What future for marine renewable energy in Portugal and Spain up to 2030? Forecasting plausible scenarios using general morphological analysis and clustering techniques

Mário Vieira [a,b], Ana Macedo [a], António Alvarenga [c,d,e], Marcos Lafoz [f,*], Isabel Villalba [f], Marcos Blanco [f], Rodrigo Rojas [g], Alejandro Romero-Filgueira [h], Adriana García-Mendoza [h], Miguel Santos-Herran [i], Marco Alves [b]

[a] *CoLAB +ATLANTIC, IPL-ESTM, Rua do Conhecimento 4, 2520-614, Peniche, Portugal*
[b] *WavEC Offshore Renewables, Edifício Diogo Cão, Doca de Alcântara Norte, 1350-352, Lisbon, Portugal*
[c] *CEG-IST, Centre for Management Studies of Instituto Superior Técnico, Universidade de Lisboa, Portugal*
[d] *IHC, Institute of Contemporary History, Nova University of Lisbon, Portugal*
[e] *NOVA School of Business & Economics, Universidade NOVA de Lisboa, Campus de Carcavelos, Rua da Holanda, no. 1, 2775-405, Carcavelos, Portugal*
[f] *Ciemat, Complutense, 40, 28040, Madrid, Spain*
[g] *Instituto Costarricense de Electricidad, Edificio Jorge Manuel Dengo Obregón, Avenida de las Américas, Calle 50, Barrio Américas, Mata Redonda, 10108, San José, Costa Rica*
[h] *PLOCAN, Carretera de Taliarte s/n (Faro), 35200, Telde, Gran Canaria, Spain*
[i] *Carnegie Clean Energy, Claudio Coello, 24 – 4A2, 28001, Madrid, Spain*

ARTICLE INFO

ABSTRACT

Marine renewables – which include mainly wave, tidal and current energy – have been hailed, for the past decades, as a potential solution to support the decarbonization of the society. Portugal and Spain have been traditionally avid for the testing and demonstration of such technologies, but the implementation of marine capacity is yet marginal, and there are many uncertainties regarding the future of the sector in the region. The main objective of this article is to show a future projection of marine renewable energies in both Iberian and Macaronesian regions for 2030 to research and technological development communities. To obtain this future projection, General Morphological Analysis and advanced clustering techniques have been used. The results are divided into five groups of potential scenarios, which vary significantly due to different political, social and technological parameters. The influence of variables such as innovation speed, infrastructure implementation, and comprehensive metocean data availability emerges as pivotal determinants shaping the sector's course. The knowledge from this systematization is expected to be used by researchers, technicians, governments or by any other agency involved in marine renewable energies in Spain and Portugal, as a guidance for their new projects and research lines.

1. Introduction

The current global energy paradigm is still strongly sustained by fossil fuels - approximately 81% of all energy consumed in 2019 was non-renewable ("Energy Statistics Data Browser), which means there is still a massive challenge for humanity to decarbonize the global economy. Decarbonization is fundamental to meet the goals defined on the Paris Agreement (UNFCCC, 2015), which intent to tackle the impacts of climate change. Furthermore, fossil fuels have shown, along the way,

high-cost volatility due to geopolitical instabilities, as seen in the most recent event of the Russian invasion in Ukraine, which resulted in spiking gas and oil prices.

Renewable sources present themselves as one of the best solutions for sustainable energy harvesting, but the current installed capacity is still not enough for fulfilling the global energy needs, which means more and new means of extracting this energy need to be developed and implemented. Ocean-based renewable energies can play a relevant role in this respect, as the oceans – and the offshore winds – possess excellent energy

---

densities.

The installed capacity of ocean-based renewable energies is expected to grow exponentially worldwide in the following years, as several offshore renewable sources, among which offshore wind stands out, have shown to be capable of contributing to the energetic transition in course. In particular, 2.9 GW are expected globally for ocean energy (wave and tidal), according to Ocean Energy Europe, by 2030. This value contrasts with the 234 GW expected globally for offshore wind for the same period (Lee and Zhao, 2020). This relevant discrepancy can be explained by the difference in the Technological Readiness Levels (TRL) of both technologies. While offshore wind is now commercially competitive, marine renewables still struggle to affirm themselves as competent technologies to support the energy transition. The most consensual explanations for this are related with the difficulty to build and maintain offshore equipment that is both efficient in extracting the power and capable of sustaining the severe loads imposed by the oceans during survivability events (Rehman et al., 2023). Because past technologies have failed to show the adequate capacity to extract relevant amounts of energy, yet sustaining these extreme loads, the political and institutional interest in these technologies has detained in the past years. However, there are weak trends signalling that recent concepts may have acknowledged past errors and could bring effective technology in the near future.

The future of marine renewables in the Iberian and Macaronesian regions, the focus of the present research, is quite uncertain and there are several aspects that may hamper its success in the region in the future. In this research, and following a PESTLE analysis of the environment of marine renewable energies, a foresight analysis of the potential plausible future scenarios for the marine renewables in these regions, up to 2030, is presented. To describe the space of the potential futures, the General Morphological Analysis (GMA) method is employed to systematize the generation of scenarios that cover a wide range of future possibilities. Different clustering methods were tested to aggregate the possible futures into smaller groups. Similarities and differences between the representative scenarios are discussed and insights into how to reach successful marine renewable energy implementation in the analysed regions are provided.

2. Methods

The generation of plausible future scenarios for a certain complex problem is many times done through an empirical basis, by obtaining feedback from different experts from the field on how they understand the future may roll out. However, this approach does not systematize the generation of these future scenarios, which means the conclusions obtained may not be scientifically reproducible. Furthermore, these experts may fail to detect the whole extent of potential futures for that specific problem.

The method deployed during this research is schematically presented in Fig. 1 – Context, Morphological Analysis and Conclusions. This method was proposed since the research team had to solve a complex wicked problem. Wicked problems can be characterized as being subjective, ill-defined, ambiguous, and sometimes associated with moral, political and professional issues (Ritchey, 2011). In fact, the implementation of renewable energies in a certain region presents a challenge that is influenced not only by technological factors, but also, many times, by political interactions, social legitimacy and acceptance circumstances, economic and financial availability, etc. Furthermore, causal relationships between these multi-dimensional parameters may not be captured by simply using a sensitivity analysis or choosing statistical distributions within stochastic optimization (Amorim-Lopes et al., 2021).

The research started with a Political, Economic, Sociological, Technological, Legal and Environmental (PESTLE) analysis of the environment of marine renewable energies in the Iberian and Macaronesian regions. Although the research was produced in close relation with specialists of the field, it was considered fundamental to systematize the different dimensions of the problem, to guarantee that the overarching influences between each of the dimensions were taken into consideration. Then, the morphological analysis was implemented, and the results obtained were processed using morphological space analyses and advanced clusterization techniques. Finally, these results were used to promote a discussion on which scenarios are plausible in the near future, what measures can be taken within each potential future, and what things should be avoided to impede unwanted scenarios from coming true.

General Morphological Analysis (GMA) allows the framing of complex problems, dependent on technical and (primarily) non-technical
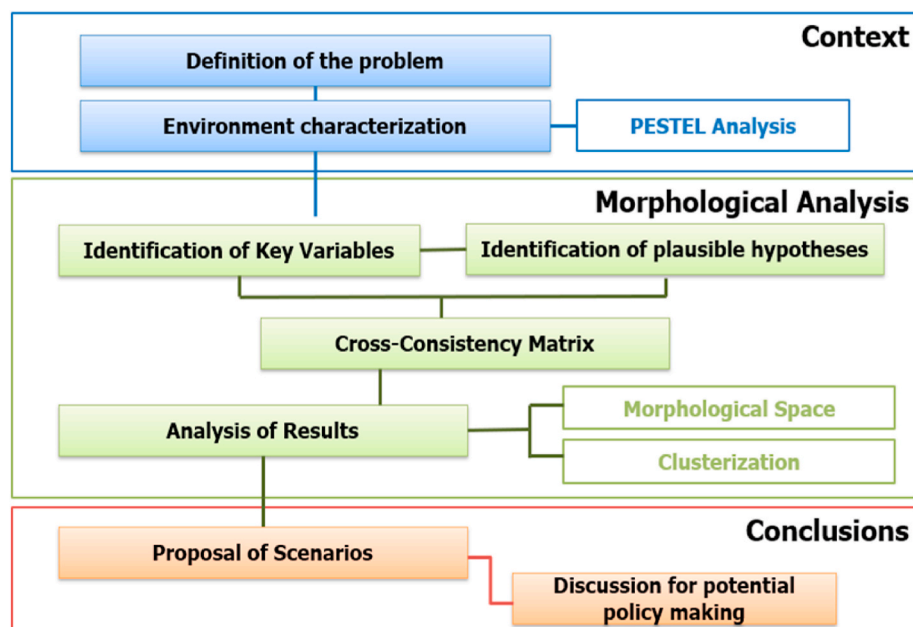

Fig. 1. Framework for the research: 1-Context; 2-Morphological Analysis; 3-Conclusions.

influences, such as social interactions, learning effects, technological disruption, amongst many others. It was first proposed by Fritz Zwicky, a Swiss astrophysicist and aerospace scientist (Zwicky, 1948a, 1948b, 1960) Interestingly, it was first implemented to support the classification of astrophysical objects, but the potential of the method for supporting the analysis of wicked problems has been steadily revealed up to today. Morphological analysis has been implemented by several research groups in the USA and Europe working in policy and foresight. It was in 1995, with the implementation of advanced computer support for GMA, that the Swedish Defence Research Agency made it possible to create complex non-quantified inference models, that significantly widen the applicability of the method (Ritchey, 2011). Michel Godet has also strongly contributed to the development and adaptation of morphological analysis for future forecasting, notably through the Morphol tool (Godet, 2001).

GMA is sustained by the development of discussion workshops with experts within a given area, led by methodologists (the researchers responsible for organizing the workshops and processing the generated data). With the support of these methodologists, experts discuss and identify.

- The key variables that influence the problem under analysis, considering the contextual specificity of each region and the socio-economic conditions that may vary across different areas;
- The plausible hypotheses that preferably cover the entire range of possibilities within each key variable;
- The respective exclusions, which are pairs of hypotheses that cannot coexist.

Afterwards, the methodologists develop the respective cross-consistency matrix, based on these results, and input the information into the computational tool. The iterative nature of the model accounts for the influence of contextual specificity, as feedback obtained from the workshops is intricately tied to the unique problem landscape and regional nuances. This recognition reveals that the same problem applied to different regions, or different problems applied to the same region, will inherently yield varying results from the proposed methodology. A series of postprocessing can be produced to the resulting morphological space using clustering techniques; furthermore, the structure of the model can be iterated from feedback obtained from the workshops, which then may improve the preliminary results obtained. The research consisted of carrying out six meetings throughout six months – approximately one per month – lasting for approximately 1h30' each. The number of experts on these meetings varied between 6 and 8, and were related to the following institutions: +ATLANTIC, CIEMAT, ICE (Instituto Costarricense de Electricidad), PLOCAN and WavEC.

3. Progress in marine energy in Portugal and Spain

The historical record of testing several concepts and innovative ocean technologies at the Iberian and Macaronesian regions is not accidental, but rather the result of policy and institutional efforts in bringing these closer to commercial TRLs.

Portugal, on one hand, has been fostering the generation of several test sites that frame the testing and demonstration of these technologies, allowing them to be demonstrated on a sandbox-type protected space. The first test site was built off the coast of Aguçadoura, back in 2001, in Póvoa de Varzim, Portugal. This test site was the host of AWS Archimedes (Archimedes Waveswing - AWS Ocean Energy), the Pelamis ("Pelamis and World"), the Windfloat 1 Prototype floating offshore wind project (Commission, 2014), and is currently the testbed of the Cor-Power Hi-Wave5 project ("CorPower rolls in €7"). The infrastructure has been continuously updated to respond to technology developer's requests and needs, and is currently managed by WavEC and INESC TEC. The second test site was proposed at São Pedro de Moel (2008), having

been legally framed to receive several ocean energy devices (Diário da República, 2012; Diário da República, 2008; Diário da República). However, it failed to attract any technology developer up to now, due to inadequate ocean resources, lack of supply chain and lack of testing infrastructure, amongst other factors.

To answer these shortcomings, the government proposed the definition of a new testing zone off the coast of Viana do Castelo, a zone with good wind and wave resources. This test zone is currently the home of the 24-MW floating offshore wind Windfloat Atlantic farm and is under infrastructural and legal reformulations to allow the implementation of more floating devices. On the legal side, the government wants to frame this test site as a Free Technological Zone (FTZ) (Presidência do Conselho de Ministros, 2021), (Presidência do Conselho de Ministros, 2020), which will hopefully speed-up the licensing and consenting processes for demonstrational concepts. As per the governmental proposal (Presidência do Conselho de Ministros, 2022), the management of this new free technological zone may be transferred to a third party that possesses the necessary skills to manage such infrastructure operationally and commercially. In this respect, the OceanACT Consortium (Vieira and Aguilera, 2021) has been proposed by five R&D institutions as one of the possibilities for this management.

The case of Spain is paradigmatic, as the deployment of commercial projects related to marine renewable energies has been on hold while several marine technologies were tested within its territorial waters. These test areas have driven forward the creation of innovation hubs for the development of new marine energies' concepts. In fact, Spain is an international leader within floating offshore wind patents, owning up to 30% of the patents worldwide (Associacion Empresarial Eólica; Deloitte, 2022).

The Oceanic Platform of the Canary Islands (PLOCAN), a public consortium created in 2007, in the Canary Islands, has been selected as the scenario for the deployment of the first operative offshore wind turbine in Southern Europe, the Elisa Project ("The Elisa Project | Esteyco"), and disruptive floating offshore wind platforms led by Flotant ("Innovative and low cost"), PivotBuoy ("PivotBuoy") and W2Power ("W2Power | Pelagic Power"). It has also hosted wave energy converters such as Welcome ("Plataforma Oceánica de Canarias |a"), Wello ("Plataforma Oceánica de Canarias |b"), the horizontal wave energy converter of Wavepiston ("Wavepiston installs a wave energy") and, in a near future, the prototype Gaia ("Launch of pilot buoy"), the buoy developed by Ocean Oasis which uses wave power for seawater desalination. The infrastructure has been updated according to the needs of developers and technologists and it currently has a smart grid fully operational in its offshore platform which manages and distributes the energy produced and consumed by the devices installed on its marine test site.

The Biscay Marine Energy Platform (BiMEP), a test area at the coast of Armintza in the Basque Country Region, also in Spain, is operating since 2015. Different wave energy converters have been deployed since then, such as Marmok A-5 ("Wave Energy Converter Prototype") and the Penguin ("Euskadi and international wave energy test"). In the upcoming years, the test site will also be hosting demonstration deployments of cost-effective WEC systems under the EuropeWave call ("EuropeWave reserves berths at BiMEP"). Furthermore, BiMEP has been selected as the test site for the Demosath ("DemoSATH"), a unique barge concept for a floating offshore wind platform. In addition to these prototypes, BiMEP operates the wave power plant of Mutriku from 2011, based on an oscillating water column technology ("Technical Characteristics").

Recently, the Government of Galicia has announced an agreement with the Port of A Coruña and Red Eléctrica Española to exploit an open sea area close to the Port of Punta Langosteira as an offshore wind experimental platform ("Plataforma eólica mariña"). This takes advantage of the high-wind resources off the coast of Galicia and the importance of the renewable energy and naval industries in the region. Indeed, Navantia Fene shipyard, a key global player in the construction of offshore wind platforms, is located at only 50 km.

Although there have been advances in terms of generating conditions

for testing these technologies, there have been some setbacks, as well. In Portugal, the feed-in tariff scheme defined for wave energy in the past is now terminated. Furthermore, the political support given to these technologies cooled down after the unsuccess of some projects and the appearance of more promising technologies – such as floating offshore wind.

Spain, in turn, has not implemented a specific policy mechanism designed to accelerate investment in marine renewable energy technologies, but it may do it according to its "Roadmap for the Development of Offshore Wind and Marine Energies" (de España, 2021), which established the need to design a regulatory framework aligned with the decarbonization goals and the specific committed targets of reaching 1–3 GW in offshore wind and 60 MW in marine energies by 2030.

3.1. PESTEL results

Although two countries are addressed in this research, it is important to highlight that Portugal and Spain possess similar technological, social and political contexts. This section presents aspects which are considered convergent – aligned in both countries – but also divergent, if specific to one of the countries, for each of the PESTLE dimension analysed. These dimensions are, political, economic, social, technological, legal and environmental.

- Political:

On the political dimension, the converging aspects identified in both countries are related to political awareness regarding the need for societal decarbonization. On this respect, several strategic plans have been developed in both countries, notably the national plans for energy and climate ((Ministerio para la Transición Ecológica, 2020) in Portugal and PNIEC in Spain). However, the experts agreed that these plans are not met with sufficient monitoring and milestone definition to guarantee the materialization of its intentions.

Spain has been guaranteeing its presence on international bodies and technical committees regarding renewable energy implementation with a greater success than Portugal. Spain has been registering delays on the approval of national budgets – due to parliament minority of the ruling party – although all the national budgets proposed during this mandate have been successfully approved. The Spanish Roadmap for Wind and Ocean Energies aims at locating the country as European reference pole for the technological development for the design, scaling and demonstration of marine renewables new technologies, taking advantage of the geographical singularities and maritime regimens of the country. It is intended to reinforce the testing platforms, deploying a "plug & play" enabling framework with aspiration to be the most agile in Europe for the testing of new prototypes, by means of activating at least 200 million euros of public investment to support the technological innovation by 2023 (de España, 2021).

On the other hand, the political interest for wave energy in Portugal has been hampered by the lack of success registered by past projects.

- Economic:

On the economic dimension, it is transversal between both countries the limited existence of public funds to support the implementation of emerging technologies, although some technology developers have been able to obtain financing funds. There is, indeed, a lack of dedicated public financing schemes for innovative techs, and no feed-in tariffs or tenders are available for ocean energy. Furthermore, private financing is difficult to obtain due to cultural aversion to risk – as marine renewables are technologies often associated to low technology readiness levels, the risk associated with these investments is usually high. Despite the current instabilities generated by the pandemic and the war in Ukraine, there are economic opportunities related to the European Recovery Plan generated after the pandemic and to the high volatility of energy

markets, which can increase the suitability and institutional interest in these renewable technologies. The experts also commented that the LCOE indicator may undervalue the merit of ocean renewable energy, and impact investing decisions.

- Social:

Regarding social aspects, both countries possess some overarching convergences. There are some public apprehensions regarding the role of renewables. Nonetheless, most of the population are aware of the economic opportunities surrounding the implementation of renewables (Delicado et al., 2016; Costa Pinto et al., 2021; Apolonia et al., 2021). Some of these opportunities are related to energy independence, but also with the generation of high-qualified jobs related with past and current projects (Delicado). For instance, in Spain, the amount of direct and indirect jobs related to marine energies has increased in 15% in five years (2015–2020) (Delicado). (Delicado).

- Technological:

On the technological dimension, both countries have been able to host the testing of several devices, as detailed earlier. There are some infrastructures already installed that can support the sector, but these may not be sufficient to accommodate the whole flux of opportunities surrounding it. Spain has several functioning test sites that can provide immediate support for the implementation of new devices. Portugal, on the other hand, has some testing infrastructure, but it needs some updates to accommodate for more projects. In addition, there is currently no Portuguese entity responsible for the commercial and operational promotion of the existing infrastructure, although the OceanACT Consortium has been positioning itself towards that direction.

Furthermore, the electrical grid in the Iberian region is not yet sufficiently decentralized to accommodate relevant production from offshore sources – this is also an issue for offshore wind implementation. The electrical grid is also constrained, as connections to the rest of Europe – namely, through France – are not capable of exporting relevant amounts of energy. This historical bottleneck has been caused by the unwillingness of France to increase the connection bandwidth ("Is France an obstacle to). The current energy crisis in Europe may serve, however, as a catalyser to foment the connections between the two regions.

Other relevant limitation is the inexistence of capable energy storage systems, which need to be used to stabilize the grids due to the variability of renewable production. Nonetheless, there are several promising projects in the region regarding energy accumulation, notably using green hydrogen, which may contribute for a status change before long.

Finally, it is worth referring that most of the marine renewable concepts tested up to now, worldwide, showed little compliance to sustain the loads of the ocean, whilst at the same time producing relevant quantities of energy. This makes the viability of these technologies to be usually questioned.

- Legal:

Both countries possess legal frameworks for the licensing of the implementation of offshore devices. However, this legislation is many times reactive to private initiatives, rather than proactive in the generation of specific tenders for these technologies. Feed-in tariffs have been available, in the past, for marine renewables in both countries, but these schemes are now terminated, which means these projects have to compete within the electricity market. Spain has already approved a plan for the development of the energy grid for the period 2021–2026 (Gobierno de España and Red Eléctrica de España, 2021), contrary to Portugal. Portugal has already approved its Maritime Space Planning back in 2019 (PSOEM - DGRM.), as well as Spain, which recently

approved it in February 2030 ("Ordenación del espacio marítimo). Portugal is registering some uncertainty on the legal framework for the free technology zones, which also contributes to the uncertainties of the sector.

- Environmental:

On the environmental dimension, both countries possess good wave resources which are adequate for energy extraction – which is particularly true in the archipelagos of Azores and in the Macaronesian region. Furthermore, the experts assume that the current environmental applicable law is sufficiently well established. Nonetheless, there is still low acknowledgement of the potential disturbances caused by marine renewables devices to local ecosystems.

4. Morphological analysis

GMA offers a methodical framework for systematically generating a comprehensive spectrum of potential future scenarios, both exhaustive and plausible, for complex problems using available information. This process entails the creation of permutations involving key variables and hypotheses, while also accounting for exclusions. Subsequently, a collection of scenarios is generated, and distances between them are computed to position each scenario relative to others on a morphological map. Notably, this mapping facilitates the identification of extreme scenarios by evaluating the values of all positions. It is important to acknowledge that morphological analysis may yield a substantial number of plausible futures, potentially reaching hundreds or thousands, even after accounting for exclusions outlined in the cross-consistency matrix. To enhance interpretability, clustering techniques can be harnessed to systematically group similar futures into clusters, streamlining the analysis of results obtained. Various clustering methods are available in the literature, including hierarchical agglomerative and k-medoids clustering, among others ("Hierarchical Clustering).

It is also worth noting that the implementation of GMA on the context of complex problems is only possible through the use of computational tools that can deal with thousands of calculations, which are required to analyse the complete morphological space associated with the problem at hands. Because of this, a computational tool – the FIL, Future in Logic – was used. FIL has been developed by ALVA Research and Consulting (ALVA Research Consulting) and WavEC Offshore Renewables (Wavec - Offshore Renewables).

4.1. Definition of key variables

Using the PESTLE analysis as a starting point, in which the problem at hands was divided into political, economic, social, technological, environmental and legal dimensions, the experts have then used the data collected to propose the variables that are perceived as highly influencing the future outcome of marine renewables in the regions. Initially, 24 variables were identified. However, as some of these are dependent on each other, and since the model should be built solely with independent variables, a systematization was done in collaboration with the experts, to reduce the number of variables to seven. These are the final key variables of our problem.

1. Political support
2. Existence of space conflicts/Existence of MSP
3. Blue Economy growth
4. Public acceptance/Social Impact
5. Support infrastructure
6. TRL/standardization/MRL
7. Existence of metocean data

4.2. Definition of hypotheses

Hypotheses for future plausible states/conditions are proposed for each of the identified key variables. Although these should cover a relevant range of possibilities, the more hypotheses exist per variable, the more complex the problem and the higher the computational effort will become, sometimes with little added value associated. The focus was therefore to only define the hypotheses that had some degree of plausibility. Below, the proposed hypotheses are described.

4.2.1. Key variable 1: political support

- Hypothesis 1 – Support reversal: it assumes that the current support given to sustainable transitions is reverted, which could happen due to changes in the political party in the government;
- Hypothesis 2 – Business as usual: it assumes that the current political support paradigm stays similar throughout the near future. This guarantees acceptable political perception, commitment and generation of policies, but little to no financing and funding mechanisms;
- Hypothesis 3 – Rise in support: it assumes the generation of funding schemes and the flexibilization of project licensing and permitting as the political agents become more aware of the need to implement more renewable capacity.

4.2.2. Key variable 2: existence of space conflicts

- Hypothesis 1 – No Maritime Space Planning (MSP) in place: it assumes that there are no measures in place to mitigate space conflicts;
- Hypothesis 2 – Existence of inadequate MSP: there is a planning, but it is not effective for conflict mitigation;
- Hypothesis 3 – Existence of successful MSP: there is an efficient Maritime space planning that provenly solves conflicts.

4.2.3. Key variable 3: blue economy growth

- Hypothesis 1 – Business as usual: it assumes that society does not have the capacity to take advantage of all the opportunities associated with the blue economy;
- Hypothesis 2 – Growth on blue economy: it assumes an increase on the relevance of the Blue Economy on the countries' Gross Domestic Product (GDP); marine renewables, being part of the Blue Economy, start to position themselves at a better level compared to other energy industries.

4.2.4. Key variable 4: public acceptance

- Hypothesis 1 – High engagement: it assumes the inexistence of disturbances in the local ecosystems, job creation, no other conflicts with local communities, and the existence of effective environmental impact assessments.
- Hypothesis 2 – Low engagement: it assumes high disturbance in local ecosystems, little capacity to generate new jobs, and little social awareness for the need of renewable capacity;

4.2.5. Key variable 5: support infrastructure

- Hypothesis 1 – No new infrastructure available: it assumes that the sector will be faced, in the future, with no new resources, as the current infrastructure remains inadequate;
- Hypothesis 2 – Onshore infrastructure needs fulfilled: it assumes the correct implementation of new infrastructure inland, such as energy storage and connection to the grid, but no new offshore infrastructure;
- Hypothesis 3 – New infrastructure needs fulfilled: it assumes the existence of energy storage infrastructure, of specialized support

vessels, and the extension of the electric grid and/or insertion of new connection points.

4.2.6. Key variable 6: TRL/standardization

- Hypothesis 1 – Slow innovation: it assumes reduced innovation on improving structures and methods and a continuous lack of standards to improve and scale the technologies;
- Hypothesis 2 – Accelerated innovation: it assumes the existence of a fast-paced innovative environment in the region that can support the path to commercialization of these technologies.

4.2.7. Key variable 7: existence of metocean data

- Hypothesis 1 – Business as usual: it assumes that the current lack of accessible data on marine parameters to support industrial developments remains;
- Hypothesis 2 – Access to more data: it assumes considerable efforts on the acquisition, processing and access of new metocean data (to support the industry and the academia) (see Table 1).

Table 1 summarizes the morphological model, namely the defined key variables and the respective hypotheses obtained from the workshops with the experts.

4.3. The FIL tool

A software for the systematization of the morphological analysis was used. It consists of a MATLAB routine whose interface contains the workflow of GMA methodology, i.e., the identification of key variables and hypotheses with descriptions of each, the choice of impossible combinations to be considered as constraints and some visualization tools for grouping and aid in the analysis of future scenarios.

Each scenario is represented as a sequence of digits, where each position represents a key variable, and each value represents the hypothesis. E.g., a potential scenario 1221311 will have 7 digits – each representing one of the assumed key variables, in which the first, the Political Support, has the hypothesis 1, meaning there could be a reversal in the support. For the same potential scenario, the second variable, with the hypothesis 2, would represent the existence of an inadequate MSP, and so forth.

Having identified the variables that framework the problem and the possible states (hypothesis) they can take, the number of possible scenarios will be a combination of all the hypotheses given by:

Table 1
Resume of the systematization of the problem at hands, with the key variables and hypotheses proposed by the experts.

Problem Variables		Hypotheses		
		1	2	3
1	Political Support	Support Reversal	Business as usual (BAU)	Good support mechanisms
2	Space Use Conflicts	No MSP in place	Existence of MSP, but unsuccessful	Existence of successful Maritime Space Planning (MSP)
3	Blue Economy Growth	Business as usual (BAU)	Growth	–
4	Social Impact	Low	High	–
5	Support Infrastructure	No infrastructure available	Onshore infrastructure needs fulfilled	New infrastructure needs fulfilled
6	TRL/MRL	Slow innovation	Accelerated innovation	–
7	Metocean Data	Business as usual	Acquisition and access to more data	–

$$n_h^{KV1} \times \cdots \times n_h^{KVnkv} = \prod_{n=1}^{nkv} n_h^i$$

Where n_h^i is the number of hypotheses the *ith* variable can take and *nkv* is the number of variables. This equation represents the product of all number of hypotheses in the model. If all variables had the same number of hypotheses, the product would equal n_h^{nkv}, i.e., the number of hypotheses to the power of the number of variables.

Because the result increases exponentially, it can give hundreds or even thousands of potential scenarios. In this study, 432 scenarios were obtained. Fortunately, there may be meaningless scenarios, as result of some variables not being compatible with one another. For example, if there is a reversal in political support for opportunities related to the ocean in the terms that were described earlier, it is very unlikely that the Blue Economy will be growing. This and other incompatibilities are then added to the model as exclusions and, as a result, a bunch of scenarios are not considered from the final set of plausible futures, allowing for a more viable analysis.

4.4. Cross-consistency matrix

The systematization of pairs of hypotheses which have very low plausibility of occurring, according to the experts, is fundamental to reduce the number of potential solutions.

Using a cross-consistency matrix, all hypotheses are confronted versus each other to create a reticulate. In each of the blank spaces, a pair of possibilities is evaluated, ending up with a table with squares corresponding to pairs of combinations variable-hypothesis with big probability of occurrence and others with low probability or even impossible to occur. This selection is done based on discussions with the experts.

Fig. 2 presents the resulting cross-consistency matrix from the pairwise comparison. It shows 24 mutually exclusive pairs (little to no possibility of occurrence) and 34 preferences (pairs that have a relatively high chance of occurring, according to the experts).

4.5. Proximity map

From the combination of variables and hypotheses with the conditions imposed by the cross-consistency matrix, the computational tool generates a batch of plausible scenarios. 23 scenarios resulted from this process. The scenarios are then organized in a table, whose last 3 columns show three indicators: CT – the sum of common hypotheses that each scenario has with all other scenarios, CM – the number of scenarios with which each one of them differ in only one hypothesis, and CX – the number of scenarios completely different from the one considered.

The resulting 23 scenarios, after the application of the conditions defined by the cross-consistency matrix, can be visualized in a proximity map – see Fig. 3. This is a two-dimensional representation of the morphological space, in which the scenarios' locations are calculated based on the relative distances between each other. A MATLAB function that uses multidimensional scaling (Seber, 1984) is used for creating a morphological space based on those distances. The distance metric is defined by the number of common hypotheses between a pair of scenarios. For example, scenarios 1111111 and 1111211 have 6 common hypotheses, and thus they will be relatively close. Each pairwise distance is inserted into a *nkv* x *nkv*+1 matrix, that is then transformed into a full distance matrix.

5. Results

Table 2 presents the main parameters of the developed model. Observing from Fig. 4, the different hypotheses for each key variable are graphically presented on the morphological space. It can be understood
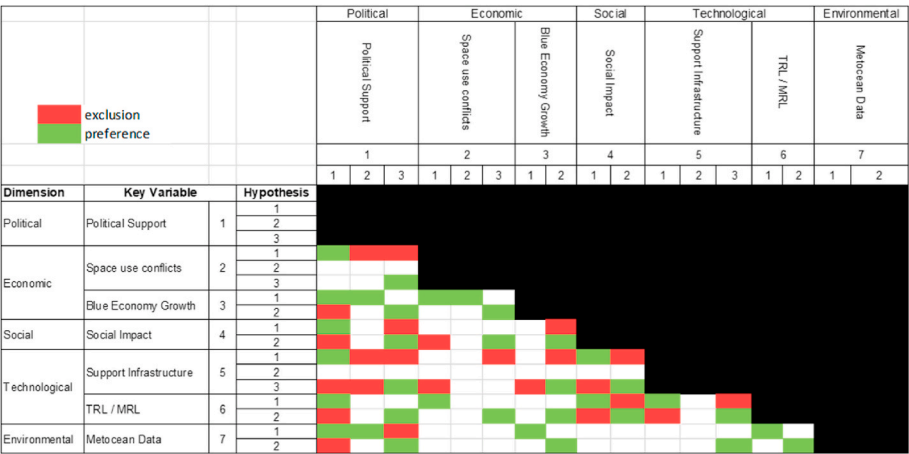
Fig. 2. Cross-Consistency matrix: In red the exclusions and in green the preferences. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)
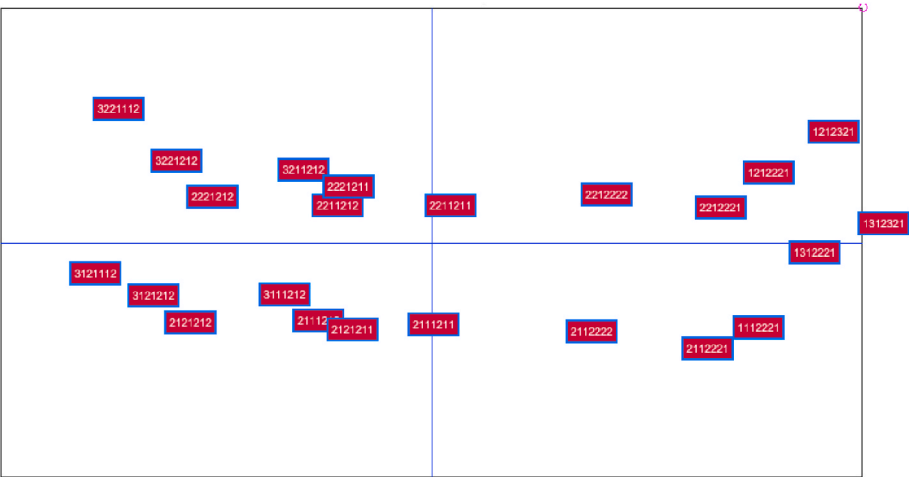

Fig. 3. Proximity Map of the scenarios of the complex problem analysed. Note that the axis have no objective meaning; the morphological space is built from relative distances between scenarios.

Table 2
Summary of model characteristics.

Number of variables	7
Total number of scenarios	432
Excluded scenarios	409
Resultant scenarios	23

that, because of the complexity of the problem, it would be complicated to manually generate clusters that would analytically distribute scenarios on different groups, according to their similarities. In fact, many times the models are too complex for visual analysis and interpretation, specifically when scenario clustering is intended for the systematization of the analysis. Therefore, more complex unsupervised clustering techniques were used to analytically systematize the morphological space into different clusters.

5.1. Clustering

The hierarchical clustering method used here is agglomerative, meaning there was an agglomeration of scenarios one by one until we ended up with a single cluster that contains all scenarios ("Hierarchical Clustering"). An example of a hierarchical binary tree produced with this clustering is presented in Fig. 5. Each branch contains only two children,

until it reaches the total of scenarios.

A vertical line is included on the figure to identify a partition that generates 5 clusters. For this specific research, the authors considered five to be the ideal number of clusters. The average, single, and complete methods were implemented for this research ("Agglomerative hierarchical cluster tree"), from the agglomerative techniques used. The k-medoids clustering method was also employed. Each method produced its unique hierarchical tree. For this document, only the results from the average method are presented, as it produced the most relevant results according to the involved researchers. In fact, the single method resulted in a distribution that generated one bigger-than-intended cluster on the positive region of the morphological map. The k-medoids method proposed clusters that were horizontally stretched. This is particularly uninteresting because, as it was shown in Fig. 5, the hypotheses of most of the key variables analysed are distributed on vertical clusters. Finally, the average and complete methods provided very similar results, but the average method presented a more adequate distribution of the negative clusters for policy analysis.

Fig. 6 presents the morphological space with the five clusters proposed by the average method, and the respective representative scenario for each cluster. This representative scenario is selected by calculating the local CT for each of the scenarios included on that specific cluster. The one with the highest CT (that is, the one which more similar to the others), is the representative.
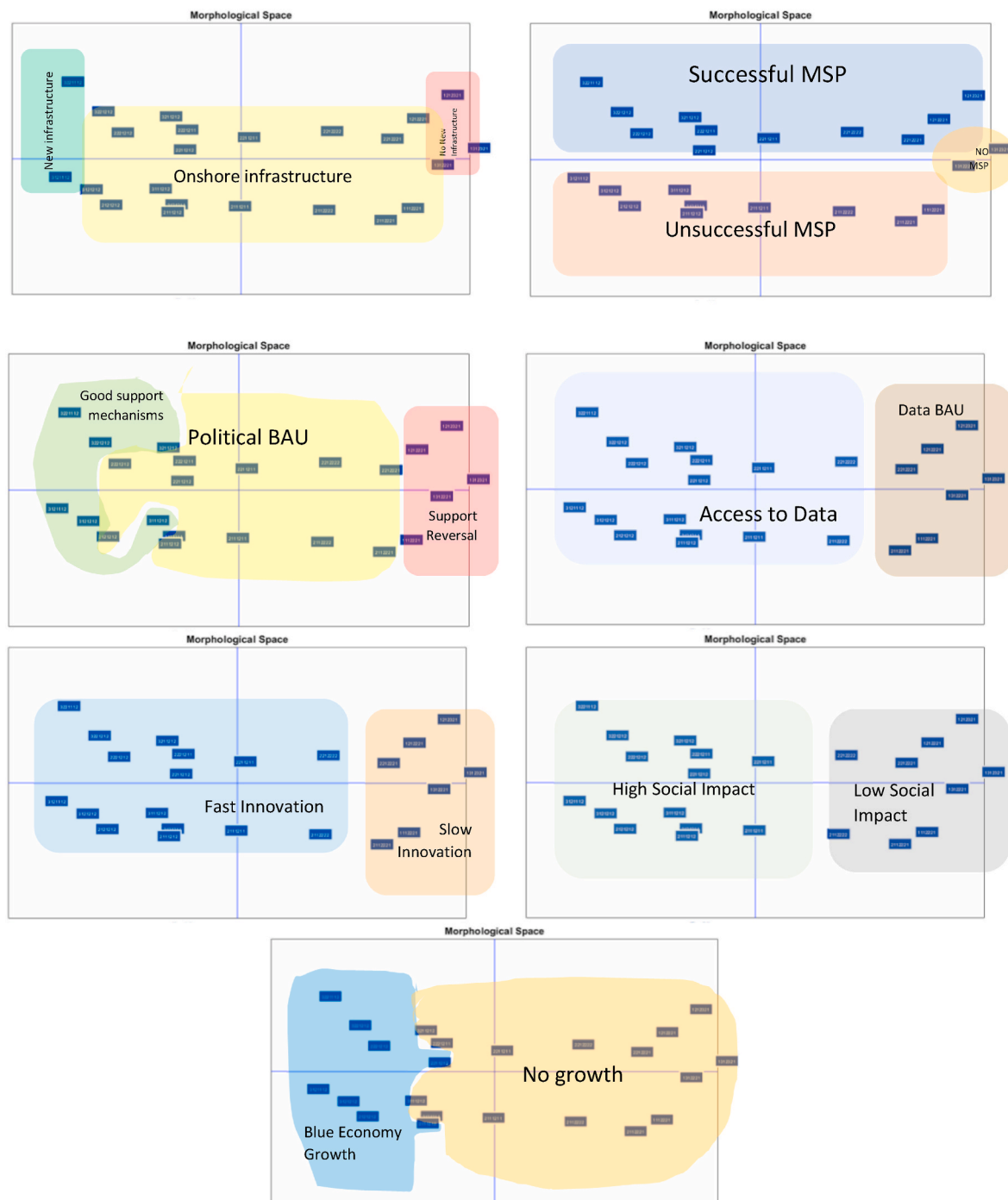
Fig. 4. Representation of how the different hypotheses for each variable distribute along the morphological space.

From the analysis of these results, this method organised the morphological space into five vertical clusters. Two clusters are formed by 2 scenarios, whilst the biggest cluster integrates 8 scenarios. The representative scenarios for each cluster are also indicated on the table. It is worth noting that, for two-scenario clusters, the CT for both scenarios is the same; thus, there is not one scenario that is more representative than the other.

Cluster 3 presents the most central region of the morphological space. The representative scenario (2212221) describes a plausible future where the political environment remains similar to that happening now. Nonetheless, the existence of accelerated innovation in the sector results in the generation of some social impact, although there is no significant growth on the blue economy sector. The representative

scenario of Cluster 2 (2212222) is quite similar to that of Cluster 3. However, it assumes that the sector is capable of accessing relevant data regarding the metocean (and other) parameters from the region's maritime space. This slight difference is sufficient to bring this cluster into a more favourable position, which may highlight how the access to more data may strongly influence the future of the sector – even with little public support, the private sector may support the development of these technologies if fundamental operational data is available. Cluster 4 describes a plausible future where new onshore infrastructure to support the sector is implemented in the region, and where there is access to more data (representative scenario 2211212). Nonetheless, as the innovation registered on the sector is slow, the impact of the sector turns out to be reduced. Cluster 5, formed by 7 scenarios, describes a region of
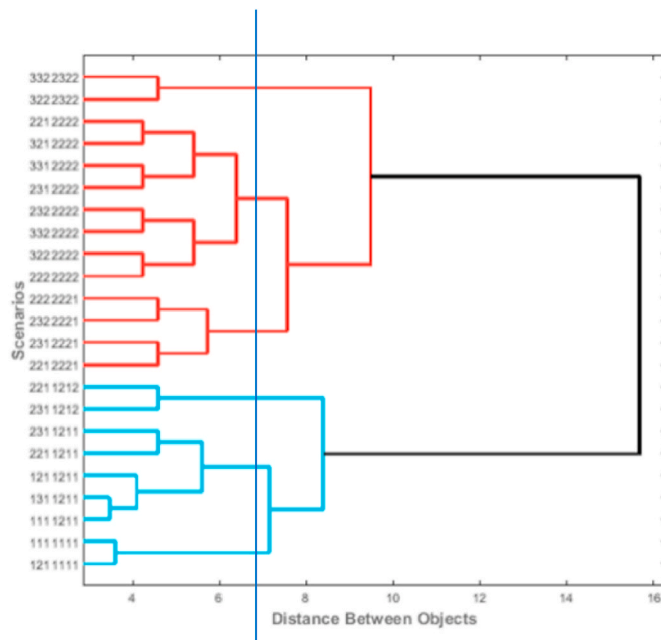
Fig. 5. Example of a hierarchical Binary Cluster Tree. Each branch contains only two children, until it reaches the total of scenarios. The vertical line shows a partition into 5 clusters.

the morphological space where the future of the sector is perceived as unpromising. Several aspects explain this region, notably a reversal of political trends, slow innovation on the sector, and low access to ocean data. Finally, Cluster 1 describes a region where the marine renewable energy sector can effectively flourish. This comes associated with good political support, new onshore and offshore infrastructure, a fast-paced innovation environment and access to relevant ocean data. Interestingly, for this analysis, the existence of a successful MSP does not seem to effectively influence the outcome of the sector. Below, these five proposed plausible futures are presented in more detail.

- **Plausible future (Cluster 1–3222322) - Wishful thinking:** This particular future presents as the most promising one for marine renewables in the region. The existence of good support political mechanisms, the implementation of new onshore and offshore infrastructures, the access to more ocean data and the existence of a fast-paced innovation environment result in a relevant impact of the sector to the society and the blue economy. This future is dependent on the existence of a greater political support – which usually requires the access to bigger funding sources.

- **Plausible future (Cluster 2–2212222) - Everything set but no new offshore infrastructure:** With the needed onshore infrastructure installed, innovation processes at a good speed and improved access to data, there is still uncertainty regarding the role of marine energies on the blue economy due to lack of offshore infrastructure. This future highlight how important the existence of offshore infrastructure is to support the sector – including the access to support vessels, offshore connections, etc. Interestingly, the representative scenario indicates that no maritime space planning needs to be in place for this future to happen.

- **Plausible future (Cluster 3–2212221) - Small Improvements:** Although there is access to new onshore infrastructure, business as usual in political support and data access result in low social impact, even though innovation processes in the sector are fast. This future emphasizes the importance of access to data to foster the sector – it is, in fact, the only difference registered from the previous future.

- **Plausible future (Cluster 4–2211212) – Lack of innovation in the field:** The first of the negative clusters suggests that innovation on the sector is critical for its success. Even with the access to onshore infrastructure (fostered by some political support) and possibly more ocean data, the impact of the sector in the economy remains low.

- **Plausible future (Cluster 5–1211211) - Everything is terrible:** The final future proposed describes a situation where marine renewables will not be, to any dimension, successful in the region. From a reversal of political support – which could happen from the appearance of new disruptive technologies, or the uprising of climate change-denying political parties, which resulted in the implementation of no necessary infrastructure, and the slow innovation pace of the sector, result in very limited impact on the economy.

6. Conclusion and policy implications

6.1. Policy implications

The systematic generation of plausible future scenarios for the marine renewable sector in Portugal and Spain can support in providing insights for the construction of future policy strategic roadmaps. These scenarios, achieved through the combination of defined hypotheses and GMA, offer diverse insights into potential sector developments. Policymakers can leverage these scenarios as strategic inputs, facilitating forward-looking policy planning that addresses challenges and exploits opportunities inherent in each scenario.

Policymakers must recognize the criticality of these variables and design policies that foster innovation, infrastructure development, and data accessibility. The intricate relationships among Actors, Networks, Institutions, and Technology within the TIS framework, depicted in Fig. 7, offer policymakers a comprehensive lens to assess policy dynamics. These innovation systems are formed by the stakeholders which
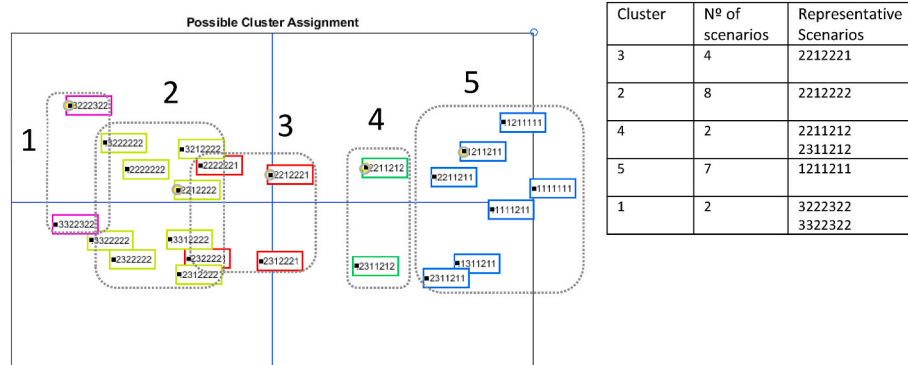

Fig. 6. At the left, a hierarchical clustering with average method and euclidean distance (representative scenario highlighted by a circle); At the right, the distribution of the representative scenarios for the five clusters.
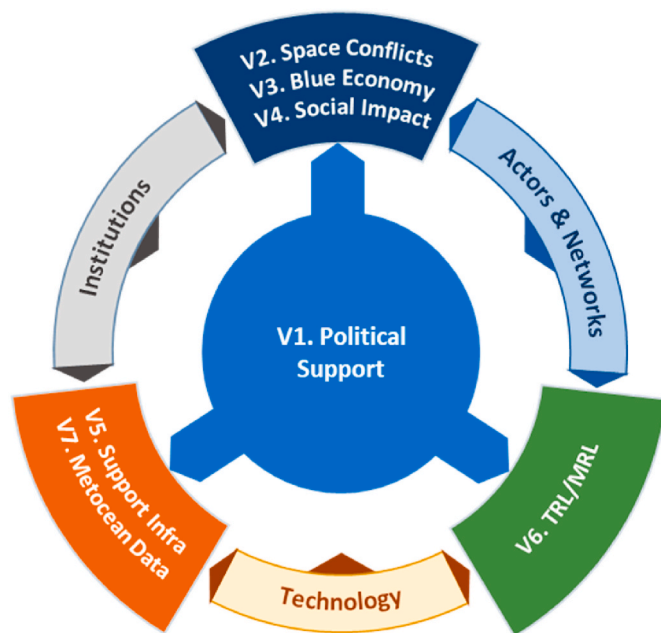
Cluster	Nº of scenarios	Representative Scenarios
3	4	2212221
2	8	2212222
4	2	2211212 2311212
5	7	1211211
1	2	3222322 3322322

Fig. 7. How the proposed variables correlate amongst each other and within the structural components of the Technological Innovation System.

interact on a certain innovative technologic field to promote the diffusion and use of a new technology or product and are usually constituted by four structural components: actors, networks, institutions and technology (Jacobsson and Karltorp, 2013), (Reichardt et al., 2016). For this specific case-study, Institutions are formed by the governmental laws of both countries, public policies taken to foster the implementation of marine renewables at both countries, and the existence of regulations and certification procedures associated with the technology, amongst others. Actors can be both public or private organizations; here, they are formed by governments, potential clients (such as utilities, project developers), technology developers, regulators, manufacturing and supporting industry, etc. Some of these actors work in close collaboration to promote the development of a certain technology: they interact amongst each other through improvable established networks. Finally, the item Technology describes the features that can be expected from the technology promoted within a TIS. In this respect, Ocean Energy Systems (OES) proposes eight evaluation areas in which ocean renewables must be evaluated for its market readiness: Affordability, Power Capture and Conversion, Controllability, Reliability, Survivability, Maintainability, Installability and Manufacturability (Hodges et al., 2021).

This depiction unveils the intricate interdependence underlying the achievement of a successful innovation system in marine renewables across Portugal and Spain, hinging significantly on the foundation of Political Support. This pivotal variable not only undergoes influences from all four structural facets of the TIS, but also exerts a profound impact on the trajectory of the other six variables in the foreseeable future. It is of paramount importance to underscore that the advancements made in Technology over the coming years will reciprocally influence the magnitude of political support anticipated. This interplay sets the stage for a nuanced feedback loop, wherein technological progress necessitates a certain level of protective policy endorsement. Ultimately, the capability of technology to effectively address the demands of various stakeholders augments this support, facilitating a substantial realization of marine renewable initiatives. This intricate dynamic characterizes the essence of Plausible Future 1: Wishful thinking. Enhancing the existing policy framework will undoubtedly catalyze the emergence of a novel TIS in marine renewables. However, the perpetuation of this enhancement hinges upon the maturation of the technology itself, thus establishing a symbiotic relationship between

policy evolution and technological advancement.

Table 3 presents the distribution of hypotheses across the proposed plausible futures, highlighting the pivotal role of specific variables in influencing the future of marine renewables. Notably, three variables emerge as influential determinants.

- the implementation of necessary infrastructure (V5);
- the speed of innovation processes (V6);
- and the availability of comprehensive metocean data (V7).

Tailored policy measures can be strategically devised to address the specific challenges and opportunities presented by each scenario, fostering a resilient and adaptable sector. In the context of the "Wishful thinking" future, policymakers can focus on generating robust and sustained political support through mechanisms such as increased funding allocation and policy frameworks that incentivize renewable energy adoption. To address the limitations posed by the absence of offshore infrastructure in the "All set but no new offshore infrastructure" scenario, policies should prioritize the development of offshore facilities, incorporating incentives for industry collaboration and technological innovation. In the "Small Improvements" future, an emphasis on data accessibility policies can amplify the sector's impact, facilitating informed decision-making and market expansion. The imperative to foster innovation, central to the "Lack of innovation in the field" scenario, calls for comprehensive policies that encourage research and development, collaboration between academia and industry, and initiatives to attract investment in cutting-edge technologies. Mitigating the challenges of the "Everything is terrible" future demands strategic actions such as building consensus on the importance of renewable energy, bolstering political support through public awareness campaigns, and implementing safeguard measures to insulate the sector from potentially adverse political shifts.

Building on the insights from this study, policymakers are encouraged to consider specific policy measures that target the identified influential variables.

- Foster an environment that supports rapid innovation in the marine renewables sector;
- Prioritize the development of necessary infrastructure to support marine renewable implementation;
- Implement measures to ensure the availability of comprehensive metocean data for effective decision-making;
- Cultivate and sustain political backing for renewable energy policies;
- Encourage collaboration among diverse stakeholders to facilitate technology diffusion and implementation.

While the paper's focus is on the Portuguese and Spanish marine renewable sector, its findings resonate globally. The study's association with the REMAR thematic network underscores its potential to guide policy development in diverse regions. As the methodology adapts to various socio-economic contexts, policymakers worldwide can harness its potential to shape effective policies. The implications of this work extend beyond national boundaries, addressing the broader challenge of renewable energy integration in the context of sustainable development.

These policy implications not only provide invaluable insights into the renewable marine energy sector's future possibilities but also equip policymakers with pertinent intel to shape policies that drive innovation, infrastructure development, and sustainable growth. Through this interdisciplinary approach, policymakers can navigate the complexities of energy transition and pave the way for a more sustainable future. While specific policy implications tailored to the Portuguese and Spanish reality are essential and should be detailed in the policy recommendation chapter, the broader conclusions obtained here aim to resonate with an international audience seeking methods for future analysis and policy formulation in the realm of renewable energy transition.

Table 3
Summary of the key variable values – representing different hypothesis - at the five plausible futures.

Problem Variables		Hypothesis				
		1	2	3	4	5
		Wishful thinking	All set but no new infrastructures	Small improvements	Lack of innovation	Everything terrible
1	**Political Support**	3	2	2	2	1
2	**Space Use Conflicts**	2	2	2	2	1/2
3	**Blue Economy Growth**	2	1	1	1	1
4	**Social Impact**	2	2	2	1	1
5	**Support Infrastructure**	3	2	2	2	1/2
6	**TRL/MRL**	2	2	2	1	1
7	**Metocean Data**	2	2	1	1/2	1

Still, in the context of the methodology used in this research, some limitations can be identified.

1. Simplification of Complex Realities and Sensitivity to Variable Selection: The morphological analysis method employed in this study involves simplifying complex real-world scenarios into distinct variables and categories. This simplification might overlook nuances and interdependencies that exist within the marine renewable energy sector, potentially leading to an oversimplified representation of the sector's dynamics.

2. Subjective Nature of Expert Input: The morphological analysis heavily relies on expert judgment and input to define variables and their relationships. This subjectivity could introduce biases or uncertainties into the results, affecting the reliability and generalizability of the findings.

3. Limited Predictive Power: While the generated plausible future scenarios provide valuable insights, they are not deterministic predictions of the future. External factors or unforeseen events that were not accounted for in the analysis could significantly impact the outcomes.

4. Assumption of Unchanging Relationships: The analysis assumes that the relationships between the TIS components remain constant across different scenarios. However, real-world dynamics can evolve over time, leading to changes in these relationships that the methodology might not capture accurately.

6.2. Conclusion

The paper's exploration of the marine renewable sector's plausible futures in the Iberian and Macaronesian regions sheds light on crucial factors and dynamic interplays that policymakers must consider. The findings underscore the intricate relationship between technology development and political support, highlighting the importance of a continuous feedback loop that propels both aspects forward. These findings also reveal the pivotal roles of the speed of innovation processes, infrastructure development, and comprehensive metocean data availability in shaping the marine renewable energy sector's trajectory in the region. Regional policymakers are urged to focus on fostering an environment conducive to innovation, ensuring the implementation of necessary infrastructure, and enabling open access to data. This paper not only intends to provide invaluable insights into the renewable marine energy sector's future possibilities but also to equip policymakers with a robust toolkit to shape policies that drive innovation, infrastructure development, and sustainable growth. Through this interdisciplinary approach, policymakers can navigate the complexities of energy transition and pave the way for a more sustainable future.

The methodology, applied to Spain and Portugal regions, is expected to be applied to other regions of study among the network, such as South America and Mesoamerica. In fact, although the key variables for these analyses may be similar to those of this research, their potential hypotheses and the respective cross-correlation matrix will most definitely be different - resulting from the analysis of the particular socio-economic

characteristics – meaning that the application of the proposed methodology to different regions, such as Latin America, the USA, or China, will yield varying results due to contextual differences inherent to each region's socio-economic, political, and technological landscapes. While the fundamental framework of the morphological analysis remains consistent, the specific dimensions and key variables will differ across regions. The contextual specificity of the methodology is inherent to its nature, requiring customization for each case study to accurately capture the intricacies of the local energy transition landscape. For instance, the Latin American context might introduce unique dimensions related to local governance, resource availability, and regional cooperation. The potential differences in key variables and hypotheses arise from these regions' distinct energy policies, technological capabilities, and geopolitical considerations. By recognizing and addressing these variations, the methodology gains relevance and applicability in diverse regions, enabling tailored policy recommendations that address specific challenges and opportunities.

CRediT authorship contribution statement

Mário Vieira: Conceptualization, Methodology, Software, Validation, Formal analysis, Data curation, Writing – original draft, Writing – review & editing, Supervision. **Ana Macedo:** Conceptualization, Methodology, Software, Formal analysis, Data curation, Writing – original draft. **António Alvarenga:** Conceptualization, Validation, Data curation, Writing – review & editing. **Marcos Lafoz:** Validation, Formal analysis, Writing – original draft, Writing – review & editing, Funding acquisition. **Isabel Villalba:** Formal analysis, Writing – original draft, Funding acquisition. **Marcos Blanco:** Validation, Formal analysis, Writing – original draft, Writing – review & editing. **Rodrigo Rojas:** Formal analysis, Writing – original draft. **Alejandro Romero-Filgueira:** Validation, Formal analysis, Writing – review & editing. **Adriana García-Mendoza:** Validation, Formal analysis, Writing – original draft. **Miguel Santos-Herran:** Formal analysis, Writing – original draft. **Marco Alves:** Conceptualization, Methodology, Software, Data curation, 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.

Data availability

Data will be made available on request.

Acknowledgements

DE INTEGRACIÓN EN REDES ELÉCTRICAS IBEROAMERICANAS DE LAS ENERGÍAS DEL MAR – https://www.cyted.org/es/remar.

References

ALVA Research Consulting. https://www.alva-rc.com/. (Accessed 10 February 2023).

Amorim-Lopes, M., Oliveira, M., Raposo, M., 2021. Enhancing optimization planning models for health human resources management with foresight. Omega (Westport) 103.

Apolonia, M., Fofack-garcia, R., Noble, D.R., Hodges, J., Correia da Fonseca, F.X., 2021. Legal and political barriers and enablers to the deployment of marine renewable energy. Energies 14 (16), 4896. https://doi.org/10.3390/EN14164896, 2021, Vol. 14, *Page 4896*.

Archimedes Waveswing - AWS Ocean Energy. https://www.awsocean.com/archimedes-waveswing/. (Accessed 16 July 2021).

Associacion Empresarial Eólica; Deloitte, 2022. LIBRO BLANCO de la Industria Eólica Marina en España.

Commission, E., 2014. Demonstration of the WindFloat Technology.

Costa Pinto, L.M., Sousa, S., Valente, M., 2021. Explaining the social acceptance of renewables through location-related factors: an application to the Portuguese case. Int. J. Environ. Res. Publ. Health 18 (2), 806. https://doi.org/10.3390/IJERPH18020806, 2021, Vol. 18, *Page 806*.

de España, Gobierno, 2021. Hoja de Ruta Eólica Marina y Energías del mar en España.

Delicado, A., 2013. Ambiente, paisagem, património e economia: Os conflitos em torno de parques eólicos em Portugal. Revista Crítica de Ciências Sociais, Coimbra.

Delicado, A., Figueiredo, E., Silva, L., 2016. Community perceptions of renewable energies in Portugal: impacts on environment, landscape and local development. Energy Res. Social Sci. 13, 84–93. https://doi.org/10.1016/J.ERSS.2015.12.007.

Diário da República, *Decreto-Lei 5/2008. Portugal*, pp. 168–179..

Diário da República, 2008. *Decreto-Lei 238/2008. Portugal*.

Diário da República, 2012. *Decreto-Lei 15/2012. Portugal*.

Gobierno de España and Red Eléctrica de España, 2021. Plan de desarrollo de la Red de Transporte de Energía Eléctrica 2021-2026.

Godet, M., 2001. Creating Futures Scenario Planning as a Strategic Management Tool. Economica Brookings diffusion [Online]. Available: www.cnam.fr/lips/.

Hodges, J., et al., 2021. AN INTERNATIONAL EVALUATION and GUIDANCE FRAMEWORK for OCEAN ENERGY TECHNOLOGY 2O21 2-Task 12.

Jacobsson, S., Karltorp, K., 2013. Mechanisms blocking the dynamics of the European offshore wind energy innovation system - challenges for policy intervention. Energy Pol. 63 (March 2016), 1182–1195. https://doi.org/10.1016/j.enpol.2013.08.077.

Lee, J., Zhao, F., 2020. GLOBAL OFFSHORE WIND REPORT 2020. Brussels, Aug.

Ministerio para la Transición Ecológica y el Reto Demográfico, "Plan Nacional Integrado de Energía y Clima (PNIEC) 2021-2030, 2020.

Presidência do Conselho de Ministros, Resolução de Conselho de Ministros 29/2020, 2020. Diário da República, Portugal.

Presidência do Conselho de Ministros, 2021, pp. 29–37. *Decreto-Lei 67/2021*.

Presidência do Conselho de Ministros, 2022. Decreto-Lei n.º 15/2022. Portugal.

PSOEM - DGRM.. https://www.dgrm.mm.gov.pt/psoem. (Accessed 18 August 2023).

Rehman, S., Alhems, L.M., Alam, M.M., Wang, L., Toor, Z., 2023. A review of energy extraction from wind and ocean: technologies, merits, efficiencies, and cost. Ocean Eng. 267, 113192 https://doi.org/10.1016/J.OCEANENG.2022.113192.

Reichardt, K., Negro, S.O., Rogge, K.S., Hekkert, M.P., 2016. Analyzing interdependencies between policy mixes and technological innovation systems: the case of offshore wind in Germany. Technol. Forecast. Soc. Change 106, 11–21. https://doi.org/10.1016/j.techfore.2016.01.029.

Ritchey, T., 2011. Wicked problems – social messes. In: Risk, Governance and Society. Springer-Verlag.

Seber, G.A.F., 1984. Multivariate Observations. Wiley Series in Probability and Statistics.

UNFCCC, 2015. Conference of the parties (COP), "Paris climate change conference-november 2015, COP 21,". Adoption of the Paris Agreement. Proposal by the President 21932 (December), 32. FCCC/CP/2015/L.9/Rev.1.

Vieira, M., Aguilera, L., 2021. OceanACT – building a European centre for the demonstration of innovative technologies from the blue economy in Portugal. In: OCEANS 2021. IEEE, San Diego, Porto, pp. 1–8.

Wavec - Offshore Renewables. https://www.wavec.org/. (Accessed 10 February 2023).

Zwicky, F., 1948a. The morphological method of analysis and construction. In: Courant, Anniversary Volume. Intersciences Publishers, New York.

Zwicky, F., 1948b. Morphological Astronomy, vol. 68. Observatory, 845.

Zwicky, F., 1960. A morphologist ponders the smog problem. California Institute of Technology 24 (2).

Agglomerative hierarchical cluster tree - MATLAB linkage. https://www.mathworks.com/help/stats/linkage.html#mw_08b425f7-fc8c-480a-b618-f768817e8e11 (accessed February. 9, 2023).

CorPower rolls in €7.3 million for Portuguese wave project - Offshore Energy. https://www.offshore-energy.biz/corpower-rolls-in-e7-3-million-for-portuguese-wave-project/(accessed July. 16, 2021)..

DemoSATH – Saitec Offshore Technologies. https://saitec-offshore.com/en/projects/demosath/(accessed January. 12, 2023).

Energy Statistics Data Browser – Data Tools - IEA. https://www.iea.org/data-and-statistics/data-tools/energy-statistics-data-browser?country=WORLD&fuel=Energy%20supply&indicator=TESbySource (accessed September. 14, 2022).

EuropeWave reserves berths at BiMEP and EMEC test sites — EuropeWave project website. https://www.europewave.eu/news/europewave-reserves-berths-at-bimep-and-emec (accessed January. 12, 2023).

Euskadi, international wave energy test centre – BiMEP. https://www.bimep.com/en/euskadi-international-wave-energy-test-centre/(accessed January. 12, 2023)..

Hierarchical clustering - MATLAB & simulink. https://www.mathworks.com/help/stats/hierarchical-clustering.html. (Accessed 9 February 2023).

Innovative, low cost, low weight and safe floating wind technology optimized for deep water wind sites | FLOTANT Project | Fact Sheet | H2020 | CORDIS | European Commission. https://cordis.europa.eu/project/id/815289 (accessed January. 12, 2023).

Is France an obstacle to the Iberian Peninsula's goal of becoming an energy supplier? | Euronews. https://www.euronews.com/my-europe/2022/06/07/is-france-an-obstacle-to-the-iberian-peninsula-s-goal-of-becoming-an-energy-supplier (accessed November. 8, 2022).

Launch of pilot buoy 'Gaia' | Ocean Oasis. https://www.oceanoasis.co/launch-of-pilot-buoy-gaia/(accessed January. 26, 2023).

Ordenación del espacio marítimo. https://www.miteco.gob.es/es/costas/temas/proteccion-medio-marino/ordenacion-del-espacio-maritimo.html. (Accessed 18 August 2023).

Pelamis, World's First Commercial Wave Energy Project, Agucadoura - Power Technology | Energy News and Market Analysis. https://www.power-technology.com/projects/pelamis/(accessed July. 16, 2021)..

PivotBuoy - An Advanced System for Cost-effective and Reliable Mooring, Connection, Installation & Operation of Floating Wind | PivotBuoy Project | Fact Sheet | H2020 | CORDIS | European Commission. https://cordis.europa.eu/project/id/815159 (accessed January. 12, 2023).

Plataforma eólica mariña - vicepresidencia primeira e consellería de economía, industria e innovación. https://economia.xunta.gal/plataforma-eolica-marina. (Accessed 26 January 2023).

Plataforma Oceánica de Canarias | PLOCAN - WELCOME. https://www.plocan.net/index.php/es/portfolio-proyectos/1186 (accessed January. 12, 2023)..

Plataforma Oceánica de Canarias | PLOCAN - New deployment at the Plocan Test Site. https://www.plocan.net/index.php/en/2015/october/1376-new-deployment-at-the-plocan-test-site (accessed January. 12, 2023).

Technical characteristics – BiMEP. https://www.bimep.com/en/mutriku-area/technical-characteristics/. (Accessed 12 January 2023).

The Elisa Project | Esteyco. https://esteyco.com/projects/elisa/elisa.html (accessed January. 12, 2023).

W2Power | Pelagic Power. https://www.pelagicpower.no/(accessed January. 12, 2023).

Wave energy converter prototype - marmok A-5 - idom. https://www.idom.com/en/project/wave-energy-converter-prototype-marmok-a-5-2/. (Accessed 12 January 2023).

Wavepiston installs a wave energy converter at PLOCAN's Test Site – Plataforma Oceánica de Canarias. https://www.plocan.eu/en/wavepiston-installs-a-wave-energy-converter-at-plocans-test-site/(accessed January. 12, 2023).