X-shaped Radical Offshore Wind Turbine for Overall Cost of Energy Reduction

D7.5

Final survey design and methodology

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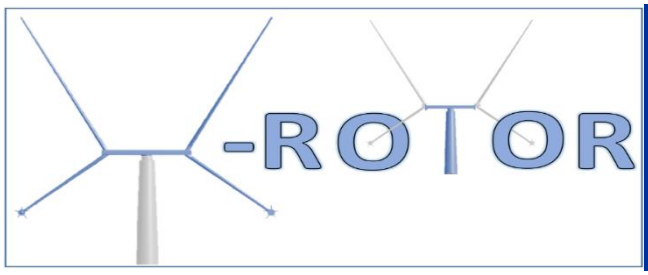
December 2021

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101007135



X-SHAPED RADICAL OFFSHORE WIND TURBINE FOR OVERALL COST OF ENERGY REDUCTION

Project acronym: **XROTOR**
Grant agreement number: 101007135

WP7 Environmental and Socio-Economic Impact
D7.5 Final Survey Design and Methodology

Lead Beneficiary: University College Cork
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Document Information

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1	21/12/2021	Final version	Deeney & Dunphy	W. Leithead	W. Leithead (Project Coordinator)

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Executive Summary

Deliverable Description:

To identify the factors on which potential buyers base their purchasing decisions. The survey will include details of at least 12 potential attributes that influence purchasing decisions influencing attributes of offshore wind turbines. In particular, the market potential of the technology will be assessed using primary data from original surveys of potential buyers and users of innovations (Stakeholder Group 2).

Responsible:

University College Cork

Outcome Summary:

A plan is proposed to continue with the online engagement with Group 2 as well as person to person if that is possible. The first stage is to use a SWOT analysis to encourage critical thinking regarding wind turbine design. The second stage is to enter a modified Delphi study which consists of two elements based on the criteria used to judge the suitability of turbines. The first element is a sequencing exercise, the second is a pairwise comparison feeding into an AHP. This Delphi study will provide feedback to participants and be repeated to allow for recollection and reflection on the part of the participants so as to produce a considered priority list of criteria.

List of acronyms and abbreviations

AHP	Analytic Hierarchy Process
ASD	Asynchronous Structured Dialogue
O&M	Operations and Maintenance
OEM	Original Equipment Manufacturers
PCM	Pairwise Comparison Matrix

Contents

1 Introduction

This report is a preparatory document which describes the methodology adopted and survey design choices applied for exploring the potential purchasing decision influencing attributes of offshore wind turbines with stakeholder group 2 (the Wider Wind Energy Community[1]). The report presents the survey methodology along with the analytical tools proposed for its interpretation. In order to combine both qualitative and quantitative data, SWOT Analysis, a sequencing exercise and an analytic hierarchy process (AHP) will be used within a modified Delphi study. The survey will take place during the second-year workshop for Group 2.

The first part of the final survey, the SWOT analysis, will build on the cumulative explorations of the annual asynchronous structured dialogues (ASDs) which will introduce the community members to each other's ideas and provide an initial set of criteria which can be used as a first step towards the final list. The SWOT analysis is an examination of a business idea or concept looking at positive and negative aspects of the idea both now and in the future, under the headings of strengths, weaknesses, opportunities, and threats. It is described in more detail below in Section 2.1.

The sequencing exercise will ask participants to arrange various criteria used to select wind turbines, in order of importance, see Section 2.2.1. The current indicative list of criteria given in **Error! Reference source not found.** is based on the work presented in D7.2 and will be amended as required as the engagement continues. These will be formed into a hierarchical tree of criteria used by those in Group 2 to determine their preferred choice of turbine designs. This is expected to produce a result similar to **Error! Reference source not found.** on page 9. Such a hierarchical system will be used as the framework for the analytic hierarchy process (AHP) which takes the pairwise relative strengths within and between the levels to produce a weighting for each criterion (Saaty, 2008; Lin, Kou and Ergu, 2014; Sobczyk *et al.*, 2017; Deeney *et al.*, 2021).

The use of AHP here assigns individual weights to the criteria used by members of Group 2 to make decisions regarding their wind turbine preferences. The method for the arrangement of the hierarchical tree is described in Section 3.1, and the methods for AHP described in Section 2.2.2. The AHP methods allow for a detailed comparison between the criteria which goes beyond simple sequencing, which is why the AHP is carried out after the sequencing exercise.

The sequencing and AHP are arranged in a modified Delphi study which will provide feedback to participants regarding the rationales used by the other participants in making their judgements. These two methods, sequencing and AHP will be repeated so that participants will have the opportunity to re-evaluate their positions, taking into account input from others who also have expertise, and possibly a different perspective.

[1] Group 2 are members of the wider wind energy community as defined in the Description of Action WP7 Description of work and role of partners. Group 2 consists of developers, academics, consultancies, standards bodies, operators, vessel companies, installation companies, O&M providers, OEMs *etc*.

The decision to conclude the Delphi study will follow the methodology of our previous work (Deeney *et al.*, 2021).

- SWOT to help the participants compare the criteria and to offer opinions on the design presented to them.
- Modified Delphi Study
  - A sequencing exercise to explore the relative importance of the criteria
  - AHP to assign weights to each criterion

The final survey will determine the attributes which decision makers take into account when choosing an offshore wind turbine. These attributes may include capital expenditure, operational expenditure, manufacturing quality, and met-ocean conditions & water depths at the installation site.

While the methods laid out below are based on the current state of the art, it is to be borne in mind that the asynchronous structured dialogues (ASDs) with both the Group 1 and Group 2 will bring new information to the project. The surveys, questionnaires, and discussions from these ASDs will widen the approach of the researchers and provide the research project with insights from industry and the communities. It is therefore quite likely that the methods proposed here will be developed in the light of the new information and new insights.

2 Survey Structure

It is proposed to arrange three methods to obtain the opinions of Group 2 regarding the importance of the criteria they use to judge wind turbines. Firstly, the SWOT analysis explained in Section 2.1 will be used to encourage thinking about the qualities of the X-Rotor design. Then the following Delphi Cycle (Figure 1) will be used to quantify the relative importance of these criteria. The Delphi Cycle will begin with a simple sequencing exercise, where participants arrange the criteria in order of importance. Then they will carry out pairwise comparisons of the four level 1 criteria of Figure 2, the economic, environmental, social and technical considerations of the X-Rotor design, followed by four sets of similar comparisons at level 2. The results of these comparisons, both the sequencing and AHP, will be given to the participants along with the rationale for the decisions. This will constitute one Delphi Cycle. Delphi Cycles will be repeated. The SWOT analysis and the Delphi Cycle will be discussed in the next two sections.

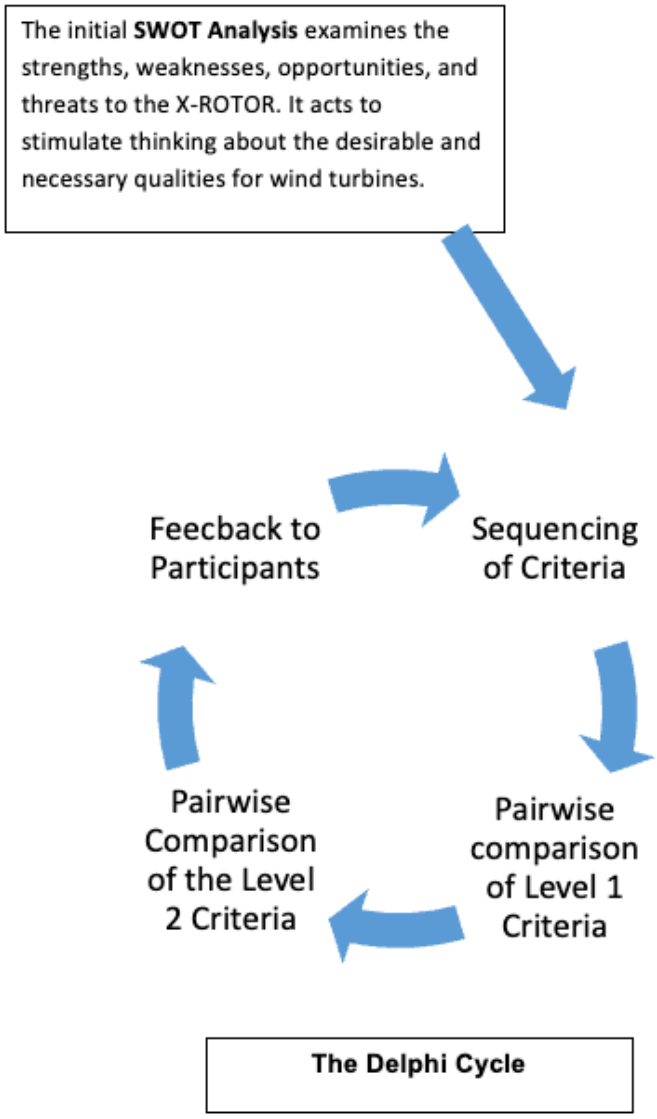

Figure 1: The Structure of the Survey

2.1 SWOT

A standard method to consider the future of a business idea is to perform a Strengths, Weaknesses, Opportunities, Threats Analysis (SWOT). This has been established in the literature as a method of analysing business models and ideas (Helms and Nixon, 2010; Tugrul and Cimen, 2016; Coelho Junior *et al.*, 2020). In the survey plan, the SWOT analysis performs two functions, firstly it introduces the current design ideas for the X-ROTOR to Group 2 participants so that they may focus their thinking, and second it acts as a reward for the participants giving them early information on the newly developed turbine design.

2.2 Delphi Cycle

After the SWOT analysis the participants will enter the Delphi Cycle. This follows a standard Delphi pattern of sharing the anonymised opinions and the rationales of the participants, so that the arguments behind decisions may be presented in a fair manner disconnected from personalities. The two exercises in the Delphi cycle are direct criteria comparison and pairwise hierarchical comparisons.

2.2.1 Sequencing Exercise

A direct method is to present a list of criteria to participants and ask them to arrange the list into their sequence of importance. This has the advantage of being simple and of encouraging the participants to consider the relative importance of the criteria, which will be relevant for AHP.

2.2.2 Analytic Hierarchy Process (AHP)

The analytic hierarchy process (AHP) to be used is a detailed method to build a pairwise comparison matrix (PCM) using the methods of Saaty (2008). The disadvantage of this method is that it requires a reasonable amount of time as there are many pairwise comparisons to be made. For example, to compare four items in pairs requires six pairs[2]. The methods used here follow the approach taken by Deeney *et al.* (2021).

While there is debate about the degree to which a Delphi study tries to impose consensus where it may not exist, the purpose of the survey is to explore opinions and probe the criteria used by Group 2 members when selecting and using offshore wind turbines. The purpose is not to develop consensus among that community.

An important concern when using a Delphi study is to decide when to stop. There is of course the practical limit of the patience and commitment of the participants. From a theoretical standpoint it would be ideal to call a halt to the cycle when there is sufficient agreement on the outcome. With a mixed group of participants, it may not be realistic to assume that there will be a consensus or that the group's opinions will converge. There are statistical tests to assess the building of consensus, and it will be interesting to discover if the Delphi process has that effect with Group 2. A standard method to measure consensus is Kendall's W statistic (Kendall and Smith, 1939; Yusof, Ishak and Doheim, 2018) which ranges from zero for no consensus to one

[2] There are *n(n-1)/2* ways to choose a pair from a selection of *n* objects.

for complete agreement. The method uses the ranking order and hence is scale invariant. Following from our earlier work, (Deeney *et al.*, 2021), a practical stopping condition may be that, $(W_{i+1} - W_i) / (1 - W_i) > 0.05$, where W_i is Kendall's W for the i^{th} iteration of the Delphi study. A further stopping condition may be that the weights produced for the criteria, converge as the iterations increase. Consider the weights produced by the i^{th} iteration of the Delphi study using the AHP method describing n criteria, to be a vector, $\boldsymbol{v_i} = (v_{i,1}, v_{i,2}, v_{i,3}, \ldots, v_{i,n})$, where $v_{i,1} + v_{i,2} + v_{i,3} + \ldots v_{i,n} = 1$. Then define the distance d_i between the i^{th} iteration and the next iteration, as

$$d_i = \frac{1}{n} \sum_{k=1}^{n} \left(w_{i,k} - w_{i+1,k} \right)^2$$

and, insist that as well as the consensus condition of Kendal, a convergence condition of $d_i < 0.05$ may be included.

It would also be interesting to compare the results of the direct comparison and the more sophisticated AHP results. This comparison will form part of the analysis of the survey. On a practical level it would not be useful to go beyond three Delphi cycles as there is a limit to the time and patience of the participants.

3 List of Criteria and Hierarchical Arrangement

The members of Group 2 were approached as part of D7.2 to find out what criteria professionals apply to the choice of wind turbine technology. Based on the feedback of this workshop in the first year of the research project, the following criteria have been suggested. These criteria have been categorised as economic, environmental, social or technical, see Figure 2.

3.1 Hierarchical Tree for the Criteria

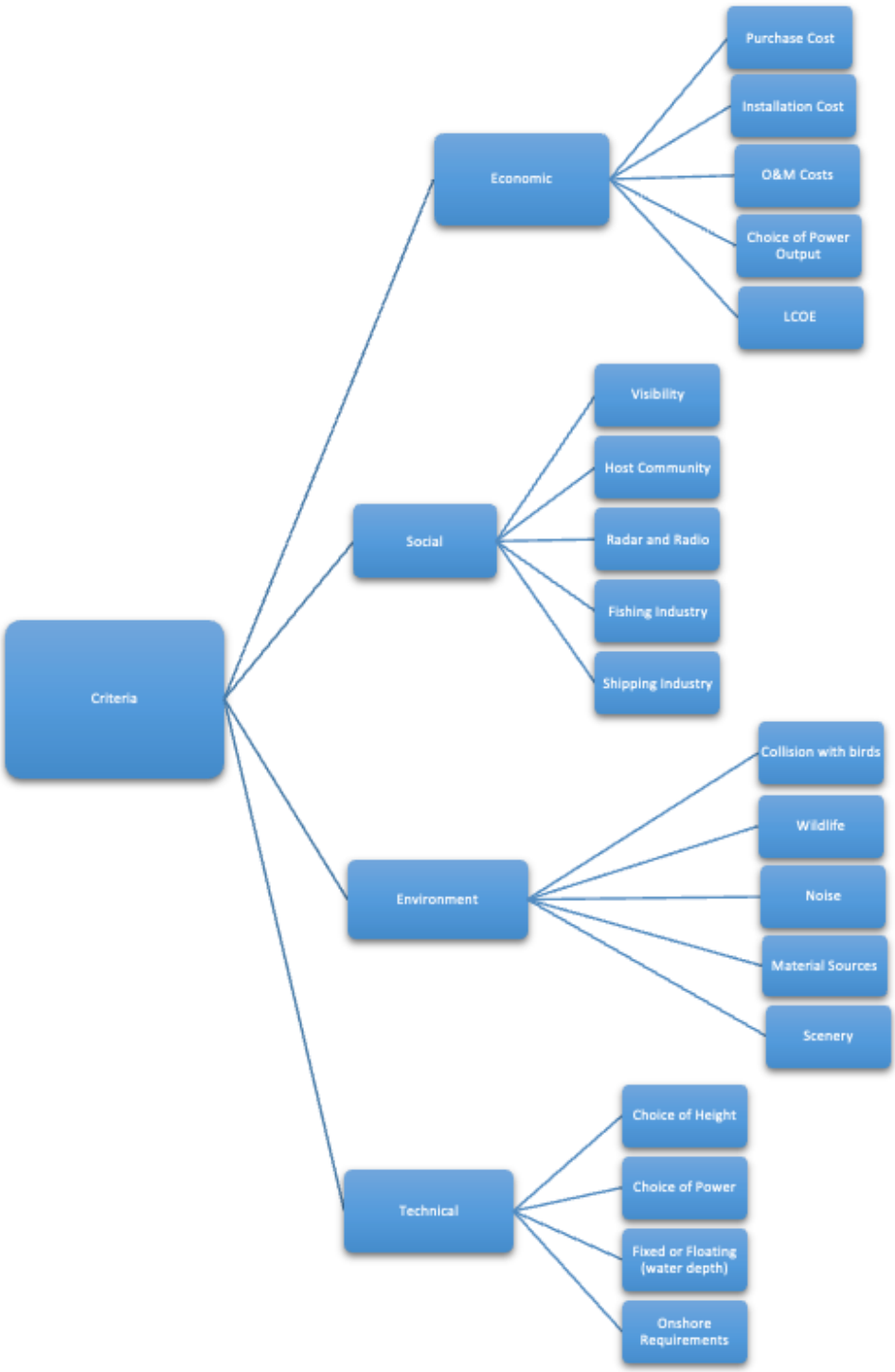

Figure 2: Hierarchical Structure of Criteria Based on First Workshop

3.2 An Indicative List of Criteria from D7.2

D7.2, produced an initial list of criteria which was presented to Group 1 for its consideration. Analysis of the Group 2 responses produced the following sequence of criteria, starting with the most important, LCOE and ending with Impact on scenery. This list is presented as an indication of a possible list to be used in the survey of Group 2.

- Levelised Cost of Energy,
- Ability to survive extreme conditions,
- Installation cost,
- Maintenance costs,
- Purchase cost,
- O&M cost,
- Choice of power capacity,
- Impact on local people,
- Impact on wildlife,
- Onshore requirements,
- Choice of height,
- Likelihood of collision with birds,
- Impact on fishing industry,
- Choice of fixed or floating,
- Effect on radio and radar signals,
- Visibility,
- Impact on shipping,
- Noise output,
- Impact on scenery.

4 Conclusion

There needs to be flexibility as new information comes from the Group 1 and Group 2 during the course of the project. It is however possible to plan for the survey. The survey will take place during the second workshop for Group 2. This may be done online or in person depending on the circumstances. The initial part of the survey is to examine the available information on the X-Rotor design and perform a SWOT analysis as described above.

A list of criteria building on the intervening engagements with the stakeholder groups, will be sequenced and will have weights assigned following the method above utilising an AHP approach applied in a modified Delphi study. The Delphi study will be drawn to a conclusion when it is clear that a consensus has emerged or after three cycles are completed. This is to take into account the ability of Group 2 to commit time and personal attention to the exercise.

The survey will give an evidence-based priority list for the criteria used by wind energy professionals when deciding which type of wind turbine to use.

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