Instituto Superior de Economia e Gestão
UNIVERSIDADE TÉCNICA DE LISBOA
DESDE 1911

MESTRADO
GEI-GESTÃO E ESTRATÉGIA INDUSTRIAL

TRABALHO FINAL DE MESTRADO
DISSERTAÇÃO

LOW-CARBON ENERGY FUTURES:
The Impact of the Shipbuilding Industry on Marine Renewables

MARCO AURÉLIO DE ARAÚJO ALVES

ISEG/UTL, 14 de Outubro de 2016

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ANTÓNIO ALVARENGA

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Contents

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to AD

Abstract

Essentially, the present study is a prospective joint project with key stakeholders aiming at exploring draft scenarios focused on the renewable energy industry. In this framework, the goal of the study was to improve the general knowledge and understanding on potential synergies between marine renewables and the shipbuilding industry, in a holistic and integrative manner that highlights socio-economic, political, environmental and technological aspects. The analysis is focused on the European context, and is based on a time horizon of 15 years.

To this end, the morphological analysis was applied since it is a fairly simple and systematic approach to build and explore possible futures. In this context, the Morphol software was used to obtain the skeleton of the scenarios. Eventually, 24 plausible combinations, or future possible scenarios, were found. Afterwards, from this set of scenarios, three were selected based on the extreme-world method, which consists of creating extreme worlds by putting all the positive uncertainties in one scenario and all the negative in another scenario.

Finally, we end up with one scenario, named “blue-ocean”, where there is a perfect symbiosis between marine renewables and the shipbuilding industry. Moreover, the second scenario, named “different-worlds”, is essentially the opposite of the first one and relies on the belief that the conservatism and reluctance associated to the traditionalism of shipbuilding prevents the industry from extending its activities into new and more innovative fields. Eventually, the last scenario, named “business-as-usual”, gathers some characteristics of the two previous scenarios and so it reflects an in-between reality.

Although this study was a preliminary analysis that needs further verification and validation, some insights that may be essential in securing a sustainable commercial

success of offshore renewables were obtained. Namely, it seems clear that it is crucial to found ways to exploit synergies with related industries in order to improve the cost-effectiveness of offshore power plants. Furthermore, there might also be a need for government support in this emergent phase, in order to promote the competitiveness of the sector. Nevertheless, it appears that policy support mechanisms should be design very carefully to avoid discouraging private investment.

1. Introduction

A European Energy Union, able to ensure secure, affordable and climate-friendly energy is still an unattained goal of Europe and therefore one of the top priorities of the European Commission (EC). An effective Energy Union is perhaps the most critical component in Europe's transition towards the desired decarbonized energy system of the future. On the way to accomplish this ambition there are, on top of many technological challenges, some cross-cutting issues that need to be better understood. In particular, those related with socio-economic, socio-cultural, socio-environmental and socio-political aspects.

Towards the energy transition into a low carbon economy, it is expected that the emergent marine renewable energy sector (including ocean energy and offshore wind) can play a significant role. The potential growth of the European Ocean Energy sector is emphasized in the roadmap of the European Ocean Energy Association (2010), which predicts an installed capacity of about 3.6 GW in 2020 and 188 GW by 2050, including wave, tidal (both current and range), ocean currents, temperature gradient and salinity gradients (osmotic). However, despite the great progress over the last years, ocean power technologies are still at a lower maturity stage of development than offshore wind, which is booming at present. This holdup is partially caused by a lack of accepted standards, a wide range of technical approaches, and large uncertainties on the performance and cost of these systems. Nevertheless, early adopter markets, such as islands where typically the cost of energy is very high, along with government subsidies (e.g. feed-in-tariffs) to mitigate the high capital cost involved, may push these technologies into a competitive market place, shortening paths to commercialization. Conversely, offshore wind, described by the European Parliament (2009) as “the energy of the future”, has been growing at gigawatt levels in added annual capacity since 2012. This growth is fostered by, among other factors, cutting-edge technologies and bigger turbines, which increase yield and cut costs to a level that may reach about 40% by 2023 in an optimum regulatory and competitive market (Offshore Wind Energy Foundation, 2015). Eventually, advances in technology and industry maturity will make marine renewable energy increasingly attractive to long-term investors and, in due course a relevant component in Europe's energy mix, contributing to the targets set out in the SET-PLAN roadmap on low carbon energy technologies of the Strategic Energy Technologies Information System (2015). It seems apparent that the growth of marine renewables is driven by technological advances but also by both political and economic aspects, ultimately aiming to improve cost-effectiveness. In this context, besides the increase in installed capacity and the deployment of larger and more powerful units (e.g. higher capacity wind-driven turbines with rated power above 5MW), the cost-effectiveness of marine renewable energy also relies on exploring synergies with the shipbuilding industry (among others).

Therefore, following the growth trend in marine renewables and aiming to ensure new business opportunities, the shipbuilding industry, including offshore engineering and other marine supporting services, has already started a process of production diversification by exploiting synergies with the marine renewable energy sector, as refers the Organization for Economic Co-operation and Development (OECD) (2015). Indeed, the marine renewable industry seems to be a very promising possibility along those lines, since they have several common characteristics. Namely, the final product dimensions in both industries are similar and so processes and facilities are well sized to handle heavy activities associated with the two industries. Moreover, both largely involve steel and welding, forming, bending and casting processes which are capable of being carried out with the existing equipment in shipyards.

Despite the existing parallels regarding supply chain, raw materials and equipment used, the reorientation of the shipbuilding industry to enter the marine renewable energy market involves various risks that must be overcome in order to guarantee and strengthen cooperation between the two sectors in the future. These risks are mostly related to customization requirements, new construction processes, stringent environmental standards and new regulatory legislation and policies (OECD, 2015). Furthermore, marine renewables require more design and production flexibility, new planning processes, close cooperation with designers and equipment manufacturers, and higher project volume.

On the other hand, offshore energy projects involve complex after-sales support services, new design engineering processes and planning methods, and non-conventional financing schemes (high levels of investment are needed in the short term). Finally, for a successful transformation process of the shipbuilding industry to face the needs of the emergent offshore renewable energy sector, highly skilled experts, who are nowadays hard to find in the job market, and constant investment in R&D are mandatory.

In this context, the present study intends to apply a scenario approach to the renewable energy industry, where socio-economic, environmental and technological aspects are integrated and reconciled within a holistic development framework. In addition, the proposed methodology will be applied in a prospective joint study with key stakeholders, to enhance the exchange of invaluable perspectives and insights, where a set of different scenarios will be built to evaluate and explore plausible futures for the synergies between marine renewables and the shipbuilding industry. Scenarios will be designed to help identify causes for distinct evolution patterns and to enable stockholders to act in a way that maximizes potential synergies between the two sectors. Moreover, such realistic scenarios might provide the right framework for assessing fundamental mid/long-term choices, in terms of R&D policies, policy support instruments and regulatory risk factors and driving corporate strategic planning towards value creation strategies, while also satisfying stakeholders' needs.

Eventually, it is expected that the set of scenarios developed, based on the proposed integrated approach, might be central to future thinking about the sustainable development of marine renewables in the European context, in a time frame of 15 years. In particular, this prospective study intends to bring light to critical questions about how the development of a marine renewable sector can be benefited by its connection to the shipbuilding industry and, to some degree, how this new emergent sector can contribute to the revitalization of shipbuilding and reverse the loss of competitiveness and to secure a competitive position for the future. In this framework, this study tries to address issues related to the

i) Impact on direct and indirect employment creation;

ii) Opportunity and risk of shipbuilding firms and organizations with regards to product diversification into new sectors such as offshore energy;

iii) Potential reduction of the LCOE (levelized cost of energy) of marine energy technologies due to the close cooperation with the shipbuilding industry and the advantages of sharing the supply chain;

iv) Capacity of shipbuilding industry for leveraging the growth of the offshore renewable energy sector and reducing financial risk perception.

The development of scenarios to explore energy and low carbon futures have been widely applied. However, commonly, scenarios for energy planning are sustained only by results from models that allow for great technological detail, but neglect the interaction with social, economic and environmental aspects "(Fortes et al, 2015)". Therefore, the proposed project aims to create a methodological framework that integrates environmental, political and socio-economic storylines related to shipbuilding with the development of qualitative offshore renewable energy scenarios, through 2030. Storylines will be sustained by stakeholders' participatory events, comparing different views on European development in terms of energy systems and energy planning.

It is expected that the proposed combined methodology might increase the robustness of the development energy scenarios, since a coherent context for modeling assumptions allows for better reasoning, which is crucial in decision-making processes. In addition, it might provide a better understanding of these cross-cutting factors and their interrelations with technological aspects, which allows the pre-identification of citizens' resistance and the promotion of social acceptability by devising appropriate mitigating strategies. Finally, the proposed project aims to better understand the political, economic, social and technological dimensions of the emergent marine renewable sector, which is a key aspect to promote the sector's development and so foster the European energy transition.

The structure of the thesis consists of six chapters. In chapter 1 the basic concepts about future thinking, such as foresight and scenario planning, are presented together with a literature review of scenario planning in general and the use of scenario planning in energy and low carbon strategies in particular. Chapter 2 presents a brief characterization of the current situation of the two industries addressed in this study, i.e. offshore renewables and the shipbuilding industry. In chapter 3, the methodology approach to build scenarios to explore offshore energy and pathways to decarbonized futures (in particular regarding the impact of the shipbuilding industry upon the marine renewables) is presented. In chapter 4, the results from the application of the proposed methodology are described and discussed, including the results from the causal maps and the morphological analysis. In chapter 5, the scenario narratives and the methodology limitations are discussed. Finally, in chapter 6, some conclusions from the scenario narratives are presented, further work is suggested and the improvements to the methodology applied are discussed.

2. Literature Review

In futures studies the term "foresight" or “prospective” has become widely used to describe activities related to scenario building, which is understood as “a set of hypothetical events, set in the future, constructed to clarify a possible chain of causal actions as well as their decision points” "(Amer et al, 2013)". In this context, scenario building studies emerged as a valuable tool for strategic planning when future is perceived with high degree of uncertainty "(Brauers & Weber 1988)". These studies normally combine methods that synthesize qualitative and quantitative data to construct multiple alternative representations of the future. In the framework of future thinking, prospective is defined by Godet as “an attitude of mind (imagination and anticipation) and behavior (hope and desire) mobilized to ensure the quality and mastery over the present and future existence" “(Godet, 1994, 1997)”. In a more practical way, prospective is described by the Institute for Prospective Technological Studies (2015) as a “systematic, participatory, future-intelligence-gathering and medium-to-long-term vision-building process aimed at enabling present-day decisions and mobilizing joint actions”.

The foundation of scenario planning as a strategic technique is often attributed to Herman Kahn who, whilst at the RAND Corporation (2015) in the 50s, developed methods to describe the future in a strategic research project for the U.S. Army. The method commonly used by Herman Kahn to describe the future consisted of writing stories as if they were written by people living in that future. For the first time, Herman Kahn applied the term "scenarios" to describe these stories. The book “on Thermonuclear War” was Kahn’s most controversial work and the first attempt to make sense of nuclear weapons during the Cold War “(Kahn, 1959)”. The book provides a deep insight into the views of leaders and policymakers on nuclear matters and uses scenario storylines to highlight the belief that defense based on nuclear weapons is inconceivable, morally questionable and unreliable.

Later, in the 60s, Herman Kahn founded the Hudson Institute where scenario planning techniques were expanded to public policies and social forecasting in order to predict changes in society “(Schwartz, 1991; Kahn, 2008; Chermack et al, 2011; Lindgren & Bandhold, 2003; Keough & Shanahan, 2008)”. The method developed by Herman Kahn has become known as the Intuitive Logics approach. It essentially relies on a heuristic approach that depends on the knowledge, communication skills, credibility and commitment of the stakeholders and knowledge holders of the process (Lindgren & Bandhold, 2003).

Another scenario planning methodology, the so-called probabilistic modification of extrapolated trends, emerged at the RAND Corporation in the USA together with the Intuitive Logics approach. This scenario planning approach, largely developed by Olaf Helmer and Ted Gordon “(Amer et al, 2013; Bradfield et al, 2005)”, comprises two different matrix based methodologies: Trend Impact Analysis (TIA) and Cross Impact Analysis (CIA).

Cross Impact Analysis was proposed by Gordon and Helmer in the late 60's has been used to capture the interrelationship between key influencing factors, in order to reflect the implication on the forecast of an event caused by the occurrence probability of other key influencing events "(Amer et al, 2013)". In view of that, the CIA methodology looks over the changes in the probability of occurrence of events that can cause deviations in the extrapolations of historical data "(Bradfield et al, 2005)". Furthermore, the TIA forecasting approach, developed in the early 70's at the Futures Group (now Palladium Group, 2016), combines traditional forecasting techniques, such as time series analysis, with expert views about the probability of occurrence of unprecedented future events, in order to produce adjusted extrapolations which may cause deviations from the extrapolated trends "(Bradfield et al, 2005)". This forecasting approach helps to solve the limitation of common techniques in which the historic data is typically extrapolated without taking into account the effects of unprecedented future events "(Amer et al, 2013; Bradfield et al, 2005)".

In 1957, simultaneous to Kahn's prospective studies at RAND, a French philosopher Gaston Berger founded the Centre d'Etudes Prospectives in France where he developed analogous scenario-based approaches to long-term planning. His method, entitled by himself as "La Prospective", had the major purpose of developing future normative scenarios to be used as a driving guide in formulating public policies. This scenario planning method, also known as prospective thinking, to some extent combines the Intuitive Logics and the Probabilistic Modified Trends methods, and essentially states that the future is not part of a predetermined temporal continuity, since it can be consciously created and modeled. According to “Jouvenel (1967)”, a follower of the pioneering work of Berger, the main purpose of this approach is to better understand the present world and the hidden opportunities and risks. In this context, “Jouvenel (1986; 1967)” used scenarios to build positive images of the future and then describe the course of actions and events that could be followed in order to achieve these future images. The work of the French pioneers in scenario planning has been expanded by “Godet, (1994; 2000)” who has developed probabilistic computer-based tools to help in building scenarios.

La Prospective scenario-planning approach is based on four major stages “(Amer et al, 2013; Durand, 1972)”: the base, which consists of an in-depth scanning analysis of the present; the external context, which refers to a general context overview on social, economic and political aspects; the progression, which consists of an historical simulation that accounts for the dynamic base and the constraints of the external context; and eventually, the images of the future in a scenario form.

During the 60’s several authors from both the French and American methodological approaches published scenario planning views such as “La Prospective” by “Berger, 1964” and “The Next Thirty-Three Years” “Kahn & Wiener (1967)”.

By the 70’s scenario planning had already attracted large interest and gained considerable recognition as an effective tool in strategic planning. Therefore, scenario thinking began to emerge far and wide from politics and economics to public policy and became a popular and recommended method to address uncertainty and to improve decision making. A number of established institutions including the Hudson Institute (2015) and the Stanford Research Institute (2015) (now SRI International) in the US, and the SEMA Consulting Group[1] in France started providing support to business using scenario planning. Furthermore, several large companies also began to embrace scenario planning, including DHL Express, General Electric and Dutch Royal Shell "(Chermack et al, 2011; Bradfield et al, 2005; Godet & Roubelat, 1996; Godet et al, 2000)". In this regard, the work developed at Royal Dutch Shell on scenario planning must be highlighted, since it represented a clear step forward in future thinking.

In the 70's, Pierre Wack, an oil executive, developed a new scenario-planning approach at Shell and transformed the company in to one of the most successful corporations by incorporating scenario planning into strategic decision making. The approach developed consisted of building scenarios in close collaboration with decision-makers in a way that prepared them for uncertainty and unexpected events "(Scearce & Fulton, 2004)". Shell's approach is sometimes called Intuitive Logics due to the similarities between the two approaches "(Kahn & Wiener, 1967)". A detailed benchmark of the characteristics of the three most important scenario building approaches, i.e., Intuitive Logics, Probabilistic Modified Trends and La Prospective is presented by "Henriques (2015)".

Normally, scenario building comprises three major elementary phases. The first one consists of a clear definition of the problem to be analyzed. In this phase a common understanding and a consensus between the experts is obtained, which allows to bound and better structure the problem. The second phase is basically the system analysis, where the dynamic system linkages to its external environment are explored and the most relevant external influences are identified. Eventually, the last phase is a synthesis process

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[1] SEMA (Society of applied economics and mathematics) was created in 1954 by Jacques Lesourne. Originally it was a research group focused on economics including future studies, operation research and cost comparisons for different solutions.

which consists of an analysis of the existing cross coupling dependencies amid the influencing factors in order to create alternative scenarios. The synthesis process creates a logical and systematic method for scanning the range of possible scenarios and selecting the most plausible ones "(Brauers & Weber, 1988)".

There are several methods employed in the first two analysis stages, including, for instance, brainstorming, roundtable discussion and the Delphi technique "(Linstone & Turoff, 1975)". For implementing the third stage there are also a variety of methodologies including morphological analysis "(Zwicky, 1967)", battelle approach "(von Reibnitz, 1985)" and field anomaly relaxation "(Coyle & McGlone, 1995; Coyle et al, 1994)". Here we highlight the morphological analysis since it is the method exploited in this study.

Morphological analysis is a fairly simple method for exploring and building future scenarios, however the scale of all possible combinations is generally seen as a less positive aspect. The method, developed, during the Second World War, by the American researcher "Zwicky (1967)", consists of decomposing the overall system dimensions or components (e.g. demographic, economic, technological, societal or organizational), where each one has several possible states (configurations) "(Ritchey, 2006)". These components must be as independents as possible and must cover the entire space of the system under analysis. Eventually, there will be as many possible solutions as combinations of states and the set of all possible combinations describe the morphological space**.** Nevertheless, usually, a cross-consistency assessment is performed in the morphological analysis in order to check the integrity and clearness of the concepts being employed and to recognize and remove all the internally incompatible relationships in order to reduce the total problem space of the morphological field to a smaller, and internally consistent, solution space "(Ritchey, 2015)". Each path within the states that combine a configuration of each component will form then the scenario "bone-structure".

The development of scenarios to explore energy and low carbon futures have been widely applied in recent years "(Nakicenovic et al, 2000; International Energy Agency, 2012; Ghanadan et al, 2005; Treffers et al, 2005; European Commission, 2011; Söderholm et al, 2011)". However, long-term energy scenario exercises are usually sustained only on modeling results, which incorporate great technological details but disregard the interactions with politics and socio-economic aspects (e.g., Söderholm et al, 2011; European Commission, 2011; Syri et al, 2008)"). A combination of qualitative scenarios with quantitative outcomes from modeling exercises is seldom considered and the two approaches have typically been applied independently. However, there are some exceptions that can be found in the literature. For instance, using Portugal as a case study, "P. Fortes et al, 2015)" developed a distinctive approach framework to link socio-economic storylines, sustained by national stakeholders' workshops, with the development of quantitative energy scenarios through 2050, generated by a technology-based model.

Another example, with wider focus, is the renowned Special Report on Emissions Scenarios (SRES) from the Intergovernmental Panel on Climate Change "(Nakicenovic et al, 2000)". The SRES comprises a set of scenario exercises on energy and greenhouse gas (GHG) emissions, combining both qualitative and quantitative approaches, where different economic, technological, environmental and social realities are explored. Afterwards these realities were translated into quantitative scenarios by using integrated assessment models, which underline how divergent realities may influence energy consumption and GHG emissions.

3. Industries characterization

This section presents a brief characterization of the two industries addressed in this study: offshore renewables and the shipbuilding industry. The current situation, main drawbacks, future perspectives and challenges ahead are highlighted as well as those aspects that can promoting synergies between both.

3.1. Shipbuilding industry

The shipbuilding industry comprises essentially the production of larger vessels intended for the merchant fleet, both cargo or passenger transport, the offshore energy industry (mainly oil and gas). Moreover, this industry supplies also products and services for the building, conversion and ships maintenance.

Historically the shipbuilding has been an important industry worldwide from both an economic and social standpoint and for its linkages to other sectors such as transport, security, energy and environment. Nevertheless, in the last decades, a rearrangement of the sector took place in many countries due to the decline of many facilities, particularly in Europe, which caused the close-down or switching to ship repair business of many shipyards. Shipbuilding activity now takes place mostly in Asian yards in South Korea, Japan and China, where the labor costs are lower, even if the sector has become less labor-intensive since automation has increased.

Despite the severe international competition, from countries like China and South Korea, shipbuilding is still an important and strategic industry in Europe. In several EU countries, the contribution of shipbuilding to regional industrial infrastructure and national security welfares (military purposes) is noteworthy. Furthermore, nowadays the European shipbuilding industry is still the global leader in the construction of complex vessels (cruise ships, yachts, ferries, dredgers and submarines) and in an extensive range of products from propulsion systems, diesel engines, safety systems and cargo handling. Current figures in Europe show that there are about 150 large shipyards active that employ roughly 120 000 people (civil and naval, new building, and repair yards), which represent a market share of around 6% in terms of tonnage and 35% for marine equipment, as mentioned by the European Commission DG Enterprise and Industry (2014).

The shipbuilding industry experienced an increase of demand of offshore vessels in the last decade. The total offshore vessel deliveries more than tripled between 2004 and 2009, driven by the need of fleet replacement and the rising of oil prices "(OECD, 2015)". Therefore, the offshore market became a key segment for the global shipbuilding industry contributing strongly to the sector turnover. Nevertheless, the growth of the offshore market (support vessels) was insufficient to lessen the excess of capacity in the shipbuilding industry since the market for offshore support vessels is itself suffering from overcapacity. It is expected, however, that the demand for offshore vessel (of all existing types) is expected to increase during the next years due to the development of deep offshore fields "(OECD, 2015)". This might require the reorientation of shipbuilding companies and simultaneously may also help in reducing excess capacity.

Despite the opportunity arising from the similarities with the offshore industry, the reorientation of shipyards involves several challenges and the risks are not negligible. These are related to the complexity of building processes, high levels of investment required, strict regulations and the need of reeducation and training for employees. Moreover, the specific need of the offshore sector might be insufficient to revitalize the shipbuilding industry. In fact, after the sharp decline of oil prices in 2014 and the reduction of investment in offshore oil exploration there was a decrease in offshore vessel deliveries of about 10% in 2015, and further decreases are expected in the following years "(OECD, 2015)".

In this context, other offshore sectors such as offshore renewables are seen as promising future markets. For instance, offshore wind installations are expected to increase up to 12 GW in 2020 "(OECD, 2015)". However, the offshore wind sector and other energy marine resources (e.g. wave and tidal current energy) are still in an emergent stage of development when compared to offshore oil and gas. Consequently, this new sector comprises significant uncertainties and challenges regarding the amount of investment required, logistics, construction and technology risks. Several types of policies on the offshore renewable sector may have a significant impact on the shipbuilding industry regarding its offshore activity, such as the discussion of feed-in tariff pricing and other policy mechanism designed to accelerate investment in order to promote the rapid deployment of offshore renewable energy sources.

3.2. Offshore renewables

In general, offshore renewables include wave energy, offshore wind and tidal current energy. These three renewable energy resources are an abundant natural alternative for clean power (especially wind and waves). However, appropriate technology must be developed so that this large amount of energy can be harnessed to generate electricity. Although, offshore energy technologies are still in the early phase of the development, and so further technological advances must be achieved in order to make future offshore energy projects commercially viable when compared to the current most competitive renewable sources.

In this framework, many governments (especially in Europe) are seeking to reduce their greenhouse gas emissions with offshore renewable technologies, lessening the dependence on fossil fuels and increasing energy security. It seems to be clear that opportunities in this field will grow further, which is highlighted by over 500 companies in the UK alone engaged to marine energy related activities, as mentioned in a recently published study by the Renewable UK (2016). Although promising, there are still several risks and challenges in the ocean energy sector that need to be addressed in order to speed up the route to market of offshore renewable technologies. These risks include aspects ranging from the technology to the definition of the global supply chain. Certainly, the estimated high cost of energy generated by offshore farms is nowadays the major challenge of offshore renewables. For example, the costs of installing an offshore wind turbine was around €5 million per megawatt of capacity in 2010, while installing turbine on land has installation costs between €2-2.5 million per megawatt of capacity, according to the Energy Alternatives India (2015). Therefore, it is nowadays commonly accepted that to make the electricity generated by offshore wind farms commercially viable a subsidy of about €100 per MWh is required, in accordance to the Power Cluster (2015).

Although there is some controversy on these values, it is expectable that subsidies (awarded by governments) might bring in to the offshore energy sector an additional political and economic uncertainty since the financial institutions see these policy mechanisms as a commercial risk. Howsoever, in order to make offshore renewables commercially viable a significant reduction in costs must be accomplished, which can only be achieved by optimizing every single stage of development, manufacture, installation and operation.

Other challenges facing the sector include the survivability capacity, reliability and operation and maintenance. These aspects are particularly important in offshore environments where it is more difficult to act if damages and accidents occur. In fact, the un-proven reliability and survivability capacity of offshore technologies has had a negative impact on the ability to raise capital to develop offshore energy projects, since the risk perceived by investors is, for these reasons, too high.

Moreover, additional drawbacks that can slow down the sector development may arise from the insufficient capacity to manufacture the estimated amount of submarine cables for offshore farms and suitable vessels for installation and maintenance. Furthermore, the lack of qualified engineers and technicians to develop marine renewable energy plants (e.g. research and design, development and consenting, technical analysis, construction and installation, and operation and maintenance) may also delay the growth of the sector, according to the Renewable UK (2016). However, to minimize this constraint it was established already in many countries education and training programs to provide a supply of qualified personnel. Universities are developing specialist courses in marine and offshore renewable energy and many companies are developing apprenticeships and graduate training programs.

In this context of opportunities and challenges it seems reasonable thinking that a large offshore renewable industry can be benefited by learning from other industries (such as offshore oil and gas and shipbuilding industry). For instance, processes and technologies developed for offshore oil and gas and shipbuilding might be useful and relevant for the offshore renewable industry (e.g. dynamic positioning systems, heave compensated winches and cranes saturation diving, ROVs, etc). Besides, in the engineering design process, learnings from related industries might be incorporated into standard engineering practice. Moreover, the supply chain that supports shipbuilding and the offshore oil and gas industry might be partially transferable to the future offshore renewable industry, which highlights the rationality of exploring synergies between offshore renewables and related industries, as referred in the report on recommendations for wave and tidal supply chain development by BVG Associates Ltd. (2015).

4. Methodology

The development of scenarios to explore energy pathways and decarbonized futures has been widely applied in recent years. However, no standard methodology has been established to provide a solid basis for building scenarios for the future of offshore renewable energy in order to set out a long-term vision for the sector. Many energy scenarios are sustained only by modeling results, which allow great technological details but neglect the interaction with social, politic and economic factors such as the potential to generate jobs or the contribution to the security of energy supply.

In this framework, this study presents a first attempt to apply this methodological approach for building scenarios in the renewable sector, testing its ability to capture, in an integrated way, cause-effect linkages between sustainability key issues from technological, environmental and socio-economic perspectives and their interrelationships. Therefore, this work aims to take a step forward towards reducing the lack of consistency in developing scenarios to explore alternative futures based on a low-carbon energy paradigm through a holistic approach, which has been commonly mistreated in scenario planning for the renewable energy sector. For this purpose, data will be collected from document reviews and in-depth interviews with energy experts to capture a diversity of perspectives on the wide range of challenges of low-carbon energy futures. Furthermore, the proposed approach also promotes the interaction between different perspectives, moving from individual reflections to group brainstorm discussions. The methodology used here for developing scenarios to explore energy and low carbon futures, in particular the impact of the shipbuilding industry upon the marine renewable sector, follows the procedure proposed by “Henriques, 2015” in his master thesis, to build population health scenarios (where a new methodology for informing health policy is proposed). This methodology combines the Intuitive Logics approach and the French approach of La Prospective, using some of its tools such as causal maps (for aggregating information collected) and morphological analysis (to obtain plausible configurations of the evolution of the problem variables). The proposed process starts with the identification and analysis of the problem and the definition of the most pertinent questions to be put to the experts through interview and group brainstorm initiatives. Then, the problem variables will be identified and reduced to find the problem variables.

Eventually, scenarios and their narratives are created through the information collected from experts. Figure 1 points out the methodology framework for building exploratory scenarios tailored specifically to the renewable energy sector.

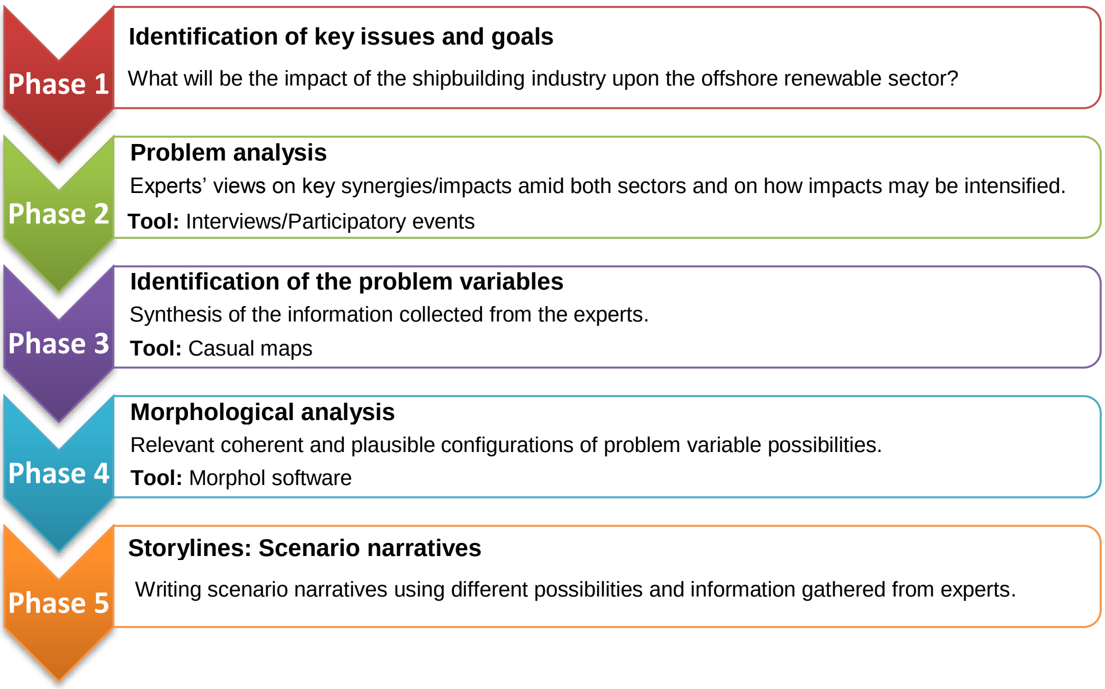

FIGURE 1 - Methodology framework for building exploratory scenarios for low carbon energy futures, in particular with regard to the impact of the shipbuilding industry upon the offshore renewable sector.

4.1. Identify the key issue and goals

The first phase of the proposed methodology consists of identifying and analyzing the key issue, decision or question of the problem and the major goals of the study. This stage should be performed through workshops and other participatory events that foster and promote interaction and diversity of visions of experts/stakeholders, as suggested by the Institute for Alternative Futures (2016) and the World Economic Forum (2013).

In the particular case of the present study the main goal is the development of scenarios that might bring light into the foreseeable impact of the shipbuilding industry on the emergent offshore renewable energy sector, identifying causes for distinct evolutionary patterns, and enabling stockholders to act in a way that maximizes potential synergies between the two sectors. In this context, the central objective of this study is to answer the question: "What will be the impact of the shipbuilding industry on the offshore renewable energy sector?”. This question may be split into sub-questions to address, for instance, the direct and indirect impacts on employment creation, the potential growth of renewable energy and its contribution to the energy mix or the capacity of the renewable energy sector to contribute to reverse the loss of competitiveness of the European shipbuilding industry and to help secure a competitive position for the future. The proposed methodology will be applied in the European context, with a scenario time frame of 15 years. However, since the evolution of offshore renewables cannot be delimited to the European reality, experts from other places in the world, including Australia and the US, were heard in order to increase diversity of opinions and broaden the views on this matter.

4.2. Problem analysis

The second stage of the methodology consists of analysis of the problem through the identification and recognition of the stakeholders and experts’ views on what are the most relevant synergies and cross-coupling influences between the offshore renewable energy sector and the shipbuilding industry. The potential synergies and resemblance between the two sectors are the basis of a questioning protocol implemented through brainstorming sessions and in-depth interviews with individual experts.

The questioning protocol will consist of a few short questions aligned with the points mentioned in the previous subsection. For the implementation of the protocol, information about forecasts will be provided to facilitate the discussion and help experts answering the questions. The advantage of this procedure is to allow experts to compare their views and perspectives with the existing forecasts and so providing a more knowledgeable response. In order to better capture the diversity of perspectives in-depth interviews with individual experts will be conducted, since often workshops are unable to effectively exploit the specialized knowledge of participants. Nevertheless, participatory events where the interaction between stakeholders is promoted will be performed to adjust and validate results.

4.3. Identification of the problem variables

The objective of the third stage consists of the analysis and aggregation of the information gathered from the experts' questionnaires (predictions for each indicator and possible measures to increase this estimate). Following the identification of the major problem and its analysis, the dimension of the problem is defined in this stage, i.e., the sorting of the relevant variables or drivers. This is usually the first step to be considered when carrying out a morphological analysis "(Ritchey, 1998b)". Therefore, throughout an extensive scanning of the answers from experts, in particular the causes attributed to the forecasts of leading indicators, it is possible to list all of the drivers that are expected to influence the future impact of the shipbuilding industry on the offshore renewable sector. Afterwards, these drivers are grouped in order to obtain the problem variables, which can be represented using causal maps[2]. Conventionally, causal maps refer to a graphic cause-effect network representation that consists of nodes and arrows. The nodes depict concepts such as entities, phenomena and their attributes, of the focal domain or issue and the arrows indicate the concepts' interlinked causal relationships as perceived by the actors.

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[2] A causal map is a subtype of cognitive maps. A cognitive map is a representation of an individual's perception of a particular topic and can help him to better structure, organize and understand the topic. When multiple cognitive maps are combined into a collective cognitive map, the entire group can use the collective map to find differences and build a shared understanding of the topic.

Causal connections represent the experts' beliefs about relationships between the nodes and show the antecedent-consequent relationships between two nodes by linking them with a unidirectional arrow from the antecedent (the one that causes) to the consequence (that one that is caused). The widely-accepted approach for capturing cognitive data for causal mapping essentially consists of informal brainstorming, formal brainstorming, and structured interview and questioning protocols "(Pande & Holpp, 2001; Delbecq et al, 1975; Chmeilewski et al, 1998a)". In this study, causal maps are built to represent experts' beliefs regarding causal relationships between indicators and drivers (problem variables). Nevertheless, to complement the information obtained from causal maps, an influence matrix will be also built to get more specific information regarding the experts' answers, such as how many experts mentioned each indicator, how many indicators are influenced by each driver and the kind of influence, positive or negative.

In scenario building the selection of problem variables is a major aspect since the process essentially depends on these variables. Usually the problem variables are grouped and categorized according to a STEEP[3] structure adapted to the specific context "(Burt et al, 2006; Wright et al, 2009)". Moreover, the problem variables/drivers may be also organized through a typology that classifies drivers into three dimensions: drivers related to the proper issue, working environment and contextual environment.

4.4. Morphological analysis

The fourth stage consists of building scenarios that must be relevant, coherent and plausible configurations of problem variables "(Godet, 1991; 1994; 2016)". For each problem variable identified in the previous section, two or three hypotheses of future

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[3] The STEEP structure is a taxonomic classification of the macro environment that consists of grouping the drivers into technical, environmental, socioeconomic and political drivers.

evolution will be defined, based on qualitative information gathered from experts. These hypotheses represent possible and relevant states or conditions that each problem variable may assume in the future. In order to create a set of scenarios in a more coherent and consistent way a morphological analysis will be performed. The morphological analysis is crucial in the proposed methodology since it is a very systematic way to obtain different combinations of plausible evolutions of the problem variables previously identified. Moreover, it helps to visualize combinations of various possible development variations for all scenario drivers and to ensure plausibility.

Essentially, the morphological analysis allows the elimination of incompatible combinations of factors in order to improve coherence and plausibility of the set of problem variable combinations previously selected. In this regard, morphological analysis is crucial to perceive the various elements and dimensions in the system "(Amer et al, 2013)". The main steps to perform a morphological analysis, according to “Godet (1994)”, are:

i) selection of components/problem variables and its hypotheses;

ii) calculating the number of solutions of the initial space – morphological field;

iii) definition of exclusion constraints;

iv) generation of the reduced morphological field/usable space;

v) selection of scenarios to be narrated, considering the proximity matrix and analyzing distances and differences between scenarios.

Figure 2 displays an example of morphological analysis with pathways to generate relevant, coherent and plausible scenarios.

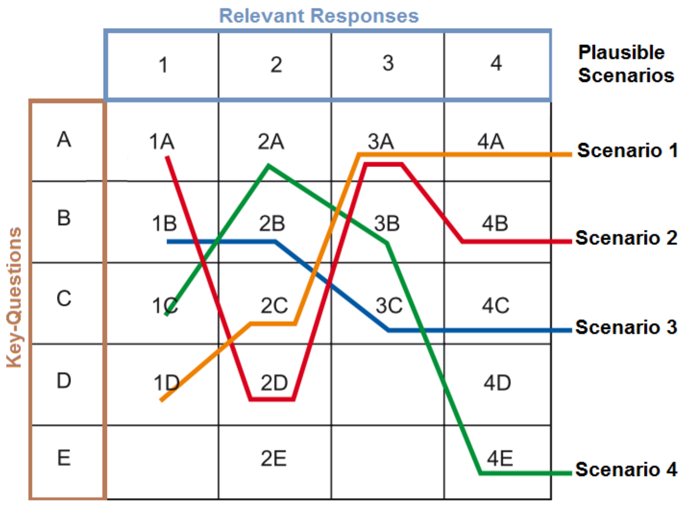


FIGURE 2 – Schematic representation of the future-building scenario process through morphological analysis. The colored lines indicate possible and plausible paths that will lead to coherent scenarios.

4.5. Storylines: Scenario narratives

The last stage of the applied methodology consists of writing the narrative of scenarios using the configuration possibilities obtained from the previous morphological analysis and the information gathered from the experts, including the causal maps built and the experts' predictions. The involvement of experts with a wide range of backgrounds is essential, in particular to ensure that the morphological analysis has a well-defined problem space.

This stage is divided into two steps: The first and somehow more complex step consists of selecting the right configuration possibilities, i.e. the "backbones" of scenarios that are more meaningful and prominent to develop scenario narratives. The Morphol software, developed by LIPSOR (2015), will be used, since it has some incorporated features to choose scenarios structures, including: a proximity matrix, which shows the number of common hypothesis between every scenario; an indicator matrix, which is calculated from the previous matrix and shows the compatibility between scenarios; a proximity map, which is produced from the analysis of distances in the proximity matrix, and a proximity graph, which highlights the distances between scenarios. The second step consists of combining the selected structures of scenarios with the obtained quantitative forecasts on impact indicators (quantitative indicators that measure effective synergies between the two sectors) and with causal relationships between indicators and drivers, which may be perceived in the causal maps developed.

Eventually, in order to adjust and validate the results, both from the morphological analysis and from the final scenario narratives, workshops/discussions with key stakeholders and experts will be, in principle, arranged. The workshops are particularly valuable when several perspectives need to be captured to find a commitment regarding the validation of results "(Kerr and Tindale, 2004)".

5. Application of the scenarios methodology

In this section a preliminary application of the proposed methodology to build scenarios regarding the impact of the shipbuilding industry upon the marine renewables sector is developed. The assumptions, outputs and main results of each phase are described along with the final scenario narratives. The main purpose of this application is testing this new method and improving the understanding on its limitations and how they might be minimized.

5.1. Identification of key issues and goals

This phase aims to identify the key issues, decisions or questions of the problem in order to provide answers to the question: "what might be the impact of shipbuilding industry upon the offshore renewable sector in a time frame of 15 years (i.e. till 2030)?"

The proposed method starts with a clear definition of what “impact” means and how it might be measured. This phase is essential since impact is a very broad and comprehensive concept that can comprise several determinants, outcomes and energy/industrial policies along with the cross-coupling effect between these three aspects.

In this study, five indicators, directly or indirectly related to the potential impact of the shipbuilding industry on the offshore renewable sector, were selected based on the believe that they are suitable to test the proposed methodology. The set of indicators used are: Levelized cost of energy (LCOE), technology readiness level (TRL), manufacturing readiness level (MRL), time to market (TTM) and public engagement (PE). Table I lists the selected determinants or indicators (which are the basis for the questioning protocol elaborated to approach experts) and a short description. In the next section a more detailed explanation of the indicators takes place.

TABLE I.

Short description of the selected determinants.

Indicators	Description
1.- Levelized cost of energy (LCOE)	The LCOE measures the cost-effectiveness of a power plant in the market place.
2.- Public engagement (PE)	The PE in an indicator of the population supportiveness to offshore renewables.
3.- Technology readiness level (TRL)	The TRL is the technology stage of development (TRL 1 – basic concept formulated/ TRL 9 proven competitiveness in operational environment).
4.- Manufacturing readiness level (MRL)	The MRL is a measure to assess the maturity of manufacturing (MRL 1 – basic manufacturing implications identified/ MRL 10 - Level of demonstrated lean production practices in place)
5.- Time to market (TTM)	Time period until offshore technologies become commercially viable.

5.2. Analysis of the problem

This phase aims at analyzing the problem through the identification of the experts' views on what will influence the determinants. Therefore, a set of experts from around the world with various backgrounds, perspectives and experiences were involved in this study.

5.2.1. Determinants selection

The five determinants selected, based on their unquestionable preeminence in the current agenda for renewable energy development, include:

- **Levelized cost of energy (LCOE)** – The levelized cost of energy (LCOE) has been the biggest drawback of offshore renewables. For instance, the cost to generate electricity from offshore wind turbines is typically between 2.5-3.5 times more than the wind farms built on land. There are a number of factors that determine the cost such as reliability, availability, survivability, cost of capital, risk (from financial to weather related risks), etc. Nevertheless, the offshore renewable sector is still in a novice state compared to the relatively mature level of land based wind industry, and so significant LCOE are expected to follow the development sector. The LCOE is straightly related to the perceived risk, which is another weakness that has been slowing down the investment in offshore renewable energy projects. The perceived risk by investors is currently decoded by the real discount rate, which typically ignores differences in risk across different technologies, or for the same technologies across time "(Awerbuch & Yang, 2008)". Nevertheless, adjustments in discount rates are quite effective in differentiating and quantifying project risk and so it is considered as a fundamental issue in most LCOE analyses. Currently, typical pre-tax real discount rates are 6 to 9% for well-established dispatchable technologies (gas, hydro), 7 to 10% for onshore wind and 10 to 14% for offshore bottom fixed wind "(Awerbuch & Yang, 2008)". It is expected that less mature offshore renewable alternatives than bottom fixed wind (e.g. floating wind, waves, tidal) might, in the near future, have considerably higher discount rates.

- **Technology readiness level (TRL)** – The technology readiness level (TRL) of many offshore renewable technologies under development is still quite low (except for bottom fixed offshore wind), and further technological advances must be achieved to make future offshore renewable technologies commercially and more competitive in a market place against conventional energy supplies (most competitive renewable and fossil fuel based power generation). There are several agencies with slightly distinct criteria to assess the TRL, however, one of the most widely used criteria is the one defined by the European commission (2015). Following this criterion, the TRL comprises the following stages:
    1. Basic principles observed
    2. Technology concept formulated
    3. Experimental proof of concept
    4. Technology validated in laboratory
    5. Technology validated in relevant environment
    6. Technology demonstrated in relevant environment
    7. System prototype demonstration in operational environment
    8. System complete and qualified

9. Actual system proven in operational environment (competitive manufacturing)

- **Manufacturing readiness level (MRL)** – The MRL is a measure developed by the United States Department of Defense (2011) to assess the maturity of a technology manufacturing readiness. The MRL provides a common understanding of the relative maturity (and attendant risks) associated with manufacturing technologies, products and processes. As in the case of the TRL there are also several slightly criterion to assess the MRL. However, the one defined by the DOD is likely one of the most widely spread criterion (Godet et al, 2004). According to this criterion the several levels in assessing the MRL are:
    1. Basic manufacturing implications identified
    2. Manufacturing concepts identified
    3. Manufacturing proof of concept developed
    4. Capability to produce the technology in a laboratory environment.
    5. Capability to produce prototype components in a production relevant environment.
    6. Capability to produce a prototype system or subsystem in a production relevant environment.
    7. Capability to produce systems or components in a production representative environment.
    8. Pilot line capability demonstrated. Ready to begin low rate production.
    9. Low Rate Production demonstrated. Capability in place to begin Full Rate Production.

10. Full Rate Production demonstrated and lean production practices in place

- **Time to market**. One of the most relevant key challenges faced by the offshore renewables is speeding up the lead time to market and reducing costs to be part of the energy mix along with the most competitive renewable and fossil fuel based power generation. With this in mind, it is still necessary to intensify funding mechanisms for energy research both in industry and academia and promoting other incentive strategies (feed in tariffs, tax leasing and other support mechanisms) to accelerate the path to commercialization and make offshore technologies competitive in the market place.
- **Public engagement with offshore renewable energy.** Lack of social acceptance can present a serious challenge to a massive expansion of offshore renewables "(Moula et al. 2013)". In this context, it is crucial to provide information to the public about benefits and disadvantages and increase the share of information and dialogue between key stakeholders to raise social acceptance, including politicians and public authorities, industry and business representatives and the general public.

5.2.2. Survey questionnaires to companies

After setting the five impact determinants, the next step consists of developing the questioning protocol for each determinant (or indicator), taking into account the information that should be obtained from the experts.

5.2.2.1. Survey protocol

This protocol consists of two questions and, in principle, might be answered in roughly 15 minutes:

i. **First question** – “What is the most expected impact on each indicator to be observed in 2025 (null, low, high or very high)?”;
ii. **Second question** – “What might influence the strength of the impact predicted in the first question?”.

5.2.2.3. Analysis of experts’ responses

Several experts from different companies and R&D centers spread all around the world where contacted to participate in this questing protocol. Table II presents the qualitative answers for the first question – “what would be the foreseeable impact of shipbuilding upon the offshore renewable sector in each one of the indicators, in a time frame of 15 years?” and Table III presents the qualitative answers for the second question – “What might influence the intensity of the impact predicted for each indicator?”

In order to collect views from all around the world, companies and R&D centers from various countries, with strong activity in the offshore renewables sector, were invited to participate in this study. Besides, the selected organizations are, to some extent, transnational corporations that spread out their operations in many countries, which reinforces a global perspective rather than locally centralized in their headquarters. Moreover, these organizations are positioned at different levels of the supply chain, including engineering, procurement, manufacturing, logistics, consultancy, R&D and O&M services, which contribute significantly to widening the diversity of views and responses. Table II and III display the responses of experts for the two questions of the survey.

TABLE II
Experts' qualitative forecasts on each determinant.

Q1: In your opinion what is the expected impact of the shipbuilding sector in each one of the following indicators.

Indicators	**Companie's answers**									
	LOC	**EDPI**	**ASM**	**WavEC**	**MARINE**	**EDPR**	**CENTEC**	**SNL**	**BOMBORA**	**APPA**
LCOE	Low	High	High	High	Very high	High	Very High	High	Low	Null
TRL	High	Low	High	High	High	Low	Low	Low	Null	Low
MRL	Very high	Very high	Very high	High	High	High	Very high	Very high	Low	High
TTM	High	Low	Very high	High	Low	Low	Low	Low	Null	Null
PE	High	Low	Very high	Low	Null	Null	High	High	Null	Null

TABLE III
Experts' views on what might promote or intensify the qualitative predictions made for each determinant, reported in Table II.

Q2: What might potentiate or influence the intensity of the impact afore mentioned?	
Companies: LOC Group	
LCOE	Promoting/adapting the application of common procedures in the shipbuilding industry (e.g. dynamic positioning of vessels) to reduce O&M, installation and construction costs.
TRL	Synergistic use of components and methodologies well known in shipbuilding (e.g. seakeeping systems).
MRL	Promoting the use of facilities, manufacturing processes and existing shipyards.
TTM	Making available and adapting existing shipyards and reducing the lack of understanding of the specificities of a different sector such as the offshore renewable sector (e.g. mass production).
PE	Promoting the growth and sustainability of employment in local areas.
Companies: EDP Innovation	
LCOE	Application/development of manufacture methodologies/processes less labor intense (e.g. mass production).
TRL	More involvement in the technology development (Currently the involvement of the shipbuilding industry is limited to outsourcing services, assembly and components manufacture).
MRL	Transforming the manufacturing cadence from labor intense to mass production.
TTM	Introducing policy mechanisms designed to accelerate the investment in offshore renewables (e.g. feed in tariffs) might potentiate the involvement of the shipbuilding sector (growth of market demand).
PE	Creating local employment and reducing the negative impact that possible subsidies (e.g. feed in tariffs or other policy mechanisms) may have on raising prices for consumers.
Companies: ASM INDUSTRIES	
LCOE	Using common tools, methodologies and processes of the shipbuilding industry (for O&M, installation, decommission, etc).
TRL	Exploring capabilities, engineering resources and underutilized infrastructures in the creation of new services and products/components for the new offshore sector.
MRL	Providing building capacity, skilled labor and infrastructures to the emergent offshore renewable sector.
TTM	Intensifying the development of products and services essential for the offshore renewable sector. This strategy can also be seen as an effective way to counteract the decline of shipbuilding (especially in Europe), which eventually can add pressure to shorten the path to commercialization of offshore technologies).
PE	Accelerating the creation of local jobs in a new industry. Public engagement can be enhanced for socio-economic reasons if sustainable local employment is created.
Companies: EDP Renewables	

LCOE	Using the broad known-how, the experience and those processes of shipbuilding that can be exported to the renewable sector (e.g. welding methods, optimization of the volume of materials, etc).
TRL	Identifying possible design weaknesses that may have strong impact in the technologies development (e.g. compatibility of components, identification of emerging conflicts, and validation of the constructive integrity). Applying to the offshore renewables technologies well known and optimized processes of the shipbuilding industry with regard to antifouling, anti-corrosion treatments, etc.
MRL	Being more proactive on optimizing the structural design to avoid bottlenecks on assembly/construction phases, using well known processes and the wide general knowledge of the sea environment. Adapting welding and anticorrosion processes to the reality of the offshore renewable sector and using the constructive capacity of shipyards.
TTM	Becoming more proactive in the technological development and also in the selection of more efficient and less complex manufacturing processes easily adaptable to offshore renewables.
PE	Promoting the idea of sustainability and strengthening activities more environmentally-friendly can make people more supportive, which is aligned with the interest the shipbuilding industry.
Companies: MARIN	
LCOE	Using the adaptable know how, facilities and other common resources of the shipbuilding industry.
TRL	Reducing the level of conservatism and reluctance to extend the activity to a new and more innovative field.
MRL	Reducing the lack of experience on offshore renewables and improving the collaboration between offshore renewables and shipbuilding. Adapting standards and classification procedures.
TTM	Reducing the industry extreme reluctance and conservatism in its relationship with innovative emerging industries.
PE	Undertaking initiatives to promote greater environmental responsibility. Shipbuilding is seen as a polluting industry and renewables is seen as environmentally-friendly so the major impact is the other way around.
Companies: CENTEC	
LCOE	Using manufacture capacity, acquisition of structural components and final integration in the shipyards.
TRL	Engaging the naval shipbuilding in the process of prototype demonstration and proof-of-cost effectiveness in operational environment. Probably shipyards will influence the TRL (see section 5.2.1) only at the highest levels, by supporting and optimizing manufacture and assembly strategies and installation processes. The aim at lower TRL stages is typically out of the scope of the shipyards activities.
MRL	Transferring know-how, best practices and manufacture experience of the shipbuilding industry into the offshore renewable sector.
TTM	Reducing the LCOE (by working actively on optimizing manufacture & assemblage, installation and O&M services) will shorten the path to commercialization.
PE	Creating local employment (direct or indirectly jobs). Raising awareness about environmental issues.
Companies: WavEC - Offshore Renewables	
LCOE	Public subsidization to support shipyards on the development of specific vessels (O&M and installation) and new manufacture processes.
TRL	Transferring the know-how (auxiliary systems, control, monitoring) to the offshore renewable sector.
MRL	Using the exiting know-how on towing and installation in the sea.
TTM	Risks and LCOE reduction will contribute to accelerate the path to commercialization.
PE	Creating local employment is important, but it won't be the dominate aspect. Cost of energy and sustainability is more valorized. Any contribution to the cost of energy would be more relevant, but the public perception of this contribution won't be, most likely, attributed to the shipbuilding industry.
Companies: BOMBORA	
LCOE	Creating new products and services (e.g. optimizing O&M) may happen specially in regions where shipbuilding is a traditional industry that has been struggling against increasing competition.
TRL	Being more proactive in the technological development of offshore technologies (which doesn't happen at the moment).
MRL	Adapting shipyards, infrastructures and manufacturing processes to the specificities of the offshore renewables sector.
TTM	Policy mechanisms designed to accelerate the investment in offshore renewables directly design to the shipbuilding industry.
PE	Contributing to growth of employment in local areas (however this is unlikely to happen).
Companies: APPA	
LCOE	Reinventing the certification processes and adjust them the specific characteristics of the sector (classification processes are old and maladjusted to the offshore renewable sector). Altering typical manufacturing processes to mass production.

TRL	A negative economic cycle can push the industry to embrace a new sector and creating new processes and services. Applying experienced manpower and know-how in a related field.
MRL	Using expertize, infrastructures and the know-how that might be easily exportable to a new field.
TTM	To some extent shipbuilding industry sees itself as the “owners” of the sea and so offshore renewables may be seen as a rival competing for leadership. Therefore, this way of thinking can enhance the interest of the industry in delaying the development of a new sector that competes in the same space.
PE	Promoting local employment in offshore renewables. A clear political incentive to the development of offshore renewables (tax leasing and other support mechanisms) can contribute to a greater involvement of the shipbuilding industry in this new sector, which may potentially increase the PE.
Companies: Sandia National Laboratories (SNL)	
LCOE	Applying well-developed practices, tools, and techniques can reduce costs associated with manufacturing. Capabilities associated with mass-manufacturing and construction can also be cross-leveraged thus again reducing costs. Leveraging already developed infrastructure.
TRL	Shipbuilding has minimal impact on the TRLs of offshore renewable technologies. However, once TRL 7-9 are hit then efficient, high quality manufacturing with a need to push towards mass manufacturing becomes very important and then shipbuilding may have a stronger impact upon many conceptual aspects of power production, maintenance, operations, determination of limit states, and system integration.
MRL	Shipbuilding has well-developed practices, tools, and techniques by using it, one will automatically be propelled to a higher MRL b/c there are not as many certainties to address. If the route of building new facilities, new tools, and developing new techniques are pursued the level of risk will be high resulting in low MRLs.
TTM	The impact of using the shipbuilding industry on true TTM is not huge as it can only come into play in TRL7-9. However, once you hit these, then having a high MRL will result in a faster TTM. So there is impact mainly through evaluation of the MRL (i.e. this is a fall-out effect of MRL).
PE	Creation of local jobs (and whatever shipbuilding location you go to is local to that location) is of huge importance to getting buy-in behind offshore renewable projects. Shipbuilders tend to have strong unions and thus have political clout. Repurposing slowing industries is an important positive sell for offshore renewable projects.

Annex A presents a short description of the activity/ies of the companies of the experts who participated in the survey questionnaire. This information allows verifying that the activities of the selected companies is aligned with the topic of this study.

5.3. Identification of the problem variables

This section consists of the analysis and processing of the data collected from the experts’ responses to the survey questionnaire. The identification of drivers/problem variables was performed through the analyses of the information collected, either the impact weight forecasted by the experts to each one of the indicators (see Table II) and those aspects/measures that might promote or intensify the impact predicted (see table 4). In this context, 5 problem variableswere identified, namely:

- **Marketplace** refers to the impact of the shipbuilding industry on shortening (or extending) the path to commercialization of offshore renewable technologies (e.g. through a new role in the technology progress, by developing new services and manufacture processes tailor-made for the special requirements of the offshore renewable sector or acting in a way that reduces the risk perceived by investors).
- **Socio-economic** refers essentially to the depth of engagement of the shipbuilding industry into the offshore renewable sector, which, to some extent, is translated by the full potential of the industry to serve as a positive force for job creation (whether direct or indirect) in new services/processes/products.
- **Policy** refers to the enhancement of the impact that the shipbuilding industry may have on the offshore renewable sector caused by the existence of support policy mechanisms (direct or indirect incentives to support the shipbuilding industry).
- **Technology** refers to the influence that the shipbuilding industry may have on the development of offshore renewable technologies or technology components.
- **Manufacture** raises the impact of the shipbuilding industry related to the adaptation/conversion of manufacture processes (methods and techniques involved in each of these processes), assembly strategies and installation, from the traditional shipbuilding approach to the production of large renewable energy power plants.

These problem variables were split in two dimensions/domains: Social, economic & political context, which includes the first 3 problem variables, and technological context, which includes the remaining.

Then, causal maps, representing cross coupling linkages between indicators/determinants and between indicators and problem variables, were built in order to better recognize, organize, structure and visualize these interactions (see Figure 3). In the scope of this work causal maps were used essentially because they allow for a straightforward recognition and better visualization of the interconnections; however, the information comprised in causal maps can be also structured using influence matrices, along with causal relationships between indicators since they are not considered in the influence matrices "(Henriques, 2015)". Figure 3 shows a glance of the casual maps built, where the 5 colored circles represent the selected offshore renewables indicators (see Figure 3 – left) and the grey circles the problem variables (see Figure 3 – right). The arrows define the causal interactions between the components.

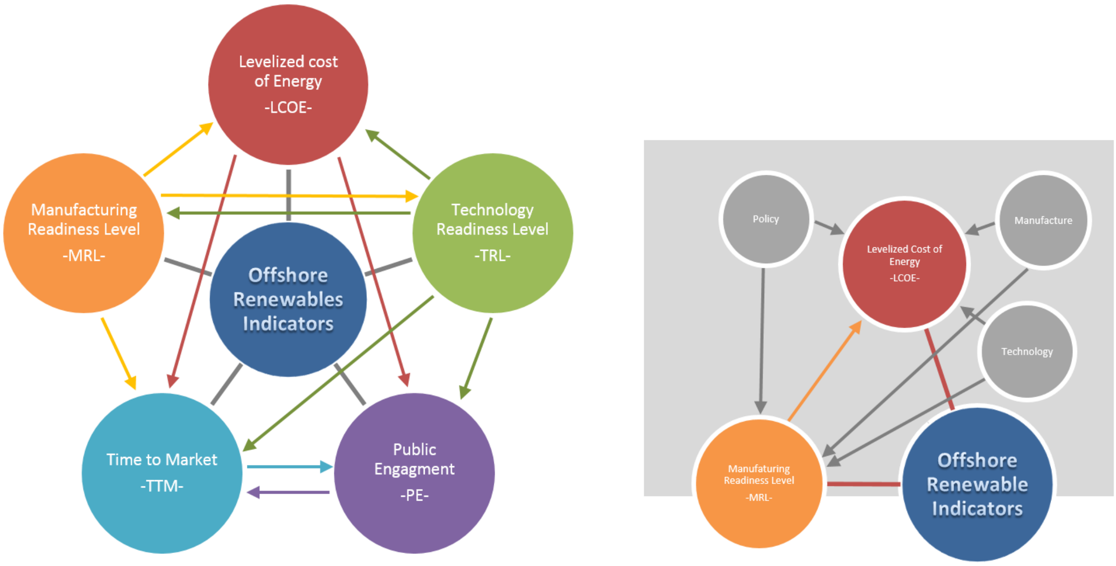


FIGURE 3 – Causal maps: causal interactions between the offshore renewables indicators (left) and zoom out of the causal interactions between the LCOE indicator and 3 problem variables -policy, manufacture and technology- (right).

After identifying the problem variables and the domains the hypotheses about the potential state of each of the variables were formulated. In order to simplify the problem only 2-3 hypotheses per variables were considered. Table IV displays the domains selected, problem variables and the hypotheses formulated.

TABLE IV
Problem identification: Domains selected, problem variables and hypotheses about the potential state of each of the variables.

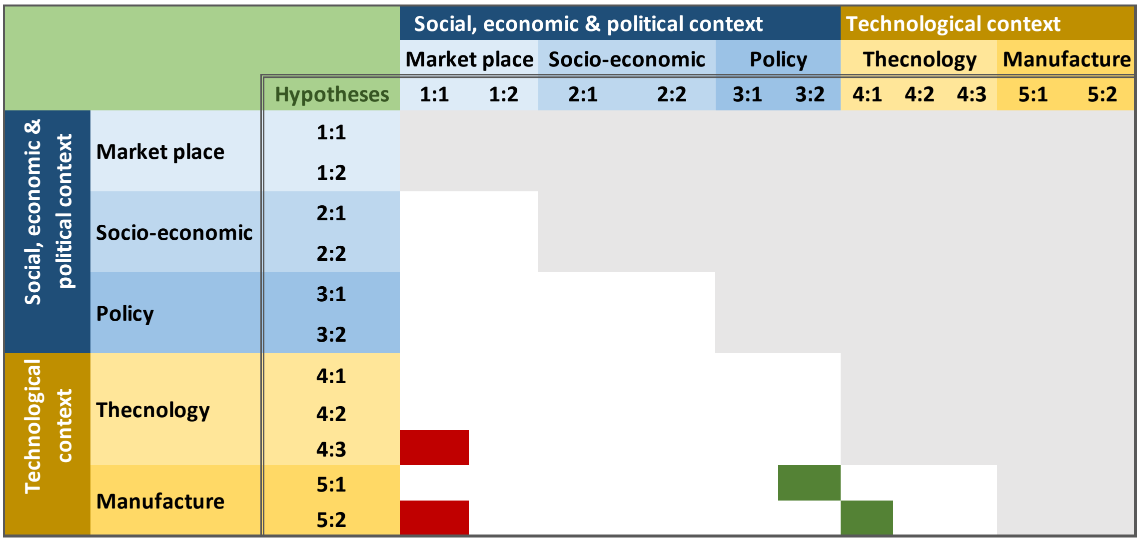
Problem variables		**Hypotheses**		
Social, economic & political context	**Market place**	Accelerate the path to commercialization of offshore renewable technologies.	No impact on shortening the path to commercialization of offshore renewable technologies.	-
	Socio-economic	Creating local jobs and developing training programs for employees	Residual or no impact on job creation	-
	Policy	Existing support policy mechanisms (indirectly or directly to the shipbuilding industry)	Nonexistence of any support policy mechanism.	-
Technological context	**Technology**	Deep involvement in R&D; development of new services and products.	Moderate involvement limited to the use of existing facilities, know-how and off the shelf components.	Lack of involvement.
	Manufacture	Adjusting methodologies, facilities and manufacture processes.	Conservative approach: keep things as they are.	-

Once set all hypotheses, the links between them with little plausibility were identified in order to set the list of exclusions. For example, it was considered unreasonable to assume that the shipbuilding industry can contribute to accelerate the path to commercialization of offshore renewable technologies if there is a lack of involvement in the technology development and if a conservative approach is taken with regard manufacturing, assemblage, installation and towing processes. Furthermore, it is also unrealistic to assume that adjusting methodologies, rebuilding facilities, adapting manufacturing processes and developing new services and products/components will be accomplished with no governmental support. Essentially this rationale was used to determine the list of exclusions, presented in Table V, with all the constraints considered to redefine/reduce the morphological space, as shown in Figure 4.

TABLE V
List of exclusion applied to redefine the morphological space.
The index 1:1 refers to the first hypothesis of the first problem variable and so on for the next hypotheses.

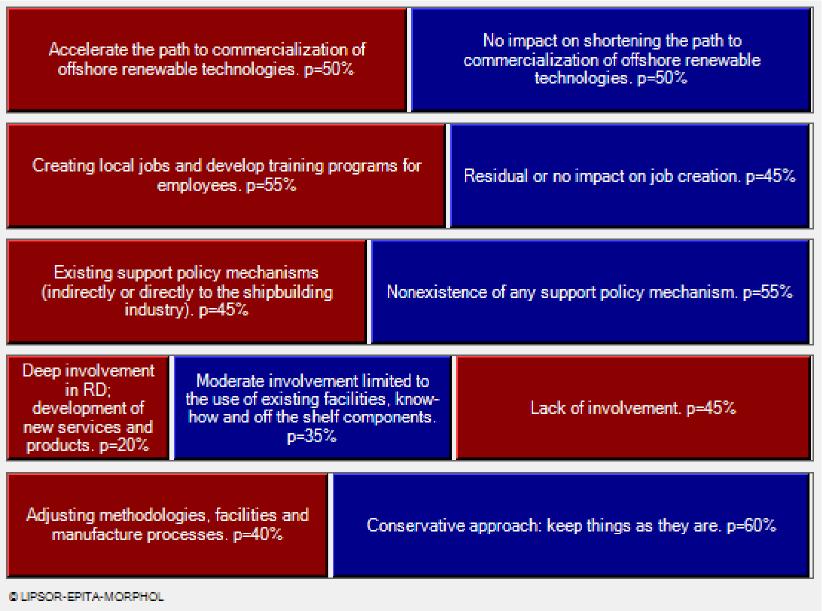
Scenario	List of Exclusions		Hypotheses	
1	**3:2 5:1**	Non- existence of any support policy mechanism.	Adjusting methodologies, facilities and manufacture processes.	
2	**4:1 5:2**	Deep involvement in R&D; development of new services and products.	Conservative approach: keep things as they are.	
3	**1:1 4:3 5:2**	Accelerate the path to commercialization of offshore renewable technologies.	Lack of involvement.	Conservative approach: keep things as they are.

TABLE VI
Cross consistency matrix.
Red and green boxes represent triplet and pairwise exclusion constraints, respectively.



			Social, economic & political context						Technological context				
			Market place		Socio-economic		Policy		Thecnology			Manufacture	
		Hypotheses	1:1	1:2	2:1	2:2	3:1	3:2	4:1	4:2	4:3	5:1	5:2
Social, economic & political context	Market place	1:1											
		1:2											
	Socio-economic	2:1											
		2:2											
	Policy	3:1											
		3:2											
Technological context	Thecnology	4:1											
		4:2											
		4:3	🟥										
	Manufacture	5:1						🟩					
		5:2	🟥						🟩				

In addition to establishing a set of exclusions to redefine the morphological space, another feature of the Morphol software used here was the option to define hypotheses probabilities, according to the experts' responses on the expected impact on each indicator, reported in Table II. For instance, looking at the indicator "public engagement", there was a consensus regarding the positive impact of the promotion of employment in local areas. Therefore, the job creation potential was taken as a problem variable and two hypotheses related to the impact and engagement of the shipbuilding industry with the offshore renewables sector, in terms of local employment was considered. However, there was a substantial dissimilarity in the responses, varying from null impact, (which means that any initiative to promote or intensify the impact is very unlikely), to very high impact (which means exactly the opposite). Therefore, in the absence of more detailed information, we assumed that the probabilities of the hypotheses are equally distributed. Figure 4 presents the probabilities of the hypotheses considered to improve the plausibility of scenarios.



Accelerate the path to commercialization of offshore renewable technologies. p=50%

No impact on shortening the path to commercialization of offshore renewable technologies. p=50%

Creating local jobs and develop training programs for employees. p=55%

Residual or no impact on job creation. p=45%

Existing support policy mechanisms (indirectly or directly to the shipbuilding industry). p=45%

Nonexistence of any support policy mechanism. p=55%

Deep involvement in RD; development of new services and products. p=20%

Moderate involvement limited to the use of existing facilities, know-how and off the shelf components. p=35%

Lack of involvement. p=45%

Adjusting methodologies, facilities and manufacture processes. p=40%

Conservative approach: keep things as they are. p=60%

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FIGURE 4 – Morphol software input: Probabilities of the hypotheses considered based on the experts' responses on the expected impact on each indicator, reported in Table II.

5.4. Morphological analysis

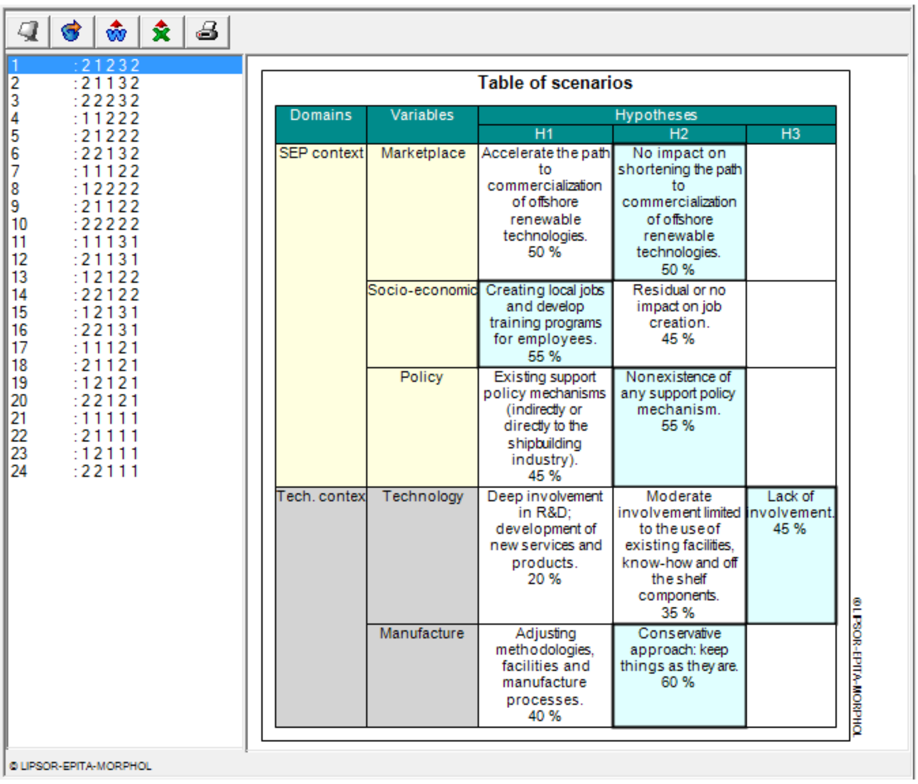
Morphological analysis aims at exploring possible futures in a systematic way by building future scenarios, through reviewing and analyzing all the combinations resulting from the decomposition of the system problem, in order to foresee new processes, methodologies or strategies. Therefore, the method provides a very comprehensive scanning process for possible scenarios. Morphological analysis is implemented using the Morphol software "(Godet et al, 2004)", within the framework of this study.

5.4.1. Morphol software

Morphol software essentially comprises two major features. The first one consists of building a morphological space, breaking down the system into its components. The accurate selection of components is critical since they must represent the entire system and be as independent as possible. Moreover, too many components disturb the clarity of the analysis and too few oversimplify the problem. Each component can assume several configurations which means that there are as many possible scenarios as combinations of configurations. These combinations, which represent the field of possibilities or morphological space, can expand exponentially and thus lead to the risk of getting lost in the middle of so many combinations. To minimize this drawback, the second major feature of the Morphol software involves the reduction of the morphological space. In fact, a closer look at the combinations allows the user to determine those which are unfeasible or unrealistic. Therefore, the software filters the combinations in order to reduce the initial morphological space to a much more manageable subspace, by introducing exclusion criteria based on aspects ranging from economic or environmental, to technical or political issues.

5.4.2. Morphol outputs

The primary Morphol output is the table of scenarios (see Figure 5), which allows the problem break-down to be verified, i.e. dimensions/domains, problem variables and hypotheses, and the list of consistent scenarios (20, in this study) after reducing the morphological space through the set of exclusions listed in table 6. This table also allows the different scenarios built in terms of their characterizing hypotheses to be distinguished.



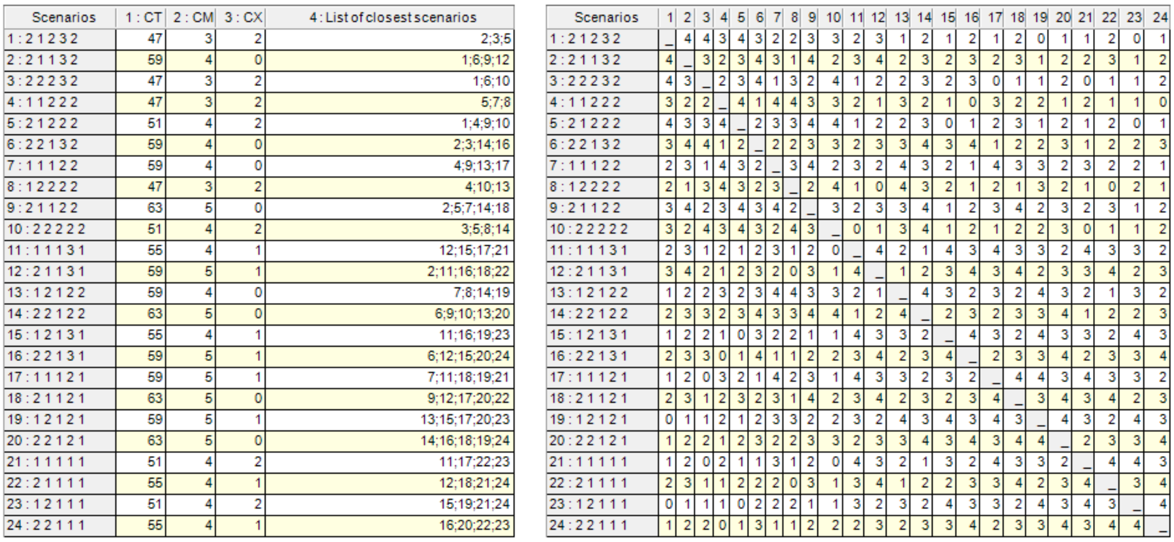
```
1          : 2 1 2 3 2
2          : 2 1 1 3 2
3          : 2 2 2 3 2
4          : 1 1 2 2 2
5          : 2 1 2 2 2
6          : 2 2 1 3 2
7          : 1 1 1 2 2
8          : 1 2 2 2 2
9          : 2 1 1 2 2
10         : 2 2 2 2 2
11         : 1 1 1 3 1
12         : 2 1 1 3 1
13         : 1 2 1 2 2
14         : 2 2 1 2 2
15         : 1 2 1 3 1
16         : 2 2 1 3 1
17         : 1 1 1 2 1
18         : 2 1 1 2 1
19         : 1 2 1 2 1
20         : 2 2 1 2 1
21         : 1 1 1 1 1
22         : 2 1 1 1 1
23         : 1 2 1 1 1
24         : 2 2 1 1 1
```

Table of scenarios

Domains	Variables	Hypotheses		
		H1	H2	H3
SEP context	Marketplace	Accelerate the path to commercialization of offshore renewable technologies. 50 %	No impact on shortening the path to commercialization of offshore renewable technologies. 50 %	
	Socio-economic	Creating local jobs and develop training programs for employees. 55 %	Residual or no impact on job creation. 45 %	
	Policy	Existing support policy mechanisms (indirectly or directly to the shipbuilding industry). 45 %	Nonexistence of any support policy mechanism. 55 %	
Tech. contex	Technology	Deep involvement in R&D; development of new services and products. 20 %	Moderate involvement limited to the use of existing facilities, know-how and off the shelf components. 35 %	Lack of involvement. 45 %
	Manufacture	Adjusting methodologies, facilities and manufacture processes. 40 %	Conservative approach: keep things as they are. 60 %	

FIGURE 5 – Morphol software output: Table of consistent scenarios (20) after redefining the morphological space by applying the set of exclusions listed in table 6.

The indicator matrix in Figure 6 (left) displays the proximity indicators between the different scenarios, which allows the distance between the scenarios to be evaluated and so the overall compatibility between them, which is relevant to detect the most representative scenarios. Thus, the column CT represents the sum of common hypotheses that each scenario has with the rest of the set of scenarios (the break-down of this sum is reported in the matrix displayed in Figure 6 - right); the column CM represents the number of scenarios with which each one of them differ in only one hypothesis; the last indicator, CX, represents the number of scenarios completely different from the one considered (no common hypothesis). Eventually, the last column comprises the list of the closest scenarios.



Scenarios	1 : CT	2 : CM	3 : CX	4 : List of closest scenarios
1 : 2 1 2 3 2	47	3	2	2;3;5
2 : 2 1 1 3 2	59	4	0	1;6;9;12
3 : 2 2 2 3 2	47	3	2	1;6;10
4 : 1 1 2 2 2	47	3	2	5;7;8
5 : 2 1 2 2 2	51	4	2	1;4;9;10
6 : 2 2 1 3 2	59	4	0	2;3;14;16
7 : 1 1 1 2 2	59	4	0	4;9;13;17
8 : 1 2 2 2 2	47	3	2	4;10;13
9 : 2 1 1 2 2	63	5	0	2;5;7;14;18
10 : 2 2 2 2 2	51	4	2	3;5;8;14
11 : 1 1 1 3 1	55	4	1	12;15;17;21
12 : 2 1 1 3 1	59	5	1	2;11;16;18;22
13 : 1 2 1 2 2	59	4	0	7;8;14;19
14 : 2 2 1 2 2	63	5	0	6;9;10;13;20
15 : 1 2 1 3 1	55	4	1	11;16;19;23
16 : 2 2 1 3 1	59	5	1	6;12;15;20;24
17 : 1 1 1 2 1	59	5	1	7;11;18;19;21
18 : 2 1 1 2 1	63	5	0	9;12;17;20;22
19 : 1 2 1 2 1	59	5	1	13;15;17;20;23
20 : 2 2 1 2 1	63	5	0	14;16;18;19;24
21 : 1 1 1 1 1	51	4	2	11;17;22;23
22 : 2 1 1 1 1	55	4	1	12;18;21;24
23 : 1 2 1 1 1	51	4	2	15;19;21;24
24 : 2 2 1 1 1	55	4	1	16;20;22;23

Scenarios	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1 : 2 1 2 3 2	_	4	4	3	4	3	2	2	3	3	2	3	1	2	1	2	1	2	0	1	1	2	0	1
2 : 2 1 1 3 2	4	_	3	2	3	4	3	1	4	2	3	4	2	3	2	3	2	3	1	2	2	3	1	2
3 : 2 2 2 3 2	4	3	_	2	3	4	1	3	2	4	1	2	2	3	2	3	0	1	1	2	0	1	1	2
4 : 1 1 2 2 2	3	2	2	_	4	1	4	4	3	3	2	1	3	2	1	0	3	2	2	1	2	1	1	0
5 : 2 1 2 2 2	4	3	3	4	_	2	3	3	4	4	1	2	2	3	0	1	2	3	1	2	1	2	0	1
6 : 2 2 1 3 2	3	4	4	1	2	_	2	2	3	3	2	3	3	4	3	4	1	2	2	3	1	2	2	3
7 : 1 1 1 2 2	2	3	1	4	3	2	_	3	4	2	3	2	4	3	2	1	4	3	3	2	3	2	2	1
8 : 1 2 2 2 2	2	1	3	4	3	2	3	_	2	4	1	0	4	3	2	1	2	1	3	2	1	0	2	1
9 : 2 1 1 2 2	3	4	2	3	4	3	4	2	_	3	2	3	3	4	1	2	3	4	2	3	2	3	1	2
10 : 2 2 2 2 2	3	2	4	3	4	3	2	4	3	_	0	1	3	4	1	2	1	2	2	3	0	1	1	2
11 : 1 1 1 3 1	2	3	1	2	1	2	3	1	2	0	_	4	2	1	4	3	4	3	3	2	4	3	3	2
12 : 2 1 1 3 1	3	4	2	1	2	3	2	0	3	1	4	_	1	2	3	4	3	4	2	3	3	4	2	3
13 : 1 2 1 2 2	1	2	2	3	2	3	4	4	3	3	2	1	_	4	3	2	3	2	4	3	2	1	3	2
14 : 2 2 1 2 2	2	3	3	2	3	4	3	3	4	4	1	2	4	_	2	3	2	3	3	4	1	2	2	3
15 : 1 2 1 3 1	1	2	2	1	0	3	2	2	1	1	4	3	3	2	_	4	3	2	4	3	3	2	4	3
16 : 2 2 1 3 1	2	3	3	0	1	4	1	1	2	2	3	4	2	3	4	_	2	3	3	4	2	3	3	4
17 : 1 1 1 2 1	1	2	0	3	2	1	4	2	3	1	4	3	3	2	3	2	_	4	4	3	4	3	3	2
18 : 2 1 1 2 1	2	3	1	2	3	2	3	1	4	2	3	4	2	3	2	3	4	_	3	4	3	4	2	3
19 : 1 2 1 2 1	0	1	1	2	1	2	3	3	2	2	3	2	4	3	4	3	4	3	_	4	3	2	4	3
20 : 2 2 1 2 1	1	2	2	1	2	3	2	2	3	3	2	3	3	4	3	4	3	4	4	_	2	3	3	4
21 : 1 1 1 1 1	1	2	0	2	1	1	3	1	2	0	4	3	2	1	3	2	4	3	3	2	_	4	4	3
22 : 2 1 1 1 1	2	3	1	1	2	2	2	0	3	1	3	4	1	2	2	3	3	4	2	3	4	_	3	4
23 : 1 2 1 1 1	0	1	1	1	0	2	2	2	1	1	3	2	3	2	4	3	3	2	4	3	4	3	_	4
24 : 2 2 1 1 1	1	2	2	0	1	3	1	1	2	2	2	3	2	3	3	4	2	3	3	4	3	4	4	_

FIGURE 6 – Internally consistent configurations: proximities indicators (left) and number of common hypotheses (right).

Morphol performs an evaluation of the distances between scenarios based on the calculation of the number of common configurations between them, and displays the results in a 2-D proximities map and in a proximity graph, as shown in Figure 7 and Figure 8, respectively. In addition to the distances between scenarios the proximity graph also enables the linkages between scenarios and the number of common hypothesis to be visualized.

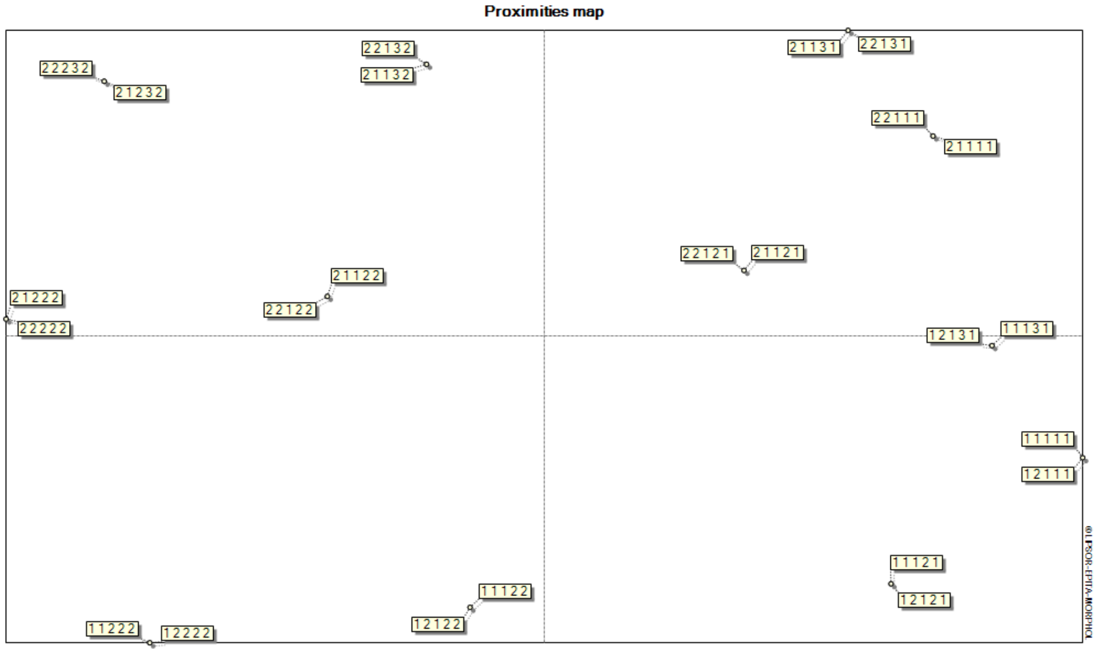


FIGURE 7 – Morphol software output: proximities map.

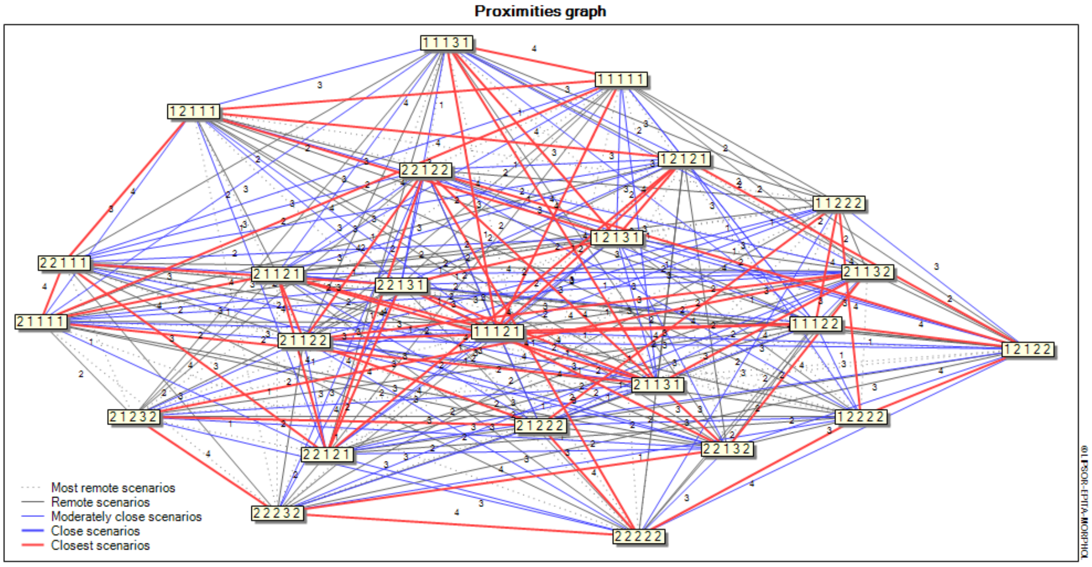
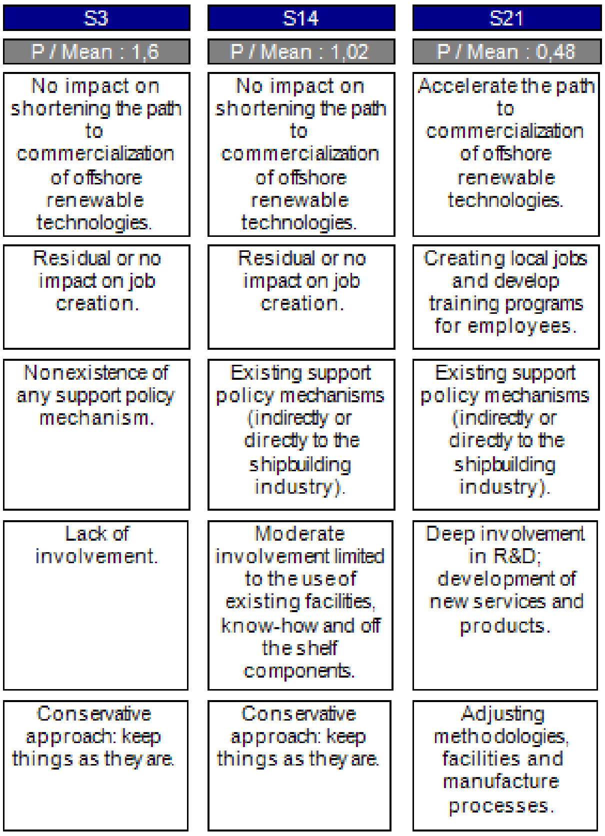


FIGURE 8 – Morphol software output: Proximities graph. The number in the linking lines represent the common hypotheses between scenarios.

5.4.2.1. Selection of scenarios

Finally, the major outcome from Morphol is the synthesis of the most representative configurations within the morphological space. These configurations might be used afterwards as a basis for the development of story lines or scenario narratives. Hence, in this study the criteria used to select scenarios was, on the one hand, the level of compatibility with other scenarios, which indicates how representative they are within the set of scenarios. This compatibility is expressed by the compatibility indicator CT (sum of common hypotheses that each scenario has with the other scenarios), shown in Figure 6. Furthermore, the criterion used is also based on the so called extreme-world method, which basically consists of creating extreme worlds by putting all the positively resolved uncertainties in one scenario and all the negatively resolved uncertainties in another scenario, in such a way that trends and resolved uncertainties coexist in those plausible future scenarios "(Goodwin & Wright, 2004)". This is justified by dynamics of the external environment regarding energy matters. Key issues, often related to society, technology sustainability or policy can change dramatically. In this context, the positive scenario comprises the positive impact uncertainties clustered together and its storyline is developed in a way that interlinks as many of these elements as possible. The main objective is to create a plausible chain of causally related events, in order to reveal a possible and plausible future within the predefined horizon. Afterwards, the same procedure is repeated for the negative scenario. Eventually, an extra scenario is selected to represent a reality in-between the negative and the positive configuration. Figure 9 displays the configurations of the three scenarios selected: S3 (22232- CT=47), S14 (22122- CT=63), and S21 (11111- CT=51). The next subsection presents the storylines for these three configurations, entitled "different worlds", "business as usual" and "blue ocean"



S3	S14	S21
P / Mean : 1,6	P / Mean : 1,02	P / Mean : 0,48
No impact on shortening the path to commercialization of offshore renewable technologies.	No impact on shortening the path to commercialization of offshore renewable technologies.	Accelerate the path to commercialization of offshore renewable technologies.
Residual or no impact on job creation.	Residual or no impact on job creation.	Creating local jobs and develop training programs for employees.
Nonexistence of any support policy mechanism.	Existing support policy mechanisms (indirectly or directly to the shipbuilding industry).	Existing support policy mechanisms (indirectly or directly to the shipbuilding industry).
Lack of involvement.	Moderate involvement limited to the use of existing facilities, know-how and off the shelf components.	Deep involvement in R&D; development of new services and products.
Conservative approach: keep things as they are.	Conservative approach: keep things as they are.	Adjusting methodologies, facilities and manufacture processes.

FIGURE 9 – Synthesis of the most plausible scenarios and its configurations.

Since the proximities graph is difficult to analyze, as there is a tangle of overlapping lines, In Figure 10 the proximities graph with only the scenarios selected in this study is represented, after scanning within the range of possible scenarios the most internally consistent configurations, i.e. the most plausible scenarios.

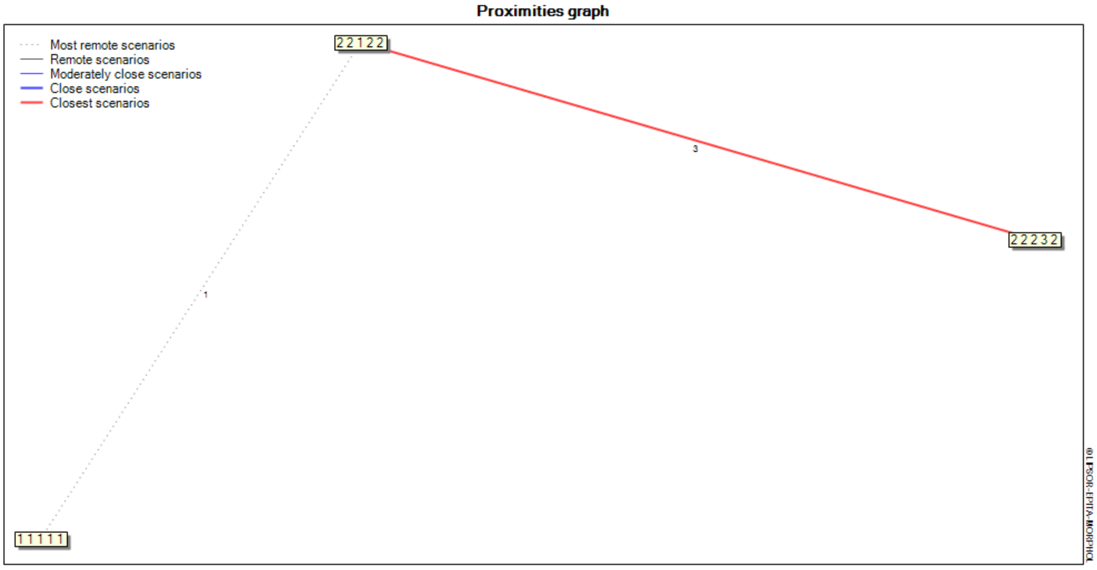


FIGURE 10 – Morphol software output: Proximities graph for the 3 scenarios selected.

5.5. Scenario narratives

This section presents the scenario narratives based on the morphological analysis performed. Ideally the narratives should be presented and discussed with experts in a last participatory event, in order to validate the scenarios. However, this was not possible due to limitations of agenda and geographical distance between participants. Nevertheless, the results were presented and discussed with some of the experts and a general agreement was obtained.

5.5.1. Scenario 1 – "Blue Ocean"

In the "blue ocean" scenario there is a perfect match between the overall strategic orientation of the shipbuilding industry and the specific needs of offshore renewables, supported by adequate policy mechanisms designed to promote and accelerate the investment in this new emergent sector. In this scenario, whose skeleton structure is shown in Figure 11, the shipbuilding industry sees the offshore renewable sector as a promising future market and as an alternative to revitalize itself and gain competitiveness to counter the decline that took place in the last decades, with the severe international competition from countries like China and South Korea.

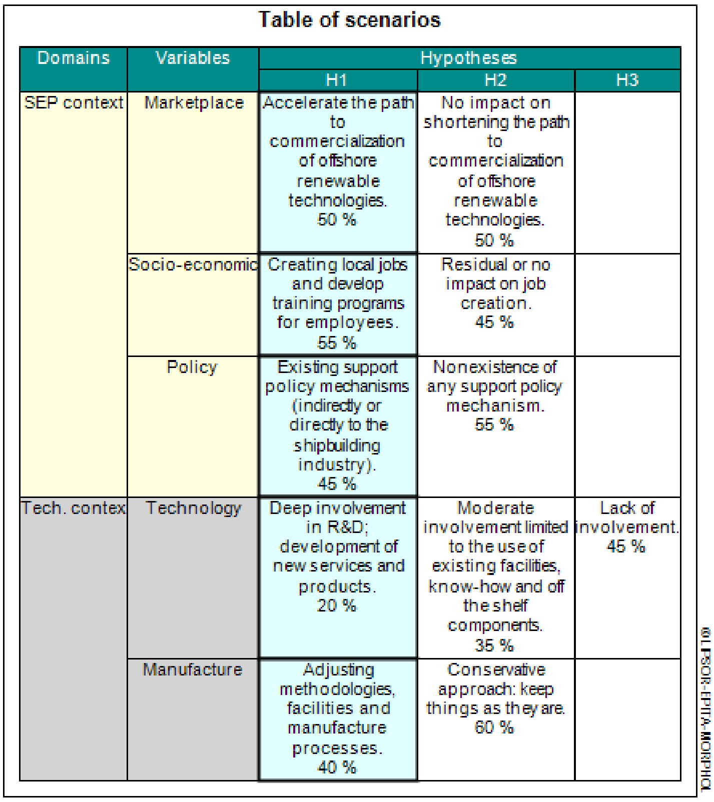


Table of scenarios

Domains	Variables	Hypotheses		
		H1	H2	H3
SEP context	Marketplace	Accelerate the path to commercialization of offshore renewable technologies. 50 %	No impact on shortening the path to commercialization of offshore renewable technologies. 50 %	
	Socio-economic	Creating local jobs and develop training programs for employees. 55 %	Residual or no impact on job creation. 45 %	
	Policy	Existing support policy mechanisms (indirectly or directly to the shipbuilding industry). 45 %	Nonexistence of any support policy mechanism. 55 %	
Tech. contex	Technology	Deep involvement in R&D; development of new services and products. 20 %	Moderate involvement limited to the use of existing facilities, know-how and off the shelf components. 35 %	Lack of involvement. 45 %
	Manufacture	Adjusting methodologies, facilities and manufacture processes. 40 %	Conservative approach: keep things as they are. 60 %	

FIGURE 11 – Skeleton structure of the scenario “blue ocean”.

The existence of support policy mechanisms designed specifically for shipbuilding, which include public subsidization to support shipyards facing the high levels of investment required for the development of vessels for O&M and installation, and for the rebuilding of shipyards to account for specificities of the offshore renewable technologies. Along with this process the transfer of knowledge and experience, adaptation of standards and classification procedures, design of best practices and manufacture processes take place, which is promoted in reeducation and training programs for employees.

Moreover, shipbuilding also plays an important role in technologic development. The industry has a major impact on the development/optimization of auxiliary systems, control, monitoring, seakeeping, assembly procedures, towing and installation processes and survivability strategies. This collaborative effort drives the development of new equipment and processes, more reliable and optimized services for O&M, installation and towing, which lead to a significant reduction in OPEX (operational expenditure) costs. In turn, this lowers the LCOE and consequently the perceived risk from investors decreases and so the cost of capital as well. A lower cost of capital has a strong impact on reducing CAPEX (capital expenditures) costs, which further reduces the LCOE. In the long run, offshore renewable projects become more attractive to investors, which endorses the growth of the sector, the revitalization of shipyards and so leads to direct and indirect job creation. Eventually, the competitive levels of the LCOE (reflected in customer's commercial pricing) and the impact on job creation along with the idea of sustainability and environmentally-friendly activities strengthens the public engagement with offshore renewables and related industries as well.

5.5.2. Scenario 2 – "Different worlds"

The scenario "different worlds", represented in Figure 12, relies on the belief that offshore renewable and shipbuilding are completely separate industries. In this scenario, the conservatism and reluctance of shipbuilding to extend their activity to a new and more innovative field prevails. Hence, the shipbuilding industry doesn't see the offshore renewable sector as a sufficiently promising future market so that it could be an alternative for its own revitalization, modernization and providing an opportunity to regain of competitiveness to counter the decline in the last decades.

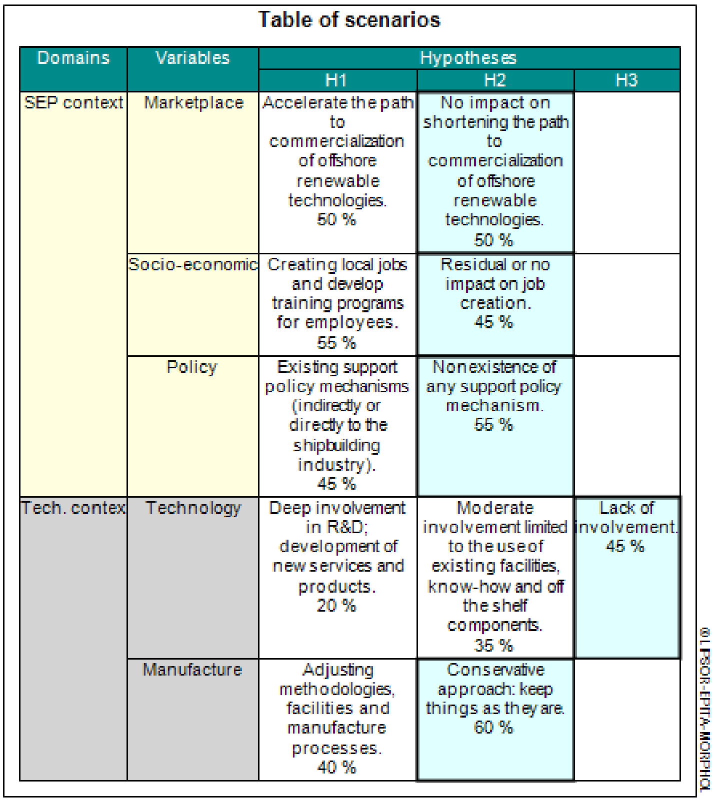


Table of scenarios

Domains	Variables	Hypotheses		
		H1	H2	H3
SEP context	Marketplace	Accelerate the path to commercialization of offshore renewable technologies. 50 %	No impact on shortening the path to commercialization of offshore renewable technologies. 50 %	
	Socio-economic	Creating local jobs and develop training programs for employees. 55 %	Residual or no impact on job creation. 45 %	
	Policy	Existing support policy mechanisms (indirectly or directly to the shipbuilding industry). 45 %	Nonexistence of any support policy mechanism. 55 %	
Tech. contex	Technology	Deep involvement in R&D; development of new services and products. 20 %	Moderate involvement limited to the use of existing facilities, know-how and off the shelf components. 35 %	Lack of involvement. 45 %
	Manufacture	Adjusting methodologies, facilities and manufacture processes. 40 %	Conservative approach: keep things as they are. 60 %	

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FIGURE 12 – Skeleton structure of the scenario “different worlds”.

There is no in place support policy mechanisms designed specifically to modernize the shipbuilding industry (e.g. subsides to develop tailor-made vessels for O&M and/or installation, or to modernize shipyards to face the specific need of offshore renewable technologies) or to promote incentives in order to shorten the route to commercialization and make offshore technologies competitive in the market place (feed in tariffs). The non-existence of public investment deters the private-sector investment in renewable energy and so the sector does not bloom at a speed desired. Eventually, this lack of investment slows the ability to reduce the LCOE to levels that make offshore renewable technologies competitive in the energy market. Consequently, the expectancy that the higher costs of renewable electrical production will be reflected in the customer’s commercial pricing reduces the social acceptance towards the implementation of offshore renewable energy plants. This faltering start, characterized by the non-existent exploitation of synergetic relationships with related industries, does not allow the sector to grow in a sustainable way, so it cannot generate employment (both direct and indirect jobs), strengthen energy security and boost social and economic well-being.

5.5.3. Scenario 3 – "Business as usual"

The in-between scenario "business as usual" gathers some of the characteristics of the two previous scenarios. The skeleton structure of this scenario is shown in Figure 13.

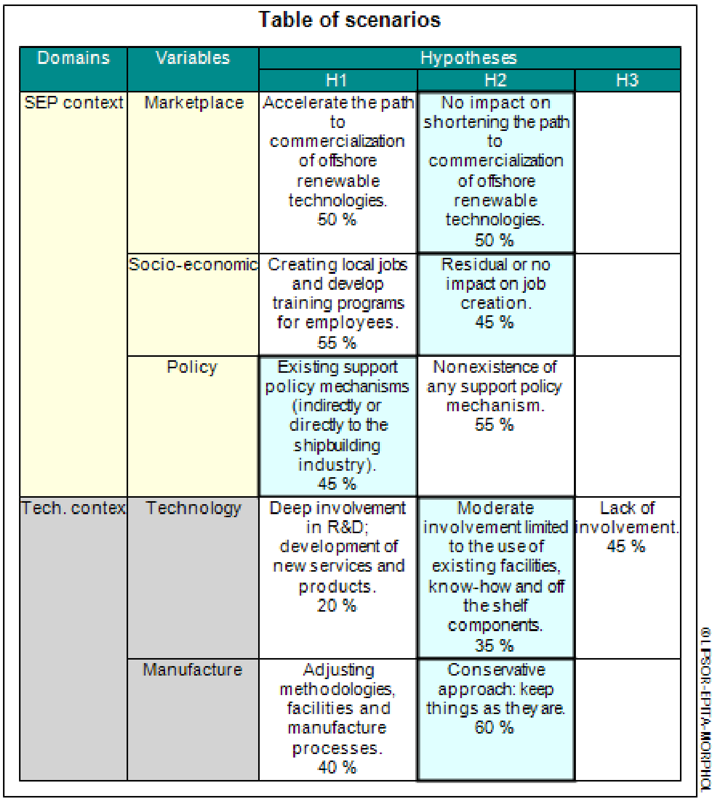

Table of scenarios

Domains	Variables	Hypotheses		
		H1	H2	H3
SEP context	Marketplace	Accelerate the path to commercialization of offshore renewable technologies. 50 %	No impact on shortening the path to commercialization of offshore renewable technologies. 50 %	
	Socio-economic	Creating local jobs and develop training programs for employees. 55 %	Residual or no impact on job creation. 45 %	
	Policy	Existing support policy mechanisms (indirectly or directly to the shipbuilding industry). 45 %	Nonexistence of any support policy mechanism. 55 %	
Tech. contex	Technology	Deep involvement in R&D; development of new services and products. 20 %	Moderate involvement limited to the use of existing facilities, know-how and off the shelf components. 35 %	Lack of involvement. 45 %
	Manufacture	Adjusting methodologies, facilities and manufacture processes. 40 %	Conservative approach: keep things as they are. 60 %	

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FIGURE 13 – Skeleton structure of the scenario "business as usual".

In this scenario, the shipbuilding industry shows a moderate interest in the offshore renewable energy industry, which is perceived as a potential way to develop new products/processes and services and, to some degree, exploit the installed capacity in different activities (e.g. existing vessels adapted for O&M, installation and towing). In this sense the role played by the shipbuilding industry is bounded by the use of existing facilities, know-how and off-the-shelf components. This involvement is supported by policy mechanisms designed specifically to modernize shipyards, since the industry cannot undertake the high costs without subsidies awarded by governments (e.g. subsides to development or adapt vessels for O&M and/or installation, to modernize shipyards to face the specific need of offshore renewable technologies). Support policy mechanisms include also feed in tariffs to promote incentives in order to shorten the route to commercialization and to make offshore technologies competitive in the market place. Nevertheless, in time frame of 15 years, these support policy mechanisms bring in to the offshore energy sector an additional political and economic uncertainty since investors and financial institutions see these policy mechanisms as a commercial risk. Therefore, the private-sector investment in renewable energy does not follow the government efforts and so the sector does not bloom at the desired speed.

Thus, as in the “different worlds” scenario the lack of investment prevents the sector from being competitive and the high LCOE associated to offshore renewable technologies increases the cost of capital and the perceived risk, which increase even more the LCOE and further deters investors. As a result, the global perception that the costs of renewable electrical production are higher than conventional sources and that this represents an additional cost to be charged to consumers affects the social acceptance and blocks the large-scale implementation of offshore renewable.

In this context, although the shipbuilding industry shows a moderate interest in marine renewables, the exploitation of synergies is not priority, which blocks the progress of renewable sector. Consequently, in the long-term of 15 years, the sector cannot grow and flourish sufficiently and so its impact in improving sustainability and employment generation is residual, in addition to its contribution to the energy mix and energy security.

6. Conclusions

This study explores draft scenarios focused on the renewable energy industry, with the main goal of decoding potential synergies between marine renewables and the shipbuilding industry, where socio-economic, environmental and technological aspects are integrated in a holistic framework. The study is essentially a prospective joint project with key stakeholders who brought invaluable perspectives and insights on both political and practice knowledge, which is crucial to build and explore plausible futures. Therefore, the analysis performed aims to further clarify the benefits for the development of the marine renewable sector, in the European context, that may result from synergetic linkages with the shipbuilding industry, in a time frame of 15 years. In addition, the current study also aims to improve the awareness on how this new emergent sector can contribute to revitalize and modernize the shipbuilding industry and reverse the loss of competitiveness in recent years.

In this context, the morphological method was applied, since it is a fairly simple and systematic approach to build and explore possible futures through the analysis of the combinations resulting from the decomposition of the system problem in problem variables. In this study the Morphol software, based on the morphological method, was applied because it enables to build scenarios in a user-friendly manner. The software comprises essentially two major features: The first one is the characterization of the morphological space by breaking-down the system into its components, where each of them can assume several configurations so that the number of possible scenarios is given by the number of combinations of configurations. Since the combinations can expand exponentially the second major feature of the Morphol consists of reducing the morphological space through the introduction of exclusion criteria. At this point some difficulties were experienced, as the software showed some inconsistency when exclusions included the combination of more than three hypotheses (possible evolution of the problem variables).

Nevertheless, the code was applied successfully so that we resulted with a set of 24 plausible combinations, or future scenarios. From this set of scenarios three were selected based on the extreme-world method, which consists of creating extreme worlds by putting all the positive uncertainties in one scenario and all the negative in another scenario. This method was applied due to the extreme changeable dynamics of the external environment regarding energy matters. The third scenario represents a possible future in-between the negative and the positive configurations.

Hence, we end up with one scenario, named “blue ocean”, where there is a perfect symbiosis between the marine renewables and the shipbuilding industry. In this scenario, the shipbuilding industry sees the offshore renewable sector as a promising future market and an alternative to revitalize itself and gain competitiveness to counter the decline in recent years. In this context, there is a deep involvement of shipbuilding in the offshore renewable sector, which is encouraged by the existence of support policy mechanisms designed specifically for the shipbuilding industry. This deep involvement promotes the reduction of LCOE and the perceived risk from investors (and so the cost of capital) making the offshore technologies more competitive in the energy market. These conditions are conducive to increased investment, which promotes the sector growth, the job creation and eventually raises the public engagement.

The opposite scenario, named “different worlds”, relies on the belief that the conservatism and reluctance associated to the traditionalism of shipbuilding prevents the industry from extending its activities into new and more innovative fields. In this scenario, there is no support policy mechanisms designed specifically to modernize the shipbuilding industry, or incentives to make offshore technologies competitive in the short term. Therefore, the lack of investment (both public and private) limits the industry's ability to improve the technology and reduce the LCOE, which, in turn, lessens the capacity of marine renewable technologies to be competitive in the energy market. The possibility of reflecting in customer’s commercial pricing the higher costs of renewable electrical production deters consumers and lessens social acceptability. Eventually the lack of competitiveness prevents the growth of the sector in a sustainable way, which slows the capacity to create direct and indirect jobs, strengthen energy security and boost social and economic well-being.

The in-between scenario “business as usual” gathers some of the characteristics of the two previous scenarios. In this scenario, the shipbuilding industry shows a moderate interest in offshore renewables, but is limited to the share of existing facilities/shipyards, know-how transfer and off-the-shelf components. This involvement is rooted mainly in incentives and subsidies awarded by governments with the specific purpose of modernizing shipyards, and accelerating the cost-effectiveness and competitiveness of offshore technologies. Although, the private-sector sees these support policy mechanisms as an additional political and economic uncertainty, which is translated into a commercial risk. Therefore, as in the “different worlds” scenario the lack of investment prevents the sector from being competitive and the global perception that renewable electrical production is too expensive affects the social acceptance and blocks the large-scale implementation of offshore renewable plants. Consequently, in the long-term of 15 years, the growth of the sector is insufficient to improve sustainability and generate large-scale employment. Although this study is a preliminary approach that needs to be further substantiated, the three selected scenarios seem to indicate that to secure the sustainable commercial success of offshore renewable energy it will be crucial to explore synergies with related industries in order to lower the LCOE of offshore power plants. Furthermore, there also seems to be a dependence on government support in the start-up phase of this new offshore sector in order to promote synergetic linkages between related industries. Nevertheless, it is essential to design policy support mechanisms very carefully so they are not seen by the private-sector as a commercial risk, which may discourage private investment.

As a final remark, it is important to highlight that the main purpose of this study was to test the suitability of the methodological approach, based on morphological method, for building scenarios focused on the renewable energy industry, and not to obtain definitive answers to the problem under study. Therefore, several simplifications in the analysis were considered. For instance, the reference to offshore renewables technologies was generic throughout the study; however, there are significant differences among the diverse offshore renewables sources as regards TRL, MRL or LCOE (e.g. bottom fixed wind is in a more advanced stage of development than floating wind, and floating wind more advanced than wave or tidal energy).

Given the fairly narrow scope of this study and the need to consider further assumptions to simplify the problem, it was admitted that all the problem variables were key variables. However, in future works, it should be used another more appropriate approach. For instance, a better approach might be to filter the problem variables, based on the information collected from experts, in order to isolate those that are more relevant for the problem characterization (i.e. key variables).

As a further work, it would be pertinent to use the same methodology in a study with a wider scope focused on building and exploiting offshore renewable energy scenarios to decode alternative energy pathways. In this framework, it could be interesting to explore, in an integrated and holistic approach, the synergic impact on the offshore renewable sector, and vice versa, of other related industries, besides shipbuilding, such as oil and gas, aquaculture and heavy steel manufacturing along with the interlinkages between them.

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Annex A: Participating entities – Brief description

Table A I presents a short description of the activity/ies of the companies that employ the experts who participated in the survey, in order to highlight the alignment of the company activities and the matters treated in this study. It is important to mention that the views and opinions expressed in this study are just the views or beliefs of the experts and not the official position of the company.

TABLE A I.
Brief description of the activity of the companies that employ the experts who participated in the survey.

Companies
LOC – Group LOC is an independent marine and engineering consultancy and survey organization established in London in 1979. Since then, LOC has being providing services to the shipping and offshore energy industries with business focused on all aspects of transportation and construction in the marine environment and upon the accidents and disputes that might arise. LOC has grown into an international, multi-disciplinary organization, with offices across the world. Based on technical expertise and hands-on experience, LOC have become a recognized industry leader in all of our fields of activity. *R V Ahilan. Group Director, Renewables Advisory & Energy Technology | London, UK*
EDP – Energias de Portugal **EDP is the Portuguese electric utility company.** EDP is a leading company in the energy sector; being among the major European operators in the energy sector; one of the largest energy operators of the Iberian Peninsula, the largest Portuguese industrial group and the 3rd largest producer of wind energy. Besides the electricity sector - generation, distribution and trading – EDP is also present in the gas sector of the Iberian Peninsula. EDP holds significant electricity and gas operations in Europe, Brazil and the United States, including a strong renewable generation profile. EDP integrates the Dow Jones Sustainability Indexes World for the eighth consecutive year, the world's most demanding ranking, that distinguishes the best performing companies on issues related to transparency, sustainability and excellence in economic management and social environment. *Pedro Valverde. Engineer at EDP Inovação| Lisbon, Portugal*
ASM INDUSTRIES Founded in 2007, ASM INDUSTRIES is the sub-holding of A. SILVA MATOS GROUP dedicated to the renewable energy sector. Its core business is the manufacturing of steel equipment for onshore and offshore applications, through its subsidiary ASM ENERGIA. ASM ENERGIA, dedicated to the manufacture of heavy steel equipment, has an installed capacity with cutting edge technology, superior quality and competitive price. Following the philosophy of total quality and excellence of A. SILVA MATOS GROUP founded in 1980, ASM ENERGIA supplied, since 2006, more than 3500 steel sections for wind towers, especially for the European and South America markets, presenting itself as a reference supplier, ensuring its customers a long-term vision, high levels of quality and competitiveness. ASM INDUSTRIES owns also the subsidiary ASM RENEWABLES, which is dedicated to the investment in technologies or projects which can add value to the core business of the Sub-Holding. *Nuno Sá. Chief Operating & Development Officer at ASM INDUSTRIES| Sever do Vouga, Portugal*

WavEC Offshore Renewables

WavEC Offshore Renewables is a private association created in 2003 devoted to the development and promotion of offshore renewable energy through technical, logistic and strategic support to companies and public bodies. WavEC has long experience in offshore renewables at R&D level and at conceptual, design, construction, deployment and operational phases. Furthermore, WavEC has been working actively in the identification and mitigation of the main technological and non-technological barriers in order to shorten the path to commercialization on marine renewable technologies. WavEC is currently formed by 13 associates that recognize the need for cooperation, both on national and international level, to accelerate the development of an offshore renewable sector.

António Sarmento. President of the Board of WavEC Offshore Renewables| Lisbon, Portugal

MARIN – Maritime Research Institute Netherlands

MARIN, the Maritime Research Institute Netherlands, is one of the leading institutes in the world for hydrodynamic research and maritime technology. The services provided combine numerical simulation, model testing, full-scale measurements and training programs and the results from fundamental research are directly integrated in applications for clients. MARIN provides services to the shipbuilding and offshore industry and governments. Customers include commercial ship builders, fleet owners, naval architects, classification societies, oil and Liquified Natural Gas (LNG) companies and navies all over the world.

Guilherme Vaz. Senior researcher at MARIN| *Wageningen, Netherlands*

CENTEC – Centre for Marine Technology and Ocean Engineering

The Centre for Marine Technology and Ocean Engineering (CENTEC), is a research center of *Instituto Superior Técnico* (IST), the University of Lisbon school of engineering. CENTEC concentrates its activities on developing scientific research on areas such as risk analysis, safety and reliability, maritime transport and ports, ocean space utilization (including coastal areas), exploration and exploitation of marine resources and protection of the marine environment and its resources. Furthermore, CENTEC puts significant emphasis on promoting knowledge transfer to the industrial and tertiary sectors and its application to sustainable exploration and exploitation of marine resources.

Sérgio Ribeiro e Silva. Assistant Professor at CENTEC| Lisbon, Portugal

APPA – Spanish Renewable Energy Association

The Spanish Renewable Energy Association (APPA) is the reference association of renewable energy in Spain. It brings together more than 500 companies and entities that carry out all clean technologies (e.g. biofuels, biomass, wind, geothermal, hydro, marine, small wind, solar photovoltaic and concentrated solar power). The section APPA Marine is composed by about twenty companies interested in exploiting ocean energy resources, which aspire to lay the foundation for the development of this technology in Spain. APPA Marine develops efforts to gather government support in order to make ocean renewable technology viable with a remuneration commensurate with the costs of generation and achieve the specific objectives of installed capacity by 2020.

Francisco García Lorenzo. President of APPA Marina| *Madrid, Spain*

EDP Renewables

EDP Renewables is a leading, global renewable energy company devoted to value creation, innovation and sustainability. EDP Renewables operate in markets around the globe and has been continuously expanding the business to new regions. EDPR has developed wind farms since 1996 and was first listed publicly in June 2008. EDPR's global presence is managed by two regional platforms which oversee the development, construction and operation of assets in their geographic areas. EDPR Europe, headquartered in Madrid, manages assets located in the European Union and EDPR North America, headquartered in Houston, manages assets in the United States and Canada. EDP-Energias de Portugal, S.A., a vertically-integrated utility company, headquartered in Lisbon, Portugal, is the majority shareholder of EDPR.

Felipe Castillo. Engineer at EDPR| *Seville, Spain*

Principle Power, inc.

Sandia National Laboratories is operated and managed by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation. Sandia Corporation operates Sandia National Laboratories as a contractor for the U.S. Department of Energy's National Nuclear Security Administration (NNSA) and supports numerous federal, state, and local government agencies, companies, and organizations. As a Federally Funded Research and Development Center (FFRDC), Sandia performs work for industry responding to certain types of federal government solicitations. A strong science, technology, and engineering foundation enables Sandia's mission through a capable research staff working at the forefront of innovation, collaborative research with universities and companies, and discretionary research projects in the following strategic areas: nuclear Weapons, defense Systems & assessments, global security and energy & climate.

Diana Bull. Senior researcher Sandia National Laboratories| Albuquerque, US

Bombora Wave Power.

Founded in 2012, Bombora is an ocean energy company located in Perth, Western Australia, that strives to create renewable energy solutions with a positive impact on our environment and our community. Bombora has been developing an innovative wave energy device for five years able to deliver environmentally friendly, large scale energy for national electricity grids. Bombora wave farms can be deployed in coastal locations throughout the world.

James McCarthy-Price. Engineer at Bombora Wave Power| Bentley, Australia