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Developing a Soft Systems Methodology for Comparing the Sustainability Performances of Ecologically Active Concrete to those of the Traditionally Used Stone as Scour Protection Material

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Abstract

Sustainability is one of the ‘hottest’ topics of our times: governments, scientists and public opinion have all been actively involved in the conversation for decades now, and, as a consequence, also companies are experiencing increasing direct and indirect pressures to take over their share of responsibility.

Today’s fast-paced technical development often proposes the introduction of a new technology as a possibility to target business and sustainability goals simultaneously. Assessing the actual sustainability performances of a new technology, though, is a typical ‘wicked’ type of problem (multidimensional, interconnected, subjective and mutable), and it requires a soft-systems way of thinking, which profit-driven organizations typically lack.

This work aimed at developing a methodology for supporting traditionally-structured businesses that do not have an organized sustainability line yet, to preliminarily assess sustainability of newly proposed technologies before deciding to embark in more expensive evaluation processes. Starting point of my inquiry was a four-month action research period within an offshore wind business context during which I was responsible for the evaluation of Ecologically Active Concrete (EAC) used as alternative to rocks for scour protection of wind turbine towers. In order to do that, drawing from soft system and sustainability theory methods, I developed a multicriteria assessment tool, that I then tested through four semi-structured interviews, to eventually perform the comparison between the sustainability performances of the novel and the traditional scour protection technologies. Despite higher production and installation costs and a bigger CO2 footprint, EAC appeared to have a significantly positive impact for local population. On the other hand, habitat enhancement performance results were too approximate to draw any conclusion.

From a case perspective, at the time this thesis was written project activities were on hold and it was not yet taken any decision about how to proceed. More in general though, by identifying a rather simple and straightforward methodology, this work provided a practical example of how to facilitate the dialogue around sustainability numerous complexities within ill equipped profit-driven environments.

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1 ABBREVIATIONS & TERMINOLOGY

CAPEX Capital Expenditure. Expenses used on investment of fixed assets.

CONCEPT PHASE is an early project phase, in which the broad outlines of projects Why, What, How, and When are articulated. It should give a high-level, but detailed enough, set of answers to the questions above so that the decision makers in the organization can determine whether to proceed to the detailed design phase.

COMPANY / CUSTOMER (with capital 'C') here refers to the enterprise that will finally own and manage the operating wind farm installation. Company relies on various contractors for construction and installation of the asset.

CONTRACTOR (with capital 'C') here refers to the contractor recruited by the Company for construction of the wind towers' sub-structures of the wind farm. The Contractor is the firm where I am employed.

DECOMMISSIONING The process of disassembly and removal of the installation.

D50 DIAMETER The median mesh size for the rock stones, for example D50=0,35 m means that 50% of the stone mix is smaller than 0,35 m.

Ecologically Active Concrete (here referred as EAC) are innovative concrete structural elements characterized by bio-enhancing additives in the concrete matrices and surface textures designed to mimic natural features (rock/coral) and small scale hydrodynamics. These technologies have been recently developed mainly for coastal human infrastructures. The available ecological data come from those applications. In this document EAC refers to both the specific here studied structural products and more in general to the type of material.

ENVIRONMENTAL PERMIT means any permit, approval, license or other authorization required under any Environmental Law. In order to be authorized to build the wind farm, through a permitting process, Company must give evidence that the requirements locally in force are fulfilled.

OPEX are the Operating expenditures. Expenses coming from operating the wind farm.

REPOWERING refers to upgrading a wind farm to extend its lifetime and increase the efficiency.

SCOUR PROTECTION refers to means to avoid scour. Scour is caused by swiftly moving water that might scoop out scour holes. This can compromise the integrity of the structure. The protection (Figure 1.1) will prevent this from happening. It is normally made up of: a thinner small-rocks filter layer, meant to minimize erosion of the soil underneath to escape, and a thicker bigger-rocks armour layer, mainly to maintain the filter layer in place. Natural rocks are commonly used for this purpose, rock type depends upon location and availability (often granite).

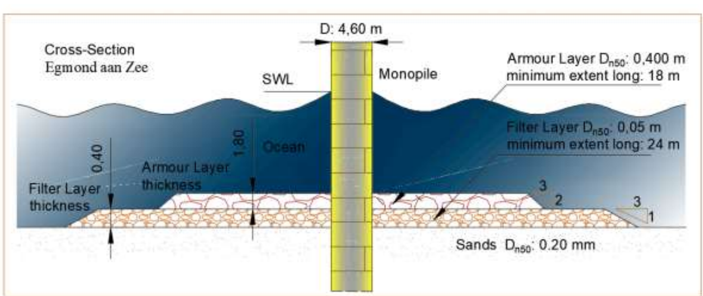


Figure 1.1: Scour protection example

SUBSTRUCTURE here refers to the partially submerged wind turbine tower supporting structure, usually monopiles, jackets or concrete GBSs (Gravity Based Structures made of concrete).

2 INTRODUCTION

While becoming ever more ubiquitous, sustainability is seldomly an easy subject: the complexity deriving from its multidimensional, interconnected and continuously changing nature makes it difficult to define (Bell and Morse 2012) and hence impossible to address in its entireness. In addition, the 'hard' biological, economic and political sustainability-related issues become even more challenging to assess when adding the subjective 'soft' elements into it: involved stakeholders are all coming into the situation with their own (more or less distinctive) sets of worldviews, adding complexity to the definition of the problematic situation and making the attainment of a satisfactory resolution improbable (Checkland 1989). Those types of challenges (continuously changing, multidimensional, subjectively interpretable, non-linearly interconnected, with time-and-space separated cause-effect mechanisms) are referred to in literature as 'wicked problems', and a soft-systems thinking approach has proved to be an effective way to address them (Armson 2011). When it comes to sustainability conversations, an important element is achieving a satisfying and agreed way to measure it, and the described complexity and wickedness might also undermine this goal. With time, multicriteria analysis and performance indicators (Sustainability Indicators, SIs) have become a standard way to partially solve the quantification issue, with all the foreseeable limitations linked to simplifying a complex reality. Typical challenges of this approach are to compile SIs into a 'composite indicator' (Commission 2008) that would ideally measure the multidimensional sustainability concept, by reflecting on each SIs' relative importance ('weighting') and on the extent of the substitutability of the different dimensions ('aggregation'). Moreover, for the process to capture the different stakeholders' individual perceptions and to reach an acceptable consensus, development and measurement of such SIs should follow a participatory and subjective approach (Bell and Morse 2012).

Such considerations are becoming more frequent in the past few decades, as the sustainability discourse is rapidly moving from the periphery to the mainstream of politics. From a global perspective, this trend culminated with the Sustainable Development Goals (SDGs) developed at the United Nations Conference on Sustainable Development in Rio de Janeiro in 2012 (SDGs 2015). As one of the consequences of these societal changes, while traditionally not involved in the sustainability discourse, also business organizations have been faced with sustainability questions more and more often. All over the world both national governments (Horrigan 2007, Chang, Soebarto et al. 2016) and international organizations (Claudet, Bopp et al. 2020) are developing frameworks and regulations that directly impact businesses on this aspect. It is now broadly acknowledged that companies have organizational responsibilities towards society: such pressures come both externally, from forces such as consumers (Sen and Bhattacharya 2001) and NGOs (Spar and La Mure 2003), as well as internally, as they have, for example, an influence on employee motivation (Skudiene and Auruskeviciene 2012).

The high speed of change in the world, the increasing number of available new technologies and the great deal of attention around corporate sustainability makes it more likely for a business to be in need of assessing the feasibility of introducing sustainability-oriented new technologies, even when the company structure is not prepared to support such evaluations. Sometimes the introduction of new technologies does seem to offer easy solutions for the sustainability issues at hand; however, given the interconnectedness with the environment they operate in and the difficulties to define issues and goals, it is not always easy to determine whether introducing a new technology would actually be the best way to improve a specific situation. This is in line with the general perception that sustainable technology innovation is regarded as more difficult than conventional innovation (R Adams 2012, Seebode 2012): in order to make an informed evaluation one would require a specific set of competencies, both in terms of multidisciplinary knowledge and ways to approach the problem. Traditional business structures, with their prevailing reductionist and hard system thinking approaches, are often ill equipped to tackle such multifaced complexity. A typical example of this type of struggle (that I have observed in my everyday job life as an engineer) is when such questions come up within a project environment, where answers have to be rapid and exhaustive enough to make decisions, while time and resources are limited. If a company is not structured to address sustainability, project support cannot be obtained from the main organization and a solution must be found at a project level (Silvius and Schipper 2014). One should find a way to quickly provide enough background information to decide whether it is worth allocating additional time and resources and further explore the new technology or not.

The aim of this work was to identify a methodology to support organizations' decision-making process at the very early feasibility assessment stage of introducing a new technology in pursuit of sustainability goals. The overarching purpose was to develop a suitable methodology for traditionally-structured businesses that do not have an organized sustainability line, to start approaching the incoming problems in a sustainability perspective.

I addressed this task by running a case study (section 3.2) within a well-established Norwegian engineering enterprise (the Contractor, section 1) operating in the energy market and currently shifting from the traditional Oil&Gas business to the area of renewable energy production. In particular, I explored the case of Ecologically Active Concrete (EAC) considered as a possible alternative to stones for scour protection (definition in section 1) in an offshore wind farm development project at a concept level of design (definition in section 1), and I developed a case-specific methodology to assess the possible implementation of novel EAC technology within the project from a sustainability standpoint. I conducted my investigation through an action research process: within my ongoing project work I took over the task of preliminarily assessing the sustainability of novel EAC technology to be potentially implemented within the project. Basically, the specific 'action' goal was to develop an initial holistic sustainability evaluation and to establish whether in the future it would be worth to invest additional time and resources on a more accurate analysis or not.

While the main objective was to constitute and apply a participatory methodology for initial sustainability assessment of suggested new technology, the enquiry had the following intermediate objectives:

- Identify a way to define relevant system and stakeholders.
- Define a way to assess from a sustainability standpoint a technology performing an assigned function.
- Define a way to involve the relevant stakeholders in the performance comparison.
- Define a way to integrate the views together and draw a conclusion.

Moving on from the introduction, the structure of this document is as follows: section 3 'Context and Case' first introduces the general ongoing discourse around offshore wind sustainability and then describes in more detail the EAC case (my 'Materials'); since the methodology development and results' generation progressively proceeded hand-in-hand (section 4), the *modus operandi* followed in the research process (the 'Methods') and the obtained findings (the 'Results') are presented and discussed sequentially according to the stepwise research process (sections 5 to 8). The work concludes with a wrap-up discussion and conclusion (section 9), exploring overall implications of the present inquiry, potential future implementations of the assessment tool, its limitations and challenges, and some recommendations for future research.

3 CONTEXT AND CASE

3.1 ENERGY PRODUCTION AND OFFSHORE WIND SUSTAINABILITY CONTEXT

Within the context of energy production business, the described demand for change (section 2) posed the dilemma deriving from global sustainability goals pointing towards apparently mutually exclusive directions: on one side reducing “energy poverty”, (Dobbins, Nerini et al. 2019) is correlated to the overall improvement of people’s life conditions; on the other, energy production, even when it contributes to reducing energy poverty, has been up to now associated with heavier environmental impacts. As a result of the social, political, technological, economic, and ecosystem interactions, organizations working within the energy production face specific tensions and challenges (Casillas and Kammen 2010, Hadian and Madani 2015).

It is then understandable why during the last 50 years the development of technologies to make use of renewable forms of energy has gained growing momentum, both as a backup for the eventual depletion of oil, as well as an environmentally sustainable alternative to fossil fuels. However, given the complexity of the systems they are embedded in, development of such technologies is not immune to the challenges associated with the ‘wicked problems’ described in 2 and, while renewable energy sources are commonly considered ‘clean’, there are controversies with respect to their economic cost, their environmental impacts and the variability of their output. “In order to make informed policy decisions on future developments of the electricity system, it is necessary to address these controversies and confirm the environmental, economic and social sustainability of these new renewable generators” (Camilla 2014).

Among renewables, offshore wind has been a fast-growing sector in the past 20 years, with turbines getting bigger and wind farms becoming larger. At the same time the scientific discourse has also intensified around the actual sustainability of offshore wind farm installations and their impacts on marine ecosystems and other related anthropological activities (Bergström, Kautsky et al. 2014). From a community standpoint, socially sustainable ocean management and food production is an important element within this discourse. Despite the fact that the wind industry is generally supported by both the government and the public opinion, the fishing businesses and communities that are directly impacted by the installations have often manifested big concerns, e.g. potential loss of access to traditional fishing grounds, short and long-term disruption to fish behaviour patterns, fish abundance during plant construction and operation, compromised safety, social implications for communities where fisheries are strongly embedded in the local economy and loss of heritage (S. Mackinson, K. McTaggart et al. 2006). Controversies also exist among developers, regulators and fisheries, mainly about the appropriateness of the stakeholder consultation process in the wind farm planning phase, the rights for fishermen’s compensation claims and the adequacy of the available site data to make fact-based decisions (Gray, Haggett et al. 2005). From an environmental perspective, the existing studies have reported significant impacts of the offshore wind industry on the involved natural ecosystems during the construction (noise and dredging alterations of seabed) as well as during the operation phases (increased vessel traffic pollution, moving blades’ danger for seabirds, underwater cable-electromagnetic fields disturbances to sensitive marine organisms (Bailey, Brookes et al. 2014)). While some argue in favour of the “reef effect” observed around existing offshore installations, the increase in biodiversity can heavily impact the ecosystem and its food web, due to the combined effects on the population composition and the increased risk of attracting invasive species (Raoux, Tecchio et al. 2017). Another big environmental concern is the risk related to the unavoidable decommissioning of wind farms (currently part of regulations) when they reach the end of their service life: direct observations have not been possible since only a few (and not representative) small farms have reached the end of their service life until now. But it is a relevant point also considering that the speed at which technology and market are developing will probably make repowering of old wind farms a rare occasion (Hermans, Bos et al. 2020).

It becomes clear, then, that how to achieve a more sustainable offshore wind development, is an urgent question, also considering the current and forecasted fast growth of offshore wind and the observed trend of increasingly bigger installations.

3.2 THE CASE OF EAC AS SCOUR PROTECTION FOR OFFSHORE WIND FARMS

Within the offshore wind context (section 3.1), a practical example of the scenario described in 2, in which an organization attempts to evaluate the introduction of a new technology for sustainability purposes, is offered by the dilemma of assessing EAC as a more sustainable alternative technology for scour protection (definition at paragraph 1), to replace traditionally used stone material. The question arose in the specific context of an upcoming offshore-wind installation offshore US east coast. Considered water depth was in the 30-45 meter interval. Being scour protection an always present element directly correlated with the dimension of the offshore installation, a reflection on potential mitigations of its possible undesired consequences is also generally valuable.

In particular one of the suppliers of commercially available EAC were involved and their products were taken into account as the targeted new technology to explore for further development. This EAC firm I worked with was founded by two marine ecologists, experts in urban marine ecology, ecological enhancement and green engineering technologies. The company mission is to enhance ecological natural processes by integrating environmentally sensitive technologies into urban, coastal, and marine infrastructure design. The only applications so far are limited to coastal infrastructures (Perkol-Finkel and Sella 2014) where, alongside with good results in terms of "enhanced ecosystem services, it was also registered an economic advantage deriving from elevated water quality, increased operational life span, structural stability, and absorption of hydrodynamic forces". However, these results are not straightforwardly applicable to the scour protection application and it had to be checked whether, in the context of sustainable offshore wind installations, this promising technology would hopefully allow to combine the needed functional protection requirements with the ecological advantages of an enhanced primary production and a potentially more suitable habitat for marine life. Depending on the associated effects on population abundance of the species impacted, implementing EAC units could also result in overall positive economic and social impacts for local fisheries and communities.

As stated, there are not yet experiences using it as a scour protection alternative for offshore wind installations. Nevertheless, EAC technologies have already been preliminarily scrutinised for this application: as part of a specific analysis of alternatives for scour protection (Lengkeek, Didderen et al. 2017) and as part of a Nature-Inclusive Design catalogue (NID) of new technologies, developed from Wageningen University and commissioned by the Dutch Ministry of Agriculture, Nature and Food Quality (Hermans, Bos et al. 2020).

The offshore wind farm project in question, currently at the concept phase and for which such evaluation is being made for the first time, will be one of the many planned big offshore installations off the US east coast. The activities are still at a very early stage, installation is planned a few years from now, and design details still have to be agreed with the local governmental organizations. The Contractor I am working for is developing for our Customer (and end-user of the wind farm) a concept study for building and installing the foundation of 150+ large wind turbines, in three successive project phases. Since scour protection is always needed for substructures, and it will be quantitively substantial for such a large scope, for the end user it is a very relevant topic to address, not only from an economical investment standpoint, but also environmentally. In fact, the amount and impact of such material represents a specific concern for the environmental department, being scour protection one of the items investigated from the US government environmental authorities during the project approval process (refer to 'Environmental permit' definition, section 1).

This is a specific case that well embodies the 'wicked problems' normally encountered in the renewable energy context: the social, political, technological, economic, and ecosystem interactions generate a multidimensional state, with several sustainability objectives at stake. The case is suitable for pursuing the research objectives on many levels:

1) It clearly showed the emergence of all typical sustainability-related, multiple degrees of complexity:
    - Impacts on nature and environment cannot be easily extrapolated, due to the variability of marine ecosystems and to the lack of existing large-scale examples.
    - There is an important anthropological side to be considered when it comes to impacts on food production and human communities (fisheries and local communities).
    - A time-discontinuity has also to be accounted for, since the effects will be different during the different stages of project life (production, installation, operation, decommissioning).
    - There is a diverse group of stakeholders, more or less directly involved, each with specific perceptions and interests.
    - The consequences of implementing this new technology could potentially spread over multiple and interdependent sustainability levels, i.e. ecological, economic and social sustainability.
2) The case is well within the renewable energy realm, and it is a particularly relevant offshore wind example since it is located in a geographical area that is currently seeing massive development planning for offshore wind installations.
3) The case provides a good trial for testing early-stage innovation development process: it gave me the possibility to face many of the generic situational challenges associated to very early sustainability assessments of a new technology, such as effectively framing the actual problem, best approach decisions, study deliveries definition, budget and schedules approvals.
4) It is representative as a case of innovation in a resource-constrained project context that, due to the limited budget available, the time constraints given by the overall project schedules and the lack of expertise within the organization, required a proactive approach to solve the problem in an effective way.
5) Also, the fact that this case was the first time that such innovation-for-sustainability assessment was done in my company, makes it an original sample for observing the specific struggles encountered by established conventional firms in the process of shifting towards relatively unknown green markets: it is within this 'unsteady' context that I have explored how to establish if the EAC could be interesting.

4 OVERALL INQUIRY STRUCTURE

This work originated from a Customer request to evaluate from a business standpoint EAC as a new and potentially more sustainable alternative material for scour protection, exploring in particular the technical feasibility and costs, as well as the possible environmental and social benefits. I formulated my research objective after collecting some preliminary information and reviewing the available literature about the topic.

Performed activities can be divided into four main steps (I considered the project topic and research objective definition stages as Step 0, as that was the necessary propaedeutic work to justify the following activities), each of which served as the starting point to the next (Table 4-1). At the end of each step, the obtained partial results had both informed my methods choices for the next phase and served as input data to be processes through these chosen methods.

Step 1 - Project field work – In the first part of my research, I assessed the situation as a team member embedded within the project team. During this phase, the usual project management practices were followed. At the end of this period, a technical report was delivered by the project team to the final Customer showing the findings regarding the potential implications of the new technology (in terms of feasibility and costs, but also including other social and environmental parameters). I was the project member directly responsible for this activity. During this period, I also gathered a first set of raw data and observations (Ch. 5).

Step 2 – Conceptualization phase – Partially in parallel with the project work and until the end of the summer, I carried out a systematic reassessment of the information collected during my action research enquiry process: through a combination of hard- and soft-system thinking, I reorganized the mostly unstructured first set of raw data in a more structured fashion, I modelled the situation and I preliminarily identified the relevant impacts and stakeholder categories (social groups). From here, I generated a first set of sustainability performance indicators, to then refine them and end up with a set of key indicators that were used as a basis for later interactions with stakeholders. In this phase, I have also identified suitable tools for weighting and performance assessment (Ch. 6).

Step 3 – Model verification – After a systematic preliminary preparation work used to outline the interactions to come, I tested my self-generated system model and performance tool through structured and semi-structured communications with representatives of the identified relevant social groups. The results of these interactions constituted my second set of raw research data (Ch.7).

Step 4 – Data Analysis - After defining a structured process to aggregate them (which completed the methodology under development), I analysed this second set of qualitative and quantitative raw data and I calculated a final score to enable technology comparison for taking relevant project decisions (Ch. 8). At the time this thesis was written, the project activities were in an on-hold phase, and a final decision whether to pursue this evaluation further or not had not been taken yet.

Table 4-1: Research Steps

Research Process	Methods and Tools	Results
Step 1 - Project field work Objective: Active participation to the project work in its everyday activities	- Project Management techniques	- Project technical report
	- Action Research	- First set of raw data
Step 2 – Conceptualization Objective: Understand the situation and identify relevant measurable elements for further field exploration	Hard and soft system thinking: - Soft System Methodology - System modelling techniques - Sustainability Indicators	- Case system modelling - Performance assessment tool
Step 3 – Model verification Objective: Develop an exploration tool and use it to verify the model and to assess performances with the stakeholders	Soft System Methodology: - Structured and semi-structured interviews	- Second set of raw qualitative and quantitative data from #Four interviews made
Step 4 – Final Data Analysis Objective: Define a process to integrate the results	- Data aggregation techniques - Multicriteria data Analysis	- Data integration process - Final technology comparison

5 STEP 1 (PROJECT FIELD WORK)

5.1 PROJECT MANAGEMENT ACTION RESEARCH

As part of my current job, I was assigned to the project in November 2019. During winter our Customer mentioned the EAC as a possible new and alternative technology for scour protection to be evaluated: as it is often the case with action research, my research topic was triggered by a real challenge that emerged after being part of the situation for a certain time. In this case the specific 'action' goal was to develop an initial multidimensional sustainability evaluation, to establish whether in the future it would be worth investing additional time and resources on a more accurate analysis.

I started working on this topic in Feb-March 2020, right after the definition of the project delivery (technical project report), scheduled for July 2020. During that period I was nominated the responsible person for the study and I had to coordinate with different parties, internal and external to my engineering organization, to produce the technical report we were supposed to deliver to Customer: meetings, focus groups and interactions have mostly been structured as it is typical within a project context (Table 5-1), and they involved both final operators as well as the suppliers of products (EAC suppliers) and services (engineering and installation providers).

More specifically, during this phase I targeted the following sequential partial objectives:

- To understand customer's main interests during an initial workshop with all major parties involved. This focus group type of interview was characterized by a formal setting as it constituted the kick-off meeting for the future work. I had a directive role, and I set it up in a rather structured way in order to make sure inputs from all relevant parties were preliminarily explored and understood by each other.
- To agree on which functionality basis to evaluate the product: after brainstorming both with the internal team and the suppliers, EAC units were deemed suitable for consideration for the armour layer only.
- To define with the relevant experts (the technical team developing barrier structural design and the transportation/installation service sub-suppliers) a set of technical requirements that the EAC product should fulfil to be considered as a viable technical alternative to traditional methods.
- To align the requirements with EAC vendor counterparts, who had in parallel performed an analysis of the literature and marine databases to assess the site-specific ecosystems.
- To identify the existing knowledge gaps and to agree on a list of necessary assumptions in order to be still able to perform an evaluation despite relative scarcity of data.
- To support EAC vendor developing an initial design, based on the ecological assessment and the received technical requirements mentioned above: an initial geometry was defined and design drawings were produced.
- To verify this design with the other functions that needed the information (sub-suppliers for installation, cost developers, etc..).

I eventually put together the final report to customer summarizing the findings from the process described above, highlighting the potential implications of the new technology, not only in terms of technical feasibility and associated costs, but also taking into consideration social and environmental parameters. Following the usual document control project routines, the document was first shared within the internal team, in particular with engineering functions to verify the accuracy of the information and with management to ensure the holistic overview was duly addressed. At last, the report was formally submitted to customer for comments and validation.

Table 5-1: Interviewing strategies during Phase 1

Type	Setting	My Role	Question Format	Purpose
Focus Group	Formal - Preset	Directive	Structured	Pre-test
Brainstorming	Formal or Informal	Non-directive	Semi-structured	Exploratory
Fieldwork Natural Interactions	Informal Spontaneous	Non-directive	Semi-structured	Exploratory
Fieldwork Formal Interactions	Formal - Preset	Semi-directive	Structured	Outcome Testing

In order to leverage my previous experience in the project and the possibility for further exploration I was given, I used a combination of retrospective and real-time data collection approaches:

- Retrospectiveness has been mostly related to the reflective observation that took place prior to the research topic definition, and the developed knowledge about the overall project context in terms of ecological and social struggles.
- Real-time approach has been adopted triangulating different sources, including informal conversations, semi-structured interviews, focus groups during meetings, reflective observations about my ongoing project activities and desk research: looking for information in different directions contributed to assure completeness and validity of the collected data.

The types of ontological data collected through project management practices during this period comprise emails, notes from informal conversations, minutes of meetings, quantitative environmental and economic data to perform the comparison. At the same time, for me as a systems thinking researcher this period offered also an opportunity for making annotations about my personal observations, not only about the fact-based side of the situation, but also about people behaviours and perceptions, that were useful inputs to development of my methodological approach in the following conceptualization phase (section 6).

In order to ensure information reliability across the project duration, I consistently shared notes from meetings and focus groups with all participants and collected and implemented their comments. On a similar note, as described earlier, also the produced project document went through a two-step quality check, first internally and later when it was sent to customer for formal feedback; the technical report hence had a dual function, constituting at the same time a display of the performed first round of analysis and a testing occasion to preliminarily verify a portion of the findings.

Since the primary goal of this technical report was to illuminate future project choices by performing a preliminary assessment of the feasibility and the impacts of the described EAC alternative, it included:

- Preliminary ecological assessment in terms of identification of the target species/habitats/functional groups and carbon sequestration potential. The aim was to support both the potential for project ecological enhancement and the NY state permitting process (refer to 'Environmental permit' definition, section 1) the project must get through for it to be executed.
- Preliminary design and analysis of ecologically enhanced scour protection as an alternative solution.
- Evaluation of the suitability of available standard installation procedures for the installation of this alternative scour protection material.
- Evaluation of impacts on society, in terms of jobs and consequences on local fishing businesses.
- Preliminary main cost elements for ecologically enhanced scour protection, mainly based upon installation and manufacturing cost estimates.

5.2 EAC SCOUR PROTECTION CONCEPT DESIGN

Since EAC units' ecological performances derive primarily from material matrix composition and their micro/macro geometries, it was agreed by the project team to narrow the evaluation of the new material for the armour layer function only, because this section is the portion where the functionally required average unit dimensions are bigger and therefore the full EAC unit potential could be explored (refer scour protection definition in section 1).

In the case study, it was assumed by the project team that the EAC unit stability would be comparable to the traditional stone material, resulting in an equivalent armour layer made of two EAC-units layers. Also, presuming that the ecological effects will mostly involve the top surface layers, it was preliminarily evaluated by EAC supplier that a replacement between 30% (equivalent to 60% replacement of surface layer) to 50% (full replacement of surface layer) of the overall armour layer volume would be the best compromise for optimizing ecological enhancement while at the same time limiting utilization of EAC units (and corresponding cost increase). In particular it was finally concluded that, in order to guarantee internal and external stability of the scour protection, the outer perimeter of the armour layer should also be made of stones leading to a volume of EAC corresponding to the replacement of 35% of the total armour layer volume. Based on the above, the two cases under comparison were defined as:

- Basecase traditional technology: 100% stone armour layer volume (variable sizes, D50=0,35m).
- Alternative solution: 35% volume EAC units 0.35x0.35x0.35 (remaining 65% basecase stones).

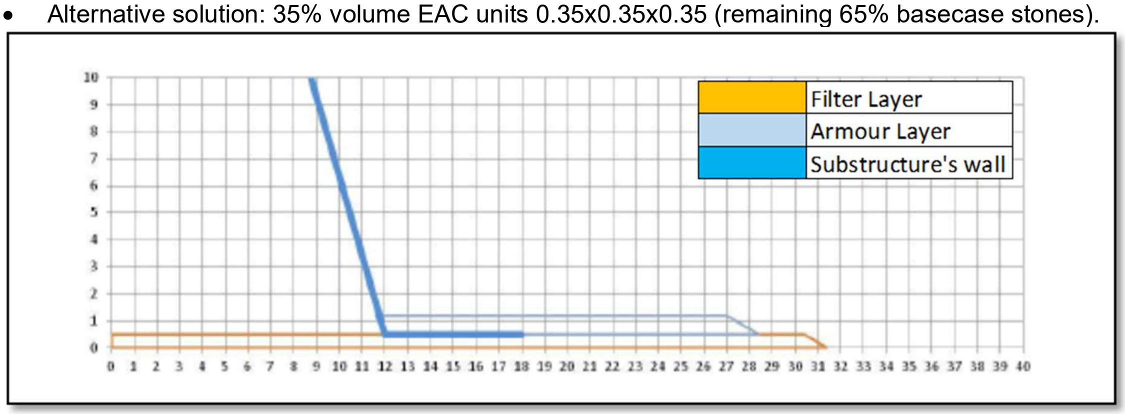


Figure 5.1: Basecase foundation and scour protection cross section: X-Y axis show the distances in meters, respectively, horizontally from the foundation symmetric axis and vertically from seabed.

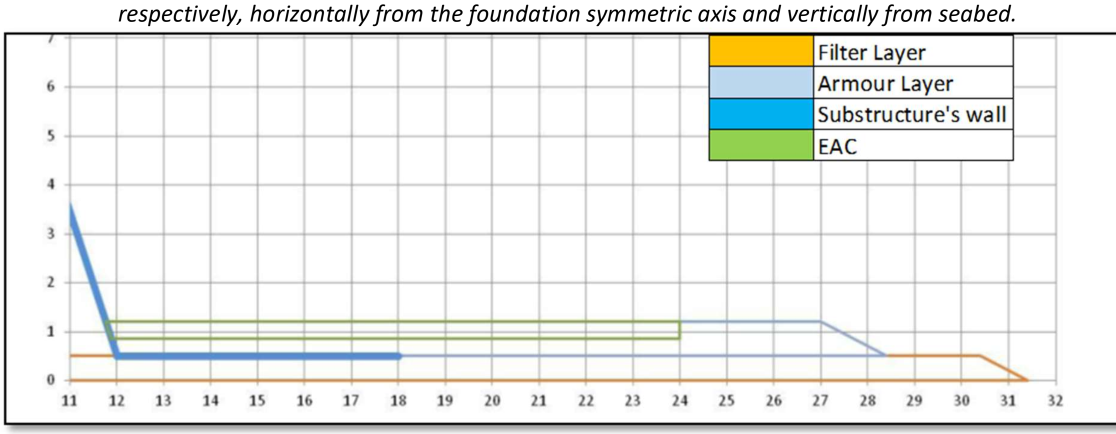


Figure 5.2: EAC part of the armour layer: X-Y axis show the distances in meters, respectively, horizontally from the foundation symmetric axis and vertically from seabed.

The report provided a multidimensional assessment (Table 5-2) of the impacts that the implementation of this new technology would have from technological, economic, environmental and social standpoints, aiming to provide preliminary results that could be used to illuminate future project choices.

Table 5-2: Summary table with main findings

Parameter	Quarry Rock	EAC Units
Cost (CAPEX and Installation)	Basecase cost per foundation	Material cost increase >3 times basecase Transportation cost increase expected but not evaluated (see below)
CO_2 Balance	Production – 4.32 kg CO_2 Mg^{-1} Sequestration – X g m^{-2} $year^{-1}$	Production – 94 kg CO_2 Mg^{-1} Sequestration – at least 2X g m^{-2} $year^{-1}$ (average values of 300 g m^{-2} $year^{-1}$)
Habitat enhancement	Small holes Homogenous surface texture Low possibility for overhangs High possibility for obstructing internal voids by sedimentation	Large holes and crevices Complex surface texture with varying rugosity Overhangs from geometrical shape Increased surface area available for colonization (Average values from case studies – double biodiversity, at least double filtration capacity)
Local Content	No local content in NY state, basecase currently included rocks from Canada (due to vessel availability)	Units can be produced in NY state and local content can be evaluated in terms of value generated within the local territory (NY state for example).
Fisheries	Related to habitat enhancement (see above).	Related to habitat enhancement (see above). EAC units potentially offer a greater flexibility when it comes to habitat design for commercial species.

Installation of these units poses additional challenges compared to basecase:

- The fact of having a two-layered armour layer adds an installation step (rocks on the bottom and EAC units on the top have to be installed in sequence), and this will increase both the duration and the complexity of the operations (and therefore related installation-vessel renting costs).
- Having homogeneous identical units will most likely increase the chances of blockage due to interlocking.
- Handling of EAC units will most likely require extra care (and time) if their geometrical characteristics are to be preserved.
- Producing in NY state (for local content purposes), is challenging from a vessel availability standpoint, due to the fact that the in-force Jones Act requires US-built vessels for offshore installations in US waters whenever the materials to be installed are also loaded from onshore US territory (Papavizas and Morrissey III 2009).

5.3 Discussion

The main objectives of this part of the study were to define an alternative design of scour protection based on EAC technology (Figure 5.2) and to conduct a preliminary evaluation of its economic, environmental and social impacts (Table 5-2). While I am not in the position to discuss the identified design (Figure 5.2), as it was developed through a collaboration of professionals in the structural engineering and the scour protection fields and the level of data design robustness reached was checked and deemed adequate by specialists (with all the reserves that are by definition associated to the concept design level), the results obtained from the preliminary sustainability assessment need to be addressed and contextualized.

Material costs and installation complexity were coupled as a way to reflect the economic implications of implementing the new design. For both aspects only a preliminary assessment was performed, and results should be refined. Nevertheless, in this case the uncertainties were mostly related to the quantification of the increases (of costs and complexity) rather than the actual direction of the change: based on the findings, it can be safely concluded that the EAC solution would be significantly more expensive and more complex to produce and to install than the stone alternative. Additional economic impacts could also come from the technical risks associated with the lack of experience around this new technology, such as the structural failure of the EAC scour protection, which could for example displace or detach, eventually causing loss of stability of the scour protection structure and possible damages to the turbine foundation (which is the primary asset for which the scour protection is installed in the first place).

The two parameters explored for the ecological dimension were carbon footprint and habitat enhancement. While it was clear that the EAC production carbon footprint could not be compensated by the supposedly greater carbon sequestration from marine growth (Table 5-2: Summary table with main findings), habitat enhancement performance assessment should be looked into more critically. On one side, EAC units' habitat enhancement properties could be tuned across three distinguished parameters (matrix composition, micro-geometry and macro-geometry), and this feature is marketed as a potential tool to get greater control over habitat design, for example supporting specific target species and/or increasing biodiversity (Perkol-Finkel and Sella 2014, Lengkeek, Didderen et al. 2017, Hermans, Bos et al. 2020). On the other side, considering that the available experimental measurements are related to coastal structures, and that the possible ecological benefits have not yet been researched and quantified for deeper water applications, these results are to be looked at as speculations, which are anyway useful to start a dialogue around the topic. A crucial difference is also the fact that, while for scour protection the traditional technology is to use natural rocky material, for coastal applications common practice is to use identical cubic or tetrapod units made of ordinary Portland-cement-based concrete. This means that the 2X biodiversity increase factor assumed by EAC needs to be checked further, since most likely it is based upon EAC vs. Portland cement concrete performance comparison data.

In relation to the social dimension, the two explored parameters were the consequences for fishing businesses and the creation of local content. For the fisheries impact assessment, the same considerations as given above stand, since abundance of commercially valuable species, like for all species, would be dependent upon the habitat around. When it comes to local content and job creation, while basecase stones would be extracted in mines outside NY state and EAC units could instead be locally manufactured inside it, an aspect to be furtherly explored would be the actual capacity (in terms of production volumes) of EAC supplier local supply chain, to see whether it is correct to consider material cost as 100% locally generated value.

Both within the project and the research contexts the obtained results were looked at as intermediate findings to be used for deciding ways to proceed, rather than to conclude on the type of technology to be actually employed. In other words, the overall approach in this case was to look at quantitative data under a qualitative lens, and the apparent level of precision of the produced numerical data did not reveal itself misleading. Nevertheless, while qualitative, the results may also be used as a guide for future assessments on other wind farm projects with analogous scour protection requirements, geographical/political areas and/or ecosystem characteristics.

6 STEP 2 (CONCEPTUALIZATION)

6.1 SYSTEM DEFINITION

After being immersed in project work throughout step 1, during step 2 I summarised and reorganised the collected data, in order to make them understandable for me and for the stakeholders I was planning to interact with. Due to the unpredictable and unstructured process data that were collected during phase 1, as a starting point my chosen way to make sense of them was a mix of hard- and soft-systems thinking. This approach enabled me, on one side, to organize the information in a functional way while, on the other side, it still allowed to maintain a broader multi-stakeholder perspective.

My very first action was to perform an individual SSM analysis (section 10.1) including drawing a rich picture, identifying emerging themes, generating system's maps and influence diagrams, applying snappy systems, ITO model and TWO CAGES schemes. The aim of this process was to put on paper what I knew and what I understood of the situation at that point (see handwritten notes in section 10.1).

I then restructured the information in an organic way through hard-system modelling techniques. More specifically, my starting point for system definition was to identify appropriate time and space boundaries (with relevant sub-systems and supra-systems), functional to the analysis to be performed.

Figure 6.1: System's Dimensions

From a system perspective, I was essentially looking at a product (the wind farm offshore installation of which the foundation scour protection is part). I therefore decided to start from the general principles that are commonly applicable to social Life Cycle Assessment (Dreyer, Hauschild et al. 2006), aligning product life cycle processes (materials, manufacture, use, disposal) to the different project phases (time-based sub-systems) as listed below:

- Material Stage (Engineering and Procurement)
- Manufacturing Stage (Construction)
- Distribution Stage (Installation)
- Use Stage (Operation)
- Disposal Stage (Decommissioning and Waste management)
- Transportation between stages

Such alignment allowed me to simplify the complexity by logically dividing it both in time and space, while still maintaining a comprehensive overview of the broader picture. In addition to that, it also provided a familiar and understandable starting point both for me and for communication with the involved stakeholders.

From a spatial standpoint, considering that the marketed properties of EAC material showed time-variable effects both on a plot and on a global span, in order to analyse the situation at all relevant levels it was important for me to keep the two scales in mind, to think locally and globally at the same time, and to highlight the social, ecological and economic aspects. Another important intervention to ensure that all relevant system qualities emerged, was to include in the system both the human dimension and the purely physical space. This is why, for a more general spatial hierarchic categorization, comprising both physical areas and abstract realms (spatial, social and economic), I decided to refer to “domains” (space-based sub-systems) as the second system dimension:

1. Plot: Domains within direct Project control. Spatially this domain referred to both the offshore wind farm area and the onshore construction sites, as well as to the human groups and the economic processes directly impacted by the chosen type of scour protection within it.
2. Landscape: Domains immediately in the proximities of the plot project areas, but outside of project’s direct control. Spatially this domain referred to the geographical areas adjacent to the offshore wind farm and the onshore building site areas, and to the human groups and the economic processes impacted by the chosen type of scour protection within them.
3. Global: domains larger than landscape and global scale. Spatially this domain referred to the larger geographical areas and to the global environmental system, and to the human groups and the economic processes impacted by the chosen type of scour protection within them.

Analogously to what has previously been done on analysing the consequences of UK offshore wind industry development (Hattam, Hooper et al. 2015), where such consequences were expressed as impacts on wellbeing of five capital stocks (financial, manufactured, human, social and natural capitals), I decided to describe my system in terms of impacts rather than qualities, as they represented a more easily understandable and relatable idea for stakeholders than the rather theoretical concepts of ‘system quality’ and ‘system themes’ normally referred to in systems thinking. In this phase I individually defined the impacts (using collected field data and literature as inputs), with the aim to refine my impact list later during the participatory research phase in ‘step 3’.

Table 6-1shows the final case system model, resulting from the use of the methods described above.

6.2 STAKEHOLDER GROUPS IDENTIFICATION

Stakeholders are integral part of a human system and, as explained in section 2, their perceptions and worldviews are important components of ‘wicked’ sustainability challenges. Considering Freeman’s definition of a stakeholder as “*any group or individual who can affect or is affected by the achievement of the firm’s objectives*” (Freeman 2001), after framing the system, the defined impacts constituted an effective way for me to readily identify the directly or indirectly involved stakeholders that would be affected by final selection of scour protection at each project phase (Table 6-2).

Table 6-1: System model, with time-based and spatial-based sub-systems and impacts

		TIME - SCALE					
	Scour Protection System Impacts in Time and Space	Design Design Completed and Permitting Approvals Obtained	Construction Materials procured and Units constructed	Installation - Seabed Prepared - Filter and Armor Layer in place	Operation Stable foundations, allowing reliable windfarm energy production	Decommissioning and Waste Management Site and seabed cleared Scour Protection Material Disposed	Future 50-years
SPACE-SCALE	Plot (Domains within Direct Project Control)	- Direct employment of Project resources involved in engineering activities, including project owners and main subcontractors resources	- Direct employment of Project resources involved in construction activities, including project owners and main subcontractors employees, as well as temporary workers from local communities - Material Extraction and Transportation activities - Site Preparation and Building activities	- Engagement of marine service suppliers - Removal of Seabed benthic habitat - Degradation in water transparency - increase in Noise levels (above and under water) - sand seabed replaced by rocky seabed	- Monitoring of Scour Protection Integrity - Data Collection - Maintenace Interventions when needed - new species attracted by the new habitat and development of a new type of community - restriction of areas for some types of fishing - changes in abundance of some commercial species	- Removal of the new seabed habitat dveloped during project lifetime - Degradation in water transparency - increase in Noise levels (above and under water) - rocky seabed replaced by underneath soil/sand seabed - onshore disposal of removed materials	- Starting of a new ecological community, at first with predominance of primary succession species - changes in abundance of some commercial species
	Landscape (Domains immediately Adjacent to Project, but outside of its Direct Control)	- Consultation (paid and unpaid) of other supply chain actors during design development	- Change in Landscape - Cash flow increase - Traffic increase (road and marine) - Air pollution (from traffic and concrete production) - Water Usage and Pollution - Noise from construction activities - Waste Disposal through local infrastructure	- Bay traffic increase - Oceanic traffic increase - Fishing and Navigation routes restrictions - Degradation in water transparency - Increase in Noise levels (above and under water) - Environmental impacts on larger ecosystem due to plot disturbances from installation activities	- Bay traffic increase - Oceanic traffic increase - Fishing and Navigation routes restrictions - changes in abundance of some commercial species - restriction of areas for some types of fishing - Degradation in water transparency - Increase in Noise levels (above and under water) - Biologic Community changes in the areas adjacent to the wind farm	- Bay traffic increase - Oceanic traffic increase - Fishing and Navigation routes restrictions - Degradation in water transparency - Increase in Noise levels (above and under water) - Environmental impacts on larger ecosystem due to plot disturbances from installation activities	- Environmental impacts on larger ecosystem due to different community developed at plot level - changes in abundance of some commercial species
	Global (Larger Domains and Global scale)	- Dialogue with govermental authorities	- Changes in gas balance at the higher atmospheric layers and consequent global warming impacts	- Changes in gas balance at the higher atmospheric layers and consequentglobal warming impacts - Disturbance of Fish migration routes	- Changes in gas balance at the higher atmospheric layers and consequent global warming impacts - Disturbance of Fish migration routes	- Changes in gas balance at the higher atmospheric layers and consequent global warming impacts - Disturbance of Fish migration routes	- global warming impacts

Table 6-2: Stakeholder Identification process

		TIME - SCALE					
	Scour Protection System Impacts in Time and Space	Design Design Completed and Permitting Approvals Obtained	Construction Materials procured and Units constructed	Installation - Seabed Prepared - Filter and Armor Layer in place	Operation Stable foundations, allowing reliable windfarm energy production	Decommissioning and Waste Management Site and seabed cleared Scour Protection Material Disposed	Future 50-years
SPACE - SCALE	Plot (Domains within Direct Project Control)	- Design approval from national authorities, including approval of scour protection design (approval to be achieved before construction starts) - Direct employment of Project resources involved in engineering activities, including project owners and main subcontractors resources	- Direct employment of Project resources involved in construction activities, including project owners and main subcontractors employees, as well as temporary workers from local communities - Material Extraction and Transportation activities - Site Preparation and Building activities	- Engagement of marine service suppliers - Removal of Seabed benthic habitat - Degradation in water transparency - increase in Noise levels (above and under water) - sand seabed replaced by rocky seabed	- Monitoring of Scour Protection Integrity - Data Collection - Maintenace Interventions when needed - new species attracted by the new habitat and development of a new type of community - restriction of areas for some types of fishing - changes in abundance of some commercial species	- Removal of the new seabed habitat dveloped during project lifetime - Degradation in water transparency - increase in Noise levels (above and under water) - rocky seabed replaced by underneath soil/sand seabed - onshore disposal of removed materials	- Starting of a new ecological community, at first with predominance of primary succession species - changes in abundance of some commercial species
	Landscape (Domains immediately Adjacent to Project, but outside of its Direct Control)	- Consultation (paid and unpaid) of other supply chain actors during design development	- Change in Landscape - Cash flow increase - Traffic increase (road and marine) - Air pollution (from traffic and concrete production) - Water Usage and Pollution - Noise from construction activities - Waste Disposal through local infrastructure	- Bay traffic increase - Oceanic traffic increase - Fishing and Navigation routes restrictions - Degradation in water transparency - Increase in Noise levels (above and under water) - Environmental impacts on larger ecosystem d[illegible] plot disturbances from installation [illegible]ties	- Bay traffic increase - Oceanic traffic increase - Fishing and Navigation routes restrictions - changes in abundance of some commercial species - restriction of areas for some types of fishing - Degradation in water transparency - Increase in Noise levels (above and under water) - Biologic Community changes in the areas adjacent to the wind farm	- Bay traffic increase - Oceanic traffic increase - Fishing and Navigation routes restrictions - Degradation in water transparency - Increase in Noise levels (above and under water) - Environmental impacts on larger ecosystem due to plot disturbances from installation activities	- Environmental impacts on larger ecosystem due to different community developed at plot level - changes in abundance of some commercial species
	Global (Larger Domains and Global scale)	- Dialogue with govermental authorities	- Changes in gas balance at the higher atmospheric layers and consequent global warming impacts	- Changes in [illegible]alance at the higher atmospheri[illegible]rs and consequent [illegible] warming impacts - Disturban[illegible]ish migration routes	- Changes in gas balance at the higher atmospheric layers and consequent global warming impacts - Disturbance of Fish migration routes	- Changes in gas balance at the higher atmospheric layers and consequent global warming impacts - Disturbance of Fish migration routes	- global warming impacts
	Stakeholders Involved	- Project Personnel - Supply chain actors - governmental authorities representatives	- Project Personnel - Temporary Site Workers - Supply chain actors - Unions - Administrators - Neighbouring Communities - Businesses sharing same infrastructures	- Marine service suppliers - Fisheries - Recreational sea users - Business sea users - Marine admistrators	- Project Personnel - Marine service suppliers - Fisheries - Recreational sea users - Business sea users - Academic and Researchers interested in collected Data - Marine admistrators	- Project Personnel - Marine service suppliers - Onshore waste management industry - Fisheries - Recreational sea users - Business sea users - Marine admistrators	- Fisheries - Recreational sea users - Global population - Environmental Organizations

I then compared the stakeholder list first generated to the online UN guidelines (Benoît Norris, Traverso et al. 2013) and performed the necessary updates or additions.

The second step was to re-organize the identified stakeholder groups into broader categories, grouped on the basis of their interests in the selection of the scour protection technology:

- Developers and Supply Chain: this category included the groups that have economic interests related to the scour protection in general and the technology selection in particular. Major representatives in this case were the project owner (the Customer), the EPCI Contractor (the company I work for), the suppliers (EAC supplier company) and the installation specialists.
- Regulators: this category included groups that have interests inside and outside the project scope and with a broad community responsibility. For the scour protection technology selection case, I referred mostly to the local community administrators (interested in local community welfare, that might be impacted for example by changes in job creation or pollution rates), seawater administrators (interested in potential changes of marine traffic, fish stocks, natural ecosystem) and onshore road administrators (interested in changes of on-land road traffic).
- Fisheries: the local fishing businesses would be in general impacted by the offshore wind farm from the installation, to the operation, to the decommissioning phases. The selection of the scour protection might have impacts on all these stages, and possibly even after decommissioning if fish stocks would be altered in composition and/or abundance. There are several examples of fishermen opposing the development of the wind power farm, whose concerns were related to the reduction of fishing grounds, and the possible impacts of the seabed changes to the fish stocks (Shiau and Chuen-Yu 2016).
- Onshore Stakeholders: I separated this category as they would be impacted by the scour protection technology selection in a way that is different from the other groups, mostly in the development phase before installation.
- Public opinion: this category included groups that, while not directly touched by the specific project in any way, would be still interested in the positive or negative impacts that it could bring from a global standpoint.

Results of this process are summarized in Table 6-3 below.

Table 6-3: Stakeholder classification

Developers and Supply Chain	Regulators	Fisheries	Onshore Stakeholders	Public Opinion
Project Owner (Company)	Local community administrators	Fisheries (small boats/Inshore fisheries, big boats Offshore fisheries, organizations,…)	Temporary workers	Pro-Renewables
EPCI Contractor	Road/ traffic administrators		Local residents	Environmentally concerned citizens (Local and global)
Scour Protection material providers	Seawater administrators	Recreational fishing		Environmental Organizations
Marine service suppliers for installation and decommissioning activities				Academic and Researchers interested in collected Data

In addition to the classification above, Table 6-4 provides an understanding of some of the existing affinities and misalignments among the identified groups, through comparisons on the basis of:

- Extent of involvement in design,
- Degree of decision power,
- Amount of interest in the impacts.

Table 6-4:Characteristics of stakeholder groups

Grouping criteria	Developers and Supply Chain	Regulators	Fisheries	Onshore Stakeholders	Public Opinion
Involvement in design	HIGH	MEDIUM/LOW	LOW	LOW	LOW
Decision power	MEDIUM	HIGH	MEDIUM	LOW	MEDIUM/LOW
Interest in Impact	MEDIUM/HIGH	HIGH	HIGH	HIGH	MEDIUM/HIGH

6.3 DEFINITION OF THE PERFORMANCE ASSESSMENT TOOL

I developed my performance assessment tool drawing from the System of Systems or SoS (Hadian and Madani 2015) approach. In that context researchers first defined sustainability criteria for each of the Systems and a way to combine them into a relative aggregate footprint (RAF), and then performed the comparison between the various alternatives through the corresponding RAFs. The system of systems that I selected for building my performance assessment tool was based upon the triple bottom line (TBL, people, planet and profit) for business sustainability, as it well represented the environmental, social and economic dimensions that I wanted to explore. I needed then to identify a suitable way to describe and measure sustainability performances of the two technologies for each of those dimensions.

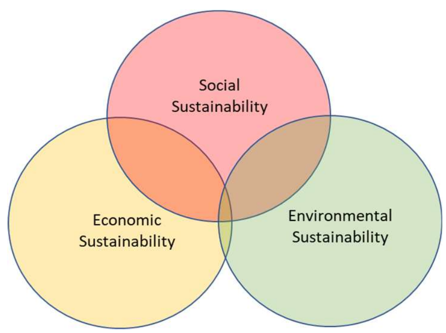


Figure 6.2: Triple bottom line System of Systems

To produce the list of sustainability indicators for my work I conducted a sequential refining process:

1) I developed the initial draft list of indicators starting from the impacts identified through the system modelling process and then integrating the work inputs available from other sustainability assessment works performed for offshore wind applications (Pebbles, Hummer et al. 2011, Hattam, Hooper et al. 2015). I also checked the list against the UN Tier Classification Sheet for the SDGs (Nations 2019) and added valid elements. Table 6-5 shows the results of applying these methods.

Table 6-5: Initial list of indicators

Developers and Supply Chain		investment sustainability - cost of production
		investment sustainability - cost of installation
		investment sustainability - cost of decommissioning
		investment sustainability - probability of access to public fundings
		risk of investment - design reliability
		Corporate sustainability - branding
Onshore Population		local economy - number of local jobs created
		local economy - manufacturing added value
		health and well being - pollution/particulate
		sharing of infrastructure - traffic
		sharing of infrastructure - water footprint /usage
		sharing of infrastructure - amount of production waste to be disposed
		sharing of infrastructure - land footprint/usage
		knowledge creation - marine environment data collection
Fisheries		fisheries economy - commercial species abundance
Public Opinion		Atmospheric composition and climate regulation - Carbon footprint
		healthy environment - biodiversity
		healthy environment - biomass
		healthy environment - risk for invasive species
		healthy environment - marine water acidity (pH)
Regulators		public opinion perception of large infrastructure

2) My second step was to create from this first list, a second shorter list of 'key indicators' (Shiau and Chuen-Yu 2016), suitable for being used as starting point for discussion with stakeholders. Given the nature of the study (mainly targeting a methodology check) and the involvement of people with very different backgrounds, it was important for me to generate a list that was short and with macroscopic, easy-to-understand indicators. Also I aimed to keep a balance among the number of indicators for each of the sustainability areas (environmental, social, economic). I achieved that by selecting my key indicators through the following attributes (Bell and Morse 2012):

- Measurability
- Significance for the stakeholder
- Communicability
- Non-redundancy

Figure 6.3 and Table 6-6 summarizes the outcomes of this process.

Performance Indicator	**Sustainability Area**
Carbon balance	Environmental
Habitat enhancement	Environmental
Local content	Social
Fisheries	Social
CAPEX	Economic
Installation	Economic

Figure 6.3: final list of core indicators

Table 6-6: Description of core Indicators

Carbon balance: the overall amount of carbon dioxide released into the atmosphere as a result of a specific technology selection. Major contributing factors are carbon released for generating the physical objects and the carbon absorbed by the colonizing organisms after installation.
Habitat enhancement: lacking ecological data at this stage, this indicator refers to the qualitative overall improvement, which could be given, for example, from the combination of the following ecological principles (Lengkeek, Didderen et al. 2017): Species-specific habitat requirements, Habitat complexity, Habitat variability, Habitat stability, Habitat durability, Source populations.
Local content: the value that technology choice would bring to the local economy in terms of jobs created for the people in the region. When a government is granting concessions to private companies for this type of large installations, the amount of generated local content often plays a big role on the contract assignation.
Fisheries: this parameter refers to the changes, due to choice of scour protection technology, in availability of commercial species for fishermen.
CAPEX: cost of the material to be installed for scour protection.
Installation: degree of complexity of scour protection installation operations. This is an important indirect economic parameter since more complex operations can introduce functionality risks and/or extend the hired vessel working time.

Once the indicators were established, in order to evaluate and compare the overall performances of the two alternatives, I needed to determine:

- How to measure the utility generated for each indicator.
- How much each indicator should count in the overall performance.
- How to aggregate impacts that take place at different scales.

In other words, in line with the Multi-Criteria Decision Making (MCDM) approach (Tzeng, Lin et al. 1989), I needed both to assign to each indicator a specific (but simplified) performance scale and to establish the importance of each criteria by assessing its 'weight'. Due to the differences in interests and impacts, weight and performance evaluations are by nature fundamentally subjective to the different stakeholders; hence I planned to repeat the described process for the different evaluators involved in step 3.

Likert scale (very good, good, neutral, bad or very bad performance) is a simple way to quickly evaluate performances and to make intuitive comparisons. Given the qualitative nature of the study, and the broad range of backgrounds for the various stakeholder categories, I considered this approach suitable to allow everyone to express their opinion even about topics where they could feel less knowledgeable.

Table 6-7: Performance(utility) scale

very good	1
good	0,5
neutral	0
bad	-0,5
very bad	-1

Assigning a weighting factor is a common way to measure how much each indicator should count. Among the various weighting methods available (Gan, Fernandez et al. 2017), for the purpose of this work I selected 'public opinion' as a weighting method to enable each of the involved stakeholders to express and quantify their concerns about each of the core indicators (Table 6-8).

Table 6-8: Weighting scale

weighting scale	
very important	4
important	3
moderately important	2
relevant	1
completely irrelevant	0

6.4 Discussion

In defining this conceptualization methodology, I started from Soft System Methodology types of analysis (section 10.1) for formulating my very first understanding of the context: at that stage using Rich Picture and diagramming representations offered more flexibility in representing the 'soft' formal and informal elements, less easily reflectable through the more rigid SWOT analysis approach typical of business contexts. However, after that preliminary assessment, I decided to depart from the methodology and opted for the described structured approach as that seemed to provide a more efficient way to convey my message in the project environment I was part of. In alternative, instead of making a purely subjective Rich Picture, one could have developed it in a participatory way together with stakeholders, establishing a shared root definition at the end of the process. In my own context that was practically not a possible approach because during phase 1 I was expected to follow project management procedures while performing my every day job and during phase 3 Covid restrictions and time limitations did not allowed to organize a plenary participatory session.

As for all the case-specific intermediate results obtained at this stage (Table 6-1, Table 6-4, Table 6-5 and Table 6-6), the findings were the result of literature research and my individual work, and that limited perspective constituted the main limitation on their reliability as tools for exact and generally valid measurements. Nevertheless, from a participatory verification standpoint, this representation was suitable also for later use in the research, i.e. as supporting tool during the interactions with the various stakeholders to funnel the conversations to the scour protection selection process and to conduct them in a structured and focused way. In alignment with Bell and Morse (Bell and Morse 2012), while subjectivity is unavoidable, subjectively derived sustainability analysis can still be useful assessment tools, especially when several subjective perspectives are involved in the dialogue.

As explained in section 2, acquiring a project sustainability perspective requires enlarged time horizon and scope/context dimensions (Silvius and Schipper 2014). The system model defined (Table 6-1, Table 6-2) provides a generalizable tool applicable to similar organizational profit-based contexts undergoing some kind of change, such as the introduction of a new technology or other, especially within offshore business areas. The identified matrix structure, in fact, is largely applicable within project organizations, with similar definitions for the x-y axes. Also, the resulting sub-system structure makes it easy to identify the elements within each quadrant's own boundaries, while keeping an eye on its interconnections with the adjacent ones, hence facilitating the enforcement of the needed systems thinking approach to a complex situation. In a similar fashion, Achterkamp and Vos (Achterkamp and Vos 2007) had previously developed a methodology for stakeholder identification based upon understanding the 'roles of involvement' and 'phasing this involvement' throughout project lifecycle. For my specific purpose, though, their conclusions were not fully applicable and I deviated in two aspects: on one side the terminology used for the different roles (client, decision makers, designers) in my context could lead to misunderstandings as these terms already correspond to specific project roles that do not match with the definitions of Achterkamp and Vos (2007); on the other side, while recognizing the advantage of the focus group activities at the very beginning of the stakeholder definition process (Achterkamp and Vos 2007), due to time restrictions, I could only perform participatory checks (during step 3, paragraph 7) of the results I individually obtained.

Both lists of indicators (the 'initial' and the refined 'core' ones, Table 6-5: Initial list of indicators and Figure 6.3) have a general value for offshore businesses as they describe dimensions that are common to many ocean-related types of projects. In this case, I deliberately generated my core list as a dialogue tool and I looked for a balance between the environmental, social and economic dimensions. An alternative to this approach, depending on the type of inquiry, might be to prioritize one of them (for example, to compensate for one or more stakeholder groups not being represented and listened to in the process). In addition to the results themselves, the methodology of having two consecutive and 'funnelling' stages is a proven approach and has a general validity for early stage analysis, where participatory research is planned (Shiau and Chuen-Yu 2016).

For the purpose of this work, where I wanted the evaluation to include all stakeholder groups, I have selected 'public opinion' among the various methods available (Gan, Fernandez et al. 2017). The project being at an early stage and the evaluations developed not being binding, this approach also allows to freely consider all kinds of opinions when there is still the maximum flexibility. More rigour would not be appropriate in a situation where so much can still change. Nevertheless, it could be later considered for the more developed stages of the project, when it will be clearer what are the important aspects to look at and it will be more practical to establish the right priorities. Analytic Hierarchy Process (AHP) was, for example, successfully implemented in urban development and agriculture sustainability studies (Veisi, Liaghati et al. 2016, Ameen and Mourshed 2019). This more sophisticated tool allows ranking based upon interdependencies among different SIs and subjective priorities of the involved evaluators.

7 STEP 3 (MODEL VERIFICATION)

7.1 OBJECTIVES OF THE INTERVIEWING

Semi-structured interviews guided the interactions I had with relevant representatives of identified stakeholder groups. I designed the interviews with a dual goal: checking the learnings from modelling stages 1 and 2, as well as doing performance assessments. These interactions also allowed me to test out and to make observations about the research methodology itself. The information I collected at this stage included both qualitative and quantitative data about stakeholders' opinions on the actual case study results and the methodology followed, as well as participants' sustainability performance assessments of the two technologies.

7.2 PREPARATION WORK

Preparation work was a necessary step to take before interacting with the various stakeholders. In particular I spent some time:

- Analysing my position within the situation;
- Identifying the gaps I aimed to fill in with this phase of the research;
- Studying how to structure the interactions;
- Planning whom to interview.

As highlighted earlier, I approached this activity with a double role, as an employee that was assigned a job task and as a NMBU student researching for my Master thesis. I reflected about my duties associated to each of the two functions (job deliveries versus meaningful research), and also about the pros and cons potentially arising from my pre-existing knowledge (useful context background information versus biases), the knowledge I had acquired in the first two phases of the research (validity of those results versus how to achieve more meaningful ones), my knowledge of the overall project and the involved people part of the project team (potential for highly-paced work versus pre-existing relationships' automatisms). Also my position towards different stakeholder categories was worth to consideration when defining the type of language and approach. For example I had to plan how to present ecological considerations about biodiversity and species abundance to stakeholders belonging to the 'Developers and Supply Chain' group, that were more used to a business language. On the other side, with the 'public opinion' representants I had to simplify the technical vocabulary. Also, when it comes to the approaching strategies, while to some interviewees I was mainly an experienced colleague with a defined role and I could address them confidently, to others I was a student at her first research experience in the study field and sometimes I found appropriate to present myself in a more formal and humble way.

Looking at the results obtained during the conceptualization phase, I then reflected about how to best use my upcoming stakeholder interactions to fill in the existing gaps and I identified the following areas for further exploration:

- Model checks,
- Methodology checks,
- Stakeholder categories perspectives.

Another preparation activity I worked at was the creation of a document ('Stakeholder interview package') for all the interviewees to familiarize with the topic beforehand, and also designed to be used as a starting point for the discussion: such document included basic glossary, some background information about the project, summary of the main results and a description of the research methodology. The main areas to be explored during the interview were also anticipated in the document as an interview guideline (section 0). I chose this sort of 'vignette questions' approach (Bryman 2016) in order to enhance focus on the very specific scour protection object of study, considering that the broader context the study belongs to (renewable energy and infrastructures environmental impacts) could have easily led to feedbacks beyond the actual research objectives. The document also allowed me to rely on some graphical representations to communicate in a more effective way, especially with those categories outside of the specific technological field.

I arranged the interview guideline questions both for enhancing a natural flow of the conversation, as well as for an easier data analysis process: stakeholders started with additional reflections on the topic (in case they had not done a thorough examination of the shared package) that allowed to go through all possibly needed clarifications about the concept and the methodology in advance, before actually assessing indicators' weighting and evaluating the expected performances to be compared. In particular the starting point was for me to verify the level of understanding of the stakeholder package and of the research topic, before moving to the actual measurements and considerations about the two presented alternative technologies. I then planned to conclude with open-ending questions with the aim to reinforce reflection of the topic and gain insights about what the interviewee saw as relevant, in case something significant was not touched upon during the interview.

At last I had to plan which individuals were best to be approached to reach my goals. My considerations included:

- Identify the decision groups that needed to be represented (from the conceptualization phase).
- Understand together with activity owners (contractor and customer) to which extent each category could be involved, based on existing policies regulating communication and exchange of information with external entities.
- Identify the actual people/organizations that would constitute good representatives for the various groups.
- Understand how to select them based on existing time and situational constraints (for example I could not directly contact Regulators, Fisheries and Onshore Stakeholders representatives due to practical project limitations and Customer company communication policy).

The stakeholder categories represented and the selected representatives themselves also strongly depended upon peoples' accessibility (note: this whole thesis was conducted during COVID times).

I held a total of four interviews between August and October 2020 with selected representatives, both for the industry and the scientific communities:

- Contractor employee_1 (representative of the Developers and Supply Chain Stakeholder Group)
- Contractor employee_2 (representative of the Developers and Supply Chain Stakeholder Group)
- Plant Biologist (representative of the Public Opinion Stakeholder Group)
- NGO Marine Ecologist (representative of the Public Opinion Stakeholder Group)

7.3 INTERVIEWING PROCESS

I selected a semi-structured interviewing process in order to maintain the degree of structure I needed for cross-stakeholder comparisons, while still allowing the needed flexibility to explore any potentially arising new point of view. In order to ensure adherence to the topic, while they were assigning utility (performance) and weighting factors, I reminded the interviewees to think about specific features such as the relevance of the indicator, the entity of the impact, the duration of the project phase or phases during which the phenomena occur, the number of people potentially involved, … Each interview resulted in a meeting minutes summarizing the main discussion points and the obtained results, which I then sent to each interviewee for information and comments.

Table 7-1: Performance Assessment by Contractor employee_1

Performance Indicator	Sustainability Area	EAC perf.	Stone perf.	Weighing	Scores EAC	Scores Stones
Carbon balance	Environmental	0	0,5	4	0	2
Habitat enhancement	Environmental	0,5	-1	3	-0,5	-3
Local content	Social	1	0	1	0	0
Fisheries	Social	0,5	-0,5	2	-0,25	-1
CAPEX	Economic	-0,5	0,5	2	-0,25	1
Installation	Economic	0	0,5	2	0	1
SCORE					**-1**	**0**

Table 7-2: Performance Measurement Contractor employee_2

Performance Indicator	Sustainability Area	EAC perf.	Stone perf.	Weighing	Scores EAC	Scores Stones
Carbon balance	Environmental	-0,5	0,5	3	-1,5	1,5
Habitat enhancement	Environmental	1	0	4	4	0
Local content	Social	0,5	0,5	2	1	1
Fisheries	Social	1	0	3	3	0
CAPEX	Economic	-0,5	0,5	3	-1,5	1,5
Installation	Economic	0	0,5	2	0	1
SCORE					**5**	**5**

Table 7-3: Performance Measurements Biologist

Performance Indicator	Sustainability Area	EAC perf.	Stone perf.	Weighing	Scores EAC	Scores Stones
Carbon balance	Environmental	0,5	-0,5	2	1	-1
Habitat enhancement	Environmental	1	-0,5	3	3	-1,5
Local content	Social	0,5	-0,5	1	0,5	-0,5
Fisheries	Social	0	-1	3	0	-3
CAPEX	Economic	-0,5	0	1	-0,5	0
Installation	Economic	-0,5	0	1	-0,5	0
SCORE					**3,5**	**-6**

Table 7-4: Performance Measurements Marine Ecologist

Performance Indicator	Sustainability Area	EAC perf.	Stone perf.	Weighing	Scores EAC	Scores Stones
Carbon balance	Environmental	-0,5	0	3	-1,5	0
Habitat enhancement	Environmental	0	0,5	4	0	2
Local content	Social	1	0	2	2	0
Fisheries	Social	-0,5	-0,5	2	-1	-1
CAPEX	Economic	-1	-0,5	2	-2	-1
Installation	Economic	-0,5	0	1	-0,5	0
SCORE					**-3**	**0**

7.4 Discussion

Compared to findings during step 1, nothing unexpected emerged during interviews with Contractor representatives. This was probably due to the fact that as a contractor employee myself, I had already analysed those results with a perspective aligned with that of my colleagues. On the other side, interactions with stakeholders from very different backgrounds resulted in major critics of what is presented in Table 5-2. In particular opinion of the NGO marine ecologist was that the best ecological performance one could expect for EAC scour protection, would be to match natural rocks. Evidently then, as anticipated, it would be necessary to further check the reported 2X biodiversity increase factor for EAC units, which was most likely based upon EAC vs. Portland cement concrete performance comparison data available at that moment. A major hole in the collected information is undoubtedly caused by the fact that not all stakeholder groups could be involved in the interviews. The lack of measurements from important categories such as regulators, fisheries and onshore stakeholders prevented me from verifying the conclusions drawn during step 1. These are some of the categories more directly impacted by the scour protection technology selection in their everyday life and involving also them in the conversation could have resulted in a significant reassessment of the sustainability performance evaluations, most likely within the social dimension. In addition to that, the very small number of interview per group also does not allow to verify whether there was any uniformity within groups and if the interviewees were actually representative of their own stakeholder groups. On the other hand some level of incompleteness is unavoidable and common to most studies (Gray, Haggett et al. 2005, Shiau and Chuen-Yu 2016) and it must be ethically addressed case-by-case from an inclusion standpoint, through considerations of diversity and representativeness of the consulted individuals (Gazley, Chang et al. 2010, Crucke and Knockaert 2016).

I interpreted the fact that the weighting factors measured during the interviewing process were not too distant from each other (even among stakeholders with very different backgrounds and belonging to different groups), as a result of a reasonably uniform understanding of the chosen sustainability indicators. This partially endorsed my choice of giving equal importance to the feedback from each interviewee. Inversely, the broad variation in performance evaluation among the different groups (and even within the same 'public opinion' group) is reflecting significantly different understandings of the sustainability performances of the two technologies (Shiau and Chuen-Yu 2016).

From a methodology standpoint, I experienced that the specificity of the questions sometimes forced the direction of the study. For example, while trying to use the interview process as much as possible to fill in the gaps identified in the gap analysis, I realized my interlocutors had little to say about methodology and therefore mainly tended to uncritically confirm what I presented in the stakeholder package document. In some instances, the limitation associated with the 'vignette questions', while directing the respondents to focus on the topic at hand, also represented an additional limitation of interviewee expression. In alignment with most common practices (Weller 1998), I partially mitigated this effect by verifying my interviewee understanding with initial more open questions, before moving to the more structured performance assessment process. An overall more unstructured approach would have probably led to different results, as proved by the interaction with the NGOs ecologist, where a close follow-up of the stakeholder document was not possible due to internet issues. The result of our more open conversation led to a new topic (possibility to use wind farm substructures for seaweed and bivalves aquaculture), which was unrelated to the scour protection case research but very relevant for all involved stakeholders.

Another field observation was the difficulty associated with talking different languages with people belonging to different worlds: it happened that I took for granted that one stakeholder would understand topics related to another stakeholder's context and *vice versa*. For example, I discovered during the interviews that my interviewees did not completely grasp some of the main concepts in the stakeholder document, a document that I had written for it to be complete for everyone: biased by my own knowledge, I overestimated stakeholders' level of comprehension and mistakenly thought the document was sufficiently clear. On the other side, the possibility to perform some of the interviews face to face and the followed interviewing structure provided enough space to make necessary clarifications before making the assessments. This experience made me reflect upon the possibilities and the risks associated with performing similar assessments through anonymous surveys instead: where interactions (and direct clarifications) are not possible, it becomes even more critical for the researcher to have a preliminary deep context understanding when formulating the questions and to adequately structure the survey design, for example introducing ‘check’ questions to verify the correct perception of the problem (Weller 1998). Also the nature of the research is determinant: for a complex and easily misunderstood topic like the one I studied, having anonymous non-interactive surveys would have imposed to seriously question the reliability of the collected data.

Regarding the interviewing process itself, ideally it would have been better to perform interviews with another researcher, to get a second opinion and ensure accuracy of the collected data. At least partially, I mitigated this issue by sending the minutes to each interviewee after the meeting both for information and for information quality control.

With more time available, a conclusive focus group would have been a possibility for me to maximize the outcome of this part of the research: it would have enhanced an alignment among stakeholders, while having them learning from each other and understanding each other’s interests.

8 STEP 4 (FINAL DATA ANALYSIS)

8.1 PREPARATORY REFLECTIONS

After phase 3 interactions with stakeholders, during phase 4 I processed the obtained data, with the aim to make the necessary predictions to draw conclusions about the two alternative scour protection technologies.

This step started reflecting upon possible methodologies to analyse and combine the learnings accumulated so far, for performing the sustainability performances comparison between the two technologies. Despite the limited number of performed interviews, the results still allowed to develop a data integration methodology to then perform the actual technology sustainability performance comparison.

In order to make a comparison between the two technologies, I had to address a challenge typical of using SIs, i.e. to compile different scale SIs into a ‘composite indicator’ (Commission 2008), ideally measuring the multidimensionality of sustainability within a single figure. As explained in the introduction, two important concepts in the determination of composite indicators are ‘weigthing’ and ‘aggregation’, respectively reflecting the relative importance of each indicator and the substitutability of the different dimensions.

8.2 WEIGHTING

Among the various weighting methods available (Gan, Fernandez et al. 2017), I selected ‘public opinion’ and I gave the same importance to the weighting factors from all involved stakeholder. It was important for me to ensure that all stakeholders’ concerns were duly taken into account in a situation that is still very preliminary, and where the available quantitative and qualitative case study field data are unavoidably approximate

As shown in Table 8-1, the values measured during the interviewing process were not too distant from each other, even among stakeholders with very different backgrounds and belonging to different groups.

Table 8-1: Calculation of Averaged Weighting factors

Performance Indicator	Sustainability Area	weighing factor				
		Employee _Contr.	Employee _Contr.	Ecologist and UNI scientist	specialized marine ecologist NGO	Average weight factor
Carbon balance (CO2)	Environmental	4	3	2	3	3
Habitat enhancement	Environmental	3	4	3	4	3,5
Local content	Social	1	2	1	2	1,5
Fisheries	Social	2	3	3	2	2,5
CAPEX	Economic	2	3	1	2	2
Installation	Economic	2	2	1	1	1,5

On the other side, there was a broad variation of results relative to performance evaluation among the different groups, even within the 'public opinion' group (Table 7-1, Table 7-2, Table 7-3 and Table 7-4). Hence, when assigning scores to each SI, I decided to average the measured performances following two alternative approaches and then to compare the outcomes:

1. In one approach, I gave the same importance to all stakeholders as it can be reasonably done with the very preliminary available field data, and calculated the mathematically averaged performances.
2. In the other approach, I took into account the fact that some of the stakeholders were actually 'experts' for specific fields, hence their measurements could be considered extra reliable on topics within their expertise. More specifically I assumed that the marine ecologist was the best person to estimate performances for Carbon balance, habitat enhancement and impact of fisheries, while the contractor employees was better to judge local content, CAPEX and Installation implications.

Table 8-2: Averaged Performances

Performance Indicator	Sustainability Area	Averaged scores	
		Scores EAC	Scores Stones
Carbon balance (CO2)	Environmental	-0,5	0,625
Habitat enhancement	Environmental	1,625	-0,625
Local content	Social	0,875	0,125
Fisheries	Social	0,4375	-1,25
CAPEX	Economic	-1,0625	0,375
Installation	Economic	-0,25	0,5

Table 8-3: Expert-judged performances

Performance Indicator	Sustainability Area	EAC perf.	Stone perf.	Weighing	Scores EAC	Scores Stones
Carbon balance	Environmental	-0,5	0	3	-1,5	0
Habitat enhancement	Environmental	0	0,5	3,5	0	1,75
Local content	Social	0,75	0,25	1,5	1,125	0,375
Fisheries	Social	-0,5	-0,5	2,5	-1,25	-1,25
CAPEX	Economic	-0,5	0,5	2	-1	1
Installation	Economic	0	0,5	1,5	0	0,75
SCORE					**-2,625**	**2,625**

8.3 Aggregation

The obtained performance values varied considerably between the two methods (Table 8-2 and Table 8-3). Depending on the school of thought (non-aggregator or aggregator) these performance values could be used in two ways (Commission 2008):

- By themselves, as measures of the corresponding indicators, following a non-compensatory approach, where positive effects on one dimension cannot compensate for negative effects on another dimension.
- Aggregating them to calculate a composite indicator for each of the two technologies, that can then be used to perform a direct comparison (Table 8-4).

Table 8-4: Aggregated results for the two sets of performance assessment in Table 8-2 and Table 8-3

	EAC material	**Stone material**
Averaged performances	**1,125**	**-0,25**
Expert-judged performances	**-2,625**	**2,625**

8.4 Discussion

Together with expert judgment, the hereby selected public opinion is presented in the OECD Handbook on Constructing Composite Indicators (Commission 2008) as one of the options available for assigning weighting factors. In my specific case, given the relative uniformity of weighting factors' assigned by different stakeholders, the weighting method choice was not particularly critical since another method would have led to similar results.

On the other side, the considerable variation among the interviewees' performance assessments, led to my decision to use more than one method to calculate average performance values (refer Table 8-2 and Table 8-3) but, for all the limitations described so far, neither of the two sets of results should be considered in absolute terms, as actual meaningful reality measurements. However, despite the reservations exposed above about the actual performance assessments, the here performed aggregation exercise (Table 8-4) was anyway useful to exemplify the drawbacks associated with composite indicators. In fact, even in a very simple case as the one under study, disregarding the process through which the composite indicators were created, could have led to simplistic conclusions or, maybe worse, it could have been misused to favour one decision over another, simply by instrumentally selecting the most favourable averaging technique. Geometrical aggregation is one alternative method to at least partially amend for the full compensability downsides of linear aggregation, while still benefitting of the simplification advantages provided by referring to a single composite indicator (Nardo, Saisana et al. 2005). Again, due to the very preliminary assessments, in this case changing aggregation method would have not led to more meaningful conclusions.

The best way to use my results would rather be to implement them as part of a participatory performance evaluation process as recommended by Bell and Morse (2012). In my case, one possibility would be to present them in conjunction within a multi-stakeholder focus-group setting and to use them as tools for initiating a dialogue among representatives of the different groups.

9 CONCLUSIONS AND FINAL RECOMMENDATIONS

Sustainability is one of the ‘hottest’ topics of our times: governments, scientists and public opinion have all been actively involved in the conversation for decades now, and, as a consequence, also companies are experiencing increasing direct and indirect pressures to take over their share of responsibility. Today’s fast-paced technical development often proposes the introduction of a new technology as a possibility to target business and sustainability goals simultaneously. Assessing the actual sustainability performances of a new technology, though, is a typical ‘wicked’ type of problem (multidimensional, interconnected, subjective and mutable), and it requires a soft-systems way of thinking, which profit-driven organizations typically lack. This work aimed at developing a methodology for supporting traditionally-structured businesses that do not have an organized sustainability line yet, to preliminarily assess sustainability of newly proposed technologies before deciding to embark in more expensive evaluation processes. Starting point of my inquiry was a four-month action research period within an offshore wind business context during which I was responsible for the evaluation of Ecologically Active Concrete (EAC) used as alternative to rocks for scour protection of wind turbine towers. In order to do that, drawing from soft system and sustainability theory methods, I developed a multicriteria assessment tool, that I then tested through four semi-structured interviews, to eventually perform the comparison between the sustainability performances of the novel and the traditional scour protection technologies. Despite higher production and installation costs and a bigger CO2 footprint, EAC appeared to have a significantly positive impact for local population. On the other hand, habitat enhancement performance results were too approximate to draw any conclusion. From a case perspective, at the time this thesis was written project activities were on hold and it was not yet taken any decision about how to proceed.

As explained in sections 5.3, 6.4, 7.4 and 8.4, from a case-specific standpoint the findings have to be treated carefully since they were based on very preliminary data and they relied on a too small sample prevents generalisation. My double role as researcher and employee also had some implications, since I unavoidably brought with me my worldview and by biases. From an ethical perspective, as the action research work was part of my employee duties, it was challenging to keep focus on the ‘research’ side. However, I was compelled by the followed step-wise approach to think in action and research cycles (Blichfeldt and Andersen 2006).

In case it will be decided to proceed with the assessment of EAC as a scour protection alternative, following an iterative learning cycle (Bell and Morse 2012) and building on the learnings from this research, the following additional activities are recommended:

- Validation of assumptions that, while fundamental to simplify the situation and to perform the preliminary study in a short time, nevertheless have to be re-discussed in detail in light of the new learnings.
- Direct involvement of local permit authorities, that would help to tailor the scour protection design to the actual environmental and social targets for the specific case.
- If the study will reach the execution phase, rather than implementing EAC scour protection for the whole wind farm, a step-by-step approach is recommended, for example starting by using EAC only for a limited number of selected wind farm structures, that would then constitute prototypes to be monitored. How to design such arrangement should include experiment set-up considerations, similarly to what was done in the north sea (Lengkeek, Didderen et al. 2017).
- Considering the lack of ecological experience within the energy industry corporate business, a close collaboration with scientists and universities is also recommended when it comes to experimental set-up and monitoring activities: “An important avenue for more inclusive and effective science-policy interfaces is the co-creation of scientific information and research. Engaging scientists with all relevant stakeholders (policymakers, managers, private sector representatives, and citizens) can

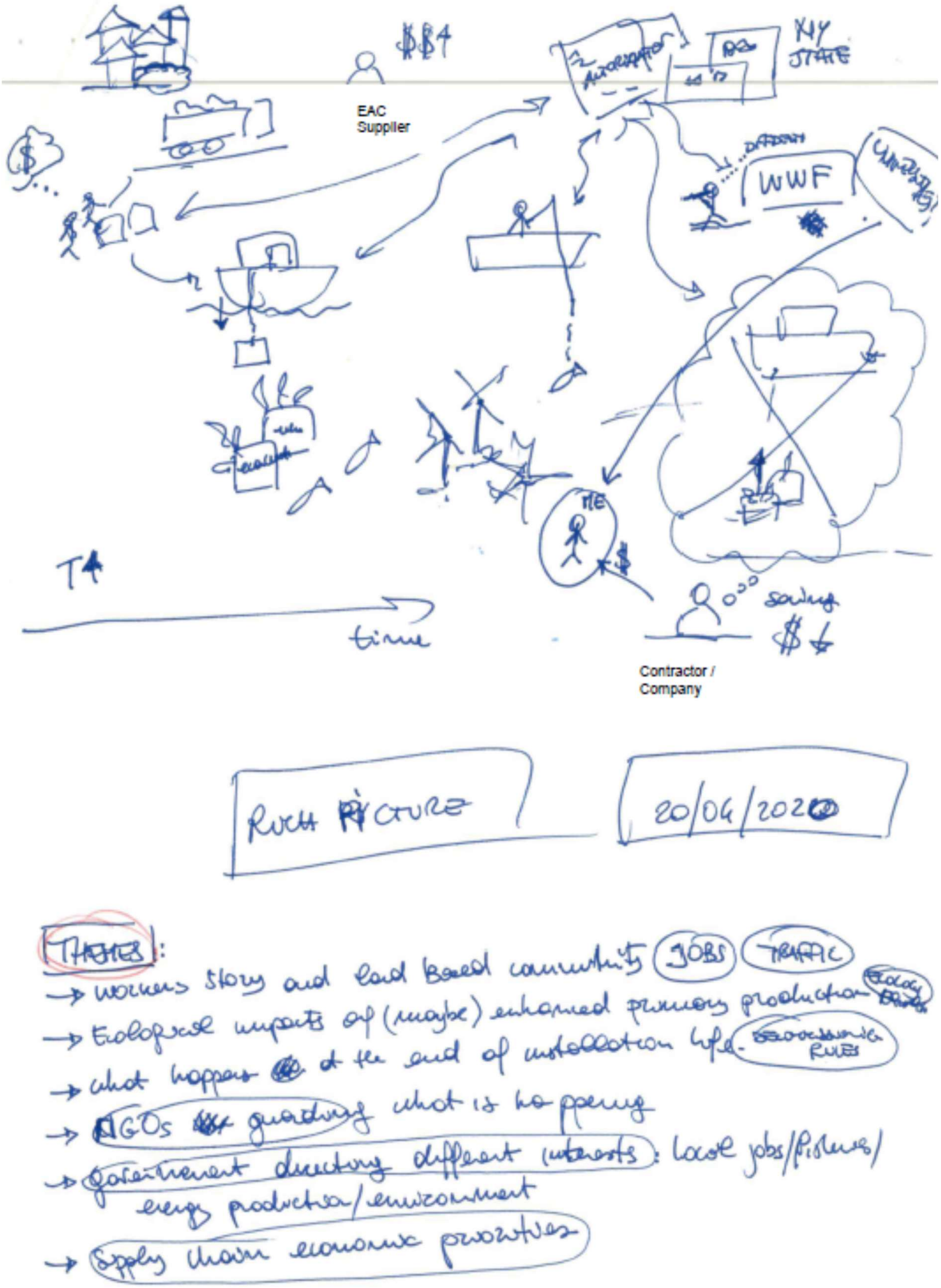
only make scientific data more trustworthy and thus help address some of the challenges that arise from a ‘‘post-truth world.’”(Claudet, Bopp et al. 2020).

From a more general innovation-for-sustainability perspective, a given fact is the specificity embedded within the case-study approach followed in my the inquiry: I studied one single type of innovation in one specific business context, and conclusions are also case specific. However that does not necessarily invalidate analytical generalisation when it comes to the more generic issues (Yin 2009) such as choices made during the sustainability assessment process (Bell and Morse 2012). In fact, due to the case selection process described in paragraph 3.2, some of the learnings are certainly transferable for similar business context and companies as the process development mechanisms can be assumed to be typical. In this respect, looking at my inquiry from a certain distance, my ‘employee’ role could also be seen as an experiment of what happens within standard business situations: rather than through a research project, it is much more usual that one of the employees is asked to address the sustainability of an innovative technology, possibly involving external resources for non-available expertise. It is then likely that in the future a growing number of employees will be expected to address sustainability performance analysis. My job-related challenges then become representative examples of the more general issue of finding effective, quick and original ways of assessing the new challenges of sustainability in a traditional firm environment. Together with the assessment of the pertinent problem (1st level), it would be interesting to better understand the role of these sustainability-pioneering employees and if/how they should be trained for the purpose (deepening of the 2nd level analysis started with this inquiry), and then take a further step about becoming more aware of the associated individual and collective learning processes (3rd level), looking at this topic through the 3-level systems thinking structure (Levin and Ravn 2007). Similar to what performed in my inquiry, a possibility is to conduct participatory research for a number of study cases within profit-driven contexts, this time with the researcher being more of an observer of the employee and of the company dynamics.

Soft-system and sustainability assessment methods represent a useful resource for traditionally hard-system thinking businesses striving to reach their sustainability goals. Assimilating such practices, though, would require a radical change of approach, shifting from a predictable and controllable project management style to one that is characterized by flexibility, complexity and opportunity (Silvius and Schipper 2014). By translating SSM into the here described rather straightforward and simplified process, I came up with a practical tool to enter the sustainability conversation even in challenging situations like the one analysed, with tight project schedules and within ill-equipped corporate contexts. The case and the methodology presented showed an exemplification of how such techniques could support the development of sustainability performance evaluations by translating the incommensurable sustainability concept into a more manageable multicriteria type of description. The resulting performance assessment is meant to be used as a starting point to facilitate much needed conversations around sustainability numerous complexities.

10 Appendices

10.1 Appendix 1: Soft Systems Methodology preliminary work



SMARTY SYSTEMS

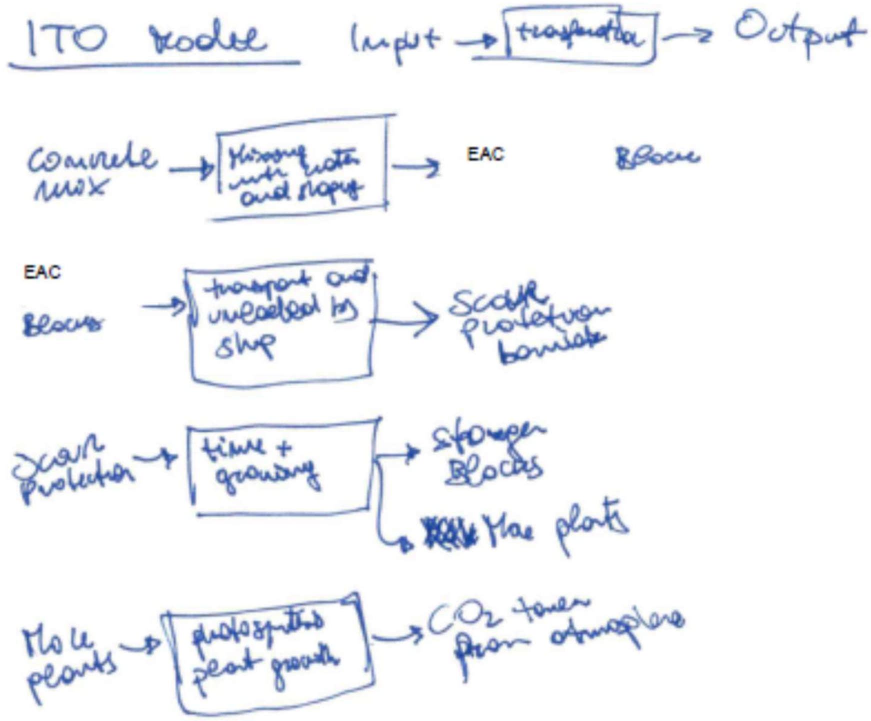
PART II

UNDERSTANDING MESSY SITUATIONS

(1) EAC is a system to:
- provide physical barrier to foundation
- comply with environmental rules
- increase primary production and fish
- increase jobs @ construction site
- buy/sell concrete mixtures
- develop technology for environmental scope
- use "green" National fundings

(2) EAC stakeholders
- EAC, Supply chain, Contractor, Company
- Government
- workers @ site
- people living nearby
- fisheries relying on that fish
- people using the ocean
- people concerned about the ocean
- fish
- benthic environment

(3) EAC is a system to:
- produce CO_2
- produce NOISE
- generate extra traffic on the streets
- generate extra dust
- generate extra traffic @ the harbor
- attract invasive species
- create an habitat more suitable for some species, unbalance natural competition
- change ecosystem community composition / extinction


ITO model
Input
Output
EAC
EAC
time +
More plants


Customer
Contractor
EAC Supplier
Supply chain Economic priorities
- supply chain
- cost
- funding for green
Company
CO2 implications
EAC
develop technology
technology tested
Contractor
increase local content
get a technology for the future
Government/Authorities
Local community
Concerned for Environment
CONSTRUCTION
more CO2
More concrete
More jobs
More blocks
more fish
more fishermen
more traffic/noise in the street
ships to pick them up
more complaints from local community
Rules from local administration
more traffic in the harbour
State Rules
Rules from sea Rules (!!)

WHAT → A system to evaluate All impacts of using EAC for scour protection [illegible]

WHY → in order to take a [illegible] final decision more informed (and to learn a different way to take decisions)

TWO CAGES

TRANSFORMATION

All impacts of using Ecomaele not evaluated → All impacts of using EAC evaluated

Why

the belief that a multiperspective decision making approach is [illegible] needed to approach a complex situation

Owners

Who would give permission for the system to exist? Company [illegible]

Customers (related to the WHAT, not the WHY)

direct Beneficiaries/victims of the system [illegible]

EAC supplier / Contractor

more specific identification with names, operator, roles

Actors participating to the transformation

Company / Contractor / EAC supplier / NY regulators / fishermen / local communities / NGOs / University

GUARDIANS create an alarm if system creates unintended consequences

NY approval committee (???)

Environmental Constraints that limit for system operation

- Budget
- people involvement/availability to get inputs
- too much interference
- time constraints

Subsystem of activities → List of necessary activities to achieve transformation (my METHOD)

Actors should then be called in for the activities in the subsystem

10.2 APPENDIX 2: QUESTIONNAIRE

1. Verification of the proposed system (questions about the validity of the chosen spatial and time scales, stakeholder categories identified, initial performance indicators)

2. Performance measurements following suggested methodology

3. Deepening questions about Stakeholder perception of the topic:
   a. Definition of what is perceived as a 'sustainable for scour protection' for offshore structures (starting from the overall environmental-social- economic sustainability model)
   b. Advantages about this new technology (Strengths)
   c. Disadvantages about this new technology (Weaknesses)
   d. Hopes about the future of this new technology (Opportunities)
   e. Main concerns about the future of this new technology (Threats)
   f. Speculate on how other categories could perceive the situation (maybe starting from assumptions on how they will respond to item 2 above)

4. Methodology Verification
   a. Comments about followed process
   b. Potential for generalization and main limitations
   c. Suggestions for methodology improvements

5. Ending questions
   a. Which question(s) would you have liked me to ask you?
   b. Have your views changed from before being involved in this study? How?
   c. Any suggestions about future follow up activities? (for example research topics, monitoring planning, etc.)

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