uses and emerging activities, an approach based on the Delphi method was applied. This method consists of different techniques, including a group of experts and rounds of consultations, which can be used in decision-making to determine weights of importance and ranking of criteria (Okoli and Pawlowski, 2004). Delphi is widely applied in scenarios where individual judgments need to be gathered to fill knowledge gaps or disagreements on a particular topic (e.g., de Groot et al., 2014; Weiss et al., 2018d). The general objective is to obtain a more reliable consensus from a group of experts (Dalkey and Helmer, 1963; Linstone and Turoff, 1975).

The classic Delphi method was adapted for the purpose of this study, thus facilitating stakeholder engagement. The Delphi-based approach was divided into three main steps: (i) Definition of existing and potential uses to be assessed; (ii) Identification of potential stakeholders; (iii) Application of online surveys.

The first step precedes all the analyses carried out (i.e., it is related to data collection, Section 3.1). A group of experts in MSP (involved in MSP projects in the study region) defined the existing and potential mid to long-term uses in the study area (i.e., first round of consultation). From the list of existing and emerging uses and activities, a search was made for spatial data layers available for each use in government sources and

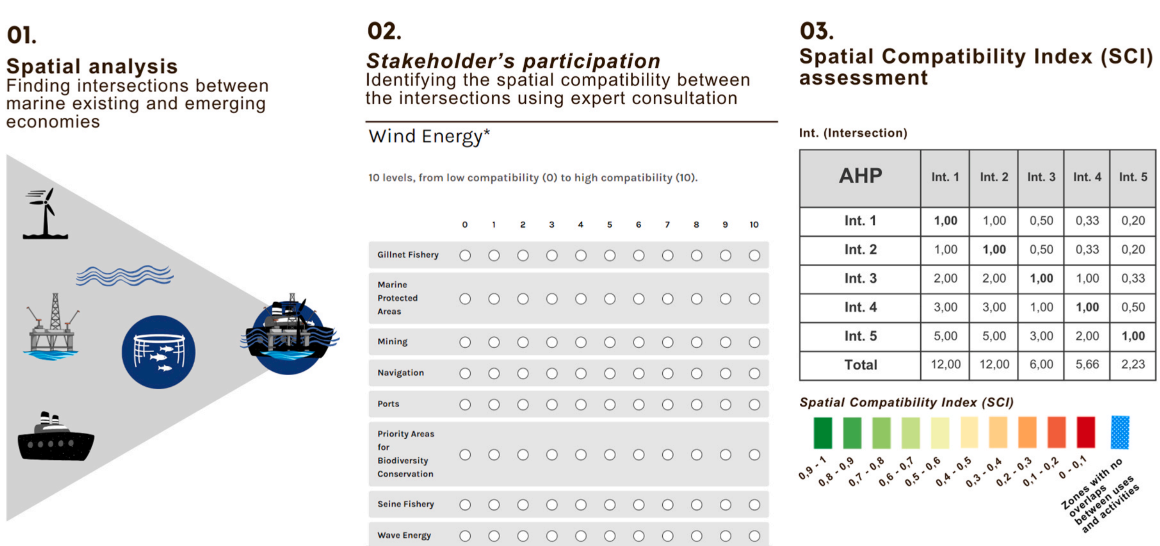

Fig. 2. Conceptual framework with the aspects considered in the Spatial Compatibility Index (SCI) for the identification of conflicts and synergies between existing uses and emerging activities.

in scientific literature (cf., Section 3.1). In a second round of consultation, the experts re-analyzed the list based on the availability of homogeneous spatial information in the study area to reach a consensus on the uses and activities to be included in the combability analysis. In this first step, the participating experts were researchers and technologists from the fields of: biology and coastal management (2 members); oceanography (2) and, geography (1).

In the second step, one of the most important according to the principles of the Delphi method (Okoli and Pawlowski, 2004), the appropriate stakeholders were chosen. In order to include most of the sectors analyzed (i.e., renewable energies, aquaculture, mining, shipping, conservation, fisheries and ports), the same experts involved in the first step generated a list of potential participants from their network. The literature recommends 10–18 experts on a Delphi panel, since the group size does not depend on statistical power (e.g., individual samples to extrapolate to a larger population), but rather on group dynamics for arriving at consensus among experts (Okoli and Pawlowski, 2004).

The third step focused on structuring the survey with all the overlaps identified in Section 3.2. The survey compiled all the mapped overlaps into a matrix with 10 levels, starting from low compatibility (i.e., possible conflict = 0) to high compatibility (i.e., possible synergy = 10, survey available in Supplementary data, Table A1). An online version of the survey was sent to all the potential participants listed in step 2.

The stakeholders' evaluation of the survey was based on indicating the degree of compatibility (scale from 0 to 10) in a conceptual way for each intersection between existing uses and potential zones (emerging activities). Four sections focusing on emerging activities (mining, wind energy, wave energy and aquaculture) listed possible interactions with existing and emerging uses and activities. Repeated interactions/overlaps in the four sections were excluded for the participants' evaluation, so there were no redundant overlaps. The survey was kept open for 2 months in order to obtain as many responses as possible, and 2 reminders were sent to the list established in step 2. The participants who answered the survey were researchers and technicians in the fields of: renewable energies (1 member); maritime governance (2); conservation (2); mining (1); integrated coastal management (4); MSP (2); fishing (2); aquaculture (1) and; shipping (1). The results of the survey were presented at a workshop, where all the stakeholders who responded to the survey were invited. On this occasion, the preliminary results of the survey (i.e., medians of responses) were presented and the participants were given one week to optionally revise their preliminary evaluations.

3.4. Spatial compatibility index (SCI) assessment

Based on the results of the survey, an SCI was generated. The AHP approach, a widely used method in multi-criteria decision-making (originally proposed by Saaty, 1980), was used for this purpose. The medians of the responses for each overlap between uses and activities were compared, adopting the intersection matrix proposed by AHP (Saaty, 2005). The median was employed because values were ordinal and do not follow a normal distribution. This comparison between the different overlaps makes it possible to create a hierarchical structure and to smooth out the subjectivity assigned by stakeholders (Parmen and Abdullah, 2022).

The SCI is the result of the intersection matrix for each overlap, parametrized from 0 to 1. The index indicates the compatibility between uses and activities, with lower values indicating possible conflict and higher values possible synergies. The SCI was spatialized using the critical value as a reference, that is, when more than one overlap occupied the same location the lowest SCI value was considered to characterize that zone. Finally, the main possible conflicts and synergies between existing uses and emerging marine economies were addressed.

4. Results

This section is divided into three parts. Section 4.1 presents the spatial analysis of possible overlaps between existing uses and potential zones for emerging activities. Section 4.2 shows the results obtained from the online survey (stakeholder participation), and Section 4.3 presents the spatialized results (i.e., SCI).

4.1. Spatial analysis

A total of 34 overlapping existing uses and potential zones for emerging activities were identified in the study area. Fig. 3 shows the percentages of overlapping zones. Aquaculture is the activity that most overlaps with existing uses. Approximately 96 % of the potential zone for aquaculture development intersects with Priority Zones for Biodiversity Conservation. In addition, 80 % of the zone for aquaculture overlaps with shipping routes and 76 % with trawling activities. In turn, around 40 % of potential mining zones intersect with gillnet and shipping activities. The potential zone for wave energy exploitation encompasses 86 % of the wind energy. The renewable energy and mining sectors have substantial common zones with shipping, trawling and gillnet fishing. In contrast, Marine Protected Areas, ports, and pipelines intersect with smaller potential zones, mainly due to their relatively small spatial extents (zones near the coast).

4.2. Survey findings

The median of the survey responses was less below 5 for 28 intersections, indicating a greater possibility of spatial conflict between existing uses and potential zones for the development of emerging activities (Fig. 4). The intersections of existing uses with aquaculture were below 5 in all cases, including a median of 0 with mining (i.e., high probability of conflict). Furthermore, 2 mining intersections also had medians equal to 0 with Marine Protected Areas and Priority Zones for Biodiversity Conservation. On the other hand, 6 intersections had medians higher than 5 (mining and shipping; wave energy and ports; wave energy and mining; wind and wave energy). The largest of these is represented by the intersection between wind energy and wave energy (value of 8), with multi-use possibilities.

4.3. Spatial compatibility between existing uses and emerging economies

Fig. 5 presents the SCI between existing uses and potential zones for aquaculture, mining and renewable energies development in the EEZSB. The aquaculture sector has the lowest spatial compatibility with other uses (i.e., low SCI). The potential zone for aquaculture corresponds to an area of approximately 11.933 km^2, located near the southern coast of Paraná and the northern and central coasts of Santa Catarina (Fig. 5a). The zones with the highest probability of spatial conflict were those that coincide with mining (warm colors, SCI = 0.12). The highest SCI values (0.38) observed for overlaps with pipelines, seine and gillnet fishing correspond to low compatibility (see the supplementary material for the specific SCI values for each overlay between existing uses and potential zones for emerging activities, Fig. A2).

The potential zones for mining cover an area of 42.348 km^2. These zones present three distinct situations: zones with potential synergies (high SCI); zones without overlaps with other activities and; zones with high conflict (low SCI, Fig. 5b). Zones of high compatibility were identified between mining and shipping (greener colors, SCI of 0.79). Potential zones for this activity that do not overlap with existing uses are represented in blue color, covering an area of approximately 17.545 km^2. Since most of the activities in the study area take place close to the coast, this zone has the lowest SCI values. The low compatibility of mining with fisheries (SCI of 0.23), Marine Protected Areas (SCI of 0.08) and Priority Zones for Biodiversity Conservation (SCI of 0.08) can be seen between Santa Catarina and southern Rio Grande do Sul states coastline.

The potential zones for the development of wave energy sector (total area of 50.679 km^2) also have non-overlapping zones and zones with

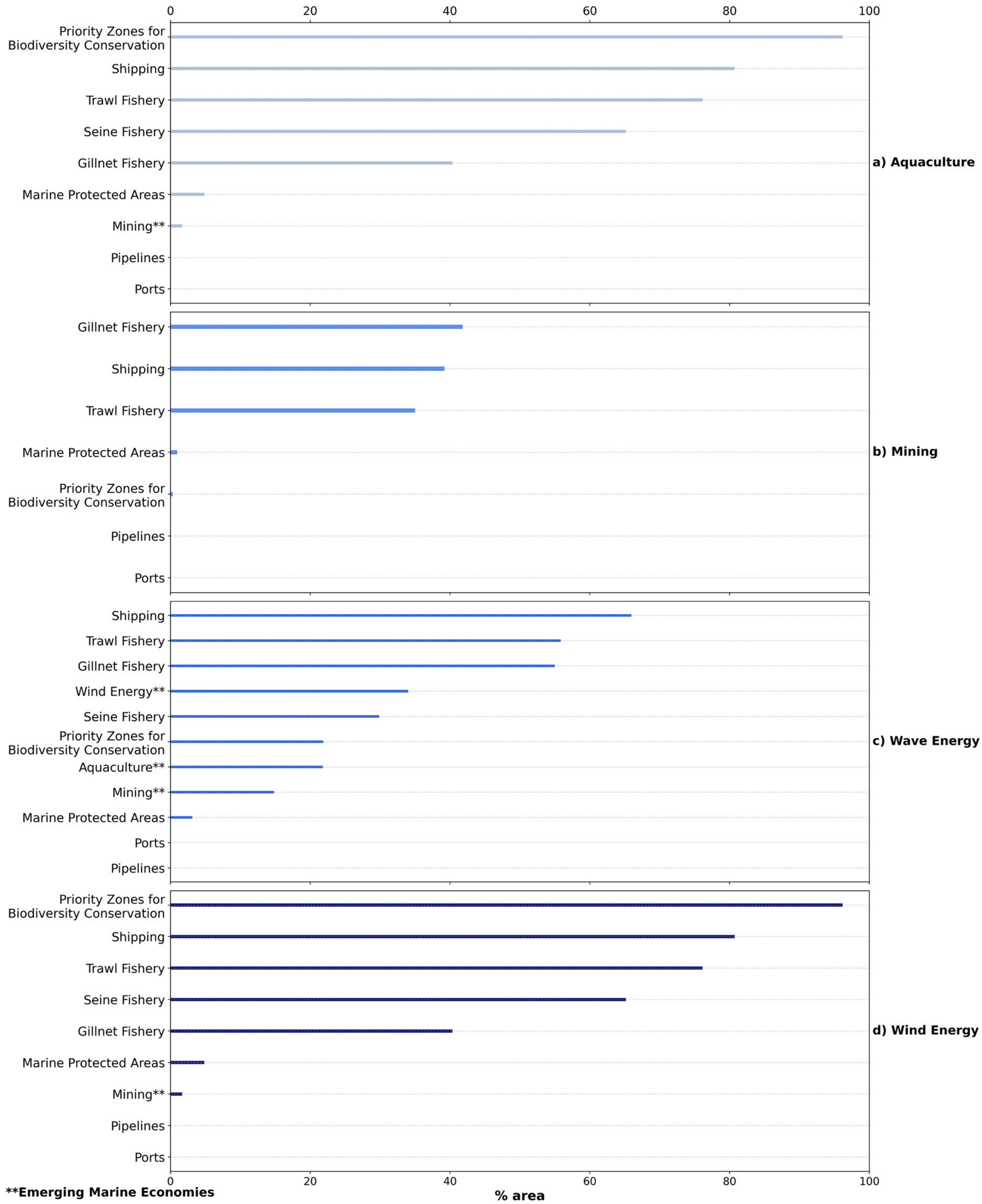

Fig. 3. Overlap between emerging and existing activities with their respective intersections (% area) for: **a)** Aquaculture; **b)** Mining; **c)** Wave energy and; **d)** Wind energy.

high and low SCI values (Fig. 5c). The possible spatial synergies (high SCI) for wave energy are with the activities of wind energy exploitation (SCI of 0.73) and ports (SCI of 0.6). These zones are located further from the coast. An area of 2.903 km^2 has no overlap with other uses (blue color). The most conflictive zones are located near the coast, with low SCI values. Besides the two situations mentioned, the other intersections with existing uses show low compatibility, especially for trawl fishery (SCI of 0.18).

The potential zones for wind energy have 3 subzones which, in total, intersect with 8 uses (Fig. 5d). The total area with potential for wind energy development is 19.952 km^2. The green color zone represents high compatibility with wind energy. The other zones have low SCI, mainly from trawling and seine fishery activities (SCI of 0.12).

5. Discussion

The integrated assessment considering the Delphi-based approach, the AHP technique and spatial data analysis allowed to integrate stakeholders' perception to generate an index spatially distributed in the study area (i.e., SCI). This approach allows different opinions to be considered in the spatial analysis in a less subjective way. Therefore, this methodological approach aims to boost sustainable development in the

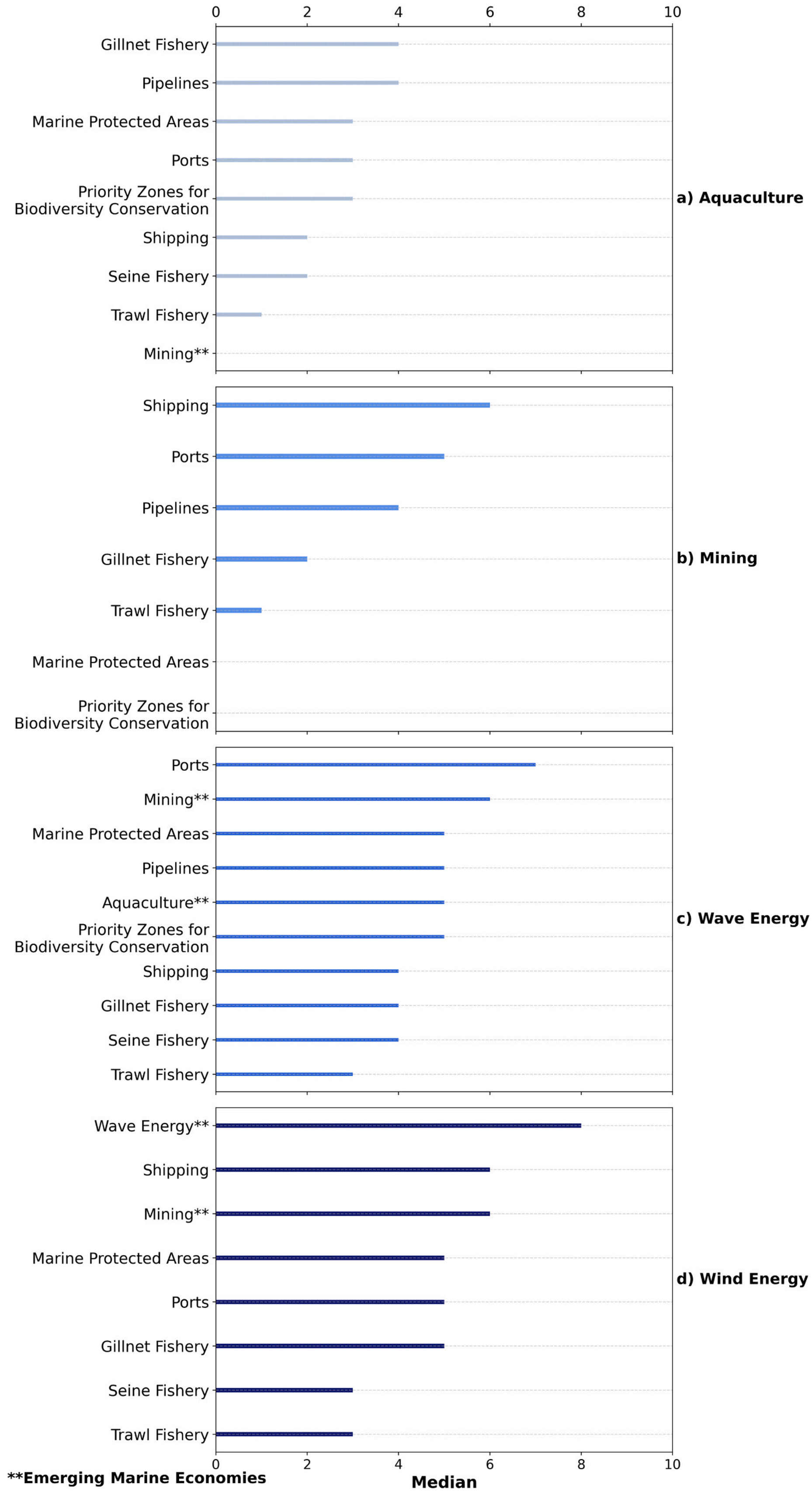

Fig. 4. Median of survey responses for each intersection identified.

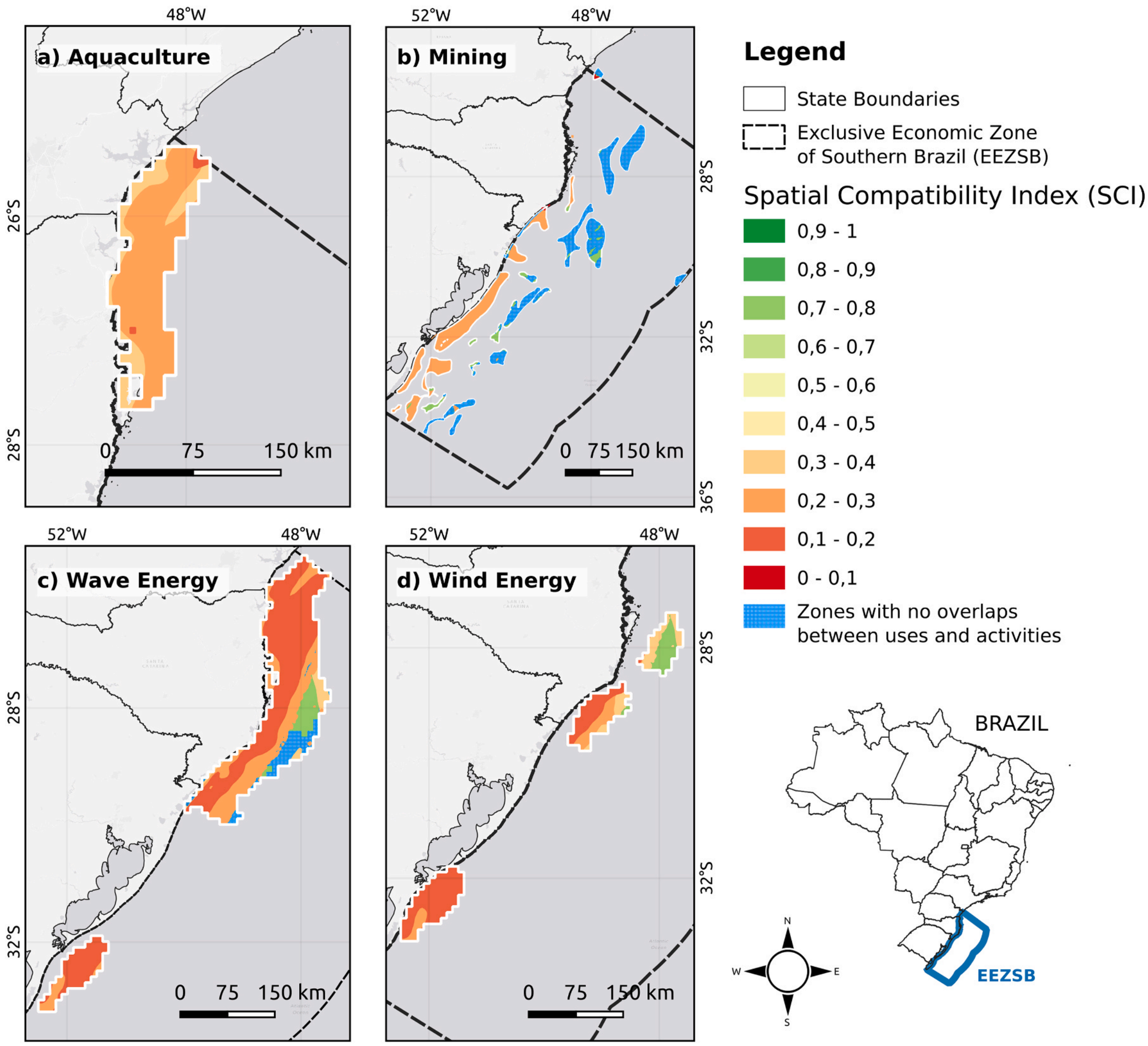

Fig. 5. Spatial Compatibility Index (SCI) for: **a)** aquaculture; **b)** mining; **c)** wave energy and; **d)** wind energy in the EEZSB. SCI values > 0,7 = high compatibility; SCI values < 0,3 = low compatibility.

marine environment, as established by the Blue Growth strategy (European Commission, 2014).

The greatest compatibilities found between the overlaps analyzed are related to the possibility of multi-use between hard uses. This term refers to activities that require long-term installation of major infrastructures (European Commission, 2018), as is the case, for example, with the combination of wind and wave energy and, ports and wave energy. On the other hand, the least compatibility (potential conflict) is found for combinations of hard and soft uses. This is the case with the potential conflicts, according to stakeholders, between wind energy (hard) and fishing (soft) and, mining (hard) and Marine Protected Areas (soft). Soft uses requires less investment and no major infrastructure (European Commission, 2018). A similar pattern was reported by Bocci et al. (2019) in their study on multi-use involving the opinions of stakeholders in different case studies in European regional seas. They indicated that multi-use combinations are more viable when the activities are of the same type (e.g., hard and hard uses).

The possibilities of combining marine renewables (wind and wave energy) stand out as the most compatible among the interactions assessed (SCI of 0.73). In this case, the possibility of combined exploitation varies according to the type of multi-use (Schupp et al., 2019). Pérez-Collazo et al. (2015) proposed a classification based on the degree of connectivity between wind and wave devices: co-located, hybrid, and island systems. Co-located systems do not share foundations, but may share, for example, grid connection, O&M equipment and staff, and port facilities. Hybrid platforms have been developed for the combined exploitation of offshore wind and wave energy, such as the W2Power hybrid system (Pelagic Power, 2010). Multi-Purpose platforms combining marine energies are also alternatives for multi-use between these activities (Kafas, 2017). The platform proposed by the English company Energy Island Ltd. is a multi-purpose example of what can be classified as Island systems (Pérez-Collazo et al., 2015).

Multi-use between these two sectors enables a reduction in CAPEX (Capital Expenditure) and OPEX (Operating Expenditure) and optimizes production per area (Astariz et al., 2015b; Weiss et al., 2018a). Legislative synergies and similarity in terms of environmental, administrative and technological constraints also support the combined exploitation (Abhinav et al., 2020; Pérez-Collazo et al., 2015). Another advantage of co-located farms is that the renewable energy source is more predictable and less variable (Gaughan and Fitzgerald, 2020).

The moderate/high compatibility between wave energy exploitation and ports (SCI of 0.6) can be explained by the decrease of expenses related to operation and maintenance (O&M) and installation activities (Bocci et al., 2019; Weiss et al., 2018a). Stakeholders' perception of the benefits of multi-use between these sectors is also reported as positive by Bocci et al. (2019). Furthermore, short distances between ports and installations reduce greenhouse gas emissions from the transport of structures and staff (European Union, 2021).

Assuming that an existing use should adapt its facilities and operation to co-exist with an emerging activity, the combination of existing and emerging uses would probably face greater hurdles than the combination of two emerging activities. This is the case with the multi-use possibilities identified between wave energy and ports (emerging vs. existing activity) and, wind and wave energy (emerging activities). Technical and economic hurdles can make it difficult to adapt port facilities and their operation to accommodate wave energy devices. Technical hurdles could be related to the transmission and storage of energy in ports or unstable supply due to fluctuating renewable energy production (Bocci et al., 2019). Economic barriers are related to the difficulty of diversifying the energy supply for ports, which depend heavily on non-renewable energy sources (Onyago and Papaioannou, 2017). On the other hand, the combination of wind and wave exploitation has many synergies, mainly structural and operational (Gonzalez et al., 2023). In addition, multi-use between these two sectors mainly takes place through hybrid devices or multi-purpose platforms (Sarmiento et al., 2019; Wang et al., 2022), which represents an advantage for combining these emerging activities.

On the other hand, the low compatibility between wind energy and fishing sector (gillnets, seines and trawls fishing, SCI <0.3) is a potential conflict in the study area. Recent study shows that increased wind farms could impose substantial negative impacts on seafood supply (Qu et al., 2023). Furthermore, this incompatibility could be explained by the high insurance costs for small-scale fishing companies against possible damage to offshore wind facilities (Bocci et al., 2019). This possible conflict is even more critical given the pressure for offshore wind expansion in the country, with around 25 projects in the EEZSB and 78 in the entire Brazilian EEZ (IBAMA, 2023).

Aquaculture and mining had the lowest degree of compatibility with other activities (SCI$\leq$0.4), except for the interaction between mining and shipping, which had an SCI of approximately 0.8. This finding is mainly associated with the risk of mining (Ocampo-Melgar et al., 2018) and the susceptibility and challenges of aquaculture farming due to live species (Føre et al., 2018). In the case of mining, interactions with other activities can be more negative and lead to damage to a specific activity and the environment. For example, mining accidents could make other activities unviable, particularly activities such as aquaculture (SCI of 0.1). In addition, in Brazil, 135 traces of oil derived from offshore mining were recorded between January 2019 and March 2020 (IBAMA, 2020). Therefore, the low compatibility of mining, especially with Marine Protected Areas and Priority Zones for Biodiversity Conservation, is due to the importance of the ecosystem service and biodiversity of these areas (Reimer et al., 2023) and the potential impact of mineral exploitation (Ocampo-Melgar et al., 2018).

The compatibility of aquaculture with other activities and uses is still a challenge, confirmed by the perception of stakeholders (i.e., low SCI). Despite political (e.g., European Commission, 2014) and technical (e.g., AQUAWIND, 2023) efforts to make aquaculture compatible in a multi-use approach, there are still few cases of combined exploitation. For instance, wave energy converters (WECs) are used to energetically power aquaculture farms (Garavelli et al., 2022). Studies on the possibility of multi-use between aquaculture and wind energy (no overlapping zones identified in this study) also point out advantages of the combination, such as: shared infrastructures, like anchoring and mooring systems (Connolly and Hall, 2019; Dalton et al., 2019) and; logistics and staffing (Chu et al., 2020; Dalton et al., 2019).

The low compatibility of aquaculture can be explained by the few multi-use studies considering this activity, except for the combination with wind and wave energy (e.g., Weiss et al., 2018c; 2023). In addition, aquaculture development in a multi-use scenario is mainly focused on offshore areas, and the sector's immaturity in this environment also reflects the perception of low compatibility. Furthermore, social acceptance has been identified in other studies as a hurdle to the multi-use of this activity. Among the social factors indicated are: lack of cooperation between the sectors (Ciravegna et al., 2024); low public awareness of the positive implications of multi-use and; limited knowledge of the cumulative impacts associated with combined exploitation (Bocci et al., 2019). Therefore, with technological advances and the expansion of other activities towards offshore (e.g., wave and wind energy), the aquaculture sector may benefit from joint exploitation.

The potential compatibilities among marine activities are not immutable. In fact, methodologies related to compatibility between uses not only serve to explore potential synergies and conflicts between sectors, but also to guide planning (e.g., MSP) and technological (e.g., Multipurpose platforms) initiatives to reduce associated impacts (Rezaei et al., 2023). Considering the early stage of MSP in Brazil, it becomes even more important to propose sustainable options to assist Blue Growth.

The proposed methodological approach was applied to a case study in southern Brazil, demonstrating its potential for assessing spatial compatibility between marine activities and uses. Integrating stakeholders' perceptions into decision-making and identifying trade-offs in the development of marine economies are essential for blue growth (Ehler and Douvere, 2009). However, some limitations in this study derive from the application of the methodological approach developed in a single case study and the limited representativeness of some sectors related to the stakeholders involved in the research (e.g., only one stakeholder from the mining area), as well as the number of participating stakeholders. Nevertheless, this case study assumes the inherent difficulty in determining compatibility based on stakeholder opinion and hypothetical scenarios. Rapid technological development in the maritime sector (Abhinav et al., 2020), as well as the specific location, type of project and technology employed can alter spatial compatibility assessments.

6. Conclusion

Tools to identifying trade-offs between existing and emerging marine activities support MSP, particularly in countries that do not have these plans or are in their early stages. In this context, this work presented a holistic approach on the spatial compatibility between emerging marine activities and existing uses in the EEZSB. The present contribution shows the potential spatial conflicts and synergies between different uses and emerging activities from a perspective of stakeholders. In this sense, the methodology can be employed in the future conditions analysis step in the MSP process (Ehler and Douvere, 2009). The methodology considers different techniques in an integrated assessment to generate SCI. Spatial analysis was carried out in a GIS environment, consultation with stakeholders was based on the Delphi method and, the AHP method was used to reduce subjectivity in the comparisons of opinions.

The combination of wave and wind energy was the most compatible interaction found, probably due to the current technical and scientific knowledge on synergies between these sectors. In turn, aquaculture presents low SCI with other uses. This sector is still considered immature in offshore zones. In addition, since it is a farming activity, compatibility with other uses should be studied in detail to verify potential impacts on the species. Mining also had low compatibility with other activities, mainly due to the risks involved in its operation.

The analysis of spatial compatibility in the study area is critical, due to the MSP pilot project in the EEZSB and the imminent pressure from the offshore wind industry. Furthermore, the unprecedented methodological approach proposed in this work should become an embedded tool within the MSP process, supporting decision-making and consequently the management of maritime space.

To improve the spatial compatibility findings of this study, specific analyses should be carried out for each interaction in order to estimate the feasibility of implementing multi-use or resolving possible conflicts. Application of the developed approach to other case studies is widely recommended, as well as taking into account the specificities of each activity (e.g., type of project, location and technology used). Although the proposed methodology was designed not to require a large number of participants (i.e., the Delphi-based approach), broadening and homogenizing participation in the topics covered (i.e., stakeholders related to the activities and uses assessed) could make the compatibility results more robust. In this sense, a more structured Delphi analysis is recommended for future studies, in order to better represent the results from the perspective of their use in decision-making. More rounds of consultation are needed to refine stakeholders' opinions. For example, a third round of consultation could be dedicated to individuality discussing each possibility of multi-use (synergy) or potential conflict between specific sectors. Moreover, it is necessary to consider the social, environmental and economic spheres to more accurately assess the sustainable development of emerging sectors of the blue economy. Nevertheless, assessments considering the influence of climate change on activities should be carried out (e.g., Weiss et al., 2020).

CRediT authorship contribution statement

Jarbas Bonetti: Writing – review & editing, Validation, Supervision, Conceptualization. **Carlos V.C. Weiss:** Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology, Conceptualization. **Júlio C. Medeiros:** Writing – original draft, Visualization, Methodology, Formal analysis, Conceptualization. **Tiago B.R. Gandra:** Writing – review & editing, Validation, Methodology. **Marinez E.G. Scherer:** Writing – review & editing, Validation, Supervision, Conceptualization.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Carlos V.C. Weiss reports financial support was provided by National Council for Scientific and Technological Development. Carlos V.C. Weiss reports financial support was provided by University of Cantabria. Jarbas Bonetti reports financial support was provided by National Council for Scientific and Technological Development. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix

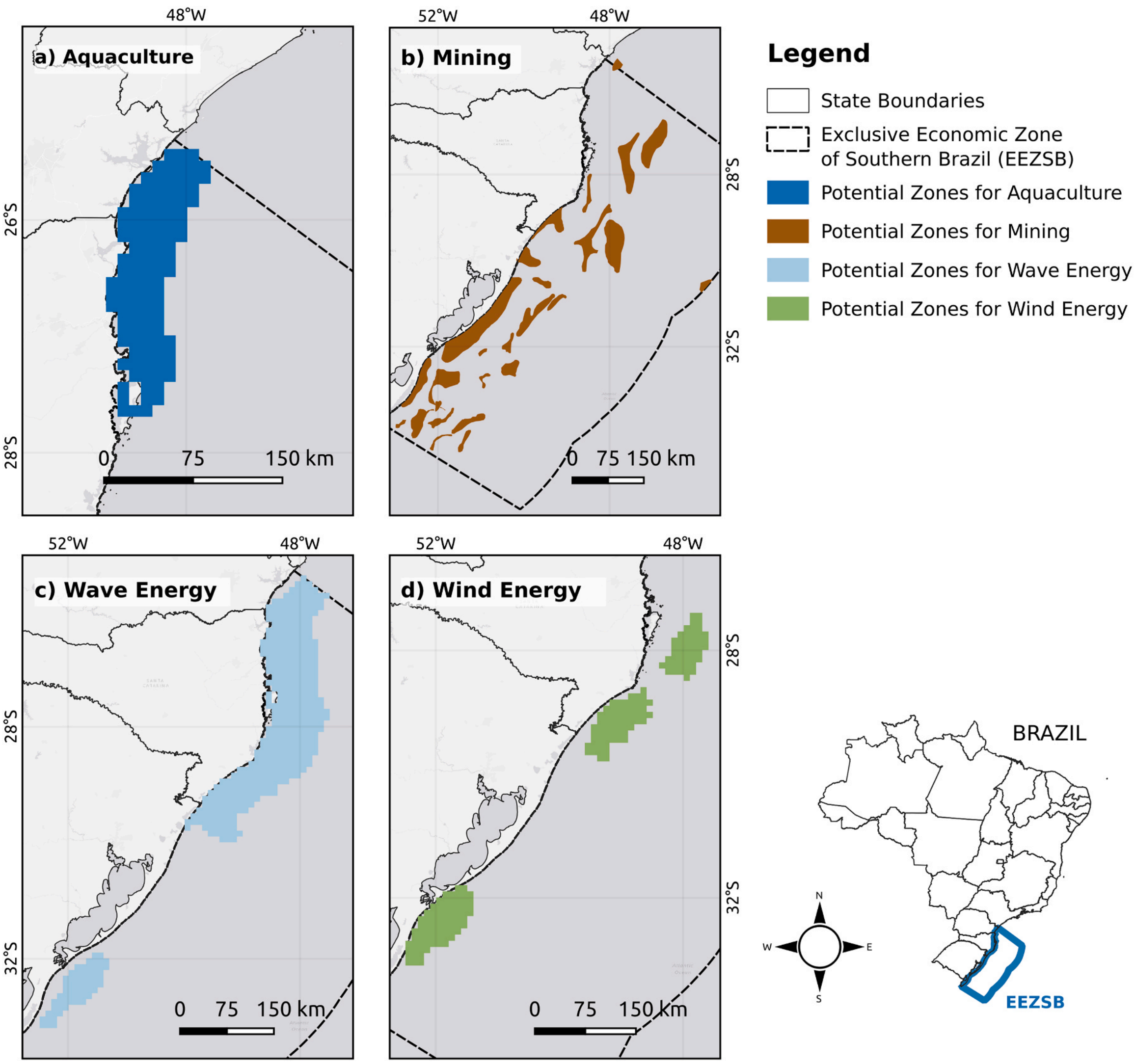

Fig. A1. . Potential zones considered for the emerging activities of: **a)** Aquaculture; **b)** Mining; **c)** Wave energy and; **d)** Wind energy.

Table. A1. Survey questions sent to stakeholders (in virtual format) to assess the spatial compatibility between emerging marine economies and existing uses in the EEZSB. The original version was applied in Portuguese.

a) Contact information: ______________
b) Please select your area of expertize:

Marine Spatial Planning
Aquaculture
Renewable Energies
Mining
Governance
None of the above? Please specify:

c) Rate the degree of compatibility between the potential zones for **wind energy** and the existing/potential uses in the EEZSB:
0 = Not compatible (i.e., possible conflict);
10 = highly compatible (i.e., possible synergy).

	0	1	2	3	4	5	6	7	8	9	10
Gillnet Fishery											
Seine Fishery											
Trawl Fishery											
Wave energy											
Mining											

(continued on next page)

(*continued*)

	0	1	2	3	4	5	6	7	8	9	10
Shipping											
Ports											
Marine Protected Areas											

d) Rate the degree of compatibility between the potential zones for **wave energy** and the existing/potential uses in the EEZSB:
0 = Not compatible (i.e., possible conflict);
10 = highly compatible (i.e., possible synergy).

	0	1	2	3	4	5	6	7	8	9	10
Aquaculture											
Gillnet Fishery											
Marine Protected Areas											
Mining											
Pipelines											
Ports											
Seine Fishery											
Shipping											
Trawl Fishery											
Priority Zones for Biodiversity Conservation											

e) Rate the degree of compatibility between the potential zones for **aquaculture** and the existing/potential uses in the EEZSB:
0 = Not compatible (i.e., possible conflict);
10 = highly compatible (i.e., possible synergy).

	0	1	2	3	4	5	6	7	8	9	10
Gillnet Fishery											
Marine Protected Areas											
Mining											
Pipelines											
Ports											
Priority Zones for Biodiversity Conservation											
Seine Fishery											
Shipping											
Trawl Fishery											

f) Rate the degree of compatibility between the potential zones for **mining** and the existing/potential uses in the EEZSB:

0 = Not compatible (i.e., possible conflict);
10 = highly compatible (i.e., possible synergy).

	0	1	2	3	4	5	6	7	8	9	10
Gillnet Fishery											
Marine Protected Areas											
Pipelines											
Ports											
Priority Zones for Biodiversity Conservation											
Trawl Fishery											
Shipping											

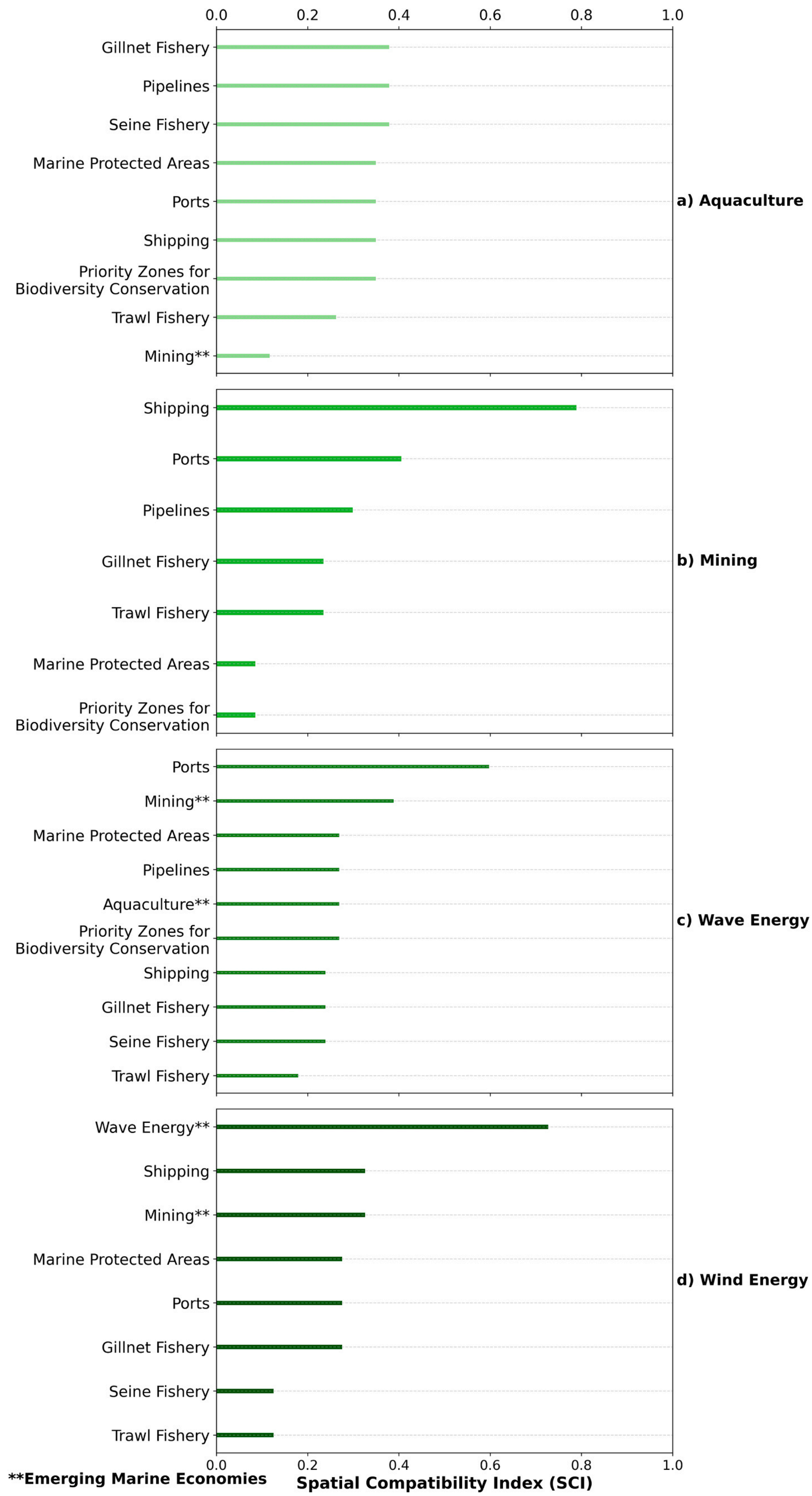

Fig. A2. . Spatial Compatibility Index (SCI) for each overlap with: **a)** Aquaculture; **b)** Mining; **c)** Wave Energy and; **d)** Wind Energy.

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