Methodology for assessing multiple combined wind and ocean energy technologies as part of the EU FP7 MARINA Platform Project

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Abstract

The integration of wind turbines and ocean energy devices in combined platforms has obvious advantages but also poses major challenges. Not least is the fact that the ocean energy industry is at a very early stage of technological development whilst the offshore wind industry forges ahead. In view of this the FP7 MARINA Platform project has the objective of presenting by 2014, three combined wind and ocean energy concepts which will have been studied to an advanced stage of development. Already the concept generation phase of the project has been completed with in excess of 100 concepts being created or identified. The concept assessment is in progress but in order to critically evaluate such a diverse group of concepts, including fixed and floating platforms with individual or multiple wave energy convertors, robust evaluation techniques were required that could grow in sophistication as the number of concepts remaining diminished.

The evaluation methodology developed, outlined in this paper, involved an initial screening process which required the concepts to satisfy five basic criteria. At the more detailed stages, physical and numerical modelling, economic calculations and technical studies were undertaken to produce the ten concept types considered to have the most potential.

Keywords: Combined, Offshore Wind, Technology Assessment, Wave,

1. Introduction

The work described in this paper was carried out as part of the EU FP7 MARINA Platform project [1]. The MARINA Platform Project is a 4.5 year funded project which began in 2010 and involves 17 project partners from across Europe, from research, industry and SME backgrounds. The main aim of the project is to provide three combined offshore wind-ocean energy platform concepts which have been assessed for numerical and physical modelling, risk, economics, critical component design, grid connection, resource assessment and site selection in Europe.

For both offshore wind and wave energy, moving further offshore has the advantage of greater energy levels in wind speeds and wave power levels.

Both floating/deep water offshore wind and ocean energy technologies have yet to become economical in their own right, in part due to the greater distances for cabling to shore and the more extreme environment and weather windows required for installation and O&M. However both technologies are also in early stages of development and have yet to converge on a given technology or achieve economies of scale.

Therefore deeper water brings with it economic and infrastructure requirements which could be shared if wind and ocean farms could be combined.

Sharing space is an obvious first step in combining the technologies but there is also a move towards sharing structure which is evident in the numerous concepts under development; the Poseidon [2], of which a scaled prototype has been tested in real sea conditions, and the proposed concept W2Power [3] for example.

Figure 1: Poseidon Wind and wave energy combined concept [2]

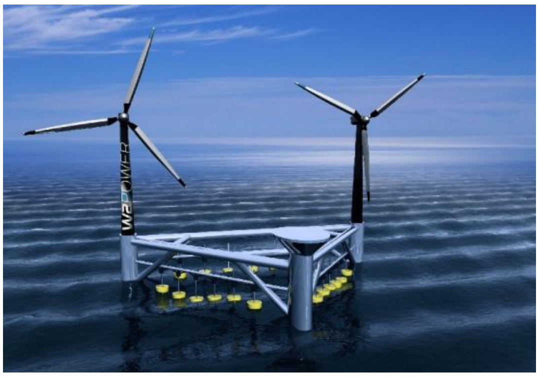

Figure 2: W2Power combined wind & wave energy concept [3]

The central body of work in the MARINA Project involves the creation of combined wind-ocean energy concepts and the subsequent assessment of these concepts to determine their feasibility based on input from technical aspects of the project. The project firstly generated as many concepts as possible (approx 100 created), and then assessed these concepts to reduce this number to the 10 most feasible concepts. These 10 concepts are currently being put through a more detailed analysis to arrive at the final 3 most promising concepts by December 2012. The public deliverable D3.3 [4] describes this process in detail however the objective of this paper is to provide a brief overview of the process used to filter these concepts to 10.

2. Overview of Concept Generation and Assessment Methodology

The following is a brief overview of the concept development and screening process in order to provide relevant background to the work outlined in this document. Figure 1 shows a flow diagram which describes the main stages of the work. Each of these, are described in more detail below.

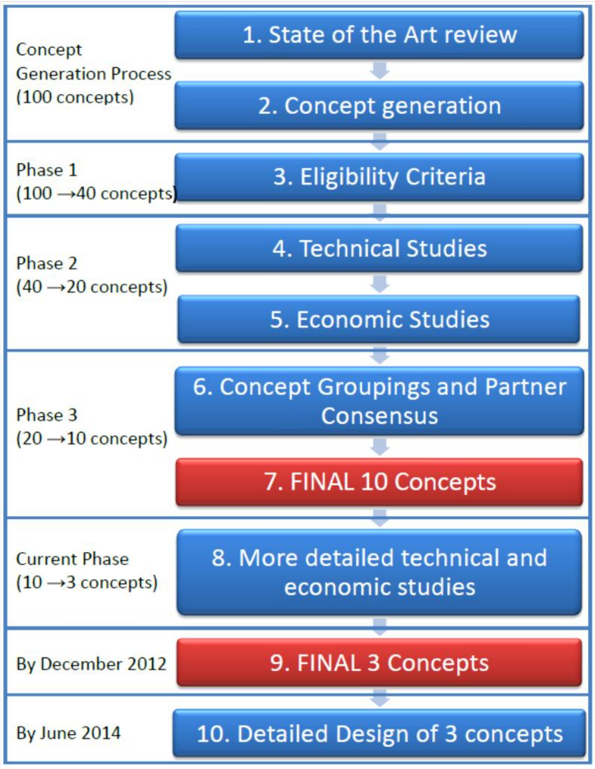

Figure 1: Flow Diagram of main stages in Concept Assessment

The concept generation process yielded a high number of diverse concepts (approx. 100). An initial screening was required to perform a quick appraisal to assess the various concepts and to discount concepts which obviously lacked potential. This process allowed 60% of the concepts to be discarded however a more technical assessment was deemed necessary to further screen the remaining concepts in order to reach the objective of 10 concepts. This assessment was designed to be an intermediate step between the screening and the detailed concept analysis which would be subsequently undertaken to decide the final three concepts.

This paper thus documents the methodology that was followed to analyse a large group of combined wind ocean concepts with the purpose to reach a critical number of potentially viable concepts i.e. 10. It is not a methodology that involves detailed design or numerical analysis and whilst it can be applied to one particular combined concept it has not been developed for this purpose. It is expected however that through the progression of the MARINA Platform project such a methodology may be developed.

3. Concept Generation Process

3.1. State of the Art Review

The partners in the MARINA Platform project have expertise in a variety of backgrounds from oil and gas, offshore wind, ocean energy, materials, structures etc. Therefore it was considered important to establish a basic awareness of all technologies by producing a state of the art document that would provide the consortium with a level of knowledge that would help stimulate concept generation. All partners were encouraged to provide feedback and information in their area of expertise, to ensure the most up to date information was included.

The report [5] gave an overview of the numerous wave and tidal energy devices, wind turbines and the alternatives e.g. high altitude turbines and vertical axis. For each technology type the criteria for spacing in a farm, structure, water depth, mooring requirements and rated power were outlined. The potential synergies between wind and ocean devices were discussed in addition to the potential constraints of their combination. Some existing combined concepts were summarised and discussed in an effort to begin the concept generation process.

This state of the art report proved to be a useful first step in the concept generation process and is soon to become an additional public deliverable from the project.

3.2. Concepts Generation

The first combined concepts list was compiled by internet and patent searches. This list was then greatly expanded by creativity sessions within the consortium in which various possibilities for combining wind and ocean energy technologies were “invented”. In addition wind and ocean energy device developers were invited to submit their concepts/ideas with the view that they would be expertly evaluated.

The concepts were sorted in a matrix with a square available for each combination of ocean energy technology and wind turbine support structure type across. These were further divided into concepts which simply shared space, called segregated concepts, and concepts which shared supporting structure, called integrated concepts.

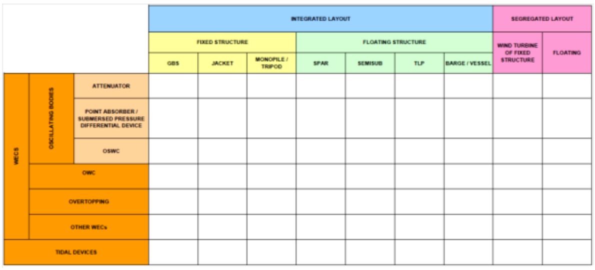

Figure 2: The initial concept matrix for generated concepts

Each partner was then tasked with generating concepts to fill the empty cells in the matrix. In some cases it was deemed not physically possible for these combinations to occur and the cells remained empty. In total 100 combined concepts were generated and included in the concept matrix.

4. Phase 1: Initial Screening

4.1. Eligibility Criteria

The first evaluation of the generated concepts had the purpose of discarding the less promising concepts and optimising the design of others. For this purpose a basic set of evaluation criteria was developed consisting of 5 main points, outlined in Table 1 below.

These criteria provided a first filter to determine which concepts should be included in the project. It was assumed that some of the retained concepts may require some alterations to become feasible.

1: Physically possible.
Some of the combined concept patents which were found do not comply with physical laws and materials properties: density, strength, admissible accelerations, etc.
2: Only positive synergies.
One technology must not jeopardise the integrity or the working principle of the other.
3: Admissible engineering.
The combination should not require extensive engineering design or create excessive difficulties in the engineering.
4: Acceptable complexity.
A combined concepts must not introduce too much complexity relative to the simplicity of the individual elements
5: Balance between operational complexity & economics.
Is there an acceptable balance between the economic benefits provided by the combination and the operational complexity of the combined device?

Table 1: Initial Assessment Criteria

It was then deemed necessary to add a second filter regarding technology readiness level (TRL).

As the MARINA Platform project has a 4 year timeframe and therefore has a set limitation on its resources, some low TRL (technology readiness level) technologies could not be investigated in depth within the constraints of the project. Therefore, some technologies were “parked” for that reason. However they are not fully discarded, they are considered suspended until such time as new information arises or they experience a significant advance during the timeframe of the project.

The following flow diagram illustrates how the criteria described above were applied:

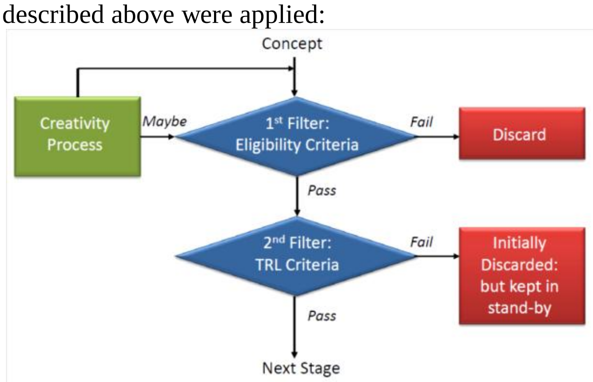

Figure 3: Concept assessment process using criteria

1st Filter - Eligibility criteria

For each concept the five criteria were given a response of YES, NO or MAYBE. If a concept received a “NO” for any of the criteria it was discarded from the assessment. If a concept received a “MAYBE” to one or more criteria (without any "NO" response), the concept was set aside for further study before a final decision was made. The aim of this "2nd chance" was to avoid potentially losing valuable concepts.

2nd Filter - TRL criteria

Concepts with a very low TRL technology received a "NO" and were suspended from further planned evaluation as described above with the intention that they could be re-introduced as new information became available.

4.2. Partner Consensus

Project partners were divided into a number of groups and asked to individually assess a given number of concepts for each of the criteria listed above and to include explanatory comments. Partners were chosen based on their expertise in certain technologies and thus the assessment was an informed process based on partner experience and knowledge. A compilation of all assessment comments were then distributed to the partners in the group. A teleconference was subsequently held to discuss these and gain a consensus decision on each concept.

This procedure is based on the Delphi Method [6] of brainstorming and allows each member to submit their comments and then to alter their opinion once all available comments are shown. This technique ensured that all members' comments were heard and no dominant personality or "group think" could override the group, ensuring that a genuine consensus was reached.

4.3. Concept Grouping

The remaining concepts were then grouped according to similarities in structure, water depth and technology in order to facilitate the comparison and ranking of the most promising concepts in each category.

The concept groups indicate a water depth range, structure type and integrated or segregated layout; they include:

Group	Structure Type /Water Depth	Structure Size	Number of wind turbines	Ocean Energy Technology	Shared Structure or Space
A	Either	Single	Single	Tidal	Both
B	Fixed	Single	Single	Wave	Integrated
C	Fixed	Large	Multiple	Wave	Integrated
D	Floating	Single	Single	Wave	Integrated
E	Floating	Large	Multiple	Wave	Integrated
F	Fixed	Single	Single	Wave	Segregated
G	Floating	Single	Single	Wave	Segregated

Table 2: Concept Groups A-G

The remaining concepts within each group were then discussed to attempt to improve upon or combine them.

A number of teleconferences were held to discuss and attempt to further eliminate the concepts using the groups outlined above. A natural progression from this was the comparison of concepts with similar principles such that if one concept had consensus as being the stronger candidate, then the other was eliminated as secondary to that within the same group. In other cases, an improvement could be made to one or more similar concepts and thus a new concept was added, replacing the others in the group for the continuing evaluation.

4.4. Results of Initial Screening

At the close of the initial screening phase there were a total of 37 contending concepts with "yes" or "maybe".

Several questions were raised in the discussions regarding the suitability of some combinations and therefore several "ad hoc" technical studies were carried out to shed light on these issues.

Figure 4 below illustrates the table used to show the status of the concepts after the initial screening phase and the subsequent sections will describe how these issues were addressed.

	A Fixed/Floating Structure + Tidal Energy device + Wind	B Single Fixed WT + WECs	C Large Fixed Structure with WTs + WECs	D Single Floating WT + WECs	E Large Floating Structure with WTs + WECs	F Segregated Fixed WTs + WECs	G Segregated Floating WTs + WECs
YES							
MAYBE (topics related to be studied)							
LOW TRL (Not enough information, so left in stand-by)							
NO (Discarded)							

Figure 4: Table used to show status of all concepts after initial screening process

5. Phase 2: Technical and Economic Studies

Throughout the initial screening process a number of technical questions regarding performance, motions and loadings of certain combined concepts were raised which could not be answered without more detailed information. In addition partner meetings and discussions concluded that economic issues related to concept development could be a definitive way of identifying the most suitable concepts. Therefore a number of technical studies were organised and undertaken by the partners and economic assessment tools were also developed.

5.1. Technical Studies

During the initial screening process, a number of queries were raised resulting in a large number of "MAYBE" results. The queries for example related to the rated and actual performance of devices; allowable and actual motions of a device on a platform; and allowable loadings of structures. It was therefore necessary for a number of technical studies to be performed to gain an insight into these issues before further reducing the number of suitable concepts. A list and detailed specifications of each such *ad hoc* study was prepared with their, their considered priority and the likely subject group which could provide insight into the topic.

All of the questions raised were sorted into subject categories so that 8 studies were organised to address them. Based on their expertise, partners were assigned to contribute to a study, with one or more partners dedicated as leaders of that particular study.
As much of the required knowledge for the studies was related specifically to the activities of groups of partners in the project some of the studies were undertaken by these relevant partners.

1	**Offshore Wind Turbines**
	Vertical axis wind turbines, Spacing requirements of floating and fixed horizontal axis wind turbines in a farm and mooring requirements, Structural loading of fixed wind turbine foundations Floating platform stability
2	**Performance of wave energy converters (WEC)**
	Collecting power matrices, Estimating power output, Scaling of performance figures using tank testing Cost estimations
3	**Characteristics of Combined Resource**
	Potential combined resource, directionality, time correlation
4	**Economics**
	Combined economics of wind and wave energy devices

Table 3: List of technical studies

The following sections outline each of the studies, the partners involved and the relevant findings, however the reports will only be made publically available at the discretion of the relevant partners.

5.2. Results of Technical Studies

The primary benefit of the technical studies was the input they provided into the economics tools, however they also allowed the elimination of certain concepts based on new information.

- The ***VAWT study*** concluded that while advantages may exist by having a VAWT on a floating platform in terms of weight distribution and service access, there are too many unknowns surrounding the VAWT performance and characteristics for the scope of the MARINA Platform project and as such VAWT concepts were eliminated from the list of concepts to be studied further.
- The ***Wind farm layout study*** gave important feedback regarding the spacing of wind turbines on a platform i.e. that if the platform cannot be ensured to weather vane according to the wind, it is preferable to have all turbines on one row. This has been applied to the relevant multiple wind turbine concepts.
- The ***mooring radius*** information supplied by this study has been fed into the comprehensive economics tool to calculate mooring length for catenary moored platforms and to calculate the spacing of devices in a wind farm for cabling length calculations.
- The 2 methodologies for calculating power output produced in the ***WEC study*** allows the power contribution to be expected from a given dimensioned and positioned WEC on a platform to be estimated.
- The ***resource study*** provided interesting information with regards to the correlation of resources such that the wave time series tends to lag the wind by between 1 and 5 hours for the cases considered [7]. The EU FP7 ORECCA project output also provided important resource information [8] and in particular highlighted potential difficulties in site selection [9] for wind-tidal combinations.
- The ***fixed foundation studies*** allowed the cost of a given foundation in a given water depth to be estimated and it has shown that in most cases the cost increases linearly with water depth.
- The cost of fabricating various types of floating platforms was provided to the economics tool by the ***floating platform study***. It was found that the spar concept gives the lowest cost for various water depths greater than 150m.

5.3. Economic Assessment

Initially some method of economic assessment was discussed in the meetings to provide an indication of cost comparison in order to select the most promising concepts. Hence a comparative assessment tool was developed to achieve this.
In parallel to this, work was being carried out to produce a comprehensive economics assessment tool with cost figures for all aspects of a project. It was not initially expected to be available in time to be of use to the concept assessment stage. Therefore there are 2 economics tools available to the project each suitable for different stages in concept assessment.
The first stage tool gives indicative cost of energy (COEI) figures for the device, ignoring moorings, cabling etc. This was deemed sufficient to provide information on the scale and cost of fabricating the device itself in comparison to the expected energy output of the combined device.
A second stage detailed deterministic economics assessment tool has also been developed which added further value to the concepts assessment. It is expected that this tool will be further developed over the coming months in order to provide a more detailed assessment to select the final 3 concepts.
Each of the technical studies outlined above provided economic figures relating to their respective subject and these were included in the detailed economics assessment tool along with other feedback from project partners.

5.3.1. 1st Stage: Comparative Economics Tool

Background

The comparative economics tool was developed in order to provide a method of simple comparative assessment of numerous combined concepts to provide a starting point for the economic assessment of the concepts. The wave energy converter power output used is based on the adapted capture width ratio methodology presented in EWTEC 2011 [10].

This economics tool simply considers base percentage costs. Additional detail of the contributing sub-costs was considered too complex for a purposefully simplified tool. Therefore this tool uses a simplified capital cost method.

The parameters for ocean energy costs were taken from the Equimar project results [11], which identified construction as the greatest cost. Other costs were assumed to be independent of device type for simplification and so were disregarded for the purposes of this tool.

As the costs are not fully quantified in this tool a "**cost of energy indicator**" (COEI) is used in place of the standard cost of energy (COE) figure. This COEI can be used comparatively across different concepts.

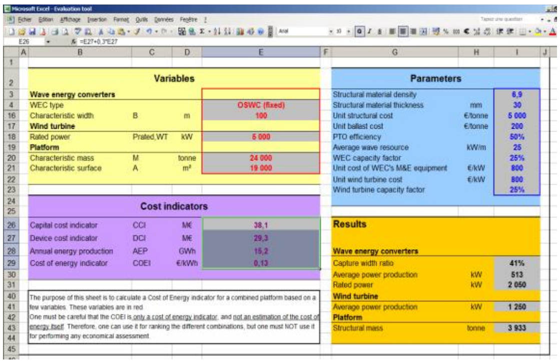

Figure 5: Example output screen of the Comparative Economics Tool

5.3.2. 2nd Stage: Comprehensive Economics Tool

Background

The objective of the more comprehensive economics tool is to estimate the power output of a combined wind/wave energy platform, with estimations for capital expenditure (CAPEX) and operational expenditure (OPEX), to generate an estimated cost of electricity (COE). Many of the costs have been taken from literature, correspondence with relevant suppliers and from the technical studies outlined above. Other figures and recommendations have been taken from an economic software model being developed within the Hydraulics and Maritime Research Centre.

Inputs

The primary inputs to the tool fall under the following headings:

- Site resource, water depth, distance from shore
- Wave energy power output – based on a power matrix and scaling factor
- Platform structure surface area and material
- Wind turbine rating
- Mooring system, line length, material & anchor
- Feed-in tariff

Outputs

The tool provides the following outputs among others:

- Capital Expenditure (CAPEX)
- Operational Expenditure (OPEX)
- Cost of Energy (COE) & Levelised COE (LCOE)
- Annual Energy Output (AEO)
- Total Lifetime Cost (TLC)
- Net Present Value (NPV)
- Internal Rate of Return (IRR)

5.4. Results from Economics Tools

In order to normalise and compare the results from the two tools, standardised figures were developed and inputted into both economic tools in order to provide rankings of the concepts.

Results from both tools placed the same 8 concepts in their top 10 ranked concepts. The remaining 2 concepts that were not in agreement were in the others top 10-15 concepts which is in very close agreement.

6. Selection of 10 concepts

6.1. Requirement for Further Discussion

The findings of the technical and economic studies resulted in further concepts being discarded as unsuitable or unfeasible however there still remained a large number of concepts which needed to be reduced to 10.

The results of the two economics tools were presented and discussed amongst the partners. As a result of this meeting, there was agreement that concepts could not be assessed on economics alone at this stage and other factors such as constructability and installation would need to be taken into account.

Many of these factors could not be quantified and so partner experience was prevailed on to reach consensus on the viability of certain concepts. To this end, a number of teleconferences were held with key partners to discuss the final 10 concepts.

6.2. Distribution of rankings among the basic groups

Once the rankings according to the economic tools were available and accepted, the rankings were applied to the basic groups categories used in the initial screening, in order to determine the most promising representatives of each group. This was then used as a starting point for the partner discussions held in December 2011.

6.3. Partner Discussions Meetings

Two teleconferences were held with the intention of using partner experience to reduce the number of concepts and to agree on the final selection of the 10 concepts. These included a number of relevant partners from both the wind energy industry and ocean energy.

Prior to each teleconference, each partner was provided with:

- a list of the concepts ranked by the 2 economics tools giving COEI and COE,
- Agreed concept groupings

During the discussions it was clear that there was consensus amongst the partners that a number of concepts stood out as the most promising, both according to economics and partner expertise.

6.4. Groupings of Similar Concepts

The concepts prior to the teleconferences were in 5 different groups based on their water depth and size. During the discussions there was agreement as to which concepts to group due to similarities in size, type of wave energy device, structure and water depth range. It was agreed that these similar concepts would be considered a variation on the same core concept and thus would all be analysed in the next stage of analysis in the optimisation of that core concept.

In this way 10 generic concepts were selected to be studied further with the aim of determining the most feasible 3 concepts for more in depth design.

7. Current Stage: Assessment of 10 concepts

7.1. Introduction

The main intention of the MARINA Platform project is to select 3 promising combined concepts by December 2012 and provide approximations for dimensions, rated power, shape, water depth and mooring type. Therefore the 10 concepts must be reduced to 3 based on detailed assessment. It is therefore intended that at this point there will be significant technical input into the concepts and in order for this to be successful, feedback and expertise from all project partners will be necessary. The work in the EU FP7 MARINA Platform Project covers a number of primary topics including:

- Site assessment and monitoring
- Concepts identification
- Modelling and testing
- Technology risk assessment
- Economic feasibility assessment
- Critical component engineering
- Grid connection and macro-system integration

The subsequent section specifies the expected future work based on these main subject areas.

7.2. Future work in concept screening

The majority of the remaining concept screening work will build on the technical and economic tools developed and described above and thus will involve physical and numerical modelling and adding further levels of detail to the economic assessment tool. Combined this work will give further understanding into the size, performance, stability and economic viability of the concepts. The modelling and economics will also require input regarding resource, farm layouts and mooring configurations among others.

Resource – Site Assessment and Monitoring

A resource modelling tool has been developed within MARINA which can provide atmospheric and resource data for any location in Europe. Currently this data is for internal use however it is likely that some form will be made available to the public in the near future.

In order to assess the commercial viability of concepts, a summary of the water depth and resource characteristics for a number of locations in Europe for combined wind and wave energy sites will be provided by the relevant partners.

In order to assess the viability of tidal and wind combinations, the tidal data collated in EU FP7 ORECCA Project [12] will be combined with wind data from MARINA to give the extent of the combined wind and tidal current resource in Europe.

An assessment [7] of the correlation of wind and ocean energy resources at a number of different sites in Europe has been produced. This will be extended to include other locations also to help identify the most suitable technologies for given sites (and vice versa).

Modelling and Testing

Existing small scale tank testing and numerical modelling will be extended to include the more specific concepts now identified. Indications of performance, motions and potentially loadings can be identified.

Partners will be performing numerical modelling and small scale physical model testing of the 10 concept groups in the next few months.

Technology Risk Assessment

There is little consideration of risk at this point as the primary risk assessment will be carried out once the 3 concepts have been identified. However a methodology for preliminary risk assessments of the concepts has been produced to aid this stage of the selection process.

Economic Feasibility Assessment

The work carried out thus far will allow the project to further develop the concepts with consideration for economic indicators to provide the most economically feasible versions of the available concepts.

The comprehensive economics tool will be further augmented and integrated with a financial risk analysis tool to give a more comprehensive and probabilistic calculation tool. This tool, to be finished at the end of 2012, will provide useful inputs during its development to the selection process.

Critical Component Engineering

An initial study was carried out looking at modelling capabilities and component design criteria for moorings and platforms. This may indicate the limitations of the project in terms of design and therefore could eliminate or force a change in some concepts.

An initial failure mode effects and criticality analysis (FMECA) has been prepared on the main sub-systems in a combined offshore renewable energy device to identify potential “show-stoppers” which will aid the elimination of concepts.

Grid Connection and Macro-system Integration

Certain concepts will require different farm layouts and this may result in an advantage for one technology over another in terms of cable costs and optimising rented area which will be fed into the numerical modelling and economic assessment toolboxes.

7.3. Selection of FINAL 3 Concepts

Work carried out by the various partners will be collated and used to analyse the concepts in more detail with regards economics, performance, loadings, risk, moorings, platform stability, potential farm layouts and commercial viability with suitable sites. The combined results will allow the selection of the 3 most feasible combined concepts, by December 2012.

8. Conclusion

This paper outlines the methodology for analysis and assessment of multiple, diverse wind-wave combined concepts. It was developed with the main objective of providing a level of technical and economic evaluation that would enable the total number of concepts remaining for detailed study to be reduced. Therefore the methodology described provided the mechanism for making rational decisions on the retention and discarding of various concepts such that the only the most feasible were left. Further study and analysis subsequent to this stage will reduce the number of concepts to 3 and these will be investigated thoroughly and quantitatively. It should be stated that the methodology outlined is not specifically designed for the evaluation of single, explicit concepts although it can provide the first step in this process. It was developed to avoid the need for detailed design work and physical or numerical modelling, tasks which are more suited to a reduced number of concepts.

There is no known existing methodology for assessing multiple combined renewable energy concepts. This challenge primarily arose due to a lack of knowledge in the industry regarding these novel combined technologies and therefore it required innovative and effective solutions to be developed and implemented. These solutions included the technical studies which relied on vital partner experience and expertise; and the economic assessment tool which for the first time provides an economic value to these combined concepts. In combination the technical studies and economic assessment tool enabled critical decisions to be made on the potential viability of a number of concepts.

As outlined in the flow diagram, Figure 1, this assessment process is still ongoing with the project currently at stage 8: More detailed technical and economic studies. A summary of the agreed next stage assessment has been provided however it is important to note that as has been the case to date, the work is very much a dynamic process and therefore it can be expected that some assessment steps will be unforseen and will be developed as demanded by the project.

Acknowledgements

The authors would like to acknowledge contributions from the EU FP7 MARINA Platform Consortium partners, particularly those in work package 3.

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