Risk Assessment report for the stand alone module

D6.5

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Executive Summary

This report provides a methodology on how to approach the risk assessment and management for the risks of technologies being used in the Space@Sea project and their associated business impact. With this framework subdividing every aspect of a specific step of the assessment, it is also possible to get precise information on a certain aspect that the reader is most interested in, by taking a look on the table of contents of this report. Overall the report tries to contribute to the correct handling of risks, based on the current progress of the Space@Sea project and therefore customizes the approach for the needs of it.

Risks affect the objectives of organizations and projects, which is why they have to be assessed and managed. Especially as a result of the innovative nature of the Space@Sea concept and the innovative technologies being used, there may be uncertainties regarding the feasibility and viability. As the report is a contribution to the "Task 6.6 Definition of the methodology for risk assessment for the energy hub", while also contributing to the Working Package 1: Business Case of the project, it aims to take a look at the interconnection between these technical uncertainties and the business case outlook.

The report assures a common understanding of the term "risk", by defining it as the result of the multiplication of the probability of occurrence and the consequence (if the risk occurs) in the beginning. Beside other advantages, this definition primarily enables the comparability between different risks. After that, state-of-the-art and industry approved risk standards that also approve the chosen definition of risk, have been applied on this report, to act as a foundation for the framework to be created. The ISO 31000, a standard that provides guidelines for the general risk management and emphasizes the need of a proper handling of risks, and the ISO 12100, taking technical aspects of the risk assessment into account, are the main standards that are applied. Based on these, it is possible to create the methodology, starting with general aspects for the risk management that should be taken into account, like setting risk objectives for the overall management process and an analysis of all kind of participants and resources being involved in it, followed by what to take into account for every core step of the process. The core steps, defined by the ISO 31000, are: risk identification, risk analysis, risk evaluation and risk treatment. These steps act as the main chapters for the rest of the methodology to assure a thorough approach for the assessment. Each of the main chapters has been subdivided into the same categories to cover all aspects of the objective of this report, either general, technical or business aspects, as well as recommendations for the case of the Space@Sea project.

For the risk identification, it has been recommended to emphasize the differences of the project to similar projects and then identify the risks that result from this circumstance. Checklists with already experienced risks are helpful, but should only be used after focusing on the particularities of the project. For the Space@Sea project, the indicator "costs" has been identified to be a consequence that is commonly shared by all risks that may occur. Therefore, there has to be an overall agreement on which costs will be taken into consideration for the definition of the consequence, which also depends on data being available for all risks. By picking the same type of costs for every risk, all risks become comparable along the same consequence. As a first and basic approach to this circumstance, it has been proposed, to use the manufacturing costs of a technology component as the consequence, because this data will most likely be available. This approach is based on the assumption that higher manufacturing costs are representative for higher consequential costs, with the component being more complex

or more material being used. The risk analysis focuses on the probability of occurrence and the consequence and is all about assigning these two elements of the risk definition with a value. Depending on the resources available and the overall scope of the risk assessment, these values have a qualitative or a quantitative nature. Methods for the determination of the probability are mentioned, but it has been found that a concrete value for the probability is difficult to determine, mostly because of limited resources, which is why a qualitative number is often used for it. With “costs” being defined as the consequence, these costs taken into consideration need to be calculated. The analysis sets the basis for the risk evaluation, which is about comparing the different risks, prioritize them and visualize the difference between each risk. The comparison is done by calculating a risk value for every risk, which makes all risks comparable, either qualitatively or quantitatively. The quantitative approach allows for a monetary risk value to be calculated, which can be further used in the project’s budget planning for example. A mixed approach (semi-qualitative/semi-quantitative) only allows for a graphical illustration of the risk situation. For the Space@Sea project and as a side contribution of this report, a risk assessment tool has been created. This tool summarizes all the mentioned aspects of the evaluation and enables a proper risk evaluation, therefore can be used for it. The risk treatment, the last core step of the risk assessment, should define measures to mitigate the identified, analyzed and evaluated risks, starting with the ones being prioritized in the risk evaluation. As this core step depends on the previous step and on the specific risks prioritized, recommended actions mostly focused on the cost aspect. It was recommended that the measures should always take the costs involved into account, because, if the measures are too expensive, the project’s realization may get endangered respectively the project is too risky, as it is too expansive to mitigate all risks.

Overall, it became apparent that it is difficult to propose a general risk management strategy for the Space@Sea project, as it heavily depends on the defined scope of the risk assessment and the resources being available to the person assessing the risks of the technologies and/or their business impact. This applies particularly to the core steps of the assessment, as a different amount of resources define, whether there will be an in-depth approach or a rather basic approach. This is also proven by taking a look into the practical experience of an offshore-related company that faces similar risks. The report shows that the approaches to the risk assessment differ in different subdivision of the company. Therefore, further research on the topic can expand the methodology being created. The possible consideration of temporal factors for the overall determination of a risk (value) may allow for a more detailed view on the current risk situation. Using the methodology of this report in a case study showed its applicability for technologies of the Space@Sea project and illustrated the risk situation of the technologies and core systems of the Working Package 6: EnergyHub@Sea and Working Package 7: Living@Sea. It was possible to create business links with regard to proactive and reactive measures for the risk management and treatment.

1 Introduction

1.1 Objective and approach

This report is a contribution to the Space@Sea project, which is an H2020, EU funded research program that is about providing sustainable and affordable workspace at sea by developing a floating island concept consisting of standardized and cost-efficient modules. The project aims to integrate different functions on top of the island, i.e. EnergyHub@Sea, Living@Sea, Farming@Sea and Transport&Logistics@Sea, every function being created in its own Working Package (WP). The Project's goal is to bring the Space@Sea concept to a Technological Readiness Level, where it is possible to successfully demonstrate system components functioning in relevant conditions. Additionally, Space@Sea aims to develop integrated business cases which will showcase the advantages of the floating modular approach for offshore operations in comparison to existing technologies and infrastructure.

By now, a considerable number of developments have been delivered by Space@Sea partners towards the realization of the Technological Readiness Level. The developments include engineering design, construction, operation, maintenance and decommissioning procedures and integrated business models. As a result of the innovative nature of the concept and the unproven technologies used, it may be deducted that uncertainties regarding the feasibility and viability of the developments need to be identified, evaluated and managed. The interconnection between technical uncertainties and business case outlook needs to be studied explicitly. The existence of a thorough risk assessment, accompanied by management strategy of the risks with the highest impact, is important for the credibility of the business case results.

The goal of this report is to write a methodology that facilitates this thorough risk assessment and management by showcasing every step needed and details that should be considered. By this, technological risks throughout the lifecycle of the Space@Sea concept can be identified and their impact assessed, while creating links to the business case. In the end, a customized framework for the identification of technological risks and their business impact based on existing state-of-the-art approaches will be developed.

This goal will be approached by identifying state-of-the-art and industry standard risk identification, assessment and management methods regarding engineering technology and the associated business impact. From this, the most relevant implementations will be customized for the needs of the Space@Sea concept, so a framework can be created, which is able to organize the (most important) developments of Space@Sea and shows possibilities to analyze their relevant risks. This is achieved by in-depth literature review to prove the state-of-the-art approach with reliable sources.

Additionally, the methodology is later applied to a case study on a specific Working Package, the earlier mentioned EnergyHub@Sea, to showcase its applicability. Input for the study will be provided by the project deliverables as those are released by the Space@Sea partners. The output of this report can be used for the development of the Space@Sea deliverables and business cases and be further used and/or specified for Working Packages or procedures in the Space@Sea project. As this report aims to be a contribution to the "Task 6.6 Definition of the methodology for risk assessment for the energy hub", references to offshore energy related aspects, like wind energy, will be made inside of the methodology.

1.2 Applied definition of risk

Before the actual methodology can be created, the term “risk” needs to be defined for it, so there is a consistent understanding of the term throughout the report. As well as for other parts of the report, the technical aspect and the deduction of business indicators have to be noted, so the report can fulfil its purpose. Based on that, the technical definition of “risk” will be applied. This definition states, also in accordance with the risk management standards that will be applied in the next chapter, that risk is the combination of probability (Note: In theory, the definition of the terms “probability” and “likelihood” differ from each other, but will be seen equally for this report) of the occurrence of damage and the extent of the damage, if damage is being done. Therefore, mathematically speaking, the following risk-formula applies:

$$R = H.S$$

with “R“ being the risk or respectively the risk-number/risk-value, “H“ being the probability of the occurrence of damage and “S“ being the extent of the damage, if damage is being done, respectively the consequence. Therefore, the risk serves as a quantitative indicator of hazard [1].

This technical definition seems appropriate for the methodology, because, unlike occurrences of natural origins, man-made risks are considered to be more easily identified, analyzed and controlled. The definition stated above results from this consideration [1]. As this report aims to identify and assess the risks given by the innovative nature of the Space@Sea concept and/or the technology being used, this definition fits best. Surely, risks of natural origins affect the Space@Sea concept and its technology in general, especially given the fact, that offshore projects are heavily influenced by aspects like weather conditions for example. However, this report does not focus on the estimation on how likely a natural origin might appear, but on how likely and in which extent a risk (e.g. caused by a natural origin) might affect the technology, being made by a human, therefore would not exist, if not man-made.

There has to be noted, that this report focuses on the risk assessment of technologies already been selected for the project. Therefore, the goal is not to provide a proposal for the decision between various technologies with the same purpose, based on a lower associated risk. It is about identifying, analyzing and evaluating, if possible even mitigating, the risks of a technology already chosen, based on technical possibilities and their related business indicators. Finding the technical and business related level of risk, prioritizing specific ones and taking action is the purpose of the assessment. Therefore, the comparability of the risks is a key factor. Besides other advantages, the stated technical definition of risk provides this kind of comparability and focuses on it as well as on objectivity [1]. It implies clear consequences and if the level of consequence can be outlined, the comparison of risks with the same type of consequences can be objectively done [1].

Similar facts apply to the probability, which is why, if the probability can be determined, an objective representation (and therefore evaluation) is possible [1]. Although the exact value cannot always be exactly determined, experience of risk management has shown that both factors of the formula are available most of the time, which is why this procedure has prevailed. If an exact quantification is not possible, a qualitative approach, by using a scaling of “low”, "medium" and "high" damage for example, can be done, which is indeed less accurate, but not necessarily problematic. It is not every time about defining the exact level of damage, but also about identifying the relatively highest risk, to take precise targeted measures [2].

This is why it is assumed that by using this definition, every risk can be decently compared, which supports the demand of a proper evaluation of different risks. Other definitions, like the social science term of "risk", do not enable the possibility of objectively comparing the level of risk or respectively compare risks in general, because variables like people's subjective risk perception and acceptance influence the calculated value [1]. With the predefined approach being the identification of risks, while making them comparable and sorting them by the highest impact in terms of technical probability and associated business impact, such definition cannot be applied.

1.3 Applied risk management standards

As mentioned in the approach description, the report focuses solely on literature review to propose a possibility to deal with risks in the context of the Space@Sea concept. Therefore, and for the obvious reason of general acceptance and credibility, industry approved norms and standards are the best sources to collect the most reliable information for the purpose.

In terms of risk associated standards, regulations or guidelines there are a lot to choose from, many relating to specific fields of expertise. However, this report aims to create a framework that is customized for the needs of Space@Sea and should support the development of the business case of this project on the side. Based on that, the standards of choice should offer the possibility, to create a state-of-the-art approach to risk management regarding technology related occurrences, business indicators can be derived from.

First of all, there needs to be a basis, which allows the framework to be developed on. Following the demand of an internationally approved and up-to-date practice of risk management the ISO (International Organization for Standardization) published an international standard in 2009, the standard "Risk Management – Principles and Guidelines" or ISO 31000:2009, resulting in a wide adaption around the globe by most G20 countries [3]. In its current updated version it is known as ISO 31000:2018 (Note: In the following of the report, the standard will be simply named ISO 31000). The standard was created with the intent, to be applicable by a large variety of organizations in any country for any type of operation, regardless of size or complexity [4]. It includes an overall approach for the risk management of an organization and does not only concentrate on a specific part of it. Nonetheless the standard describes its content very detailed, which is why there is the possibility to select the standard's parts most needed for creating a framework. In this case, the general process of the methodology in this report will be based on the ISO 31000. That is because besides outlining a long list of attributes for risk management, e.g. an improved corporate governance, stakeholder trust and financial reporting, it constructs a management process for the handling of risks, which incorporates every step needed to make a complete assessment, whether it is a single risk or risks in general. This risk management process includes the identification, analysis, evaluation and treatment of risks [5].

This process, the required parts being extensively described in the methodology itself, is chosen to be the basis for the creation of the risk assessment and management framework. This has one specific reason. Its universal applicability allows the addition of a customization for special interests, in this case the Space@Sea concept, because no certain field of expertise influences the basis of the methodology, which might cause problems in the long run. Following the steps and information given their makes the creation of an own development practicable. This is underlined by the wide adoption of the ISO 31000 around the world, which shows the practicability and reputation, therefore promotes the usage of it.

For the specification of the framework for the needs of Space@Sea, the usage of (new) technologies has to be noted and implemented in a way, that manages the technology‘s associated risks. Therefore, a standard has to be found, that includes principles for handling the assessment and management and can be combined with the operational risk management process given in the ISO 31000. After in-depth literature research, the ISO 12100:2010 (Note: In the following of the report, the standard will be simply named ISO 12100) was identified to be appropriate. The principles included in this standard help constructors to achieve their goals. Those principles are based on knowledge and experience of construction, like usage, incidents, accidents or risks in general associated with machines. Methods are explained on how to assess and even mitigate such events and risks [6].

In regard to the chosen basis given by the ISO 31000, for every part of the risk management process mentioned there, there is a technology related explanation in ISO 12100. Based on that conformance, applying both standards in this report will secure the compatibility of a general and technical risk assessment and management. Therefore, conclusions outside of the purely technical judgment in the ISO 12100 can be drawn, which supports the objective to create links to the business case, while still being industry approved and a state-of-the-art approach.

Generally based on those two standards, ISO 31000 and ISO 12100, a methodology will be created to function in its existence as a framework and support the Space@Sea project in its dealing with risks. It is important to mention that both standards do not get mixed up too much, as there is no mentioned interconnection in the standards themselves and too intensive merger could possibly cause confusion, if not resulting in the loss of credibility, because the framework differs too much from statements in the standards and therefore can´t be associated with them. It is more about adding technical aspects to the already given method of the ISO 31000 standard. That is why the chapters’ structure of the methodology separates the technical aspect of the assessment from the general approach of a certain step.

2 The methodolody

2.1 Structure

To fulfil the purpose of this report, a methodology will be created that includes every step of risk management. The goal of this methodology is to enable experts in the specific field of interest to do an assessment in a structured and comprehensive way. Because of experience and education, those experts have the most knowledge in the field of expertise they are working in, so they are most likely able to identify and analyze a risk that might occur. But a method on how to approach the risk assessment process and structure it along the way is missing most of the time. That is why this methodology focuses on how the process of risk assessment and management can be handled, especially in the Space@Sea context, which then enables experts to apply it on their specific technology. It is considered that the methodology takes the technical aspect of the Space@Sea project into account and then derives business aspects.

To achieve this goal, there will be an overview on risk management in general, to establish a sense for the need of it. After that, every step of the risk management process, including the risk identification, risk analysis, risk evaluation and risk treatment, will be explained in-depth, while the relation to the Space@Sea concept will be shown or created wherever it suits throughout the methodology. To cover the needs of the Space@Sea project, every step of the process will be subdivided into sections (see table of contents), which will focus on every aspect of the purpose of this report.

First, there will be a “General” section, where the theoretical background of the step of the assessment will be explained, which is mostly related to the statements of the ISO 31000 and other theoretical content related to a certain step. A reference to the Space@Sea project will be created, if relatable relations appear or documents of the project state any information on the topic.

For the second section, the technical aspect will be examined more closely by searching through the applied technical standard ISO 12100 for relevant information, to find the appropriate dealing for risks of technologies being used in the project. This part focuses the most on norm related approaches as technology risks are often related to the health of human beings, therefore a generally accepted norm that assures the safety of health is most commonly used. Nonetheless, it is a matter of common knowledge, that the risk of a technology is often related to the failure of a system or damage to a system, then endangering people. That is why this section refers to a possible system’s failure or damage taken by the technology as the report focuses on the technologies themself, not explicitly on the health related issues. Also, the system’s failure or taken damage in general seems to have the most obvious link to the business aspect.

The third section will take the business aspect into account. By this, the topic of business and technological risk assessment and management is completely covered. This is done by showing which business factors are in relation to risks. Because this report aims to check for industry approved and state-of-the-art approaches, this part will also take a look into the practical risk assessment implementation of a company with a similar field of expertise. The consideration of another offshore related company seems most appropriate, as the Space@Sea project relates to the offshore topic. From a business point of view, it allows to take a look at which business indicators should generally be considered in an offshore operation, which is necessary, if the business aspect needs to be derived from a technology being used. It can also work as some form of inspiration to look at industry approved techniques, which might also work in the Space@Sea field. As said in the beginning, this methodology aims to provide a basic framework for the experts working on the Space@Sea project. Therefore those kinds of inspirations might help to approach a certain step of the assessment, because the theory does not always allow an easy practical approach. The E.ON company and three subsidiary companies of it, each subsidiary company with a different execution of the risk assessment, will be the chosen company for this purpose, as it does have experience in the offshore business and shows a very diverse approach in each subdivision, which is why it is considered to offer the most useful inspiration for the Space@Sea project. By this, it is already obvious that there is not that one norm in practice, everybody does take a look at and orientates their execution of the single steps of the risk assessment on. This may be due to the fact that business risks do not endanger the physical health of humans in the first place, so there is no public or even social need of a norm or law that covers every explicit step of a procedure in-depth. Therefore, the adaption of business risk procedures and indicators can be positively inspired by different already used approaches. As this company works in the energy sector, this also fits with the aspiration that this methodology serves as a contribution to the WP6: EnergyHub@Sea. By all of this, the second and third section will progress the research on how a business impact can be derived from risks of technologies and will show it for every step of the risk management process.

The fourth and last section is called “Recommended approach“. This section will provide tips and proposals based on the previous sections and the overall research on the topic. It has to be noted, that this recommended approach is not always taken from literature, but also includes self-created proposals. As this methodology is all about the implementation in the organization/the project, this section is about creating a practical approach for the people working on the Space@Sea project. Therefore it is fundamentally based on the research, but customized for the needs of Space@Sea. It serves as the result of the research for the single steps of the risk assessment process and will function as a summary of aspects, which should be considered.

The fact that this methodology is customized for the needs of Space@Sea does influence its scope decisively. That is why it should not be seen as generally applicable for all projects of any company. Most importantly, the state of the Space@Sea project has to be noted. Certain steps of the risk management process, like risk identification and risk analysis, are mostly already done in the project respectively their execution can be done more precisely by the experts of the field of expertise. In which parts of the project and how it is already done will be mentioned in the methodology, if known by the author of this report. The objective of the author is to base this methodology on the progress of the project. This progress shows that the step of evaluating and prioritizing the already identified and analyzed risks is not (universally) explained for the risk assessment of the project or parts of it. That is why this report aims to provide an approach to this aspect. It tries to bring up an own solution for the evaluation that fits the needs of the Space@Sea project and can be applied in various parts of it, most importantly the WP6: EnergyHub@Sea and also the WP1: Business Case. Therefore, this step of the risk management process will have the most practical relevance and will be customized the most, while the other previous steps are covered by theoretical approaches and act as a summarized research of the theory, if needed in practice. As the following step of defining concrete measures for the risk treatment is depending on the assessment done by the mentioned experts, this chapter will act as a summary of which aspects should generally be considered for the treatment. This summary includes norm related information, derives aspects from the research done in the previous steps, but also includes aspects from an external point of view that the internal experts should keep in mind.

Although it is recommended to read the methodology as a whole, it is possible to pick a single core step of the risk management process, to get input on this topic. That is why the described structure has been chosen, as it splits up the whole process to take an in-depth look on every aspect of it. This allows for a fast and precise usage in the day-to-day work, which contributes to the practical applicability in the project.

2.2 Risk management

Generally, the methodology focuses to deliver a concrete step by step manual for the risk assessment and management. To have an introduction into this topic, it is necessary to provide some information on risk management, as it is the key term, used for the overall handling of risks.

The ISO 31000 bases the need of risk management on a course of argumentation, starting with the statement that all organizations exist to achieve their objectives. Those objectives are affected by many internal and external factors, causing the uncertainty about whether the organization will achieve its objectives or not. The resulting effect of this uncertainty on the objectives of an organization is “risk”. Therefore the management of risk is central to the success and livelihood of all organizations [4].

Although the report will use the technical definition of risk explained in chapter 1.2, because of the advantages stated there, this course of argumentation demonstrates the fundamental reason of doing a proper risk management.

The reason, why the constructed risk management process of the ISO 31000 is different to other traditional processes, is the addition of elements like “establishing the context“, beside the core steps of risk identification, analysis , evaluation and treatment. Before the process of assessing risk starts, the organization has to establish the detailed context, which sets the risk criteria and scope for the process. This varies according to the structure and the needs of the organization. It includes activities like setting objectives and goals for the risk management as well as defining responsibilities and the depth of the process. This is seen as critically important, because it assures an appropriate risk management process for the organization and its objectives and risks. A detailed analysis of external and internal stakeholders, environment, key drivers and trends, that impact the objectives of the organization, should also be included in the overall process [4].

In addition to the mentioned core steps, the ISO 31000 standard also underlines two important functions that should be noted continually throughout the risk management process. First, communication and consultation” needs to be a part of the process and involve external and internal stakeholders, because it is seen as necessary for the success of the risk management. Second, “monitoring and reviewing” have to be established and should occur continually during the process. This is critical, because it ensures that the controls are effective, risks are appropriately addressed, the lessons are learned, and the organization is resilient as well as ready for change [4].

With regard to the execution of the Space@Sea project, several factors of the risk management mentioned above are already implemented within. The general Space@Sea project proposal (at the start of the project) states the intention to monitor its risks from the beginning. It is proposed to set up a risk register at the project's start and then update it at least every 6 months with the goal, to monitor the major scientific, industrial and organizational risks of the Space@Sea project. The risk register is maintained by the Project Office and hosted on the project website. All risks identified at the start of the project and added to the register are assigned to a risk owner, each mitigation measure assigned to a person in charge of taking action and newly arising risks constantly added to the register to update it. These risks are subdivided into different factors such as cause, effect, status, categorization, ranking, treatment strategy and treatment description.

By taking a look at this information, it is recognizable that a commitment to risk management already exists inside the project. Documents of Working Packages, for instance the WP6: EnergyHub@Sea, prove that the partners of the project use such risk registers. This fits the demand of the ISO 31000 to establish such commitment [4]. There is a clear vision on the project's risk identification and analysis from the beginning. Also, the communication is defined by the Project Office, the need of addressing responsibilities as well, while having several project partners to choose from. The continually monitoring is addressed by setting up and updating the mentioned risk register. But the process on how to exactly assess the risks, including the process of evaluating them, is not predefined. It is the main focus of the methodology, to find a solution for this. To establish the context, as being mentioned in the ISO 31000, the overall risk criteria and concrete scope for the risk assessment of this report can be taken from chapter 1.1. Basically, in this case it is the assessment of the risks of the (unproven) technologies and their business impact, which is why the process will focus on this aspect and does not consider a wider context.

In the following, the core steps of risk assessment will be described in-depth. As stated before, both applied standards mention the steps risk identification, analysis, evaluation and treatment. A general approach to them, approved by the ISO 31000, will be described first, followed by the technical approach, approved by the ISO 12100.

2.3 Risk identification

2.3.1 General identification

The purpose of risk identification is to detect and describe risks that could affect the organization's goals, even if they are out of the direct control of the organization. Therefore up-to-date and relevant data is needed, which can be used in multiple procedures for the identification. It should be noted that an identified incident can have different outcomes, like a material and immaterial nature. Factors (and their interconnections) to be considered are material and immaterial risk sources, causes and incidents, threats and chances, indicators for upcoming risks, limitations to knowledge and the reliability of data, but also subjective assumptions of persons involved [5].

For the Space@Sea project, several risk identification processes are already stated. The Working Package 2: Health, Safety and Environmental Impact, obviously related to different forms of health risks, mentions in its Deliverable 2.1, following from previous analysis on technology options, a full HAZID study, reviewing potential hazards respectively risks for the proposed floating modules. An output of it can be seen in the Deliverable 7.2 of the Working Package 7: Living@Sea. As mentioned there, usually the hazard identification is a qualitative exercise based primarily on expert judgment. But the HAZID described in the Deliverable 7.2 is a high-level, systematic study of the hazards. It is used for the early identification of them and is typically made at the conceptual project phase and carried out to the detailed design stage. This was also used to identify the potential hazards for the floating islands, while the offshore and shipping industry served as input and inspiration. It started out with the identification in which stage of the life span of the floating islands the hazards may occur. Afterwards it focused on the system, the subsystem and the component, which the hazard relates to, followed by the cause, name, description and typology of the hazard.

This structured approach already shows the elements, which should be noted. All this information offers a detailed description of the identified risks. By this subdivision into system, subsystem and component, the risk identification can be done separately on every part.

2.3.2 Technical identification

The ISO 12100 states that the risk assessment starts with defining the limitations of the technology, considering all stages of its life cycle. Therefore it is necessary to define the characteristics and performance of the technology and all persons, surroundings and products associated with it. After that, a systematic identification of predictable, permanently present and unexpected hazards can be done. The stages of the life cycle include the transport, assembly and installation, commissioning, operation, disassembly, decommissioning and disposal. The constructor has to consider the intervention by persons during the whole life cycle of the technology, possible operating states and unintended behavior or predictable incorrect use of the technology by a person [6].

2.3.3 Business identification

As stated in the ISO 31000, an identified incident of risk can have different outcomes like a material and immaterial nature. In regard to the Space@Sea context, it has to be noted that the existence of a technical risk may not only result in physical damage to the technology, but also results in immaterial consequences. With regard to the objective, to do research on the associated business impact, a commonly resulting consequence of physical damage is the occurrence of costs, for example for repairing the damage being done. Therefore it needs to be identified, which specific costs will be affected, if a certain risk causes damage.

The following overview of practical experience will demonstrate, which factors may be generally affected, when talking about business risks. Here, it becomes obvious, that costs are the key indicator to business related issues. The upcoming chapter “Recommended approach for the identification” will explicitly relate to the Space@Sea context.

Practical experience

This practical experience section shows the risk identification approach of three different subsidiary companies of the E.ON company [7], all experienced in the offshore industry. It has to be noted that the aspects listed only show the particularities of the special subsidiary company and not the whole process. Therefore, they might be very short explained, but they are based on a wider context inside the company. Listing the particularities serves as an overview to see which techniques are already used in practice of this industry and might inspire to use similar techniques in practice of the Space@Sea project. This circumstance for the practical experience section also applies to the upcoming chapters “Business analysis”, “Business evaluation” and “Business treatment”.

First subsidiary company: The identification of risks is done by using a pre-specified checklist created for wind farms. This checklist includes the main risks for the construction and operation phase. Other project-specific risks have to be identified as well, to then create a project-specific risk list, which includes the effect of the risk. An extract of this list can be seen here:

Table 1: Extract of E.ON’s checklist

Risk	**Effect**
Construction	
cost overrun	investment costs increase
insolvency	investment costs increase
missed deadline	(internal fault) later commissioning
missed deadline	(external fault) later commissioning
exchange rate risk	exchange rate shift
Operation	
service and maintenance cost risk	service/maintenance costs increase
subsidy risk	reduction of the subsidy, allowance
wind risk	variance for the wind forecast
performance risk system	less system efficiency
unplanned downtimes	less operational readiness as guaranteed from the manufacturer
force majeure + other cases of damage	loss of the entire system
exchange rate risk	exchange rate shift
tax risks	income taxes increase
liability risks	using E.ON-specific corporation guarantees
…	...

Second subsidiary company: Risks are identified by brainstorming in workshops. They are categorized by type and put into different risk catalogues, the one with time and cost effects being the “Investment Decision Paper Risk Evaluation“, which are constantly updated. The catalogues are created for the first time, when the project phase starts. In some parts, keywords are used in these workshops to most likely cover all areas of hazard and direct the attention to certain fields of risk. Experts and externals of the contracted companies of the different project phases, e.g. development, procurement and construction, are involved. Additionally, specific Working Packages are defined, which focus on the risk assessment of different technologies, for the E.ON case for instance “wind turbine”, “foundation”, “transformer platform” and “cables”. For the business aspect, the risk assessment is divided into two phases, one before the signing of the contract and one after the signing. This is because the risks of each phase differ fundamentally. Before the signing the contractual conditions are uncertain, after the signing the compliance of the conditions is uncertain. Based on the defined phase and Working Package, the risks can be identified. The associated effects refer to additional costs and days of time delay.

Third subsidiary company: The risk identification is done by creating scenarios and a structured risk tree. The risk tree divides the risks into generic (external) risks, organizational risks and project's execution risks, followed by many subdivisions. An "evaluation group" directly identifies the risks by creating imaginable or already happened scenarios, which are then edited in regard to the risk tree. In a workshop, with the participation of the "evaluation group" and the project manager, the final description of the risk is stated, based on the scenario list and the risk tree.

2.3.4 Recommended approach for the identification

In regard to the overall done research on risk identification, but also in regard to the upcoming risk analysis, the following questions should be kept in mind (additionally to the content of the previous chapters), while approaching the risk identification process.

Table 2: List of questions for the risk identification

Question	Explanation
How is "risk" defined for the approach of the assessment?	A common understanding of the term, e.g. the definition of chapter 1.2., ensures the same mindset for everybody involved in the overall risk assessment from the beginning.
What are the factors that are taken into consideration for the determination of the elements of the risk definition?	Determining the consequence, as one element of the risk definition, has to be based on the same factors for all risks respectively on the same understanding on how the consequence is defined. Which factors to choose is also depending on the profundity of the upcoming analysis (see list of questions for the risk analysis in the chapter "Recommended approach for the analysis"). Defining the same factors for the determination of the consequence ensures the comparability of the upcoming evaluation, especially in a (semi-)quantitative approach that includes business indicators. Further explanation on this is given within the current chapter.
What is the scope of the assessment respectively which type of risks will be identified for the assessment?	For a project with the size of Space@Sea, there are many different types of risks. After the research on risk identification, it seems more applicable to first assess all risks of the same type to get an overview on the risk situation regarding this type. Then, the risk situations of every type can be compared to each other to then conclude the risk situation of the overall project and if there is any field, where the project is in a critical situation. For example, this report is focusing on the technical risks and their business impact. Mixing different types (e.g. technical and

	legal risks) within the same assessment process from the beginning, would distort the overall assessment as it might get difficult to make different types of risks comparable along the same consequence.

Based on approaches of similar onshore or offshore projects (e.g. wind farm projects as this report aims to be a contribution to the WP6: EnergyHub@Sea) some basic advices and practices can be derived for the general risk identification of the Space@Sea project. Overall, the project's risk identification should be done continually throughout the project's life cycle. Most of the risks should be identified and documented in an early workshop, while the resulting risk list should be extended permanently. As an example, some risks, like the further development of the technology being used between the start and finish of the project and its associated price development, can be identified early. However, the change of regulations, laws or norms can suddenly happen, due to some accident in the industry's field. These aspects should always be remembered [2].

For the identification process, it is recommended that the approach is done in a predefined order. First, the search for project-specific risks should be done uninfluenced from other sources. As an example: what can be expected at a specific point in time at a specific location (regarding a technology or a place/situation in general)? This applies to the overall project or even in cooperation with a partner. A structured and logical searching process including all thinkable factors on all phases of the project's life cycle can guarantee the completeness of all identifiable risks. Using different questioning techniques by a moderator in a workshop can support the searching algorithm. Only in the second part should one use experience based risk lists, as they might be available from previous projects or field reports of constructors/manufacturers, to see what worked best or did not work. Most of the time, there are also associations, which focus on a field of expertise and offer risk related checklists. In the third and last part, statistics of standard risks can be considered, e.g. only partially calculable weather conditions for the technical part or exchange rates for the business case. For these risks, there is often some kind of standard measure [2].

The reasoning of this particular order is based on one key aspect. To begin with the standard risks seems to be the most obvious start of choice, because many risks and their associated treatment are quickly identified. The problem: most of the time, the motivation and needed creativity to find more project-specific risks are missing after this. Exactly those risks are the most important and most surprising risks [2].

For the business aspect, a business indicator should be found which makes the risks overall comparable and prioritizable, so research on the business impact can be done. In general, there are some to choose from as the business aspect includes many factors, like economical or temporal ones. In regard of choosing the appropriate one for the business impact of the risks of the (unproven) technologies used in the project, the factor "costs" is commonly shared by all technologies and therefore seems applicable. As an example, the consequence factor in the applied risk definition in chapter 1.2 being the damage done to a technology, the costs of repairing this damage could be defined as the business consequence. These costs can ultimately be seen as the business impact from an economical point of view that results from the risk associated to the technology. Using this conclusion, it has to be defined, what these costs consist of. Manufacturing costs, delivery costs and costs for the personnel that repair the damage are only a few factors to be considered. It is important to identify the cost factors that every technology commonly shares for the repair. In the end, there has to be an agreement on the definition of the business consequence, that will be applied on every risk identified. By this, the definition of the consequence, as an element of the risk definition, is the same for every risk and upcoming conclusions will be based on the same foundation, allowing a correct evaluation.

In regard to this aspect, the identification of the business consequence is already in heavy relation with and dependence on the following analysis. The definition of the consequence (respectively the costs to be identified) also depends on the resources being available for the determination and the scope of the assessment. For example, the delivery costs of a supplier may still change in the future, if there is not any form of contract that defines the delivery costs for the future. This circumstance could be taken into consideration in the following analysis. But it could also already be taken into consideration for the identification, because this is a factor, which is very variable. If the scope of the assessment is not in a very wide context, these variable cost factors could be ignored for the assessment, to make it an easier approach. Cost factors like the manufacturing costs for the spare part, replacing the damaged part of the technology, are most likely to be non-variable and set for the future. In terms of resources for the research, these costs are easy to determine, as they can be taken from statistics or the tables of cost, which simply state all costs of the components of a technology. However, using only the manufacturing cost as the consequence of damage being done to a technology might distort the determined risk value, because it does not consider every cost aspect to be faced in reality. The possible assumption of higher manufacturing costs resulting in higher consequential costs overall is a very vague approach, but might do the job, if the overall assessment does not need to be precisely in-depth and is more about getting a basic overview on expected economic risks, while showcasing which of them might have a higher impact compared to others.

2.4 Risk analysis

2.4.1 General analysis

The purpose of the risk analysis is to understand everything about the risk, like its extent and its characteristics. Those analyses include an in-depth look on the cause and effects of risks, probability and different scenarios. The risk analysis can be done with a variable level of complexity and detail, depending on the specific purpose of the analysis as well as on the reliability and availability of the data and resources. The technique of the analysis can be quantitative, qualitative or a combination of both. The factors to be considered are the probability of cause and effect and the type and extent of the effect, but also factors like the complexity and interconnection, the sensitivity level or the effectiveness of current management.

It has to be noted, that the risk analysis can be influenced by subjective factors and the quality of the available data. If those circumstances are known from the beginning, it should be documented for the organization. Overall, the risk analysis provides a contribution for the decisions on how to handle risks and the strategies and methods associated with it [5].

By defining the term "risk" in chapter 1.2, the term was segmented into different parts, which can be analyzed on their own. This was done, to make the different risks also comparable by the single elements of the risk and analyze the risk from different points of view. With those two elements being the probability and the consequence, the key question is how to assign them with a value, so the risks can be sorted by their impact and prioritized for measures (later done in the risk evaluation). The usage of terms like “low“, “medium“ and “high“ as a value for a qualitative approach was already mentioned in chapter 1.2, but it is also possible to determine a concrete value for the quantitative approach, which is more complex.

Due to the increase of modern technology and thus the associated hazards, there is the need of a generally valid description, assessment and regulation of them. The determination of a tolerable risk by subjective assessment criteria is insufficient for the wider context of risk assessment. For technical systems, two methods have prevailed. One is the deterministic approach. There, the approach is solely based on known courses of incidents, where the system will technically fail. The technical system will be designed to compensate, even overcompensate, critical occurrences, so the system can still be handled in such cases and a defined limit of risk is not exceeded. For the Space@Sea context, the second method, the probabilistic approach, is more applicable. This is because the risks of modern and complex technologies (even unproven technologies, as being used in the Space@Sea project) cannot always be solely derived by statistic observations. Also, the probabilistic approach does not solely base on known courses of incidents of system’s failures (as the deterministic approach does), but, if possible, on the complete spectrum of possible damage scenarios. It is about an as detailed as possible course of damage. The probabilistic approach aims to quantitatively determine the probability of negative occurrences in general and their consequences. Therefore, there is a strong connection to the technical definition of “risk” [1].

This is why the probabilistic approach is the best for the report. The approach’s relation to the technical definition supports the overall emphasis of the report, with regard to the benefits of the technical definition of “risk” that are already mentioned in chapter 1.2. Additionally, the methodology aims to assess risks that do not always have the consequence of the failing of a technical system. For example, a technology can be damaged by a risk, but still function. The probabilistic approach focusing on consequences in general allows the choice of specific consequences for further analysis. That is why “costs” can be chosen as the consequences for this report, as it is the objective, to create links to the business case and it is assumed, that any damage being done results in some form of costs.

The required input for this approach can be taken from documents or statistics of the organization, literature review or databases, which base on analysis of certain occurrences, and systematic hazard-field analyses, like the Fault Tree Analysis or Event Tree Analysis. But most of the time, the data to be used has to be estimated. If data is not proven by statistics, an estimation has to be made, to portray the reality. By all of this, the reliability of the system and the risk in general are covered. The combination of statistic proven elements and probabilistic predictions makes it also possible to call the approach a “semi-probabilistic approach” [1].

The ISO 31000 also states that the estimation of very uncertain occurrences might be very difficult, so a combination of different procedures leads to the best result [5].

Sorting different technical risks by cases with the same consequences and analyze them by their probability of occurrence is an illustrative method to make them comparable. The death of somebody is often chosen to be that consequence, because the risk analysis focuses on the safety of people in regard to the used technology [8]. With the report focusing on business aspects instead of safety issues, this illustrative method is still applicable with the business indicator "costs" as the consequence, because every technology commonly shares the (business) consequence of costs, if risks lead to damage being done.

The second factor is the probability of the occurrence of this damage, which needs to be determined. There are different ways to calculate a value, for example to retrospectively evaluate statistic data, to project statistic data, if there is little data available, or to use model calculations. It seems possible to derive risk related values from the reliability of a system. However, this only allows a certain part of risks to be analyzed. There are still risks affecting the technology while functioning correctly and the technology itself entails risks while functioning correctly. Additionally, it is possible to use mathematical probability calculations, but most of the time, the practical realization shows some problems, because the statistic data is not always representative and in terms of temporal factors, it is not safe to say that the data will stay constant in the future. Furthermore, the linkage of courses of incidents happens randomly through the period of time, so it is not possible to keep a statistical record of that [8].

In the technical field, the relative frequency is used to partly compensate that problem. By this, incidents are related to a defined period, e.g. one year. To then find an appropriate approximation of upcoming incidents, the stability of the relative frequency is been introduced. By a long series of independent repetitions of the same experiment, all the determined values will be around one value. This value is not a mathematically concrete value, but a good approximation for the real value of the probability. Even though it cannot always be applied to all technical risks, as the linkage of courses of incidents happens randomly (which was mentioned above), with the result of approximately constant values of the probability, the relative frequency of occurred incidents can be used to derive the future probability [8].

2.4.2 Technical analysis

The ISO 12100 does not differ much noticeable in comparison to the statements in the "General analysis" chapter apart from some small aspects, which is why the most content is already explained there.

The previously identified hazards need to be analyzed. The risk analysis provides information, which is required for the upcoming evaluation and assessment in general. After that, decisions can be made, if risk mitigation is necessary or not [6].

This is based on a qualitative or, if appropriate, quantitative estimation that is associated to the risks caused by the technology. The quantitative approach can be useful, but is not always applicable. It is limited to the data available to the person doing the risk analysis, which is often under the influence of restricted resources. That is why a qualitative approach is the only option in most cases [6]. The analysis is done by defining risk elements, which are, as already mentioned, the extent of damage and the probability of occurrence of the damage. It has to be noted that the technical risk analysis subdivides the second element into exposure to the hazard (respectively vulnerability), the occurrence of the hazard incident and the possibility of avoidance or limitation of the damage [6].

The most important aspect is the further subdivision of the risk elements. As described in the chapter 1.2, the qualitative approach assigns values like "low" or "high" to the risk elements.

This being done on experts' expertise, those values will be useful for the upcoming technical risk evaluation.

2.4.3 Business analysis

The business analysis is all about assigning the identified risks with a business value for their elements, either in a qualitative or quantitative approach. Therefore it is in relation to the risk identification process done before. For the Space@Sea context, it was identified, that the consequences of risks for this report will focus on the business value "costs". Therefore the costs caused by the risks and their values need to be determined. The following section with practical experience will demonstrate some ways, which are used in practice, as there are different ways to do the analysis from a business point of view. This acts as a continuation of chapter 2.3.3. From that, aspects for the recommended approach for Space@Sea can be derived.

Practical experience

First subsidiary company: For the risk analysis, explicit values are added to the effect of the risks, which were already identified in the risk identification. They are stated as relative deviations to the original value or as an absolute value. This addition happens simultaneously, so there is no separated risk analysis. Examples of the value of the risk's effect can be seen here:

Table 3: Extract of E.ON's checklist with values added

Risk	**Effect**
Construction	
cost overrun	investment costs **+10 %**
insolvency	investment costs **+30 %**
missed deadline	(internal fault) commissioning **6 months** later
missed deadline	(external fault) commissioning **6 months** later
exchange rate risk	exchange rate shift by **30 %**
Operation	
service and maintenance cost risk	service/maintenance costs **+10 %**
subsidy risk	reduction of the subsidy, allowance **-20 %**
wind risk	variance of **-20 %** for the wind forecast
performance risk system	**10 % less** system efficiency
unplanned downtimes	**5 % less** operational readiness as guaranteed from the manufacturer
force majeure + other cases of damage	loss of the entire system
exchange rate risk	exchange rate shift **by 30 %**
tax risks	income taxes **+10 %**
liability risks	using E.ON-specific corporation guarantees
…	...

By the procedure of a sensitivity analysis, the effect of each risk on the project's internal rate of return is determined.

Second subsidiary company: The additional costs and days of delay are quantified. These values are determined for a scenario of high and low probability of occurrence. By summing up the individual cost risks and summing up the individual time risks, an overall risk for the more likely and less likely scenario is calculated. If the risks of a risk catalogue are only qualitatively registered, the assigned value is limited to the terms “low”, “medium” and “high”.

Third subsidiary company: The identified risks will receive a value based on the subjective opinion of an evaluation group. Probability of occurrence and effect of the risk are rated on a scale of 1 to 4, with 1 being very unlikely respectively low consequential damage and 4 being the opposite. If the subjective opinion differentiates between the group members, the average is applied.

2.4.4 Recommended approach for the analysis

In regard to the overall done research on risk analysis and also in regard to the aspects mentioned in the “Recommended approach for the identification” chapter, this list of questions should be kept in mind, while approaching the risk analysis process.

Table 4: List of questions for the risk analysis

Question	Explanation
Which resources are available for the analysis?	Based on the resources (time, information, data, personnel, experience, education …) a qualitative, quantitative or mixed approach works best (or is the only option).
To which extent is the analysis reasonable?	Depending on the scope of the assessment, the analysis (especially) on the probability needs to be more or less detailed, as the determination of the exact probability (in a percentage unit) is often very complex. For a basic overview on the risks, an estimation on expert’s expertise might do the job.
Is it possible to assign all factors, forming an element of the risk definition, with a value?	For a (semi-)quantitative approach, where the consequences are assigned with a quantitative value, that value can consist of different factors. E.g. in the Space@Sea context, the business impact of the risk of a technology can be derived by the repairing costs associated to the damage being done to the technology. Every technology’s data of every single cost forming the overall repairing costs (respectively the consequence, an element of the risk definition) needs to be available or determinable for this. If the data for one part of the repairing costs is missing, the risk will not be properly comparable, because the determination of the risk value is distorted by an incorrect element of the risk definition. As mentioned, this is mostly related to a quantitative approach. Simplifying the definition of the consequence is a solution to this circumstance, because it becomes more likely, that all the needed data is available. The risk value to be determined

	might deviate more from the reality though. A more detailed explanation to this was given in the “Recommended approach for the identification” chapter, additional information can also be found within this chapter.

An overall strategy for the risk analysis can´t be recommended, as it heavily depends on the risk situation and the overall scope of the assessment. For example, it depends on the objective of the assessment being done. It can be about determining, which risk has the highest technical or business impact, to then approach the mitigation of this risk firstly. Or it can be about determining the exact value that needs to be taken into consideration for the planning, like the exact costs that may be handled in case of the occurrence of a risk, which need to be taken into account for the budget planning. By setting this scope, the choice of a qualitative, semi-qualitative/semi-quantitative or quantitative approach has to be made. This also comes down to the resources being available. If the risks elements can´t be assigned with a concrete quantitative value or the risk assessment is just about getting a simple overview for the prioritization of risks, therefore is kept in a basic manner, a qualitative approach might do the job.

For the process of analyzing, it is all about defining the probability and extent of damage, as these are the main components of a risk. The technical analysis made an even more detailed subdivision. It depends on the specific risk analysis needed, if a further subdivision is appropriate. The determination of the values of the risk elements sets the basis for the following evaluation. Its in-depth and thorough execution is the precondition for having an analysis that portrays the risk related reality.

For the associated business impact, the previously identified costs resulting from the damage being done to the technology, representing the consequence of the risk, need to be assigned with a value. Therefore it has to be examined, what amount of costs can be expected. In the chapter “Recommended approach for the identification” there was already an explanation on why the risk analysis and risk identification of the costs are in interrelation, which is why the risk analysis depends on which approach was taken in the beginning. It depends on how many costs are taken into account for the consequence and if there is more or less effort for getting the information about the amount of costs. Costs like the manufacturing costs/material costs are easy to research, but it is more difficult to research costs that relate to temporal factors, which is why it may require more complex calculations. For example, including personnel costs is related to personnel being available for the repair. Depending on the number of persons being available for the repair, the repair takes a different amount of days, resulting in different costs based on the time needed.

2.5 Risk evaluation

2.5.1 General evaluation

The purpose of the risk evaluation is to support decisions. That includes comparing the risk analyses with the stated risk criteria to decide, if additional actions are necessary. By this, the appropriate risk treatment can be prioritized and chosen. The decision might be to take no further actions or to do further analysis to understand the risk better. Options for the upcoming risk treatment need to be considered, which might involve keeping the current management of the risk on the one side or even rethink the overall objective on the other side. Decisions and their evaluation should be documented and communicated to internal and external stakeholders and evaluated through the responsible levels of the organization [5].

In order to be able to compare the analyzed risks of the previous step, there needs to be a method that enables this comparison. This method has to visualize the difference between the risks, so a proper prioritization can be done afterwards. This is based on the analysis done before, so there already is a qualitative or a quantitative basis. An often used and by different norms approved method is the evaluation with a risk-matrix, where the probability of occurrence and the extent of damage are shown in their relation [1].

The basis of the risk values has a qualitative nature most of the time, but the usage of a quantitative basis is increasing for all elements of the risk definition. Risk-matrices typically comprise a square divided into a number of boxes. Every box represents a different risk value. For a qualitative approach, there may be at least three categories for the probability and the consequence, both having a similar number. The categories can be defined with numbers or a description. The description can use terms like "Low", "Medium", "High" or slightly more concrete ones, like for the probability "Extremely unlikely", "Unlikely", "Probable" or for the consequences "Minor", "Significant", "Catastrophic". To apply a risk to the matrix, the scenario or event describing the risk is categorized in terms of its probability and consequence and then put into the appropriate square on the matrix [9].

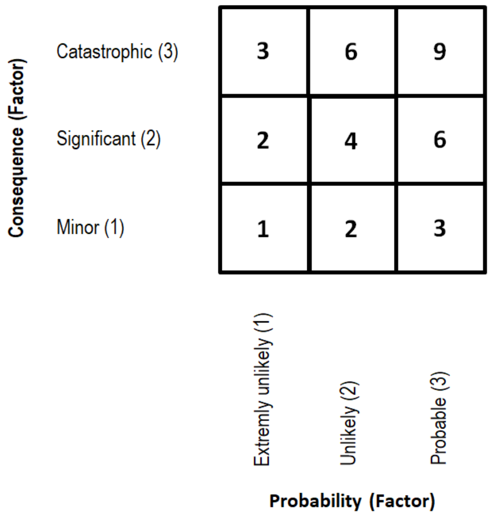

Figure 1: Basic matrix with factors

This matrix is taken from [9] and customized for this report. The implementation of such a matrix allows various risks to be compared. For the qualitative approach, each category is assigned with a number, with higher numbers indicating a higher probability or a higher consequence, while each box inside the matrix is a number obtained by multiplication of the two risk factors (as seen in the picture). Adding the factors up is theoretically also possible, instead of multiplying them. Following this calculation, a risk with a higher calculated value is more problematic. The values can be used to prioritize actions and to group consequence outcomes within similar categories. It is possible to transform the matrix into a semi-quantitative approach by using definitions (explaining the mean of a term like "catastrophic") for the probabilities and consequences. Those definitions can be used in a wide range, (the most interesting for this report being) the business interruption for example [9].

This method provides an easily understandable representation of different risk levels and can be compiled relatively quickly. But most importantly, it enables the combination of probability and consequences represented graphically [9]. This is required in order to visualize the identified risks and makes them comparable, as demanded in the ISO 31000. The possibility to even visualize the multiplication of the two risk factors, the probability and the consequence, functions perfectly with the definition of “risk” for this report and the associated risk formula, described in chapter 1.2. This is why this method seems highly applicable for risk evaluations in the Space@Sea project respectively the risks of the used technologies and the associated business impact.

For the context of this report, it is possible to slightly transform the qualitative approach into a quantitative approach, to make it semi-quantitative as a concrete quantitative approach is often very impracticable because of missing data, especially for a concrete probability value. That is why the different terms of probability can be maintained as “low”, “medium” and “high” or any other similar words, for a basic approach to the evaluation.

With a certain cost earlier chosen as the consequence, because it is a commonly shared business indicator, there is the possibility to create a more defined scaling for the consequences. The costs with the highest value will be the consequence at the top of the scale. All the other consequences (costs) can be scaled in relative to the highest cost possible (being 100 %) along the axis of the risk matrix. It is then to be decided, if a monetary unit is needed for the risk value. If not, both the probability and the consequence could be transformed into a level that is relative to the other probabilities and consequences. As an example, with the highest consequence being a damage of 100.000 €. This number is not representative for this project and is only for example:

Table 5: Example of risk elements and their qualitative level

Probability	Level	**Consequence**	Level
Low	1	0 – 20.000 €	1
Medium	2	20.000 € - 40.000 €	2
High	3	40.000 € - 60.000 €	3
		60.000 € - 80.000 €	4
		80.000 € - 100.000 €	5

A risk with medium probability and a damage of 50.000 €, if the risk occurs, would have a risk value of 2 * 3 = 6, by this classification. This is the qualitative approach. Keeping the consequence in the monetary unit, while keeping the probability in a qualitative manner, is the semi-quantitative approach. The semi-quantitative approach does not allow a risk value to be determined. The reason behind this circumstance will be explained in the “Recommended approach for the evaluation” chapter as well as how to handle all the approaches in practice.

If a monetary risk value has to be determined, a value with a percentage unit has to be found for the probability, so the result does not get distorted, as the consequence already has a concrete value with a monetary unit. For this, the single terms of probability can be assigned with a range of probability, for instance with the ranges being:

- Low = 0 – 33 %

- Medium = 33 – 67 %
- High = 67 – 100 %

Nonetheless, the problem of assigning a concrete probability value to the risk remains unchanged. In the previous chapter "General Analysis" various methods to determine a value for the probability were explained. If such methods are not available, the reason being no resources available, no time being available or it is just about getting a general overview with non-concrete risk values, a vague value for the terms of probability may be applied by experts, who have the expertise and experience to estimate such value (if a quantitative value is absolutely needed). In regard to the earlier stated terms that may be for instance:

- Low = 0 – 33 % → 20 %
- Medium = 33 – 67 % → 50 %
- High = 67 – 100 % → 80 %

Note, that this approach with a vague quantitative value is not based on norms, but on the sole purpose of applicability. It should only be applied, if there is a need for a quantitative value, but the resources are limited and do not allow a more in-depth research on the probability. Calculating a risk value with this vague number does not portray the exact value to be expected in reality. Due to these difficulties, in most cases the usage of qualitative numbers is sufficient for the risk assessment. After researching on several topics of risk assessment and management, a qualitative approach seems applicable for a basic overview, which risks may have the highest probability in terms of a business impact, and therefore serves for the purpose of this report to create business links from the technology associated risks. Most of the time, it is simply not needed to receive a value determined to the decimal point.

The difficulties for the quantitatively calculation of the probability also apply to the consequence. The value, calculated by a quantitative approach, does not provide the exact cost value (respectively business value), which can be expected from the risk in reality, as the value heavily depends on the chosen cost consequence that may miss certain aspects of costs as explained in the chapter "Recommended approach for the identification". That is why a qualitative approach can also deliver a first overview on the level of expected risk-associated costs. For the precise values, a more in-depth research of the experts in the fields of science needs to be done. The approach given here generates a value that is more about the comparison to the other values generated, to then determine, which scenario may be in conjunction with the highest costs respectively which risk-associated costs may be attached to the overall operation or technology (component). This could be achieved by summing up all monetary risk values for the operation or technology (component). By this, a small contribution to the overall risk budget planning could be created and a business impact could be derived.

2.5.2 Technical evaluation

As mentioned in the "Technical analysis" chapter, the risk elements are divided into different parts: the extent of damage and the probability of occurrence of the damage, while the second element is subdivided into exposure to the hazard (respectively vulnerability), (probability of) occurrence of the hazard incident and possible avoidance or limitation of the damage.

For the technical risk evaluation, there needs to be a method that includes the given subdivision. The already described risk matrix method provides solely the evaluation of extent of damage and probability of occurrence in order to visualize and rank the risks, but does not provide the possibility to subdivide any elements of it. The ISO 12100 makes a reference to another norm that is applicable in combination with it, the ISO 13849. The ISO 13849 is a norm for the safety of machinery, focusing on safety-related parts of control systems, and includes an evaluation method that covers all the elements. Although it is meant to be used in specific fields of expertise, this method seems applicable for the overall technical evaluation of risks and provides the possibility to get a risk value out of the subdivided risk elements that enables the ranking of different risks in order to prioritize them.

After the risks were analyzed, each risk element was assigned with a qualitative value like “low” or “high” risk. For the technical risk evaluation, these values will be transformed for each risk to get one overall risk value for every risk. By this, all risks are generally comparable and the one with the highest impact can be identified. This prioritization allows for targeted measures, where measures are needed the most.

The method of the ISO 13849 is a risk graph, which, customized for the needs of the Space@Sea project, can be seen here:

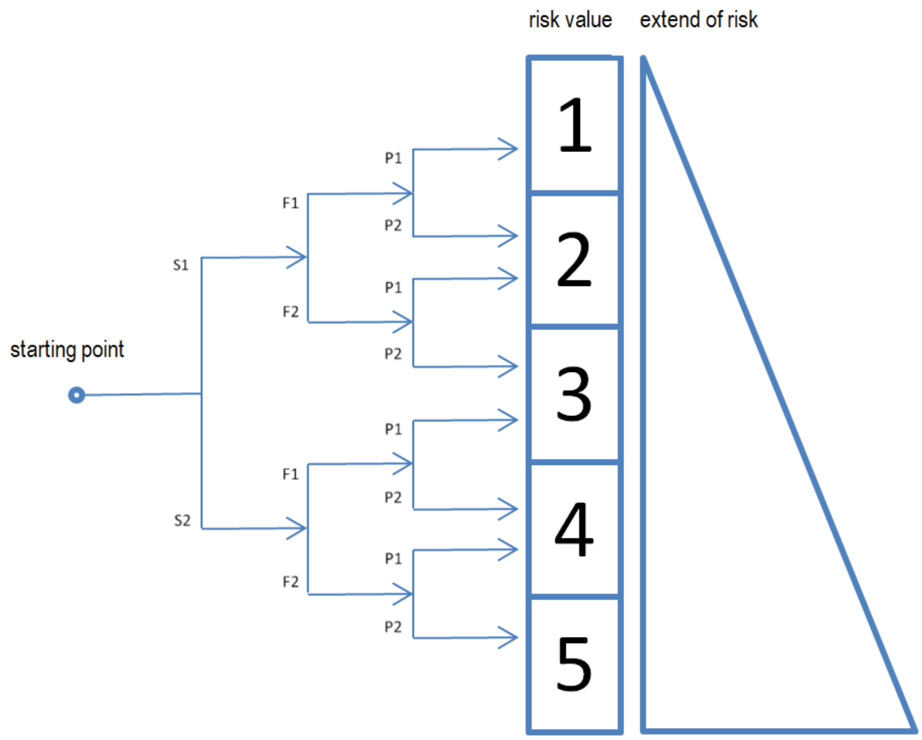

Figure 2: Technical evaluation method of the ISO 13849

<u>Legend</u>

S1 = low extent of damage

S2 = high extent of damage

F1 = low frequency/exposure/vulnerability

F2 = high frequency/exposure/vulnerability

P1 = low probability of occurrence of the hazard

P2 = high probability of occurrence of the hazard

The figure is taken from [13] and customized for this report. Starting at the “starting point“, a risk value can be determined by following along the graph. At every branching, there has to be decided, if there is a low or a high extent of damage/vulnerability/probability. The disadvantage of this method: there is not the possibility to assign a “medium” value to a risk element, as there is no straight path for the graph. Therefore, by applying this method, there has to be a clear agreement on the amount of the value of the risk element, either being “low” or “high”. How to assign the values to the extent of damage and the probability of occurrence was already described in the chapters of the “Risk analysis”. The extent of damage is defined as harm to persons, being reversible (low) or irreversible (high, also including death), in the (unchanged) version of the risk graph of the ISO 13849. For the purpose of solely focusing on the technology itself, it could be changed to physical damage to the technology. Even though this chapter does not focus on the business aspect, the damage could also be considered as upcoming costs resulting from the damage being done. The frequency of the damage being done and the exposure to the damage (or vulnerability) are summarized, as they seem, at least in a much generalized way, similar. As this methodology aims to be as applicable as possible, a more elaborate definition of those three terms was not made. If needed, the differentiation can be taken into account more precisely, by simply adding another subdivision to the graph. By this, the risk value would be even more concrete in regard to the reality.

Following along the determined path will always end in a category that states a number which can be taken as a general risk value for the risk, which then can be compared to other risk values of other risks determined by the same approach. This enables a prioritization of risks. From the evaluated risk value, it can be derived how much effort needs to be done in order to mitigate the risk, graphically demonstrated on the right side of the picture. A high extent of risk, results in much effort for the mitigation. By this method, a proper technical risk evaluation is possible.

Because of the circumstance that one of the goals of the evaluation of this report is the prioritization of the risks, the risk element “possible avoidance or limitation of the damage” has been taken out of the determination. This risk element is about the treatability of a risk. But the evaluation of risks in this report is more about how the identified risks can be compared and prioritized, so measures can be explicitly targeted. The determined risk value should cover this aspect. Including the factor, if identified risks are even able to be mitigated, would distort the risk value. The whole evaluation process in general is about the preparation, to then define measures and addressing the risks. The possibility to avoid or limit the risk is part of the risk treatment and this aspect of the risk management process is separated into the “Risk treatment” chapters in this methodology. Also, if it is not possible to mitigate a risk, it should definitely be mentioned in the process, but after the risk value is assigned as nothing can be done anyway. Considering those risks into the risk value would increase the risk value. The problem with this: If a risk has a high impact, but is easy to mitigate, it would have the same risk value as a risk, which has a low impact, but is very hard (even impossible) to mitigate. The first risk could not be prioritized by the determined risk value, even though it can be mitigated, while the second one cannot (if impossible). That is why every aspect of the treatment is separated from the evaluation process, therefore separated from this method of the technical evaluation. If needed, the treatability aspect can be added to the method by simply adding another subdivision to the graph.

2.5.3 Business Evaluation

As explained in the "General evaluation" chapter, a risk value has been determined. Now, a decision needs to be made about the severity and ways to manage it. In the most basic approach, the evaluation allows the examination, which risk should get the most attention. Several authorities propose ways, how to handle these risk values in businesses. For example, the Queensland Government proposes, that the risk values can be subdivided into ranges, which then give information, when corrective action is needed. By this, the highest risk values need immediate corrective actions, lower risk values need corrective action within a few months and the range with the lowest risk values represents, that currently no corrective actions are required. The risk evaluation should consider the importance of the activity to the business, the current amount of control over the risk, the potential losses to the business and the benefits or opportunities presented by the risk. After that, the risks need to be ranked by priority, to then decide which measures will be used to treat unacceptable risks [10].

If the risks are not related to endangering the life of a human being, the additional usage of a cost-benefits-analysis for the evaluation (and upcoming treatment) of the risks, which bases on the consideration of the previously done risks analysis, seems also applicable. This could be supported by an earlier conducted sensitivity analysis, as the ISO 31000 states that the risk analysis should consider the sensitivity level, mentioned in the "General analysis" chapter. This might help for the prioritization of risks with regard to the project's budget.

A more detailed description for the handling of this topic in the Space@Sea context will be shown in the "Recommended approach for the evaluation" chapter. For now, it should be remembered that a correct evaluation can only be done, if the consequence shares the same definition for all risks. As the consequence was defined as costs for repairing the damage being done to a technology, all types of costs that form those repairing costs need to be included in the value of the risk, now to be evaluated. For example, if only the manufacturing costs were taken into consideration, as a simplified way of assessing the risks for a first overview of what to expect, all risk values should only be based on these costs as the consequence. That circumstance is crucial for the comparability.

In the following section of practical experience, the usage of the evaluation methods, earlier described in the "General evaluation" chapter, become apparent in practice. This also acts as a continuation of chapter 2.4.3. Additionally, the fact, that the risk evaluation of a wind farm project is done with the same aspects as in the literature‘s theory of risk, shows the applicability of these methods and definitions.

<u>Practical experience</u>

<u>First subsidiary company:</u> This subsidiary company uses the probability of occurrence and the extent of the maximum potential loss, if the risk occurs, for the evaluation. It only uses one value for a risk, so the risk is associated to that value and the risk will not be viewed from a different point of view.

Second subsidiary company: If the risks in a risk catalogue are only qualitatively registered, the assigned value is limited to the terms “low”, “medium” and “high”. The prioritization is based on these values.

Third subsidiary company: The prioritization of risks is done by multiplying the probability value and the damage value. A risk portfolio is also used to create a graphic illustration of the risks. By this, it can be determined, which risks need measures first.

2.5.4 Recommended approach for the evaluation

This chapter bases on the content that was described within and after the “General evaluation” chapter. With regard to the overall research on this topic, these questions should be kept in mind, when evaluating risks.

Table 6: List of questions for the risk evaluation

Question	Explanation
Is it possible to make a well-founded risk decision after the evaluation?	By doing the evaluation, there should be a detailed overview on the overall risk situation regarding the risks included in the assessment, which also allows creating different measures to choose from. The overview should assure a well-founded decision. If there is the opinion, that this overview is not detailed enough, it should be considered to go one step back, to examine the earlier done analysis and maybe do more research on the risk elements. It is even possible to consider more factors in the risk definition, like a more detailed consideration of the vulnerability or frequency, as mentioned in the “Technical analysis” chapter. This may result in making a more appropriate statement on the actual risk situation or objective.
Is the risk acceptable?	After identifying the risk and analyzing everything that is assigned to it, a conclusion has to be drawn, if the risk is acceptable or not. This does include several aspects. On one hand, it is obvious to evaluate, if the level of risk is too high or not respectively if considering a risk treatment in form of measures is necessary or not. On the other hand, it should be considered that several risks could be accepted, even though the amount of risk is relatively high and a treatment might not mitigate the risk extensively. The circumstance might offer a chance to profit from, which makes the risk, associated to a technology for example, acceptable, as long as it does not endanger the health of human beings.
Should the overall risk objective be rethought?	Based on the evaluation, there could already be the conclusion, that the set goals for the risk management of this specific field might be too ambitious respectively set incorrectly, therefore need to be rethought. For example, the risks might be way higher than expected at the beginning of the project. This can result in considering more resources for the coverage of risks or even rethink the overall feasibility of the project.

As a result of the research on risk assessment, the “Recommended approach for the evaluation” chapter proposes a risk assessment tool (RAT), which can be used to evaluate identified and analyzed risks in the project. This is based on the content provided in the previous chapters and also acts as a foundation, to properly enable the upcoming risk treatment in the next chapter. In the following, the tool and the intention behind it will be explained. It covers all the steps recommended for an evaluation approach and includes the qualitative, the semi-qualitative/semi-quantitative and the quantitative approach.

Generally, the tool consists of three parts, which all contribute to the prioritization and visualization of different risks in relation to each other, to compare them in the evaluation. The first part is the risk register, each column providing different information on the risk to be added.

RISK REGISTER (Qualitative Approach)					
Risk (name)	Consequence	Probability	Risk value	Relative risk value [%] (practical)	Relative risk value [%] (theoretical)
	(qualitative number)	(qualitative number)	(Consequence * Probability)	(relative to highest currently calculated risk value)	(relative to highest theoretical risk value)
Risk1	1	2	2	66,67	22,22
Risk2	2	1	2	66,67	22,22
Risk3	3	1	3	100,00	33,33
Risk4			0	0,00	0,00
Risk5			0	0,00	0,00
Risk6			0	0,00	0,00
Risk7			0	0,00	0,00
Risk8			0	0,00	0,00
Risk9			0	0,00	0,00
Risk10			0	0,00	0,00

Figure 3: Risk register (Qualitative approach) of the RAT

RISK REGISTER (Quantitative Approach)					
Risk	Consequence [€]	Probability [%]	Relative consequence [%]	Business impact [€]	Business impact [%]
	(e.g. costs)		(relative to highest potential consequence)	(Probability * Consequence)	(relative to highest potential business impact)
Risk1	100000	5	100,00	5000	6,17
Risk2	80000	30	80,00	24000	29,63
Risk3	50000	50	50,00	25000	30,86
Risk4	70000	10	70,00	7000	8,64
Risk5	10000	80	10,00	8000	9,88
Risk6	90000	90	90,00	81000	100,00
Risk7	7000	15	7,00	1050	1,30
Risk8			0,00	0	0,00
Risk9			0,00	0	0,00
Risk10			0,00	0	0,00

Figure 4: Risk register (Quantitative approach) of the RAT

RISK REGISTER (Semi-Qualitative/Semi-Quantitative Approach)					
Risk	Consequence [€]	Probability	Cause description	Effect description	Risk treatment
	(e.g. costs)	(qualitative number)			
Risk1	100000	1	Cause1	Effect1	Treatment1
Risk2	80000	1	Cause2	Effect2	Treatment2
Risk3	50000	2	Cause3	Effect3	Treatment3
Risk4	70000	1	Cause4	Effect4	Treatment4
Risk5	10000	3	Cause5	Effect5	Treatment5
Risk6	90000	3	Cause6	Effect6	Treatment6
Risk7	7000	1	Cause7	Effect7	Treatment7
Risk8			Cause8	Effect8	Treatment8
Risk9			Cause9	Effect9	Treatment9
Risk10			Cause10	Effect10	Treatment10

Figure 5: Risk register (Semi-qualitative/ semi-quantitative approach) of the RAT

Based on expert's expertise, the first three columns (risk name, consequence and probability) will be filled in with the appropriate information respectively the values of the risk elements already determined in the previous steps of the risk assessment process. The needed comparable risk values will be automatically generated in the risk register, extended by additional information about the relation to other risks. Depending on the qualitative or quantitative approach, chosen for the assessment, the risk value will either have a qualitative number that can be compared to the other qualitative numbers calculated or a monetary unit (for the quantitative approach), representing the business impact of the risk in this case. Summing up the business impact of each risk may result in a value for the costs that should be taken into account for the business-related risk situation. The semi-qualitative/semi-quantitative approach does not enable the determination of a properly comparable risk value, as there would be a mix of a real quantitative unit and a freely chosen qualitative number. Although that number is chosen by expert's expertise, it is still affected by subjective influence. This is why the risk register of this approach is the most simplified. The risk value that would be calculated by this would heavily depend on the subjectively chosen scale for the qualitative numbers, which does not allow for a secured conclusion with regard to the real unit included. A purely qualitative approach is not affected by this, as both risk elements are not assigned to a real unit, therefore the calculated risk value solely has the purpose of allowing the comparison, without the regard to a real unit. The maximum qualitative number for the probability and consequence will be set in the beginning of the qualitative approach. For all approaches, the descriptions of the effect, cause and treatment of the risk can be added to the risk register. The figure of the semi-qualitative/semi-quantitative risk register illustrates that.

The second part is an overview that shows the information of the most important risks from the risk register.

OVERVIEW of the most important risks	**Risk name**	**Risk value (qualitative)**
Highest currently calculated risk (value):	Risk3	3
Lowest currently calculated risk (value):	Risk1	2

Figure 6: Overview (Qualitative approach) of the RAT

OVERVIEW of the most important risks	**Risk name**	**Value [% or €] (quantitative)**
Risk with the lowest probability [%]	Risk1	5
Risk with the highest probability [%]	Risk6	90
Risk with the lowest consequence [€]	Risk7	7000
Risk with the highest consequence [€]	Risk1	100000
Risk with the lowest business impact [€]	Risk7	1050
Risk with the highest business impact [€]	Risk6	81000

Figure 7: Overview (Quantitative approach) of the RAT

By this, it is possible to get a fast input on the current risk situation without the need to search within the risk register for the most and least important risks regarding probability, consequence and risk value (respectively business impact). The overview of the qualitative approach does not go much into detail, as the highest and lowest probability/consequence will already been identified by setting the scale of the qualitative numbers. The semi-qualitative/semi-quantitative approach does not have an overview of the most important risks as there is no risk value that will be calculated, because of the reason already explained and also because of the third part of the tool, which is the primary focus of this approach.

The third part provides a graphic representation of the risk situation. This risk assessment chart (RAC) is based on the risk matrix explained in the chapters before and graphically demonstrates the relation of probability and consequence.

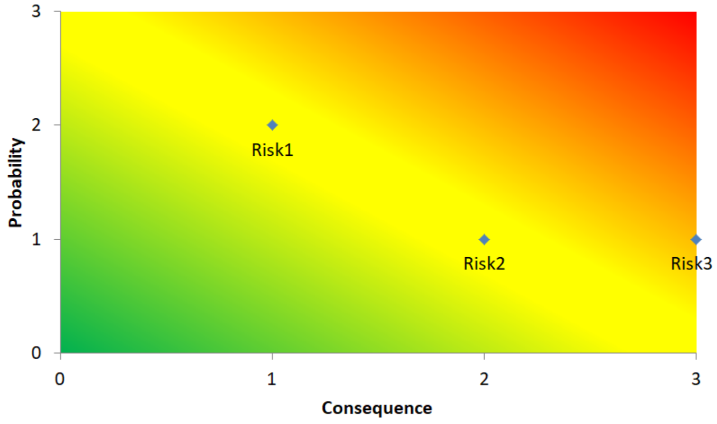

Figure 8: Qualitative RAC of the RAT

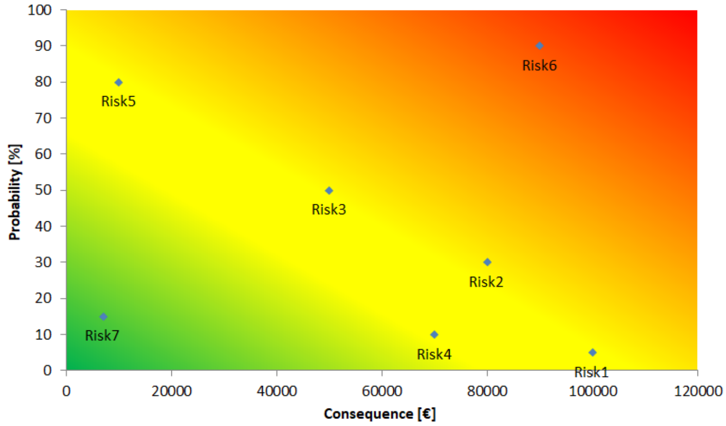

Figure 9: Quantitative RAC of the RAT

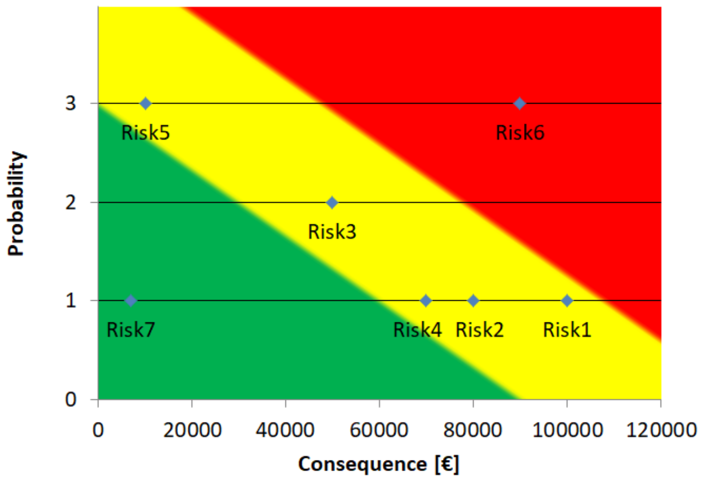

Figure 10: Semi-qualitative/Semi-quantitative RAC of the RAT

It gets the values from the risk register, where the values of the risk elements are filled in. The dots in the chart show, where the individual risks are located in it, attached with the name of the risk, which is taken from the risk register. The colored background of the chart indicates the threat of the risk with regard to the technology or the project (compared to the other risks), with green being the least critical, yellow being the transition and red being the most critical. The background was modified for each approach to take the differences of each one into account.

For the semi-qualitative/semi-quantitative approach the background was strictly divided into each color, because this approach is all about illustrating the risk situation in the chart without a specified comparison of risk values that also have to be taken into account. That is why the yellow area, an area where risks should get more attention, exactly starts in the top left corner, where the probability has the highest qualitative value and a consequence exists, illustrated by the risk being slightly placed to the right of the y-axis. This is a risk that will most likely occur and impact the business, even though with a small effect. But as there is an effect, attention should be paid to it. In case the risk elements are swapped on the axes, because the probability has a quantitative value and the consequence has a qualitative number, this aspect becomes even more relevant, as risks with a very high consequence tend to have a small probability. If the yellow area would not start in the top left corner, those important risks would be in the green gradation and most likely overlooked. The risk assessment tool provides a chart for this case to prevent this from happening. There, the probability is placed on the x-axis. For the shown example, the consequence is placed on the x-axis, it is assumed that the costs are quantitatively available. Based on the color grading, decisions can be made. They should not be made strictly by this though. Risks that are very near to the transition should at least be partly considered with the other color, so all possible scenarios are covered. Also, as all risks are listed along the horizontal lines, the space between the lines does not allow for conclusions that are based on it, as the probability is just illustrated on the lines created by the qualitative numbers.

The risk assessment chart of the qualitative approach has a fluent transition. This is because the maximum qualitative number of the probability and the consequence can be chosen in the beginning of the evaluation, which is why the overall scaling of the chart is variable and a predefined strict gradation is difficult to implement. Nonetheless, the chosen gradation takes into account that the minimum value for the qualitative approach can only be at x=1; y=1, which is why the green area has been enlarged with regard to the distance to the axes, as no value will be closer to the axes. This is because, if the probability or the consequence would be assigned with the value 0, there would be no risk at all, as the determination of a risk value is based on multiplication and the multiplication of the factor 0 does not allow for a result other than 0. The axes were intentionally not assigned with a starting value of 1 instead of 0, as the impression may arise, that the value 1 does not have an impact, as it is placed on the axes. But the value 1 only implies a "low" risk, not a non-existent risk, therefore can still occur and affect the business or the technology.

Unlike for the qualitative approach, the color grading of the chart of the quantitative approach has been modified and enlarged in terms of the red area. This is based on the fact, that the x-axis (the consequence) is scaled variably with a real unit. By this, even the highest consequence does not reach the edge of the chart on the right side. It was intentionally done to raise awareness for the circumstance, that there could always be a risk, which is assigned with more costs, as costs can theoretically be unlimited high, while the probability, for the quantitative approach assigned with a percentage unit, is limited to 100 %. The new risk would have a higher impact in terms of the consequence, therefore would be closer to the red area respectively in the red area with regard to the current chart. For the quantitative approach, a fluent color gradation was chosen. In this case, this is because of the usage of real units and the probability not limited to horizontal lines (therefore the whole space of the chart allows for conclusions). The calculated risk values have a monetary unit, which might get used for the planning of a project's budget for example. Those risk values provide a more precise foundation for making comparisons and decisions than the chart. Solely focusing on the gradation may result in the circumstance, that a measure for risk mitigation will not be defined or executed, just because it is not in the appropriate color grading. That could be a failure, especially for the planning of a budget, as risks, near to the transition of a color, could still be relevant in a certain context. Exceeding the calculated budget, because of an underestimated risk, may result in the project not being realizable at all. The fluent gradation emphasizes to concentrate on the more comparable risk values and use the chart as some form of assistance.

Overall, all values to be calculated (either in the risk register or the overview) and the risk assessment chart update automatically, when adding or changing the values for the probability or the consequence. Only the risk names displayed in the chart need to be updated by the "Update"-button that is implemented in the tool, in case of renaming them in the risk register.

2.6 Risk treatment

2.6.1 General treatment

The purpose of the risk treatment is to choose treatment options and implement them. This is done by defining the options, plan them, evaluate them by their effectiveness and deciding, if the rest of the risk, after implementing the treatment, is acceptable. Other options need to be defined, if it is not acceptable. The selection of the best risk treatment option includes weighing up the advantages against costs, effort and disadvantages of the option. Those options might include avoiding risks by not doing the activity that causes the risk, eliminating the cause of risk, changing the probability of occurrence, changing the effect or keeping the risk based on an informed choice. The selection of risk treatment options should be done according to the objective, risk criteria and available resources of the organization [5].

In the following, a plan on how to implement that treatment needs to be created, so everyone has an overall and agreed understanding of it. It should include the order, the treatments will be implemented. Beside this, it should, amongst other things, provide information on why the treatment was chosen, its benefits, proposed actions, needed resources and monitoring as well as when to take action [5].

2.6.2 Technical treatment

The technical part of risk treatment is all about technical occurrences, that should be mitigated step by step, therefore can be described very shortly. The ISO 12100 states that this can be achieved by eliminating the hazard or by mitigating one or both of the elements that are responsible for the associated risk, the extent of damage of the hazard and the probability of this damage. The measures taken have to be in a specific order, which is included in a procedure with three different stages, provided in the ISO 12100.

(1) Inherently safe construction

This step eliminates hazards and mitigates associated risks by choosing appropriate construction characteristics, e.g. geometrical or physical aspects, of the technology and the interaction between a person at risk and the technology. It is the most important stage as these measures for the technology are most likely to stay effective, while experience has shown that general technical protection measures may fail. As this is the only stage where hazards can be completely eliminated, additional technical measures are not needed in this case.

(2) Technical protection measures and/or additional protection measures

If the inherently safe construction does not provide enough mitigation, separating and non-separating protection measures can be applied. These measures aim to protect persons, e.g. separating measures keep the persons at risk in a defined distance to the technology, while additional protection measures include extra equipment to shut down the technology for instance.

(3) User information

If there are still risks after the previous steps were taken, those risks have to be noted in the user information of the technology. This user information has to at least include a guideline for the person at risk‘s working procedures regarding the technology, education requirements, warnings for remaining risks in the technology’s life cycle and a description of recommended safety equipment and its appropriate usage. The user information is not a replacement for the correct implementation of the two other stages.

2.6.3 Business treatment

For the business risk treatment, decisions have to be made according to the risk matrix, created earlier in the process. From this, based on the calculated risk value, the extent of impacts on material resources but also on business indicators like capital resources and the cash flow can be derived. The treatment is often based on risk values that are assigned to single elements of the project. For the case of offshore projects/offshore wind farms, the following graphic illustrates elements that are considered into the treatment [11].

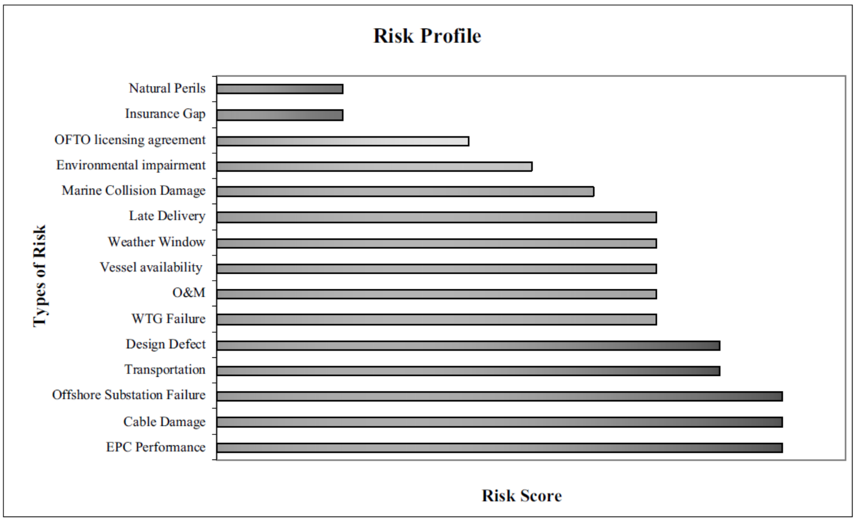

Figure 11: Risk profile from an insurer’s point of view

As the risks are associated with costs, a look on who covers the expenses needs to be taken, so conclusions for the business risk treatment can be drawn. Different approaches are possible. Taking risks by the persons responsible for the overall project or sharing them with/delegating them to different parties, decreasing the probability or decreasing the impact in case of risk occurrence. This process does not only have a technical manner, but also a contractual one.

Several topics are relevant for this, like the contractual risk sharing, insurance requirements, different groups of interest and other partners, for example supplier and developers. The overall quality of the risk management influences the estimation of the expanses to be covered by the project or the availability and the price of insurance protection [11].

With regard to the graphic above, insurances that may cover the business risk, will especially take a closer look on risks that are known to have the highest impact or are known for the highest frequency of occurrence. In regard to the wind farm example, offshore wind farms are known for having cable damage as the prime type of damage, they having to deal with. Therefore, the insurances will pay attention to an appropriate cable supplier. Inexperienced suppliers or suppliers, which are known for having frequent problems with their supplied cables, will stand out [11]. Choosing such suppliers, especially in combination with the development and usage of unproven technology as an integral part of the Space@Sea concept, may have a negative effect on the financing. The appropriate choice of partners and people responsible for the prevention and mitigation of risks in the first place is important, but also to take care in case of the occurrence of the risk. By this, the needed handling for the risk circumstances is assured. Therefore it is not only obvious from a technical point of view to treat the risks with the highest impact first, there in terms of functionality or safety of the technology. Instead, it is also important to prioritize the ones with the highest business impact, as it affects the costs, potentially assigned to the determination of the price of insurances, and therefore affects the profitability of the project in the long run.

By the context described above, several important aspects for the Space@Sea context were already shown in terms of a business and especially economical point of view. In regard to the following practical experience, it becomes apparent that the mentioned correct assignment of responsibilities is essential, as attention is paid to it in practice and it is also highlighted in the ISO 31000, already described in the "Risk management" chapter. This section acts as a continuation of the practical experience in chapter 2.5.3.

Practical experience

First subsidiary company: For the risk treatment, the subsidiary company names measures to reduce the probability of occurrence or the potential loss. The effectiveness of the chosen measure will be documented by quantifying the rest potential loss after implementing the measure.

Second subsidiary company: For every identified risk, a measure and a responsible person are assigned.

Third subsidiary company: No particularity is mentioned, that is different to the other subsidiary companies.

2.6.4 Recommended approach for the treatment

The previous chapters showcased that the treatment of risks depends on the point of view. For an economical point of view, the "Business Treatment" chapter provided information. The "Technical treatment" chapter focused especially on the construction of technologies and provided the appropriate approach for the treatment of risks that are related to the functionality and safe handling of technologies.

Overall and in relation to the earlier done research on risk evaluation, these questions should be kept in mind, when treating risks:

Table 7: List of questions for the risk treatment

Question	**Explanation**
Is the risk endangering the health of a human being?	Even though the risk assessment of this report focuses on the associated business impact of the risks of technologies being used in the Space@Sea project, from all the research done on risks, especially related to technologies, it became clear, that the handling of risks puts the safety of humans first. Therefore, cost-benefits analyses should never come to the conclusion, that saving expenses is acceptable, while there is still the possibility to mitigate the risk of a technology endangering the health of a human being.
From which perspective is the treatment defined?	While defining and applying measures for the risk treatment, the point of view of the persons treating the risks should always be kept in mind. For example, inside a project, the opinion on treating risks might differ between a technical and an economical point of view. Persons responsible for defining measures are influenced by their background of experience and education. This generally helps defining the appropriate treatment, but could also make the decision too biased. The appropriate treatment in the opinion of one person might not be the right treatment in the opinion of another. In the end, there has to be a treatment that mitigates the risk to an acceptable level, while still keeping the feasibility of the project in mind. Therefore, the measures should not be influenced to heavily by one point of view, but should consider several opinions.
Which aspects are associated with the treatment options?	This mainly focuses on the resources needed for the realization of the measures, like personnel, material, technology, organization, time and money. It has to be checked, if these resources are available. If not, there has to be considered, if these resources will be available in the future or if the measure is not the appropriate one, because of the resources missing. This could also result in the risk not being acceptable for the overall project, if there are no other measures to choose from. It could endanger the realization of the project, as the measures for risk mitigation might be too expensive or there a not enough resources to

	mitigate the risk to an acceptable level. This does not have to be related to resources, as there are risks that simply cannot be mitigated to an acceptable level, whatever treatment is chosen for them.

Recommending an overall risk treatment strategy is not easy, because there are many different forms of risks and the treatment depends on the appearance (type, extent, cause and so on) of them, as explained in the previous chapters. In the end, it is the responsibility of the decision-makers to choose the treatment. Therefore, proposing different advises for the overall process of decision-making seems more applicable.

Basic recommendations like keeping attention to norms and standards for the relevant fields of expertise, especially for technical aspects, are obvious. The experts working for the project on these fields have the most experience and education on the risk related topic, therefore should be able to define the best risk treatment options. By considering the applied risk definition of this report, it should be noted that the risk in its pure form is defined as the combination of extent of damage and probability of occurrence. If it is foreseeable that the extent of damage of a risk is very high and it turns out to be very hard to decrease that extent, the probability of occurrence should be decreased to the minimum to keep the risk somehow balanced (respectively the associated risk value).

Although the risk treatment is mostly considered to be measures for already identified, analyzed and evaluated risks, the topics of risk treatment can also be viewed from a different point, which will be taken into account here. As the prevention of potential appearing risks mitigates the need of risk treatment (as it is defined in the previous sentence) in the first place, this aspect should be kept in mind in form of a proper risk management to begin with, that includes a thorough analysis of the whole project, including all technologies being used. The chapter “Risk identification” already included how to identify risks and what aspects should be taken into account. But especially external stakeholders of the project will probably not be interested in smaller internal project risks. This means risks that are related to small damages being done to the functionality or appearance of a technology, which can be fixed within one or two days with a relatively small amount of money. Instead, they will be interested, if the project is profitable as a whole and if the chosen technologies are the right choice to assure that profitability.

A process that covers this circumstance, either from a business or technical point of view, is the due diligence process, which basically is about providing information to investors from the projects point of view, so the investors minimize their risks. Besides the differentiation of type and occasion, due diligence processes are also differentiated by functional content. That is why offshore projects are also viewed by a financial and a technical point of view [11].

From the need of providing viable information to investors, which are needed to fund the project, risk associated aspects can be derived for the project. This will be explained after a short overview on the financial and technical due diligence and what they are about:

Normally the financial due diligence relates to the acquisition of companies, which is why it is all about examining the historical financial data of the company and their upcoming business plans. In regard to a conceptual offshore project, there is no historical data until the commissioning, so this point becomes obsolete. For this, the in-depth analysis of the profitability of the project is the main focus. The profitability is, apart from others, influenced by external random factors, like weather or wind conditions, if the offshore project is about wind energy. Beside this, running costs like insurances or contracts for maintenance have to be assessed, because they decrease the cash flow [11].

The technical due diligence also has a big impact on offshore projects. This circumstance especially appears, if unproven technologies are used, as it is the case for the Space@Sea project. For example, for offshore projects related to wind energy, the technical inspections of the planned wind turbine and the wind farm equipment are the main focus of the overall inspection. The assessment of the technical feasibility of the project, within the planned period of time, in compliance with the legal requirements and the durability and functionality of the technologies, with exposure to the influence of the sea, are also considered. Besides the purely technical inspection, it is recommended to check the project's contract and its included services from a technical expert, to avoid gaps in the project's planning. Incorporating a technical consultant for the negotiation of the contracts is useful too [11].

By looking at the factors of a due diligence, risks can be identified, but they might have been already identified from a different point of view. More importantly for this chapter, they influence the risk treatment. In regard to the previously explained factors for investors, it primarily all comes down to two aspects: profitability and certainty. These two aspects are also related to the project's budget. With regard to this, it can be derived that defined measures, as good as they may sound, will not be suitable in the end, if the project as a whole cannot be realized by implementing them, e.g. if they are too expensive, so external stakeholders will not invest or the project's budget does not cover these expenses. Consequential, the risk itself is too high to be acceptable. If the risk can only be mitigated (to an acceptable extent) by that one measure, that results in the project being questionable in itself. That same circumstance applies to technologies. If their risks are too expansive to handle, it could lead to the conclusion of the technology being not fully developed and even not suitable for the project. Therefore, considering the business impact of every risk is inevitable and should always be assessed within a project. This can be done with the risk assessment techniques proposed in this methodology, as they covered business aspects for the measures by including costs as the consequence.

3 Case Study

3.1 The Working Packages and their technologies

With this case study, the developed methodology will be applied to technologies of two different Working Packages. Their risks will be identified, analyzed and evaluated, while an appropriate treatment will be proposed. By this, the applicability of the methodology will be tested and demonstrated, while contributing to the assessment of the technology risks that the project will face in reality. The case study includes the Working Package 6: EnergyHub@Sea and the Working Package 7: Living@Sea. EnergyHub@Sea aims to provide an economically viable as well as ecological maintenance hub for e.g. renewable offshore wind. The main objectives are to investigate possibilities for harvesting and storing energy for a self-sufficient maintenance hub. For this purpose, among others the technologies wind turbine and photovoltaic system are used, which both will be assessed regarding their risks. The Working Package 7: Living@Sea addresses the conceptualization of marine floating islands that are intended for human habitation (working, living). The objective is to develop new technologies that enable a more permanent living/working environment that is safe and comfortable. For the risk assessment, not an individual technology will be assessed regarding its risks, but the technological core systems of this Working Package as a whole. As there are many core systems, they will not be assessed regarding every single component of the core system, but regarding their risk situation in relation to the overall functionality of the Working Package.

How and to which extent the methodology is applicable with the available resources for this report will be shown using the wind turbine, as this is the most complex technology with regard to its related risks and therefore offers the most details. For the other technologies and core systems, the methodology will be applied to the appropriate extent identified.

3.2 WP6: EnergyHub@Sea - Wind turbine

3.2.1 Technological background of the wind turbine

Wind turbines use the natural existence of wind to generate usable electricity. The existence is caused by the solar radiation, which warms the earth’s surface and the layers of air above it differently. This circumstance results in differences in density and pressure in various areas of the earth’s surface, which are balanced by fluctuating air flows. Those air flows, respectively the wind, can technically be used by the wind turbines by transforming the kinetic energy of the flowing air masses into electrical energy. The energy of the wind is converted into mechanical rotational energy via rotor blades first. Then it is converted into electrical energy via a generator. The amount of energy, being transferred to the rotor, depends on the air density, the surface of the rotor and wind speed [14].

There are two physical principles for gaining the power of wind. On one hand, there is the resistance principle. It is based on resilience, which affects a surface exposed to the wind. On the other hand, there is the principle of lift as a force, resulting from a fluid flowing around the rotor blades and causing the rotor to rotate. By this, a far better outcome of usable wind power can be achieved, as this principle is way more efficient. That is why modern wind turbines are built upon this principle and why it is used for commercial power generation [14].

Although there are many technical variants of wind turbines, the usage of three blades and a horizontal axis of rotation has prevailed. Amongst other components, the main components of this system are:

- Rotor blades, rotor nacelle, rotor brake
- Electronic generator
- Wind measurement system and wind tracking (azimuth drive)
- Rotatable nacelle on top of tower and foundation
- Electrical system, switch gear

As the Space@Sea project is offshore related, special circumstances have to be considered in comparison to onshore wind turbines. From a technical point of view, they only slightly differ. Because of the different environmental conditions, like salty air, the components need to be designed and dimensioned differently. One of the main differences is the foundation, as it has special anchorages on the seabed [14].

Generally, offshore-systems should not be susceptible to maintenance. Bad weather conditions, that might appear, only worsened the already bad access to the system. The Space@Sea concept allows people to already be there though. The salty water requires enhanced corrosion resistance of the system's components. Additionally, the electrical conception is more complex as a transformer substation is needed, if high distances or power has to be handled [14].

The special circumstances will be taken into account for the risk identification and analysis of wind turbines of the WP6. Also, the listed main components' risks will we identified and analyzed, as their manufacturing costs can be researched and therefore used as the consequence of the risk, with regard to the proposed approach of the methodology, earlier mentioned in the report.

3.2.2 Risk identification and analysis for the wind turbine

Using the approach of the methodology being created in the beginning of this report, the risk management process starts with the risk identification followed by the risk analysis. As previously mentioned, there is an interconnection between both steps, which is why they are often executed in close succession. This was demonstrated, when taking a look at the practical experience of offshore related companies in the methodology. It often makes a clear differentiation unnecessary as long as the elements of each step are covered. This is why for this case study, the risk identification and risk analysis are combined into one chapter.

In the previous chapter, it already became apparent that the technology being used in the WP6: EnergyHub@Sea requires in-depth knowledge to be handled correctly. Knowledge, which is especially developed by experience in the field of expertise. For this report, the experts of the WP6 shared their knowledge and provided a table that includes all the risks, which might or will occur in the life cycle of a wind turbine. All risks were identified and analyzed by the HAZID method, already described in chapter 2.3.1. From all imaginable risks sorted and categorized in a big overview, the most relevant risks for the business and technical approach of this report were identified, given a number and listed. The list includes many details, which is why it is placed in the annex. To understand the comparison between each risk in the risk evaluation later in this case study it is important to have the annex.

The experts of WP6 focused on source, pathway, receptor and consequence for each hazard related to a certain (part of a) component. By this, the elements of the risk identification and risk analysis are sufficiently covered for the scope of this report. The pathway and the receptor have been taken out of the table in this report, as they do not primarily contribute to the technical aspect, which focuses on the damage of a component, and the business aspect, which focuses on the monetary value of the damage being done, of this report.

By taking a look at the table, all information needed for a proper risk assessment is stated. On one hand, there are plenty of details, which allow for the estimation of the probability of occurrence, which has been added to a column of the table by the experts. On the other hand, it has already been mentioned that it is difficult to determine the exact monetary value of a consequence of a risk. The same applies to the technologies of the WP6. The columns „Costs due to…" and „Additional comments" make it apparent that there are various origins for arising costs. As an example, the indication of a range for the days of personnel needed depending on the extent of the consequence of the risk opens a wide range for the costs of personnel.

For this circumstance, the methodology proposed the usage of the manufacturing costs of the damaged components as the consequence, to have a simplified approach that makes the different types of risks comparable regarding their consequence, as the manufacturing costs of the components should be relatively easy to research, especially with limited resources. With the main components already being identified in the previous chapter, the researchable manufacturing costs for specific main components are listed below [18] and some of them will be used in a first approach for the risk evaluation later in this case study.

Table 8: Main components and cost drivers of the wind turbine and their manufacturing costs

Main Component	**Costs**
Rotor	14200 €
Hub	5600 €
Azimuth system	1200 €
Electrical system	56300 €
Nacelle	43100 €
Tower	42500 €
Foundation	3200 €
Generator	20000 €

It is not predetermined that all of these manufacturing costs will be used in the evaluation as the applicability is not necessarily given. This derives by taking a look at the identified risks and their analysis. First of all, most of the affected components, which are listed in the table, are subcomponents of the mentioned main components. The manufacturing cost of the main components cannot be applied to subcomponents as they differ, in some parts immensely. For example, one risk identifies the possibility of a mechanical failure of hinges of the tower door.

The tower door being a subcomponent of the tower, it would be very disproportionate to apply the tower's manufacturing costs as the consequence of this risk. Other main components and its risks have similar circumstances, like the azimuth system and its risks being targeted towards subcomponents like the azimuth drive, the azimuth brake (disk) or the azimuth bearing. The research of the costs of those subcomponents, especially a subcomponent like a tower door, takes an in-depth effort that is out of the scope of this report and the available resources. On a second note, the extent of damage that is associated to the risk does not always justify the usage of the full manufacturing costs. This has to be considered with their application. The „Comments" column often states that the damage to be expected is rather low, which is why it would also be very disproportionate, to apply the rather high manufacturing costs, if there are only some loose bolts that need to be adjusted for example. Another example is the electrical system. Its manufacturing costs have been identified, but by taking a look at the table, it becomes apparent that literally all of its risks, subdivided into its subcomponents, have a low consequence on the system respectively low damage to be expected. As a result, it becomes clear, when applying the manufacturing costs of a (main) component as the consequence of a risk, the consequence needs to be the total loss of the (main) component, respectively the replacement, demolition or reconstruction, to justify such a monetary value. To repair a component, when its replacement is cheaper, does not make sense and would not be executed in reality.

Those aspects need to be taken into consideration when properly assessing the risks being identified and analyzed. It defines the further procedure and affects the upcoming risk evaluation in the next chapter.

3.2.2 Risk evaluation for the wind turbine

<u>Quantitative Approach</u>

As the risk evaluation depends on the approach taken for the assessment, either quantitative, qualitative or semi-qualitative/semi-quantitative, the further procedure depends on the data generated in the risk identification and analysis. The risk analysis showed that it is difficult to assign a concrete monetary value to the consequence of the risks of the wind turbine of WP6: EnergyHub@Sea. Following the description of this circumstance in the last chapter, a comprehensive quantitative risk evaluation seems to be not applicable, as this value does not exist for all risks. This can be seen, when applying the value to all risks, where it is possible. Table 9 offers four risks, where the application of the manufacturing costs seems to fit. Those risks have the number 3, 4, 6 and 15. Risk 3 refers to the risk related to rotor nacelle interface, risk 4 refers to the risk related to generator and blades, risk 6 refers to the risks related to rotor hub and risk 15 refers to the risk related to tower segment respectively. All of them seem to fit as their consequence is the highest consequence imaginable related to the component on its own, which is the total loss of it and its reconstruction. The monetary values for the affected components of these risks are available, as these components can be found in the list of the main components, stated in the previous chapter. By this, both elements of the risk definition, probability of occurrence and consequence, have a quantitative value, with the probability being stated in the table. Using the risk assessment chart and risk assessment tool proposed in the methodology, the following chart is created:

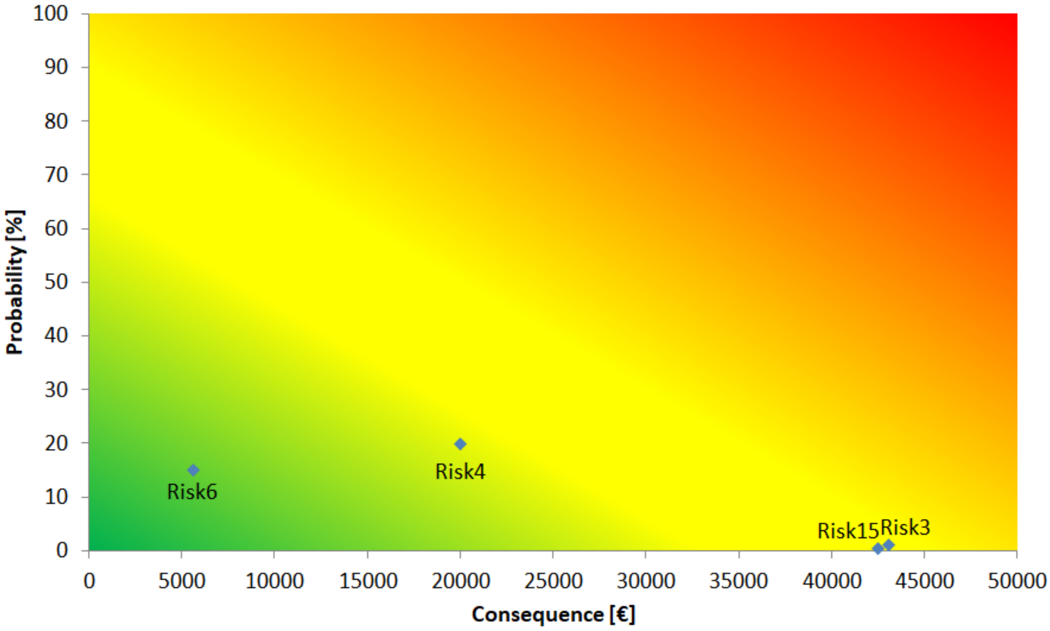

Figure 12: Quantitative RAC of the wind turbine

What stands out the most is that this chart shows that the risks do not occur frequently, some even very unlikely. All dots, each representing a single risk, are in the lower part of this chart, because their probability to occur is (very) low on a scale from 0 to 100 %. The risks with the number 4 and 6 stand out the most with regard to the probability. Both have a probability of more than 10 %, which is a relatively big gap in comparison to the other two risks that have a probability around 1 %. With regard to the consequence, the risks with the number 3 and 15 stand out the most, as they have more than the double amount of costs compared to the next lower consequence.

From the point of view of this chart, it is reasonable to concentrate the efforts on risk 4 and 6, because there might be a chance to mitigate their probability. Their percentage value indicates room for improvement, while the consequence value is set for this assessment, therefore cannot be improved. The focus on those two risks is approved with regard to the business impact (the multiplication of the probability value and the consequence value), which was proposed as a quantitative method for the comparison of risks in the methodology.

Table 9: Business impact of quantitatively assessable risks of the wind turbine

Risk	**Probability**	**Consequence**	**Business impact**
Risk 3	1 %	43100 €	431 €
Risk 4	20 %	20000 €	4000 €
Risk 6	15 %	5600 €	840 €
Risk 15	0,5 %	42500 €	212.50 €

Out of the four listed risks, risk 4 and risk 6 have the highest business impact, therefore should be prioritized. Besides that, it has to be noted that every listed risk has a very extreme consequence that is not representable for the overall risk situation. Risk 4 has the possible consequence of replacing the generator, which seems reasonable from a monetary point of view in relation to the overall functionality of the wind turbine. However, risk 15 includes the structural failure of the tower segment and the loss of stability due to buckling. For such damage, it simply does not make sense to replace the damaged component. Instead, it is more reasonable to replace the whole wind turbine, which results in significantly more costs than just the manufacturing costs of the tower.

Based on these aspects, it can be derived that the quantitative approach is not applicable for this case study. Because of very specifically identified risks, not all consequences can be assigned a monetary value. For those risks, where it is possible to assign a monetary value for their consequence, it becomes clear that they always have a rather low probability. But there are also risks that have a different probability and are not mentioned, because of a missing consequence value, which still need to be assessed. Even the quantified consequence values that were available do not represent the reality, not even in a simplified way, as the occurrence of some risks results in the reconstruction of the whole wind turbine. More information is needed to make a quantitative approach for the risk wind turbine. More information is needed to make a quantitative approach for the risk assessment useful. Such research would identify the missing values, but is out of the scope of this case study. For now, this small quantitative approach just functions as a first overview. It is not representative for the overall risk situation of the wind turbine, which is why there needs to be another approach.

<u>Qualitative and semi-qualitative/semi-quantitative approach</u>

The data generated in the risk identification and risk analysis as well as the findings previously generated in this chapter showed, that a comprehensive quantitative approach is not applicable for the risks identified. That is why a qualitative approach needs to be taken to cover the overall risk situation. However, the table with the identified risks offers a quantitative value for the probability of all risks. The key problem was the assignment of a quantitative value for the consequence. Based on this, a qualitative approach only needs to be taken for the consequence, while the probability theoretically can remain quantitative.

With the extreme consequences that were explained previously, a range of qualitative numbers for all consequences needs further explanation. Obviously, those risks have the highest number of the range. But with a qualitative approach, the key problem of not knowing the exact costs to be expected from the risks can be worked around. This makes it also possible to include other risks, which affect subcomponents (of which the research of manufacturing costs is out of the scope of this report) and/or risks, which result in high costs, but not necessarily from manufacturing costs regarding the damaged component. For example, the risks 12 and 13 affect the subcomponents azimuth bearing and the azimuth brake disk of the main component azimuth system, but their „Comments…“ column states that the repair gets very expensive because of taking down the rotor and the nacelle. Therefore, the high costs also notably result from personnel costs. A qualitative number can take this circumstance into account by assigning the highest number inside the range of possible numbers. In comparison with the „tower segment“ risk, the assignment of the highest qualitative number does not mean that they both have approximately the same amount of costs. It just indicates that the consequence has a big (cost) impact on the functionality of the component itself or respectively the whole wind turbine. The representation of this impact in a risk assessment chart makes it possible for experts, to easily spot the risks with regard to this aspect. Otherwise the sole use of the manufacturing costs of the affected (sub)component might result in overlooking risks that actually have high costs. This thought is proven by the fact, that the manufacturing costs of the tower are enormously higher than the costs of the azimuth system, therefore also its mentioned subcomponents. But both components' risks can result in expensive consequences, according to the risk analysis of the wind turbine.

This explanation allows defining a range for qualitative numbers, which will be set from 1 to 3 for clarity reasons, while each qualitative number is assigned a defined meaning. This procedure is consistent with the approach of the methodology, where it was proposed to use definitions for numbers or terms to create a semi-quantitative approach for the risk evaluation and set qualitative numbers for a range of percentage values for the probability (see chapter 2.5.1 General evaluation). As there are quantitative values available for the probability of risks of the wind turbine, it is not necessary to create qualitative numbers for the probability, because quantitative numbers are more precise, therefore more informative in most cases. Nonetheless, they will be created to cover all possible approaches. It allows for another point of view on the risk situation, which might help for a more simplistic view or in terms of personal preference. Additionally, it makes it possible to compare the risks by value, because a number for the impact can be created through multiplication of probability and consequence. With this and the previously elaborated explanations, the following definitions will apply to the qualitative and semi-qualitative/semi-quantitative risk assessment chart.

Table 10: Qualitative numbers and their meaning for the risk elements

Qualitative Number	**Meaning for the probability**	**Meaning for the consequence**
1	Less than 10 %	Low damage; low associated costs; quickly repaired with little effort for personnel
2	10 % - 49 %	Medium damage; special personnel needed; consequence depends on different factors that influence the extent of the consequence (from very low to total loss of the wind turbine)
3	50 % and more	High damage; very high costs regarding personnel or actions to be taken; total loss of the component or even the whole system; replacement of component; demolition and replacement of the wind turbine

It has to be noted that not necessarily all named aspects of the meaning for the consequence of a certain qualitative number have to be assigned to a risk that is given this qualitative number. The named aspects function as indicators and a description of the consequence to be expected, to get an understanding on how to categorize the different risks and even group the ones with a similar impact. For the specific consequence expected, the risk analysis was done and still functions as the source for precise information on the risk. As an example, the mentioned risks of the quantitative approach all have an extreme consequence with regard to the component respectively the whole wind turbine. Therefore, they all will be assigned the qualitative number 3 and can be grouped into one category regarding the consequence, even though they do not all have the same possible consequence of the total loss of the wind turbine. The ranges for the probability are chosen with regard to the actual identified probabilities. If the ranges would be divided into three parts of equal size from 0 to 100 %, the majority of risks would be assigned a low probability, which could lead to a wrong interpretation regarding the overall risk situation. A precise differentiation between each risk with regard to the probability would not be possible, the prioritization for risk mitigation measures could be disturbed. That is why the chosen ranges are most appropriate.

Based on this and the data from the risk table that was generated in the risk identification and risk analysis, of which the information on each risk provides the basis for formulating the qualitative numbers, the following risk assessment charts are created, starting with the semi-qualitative/semi-quantitative one:

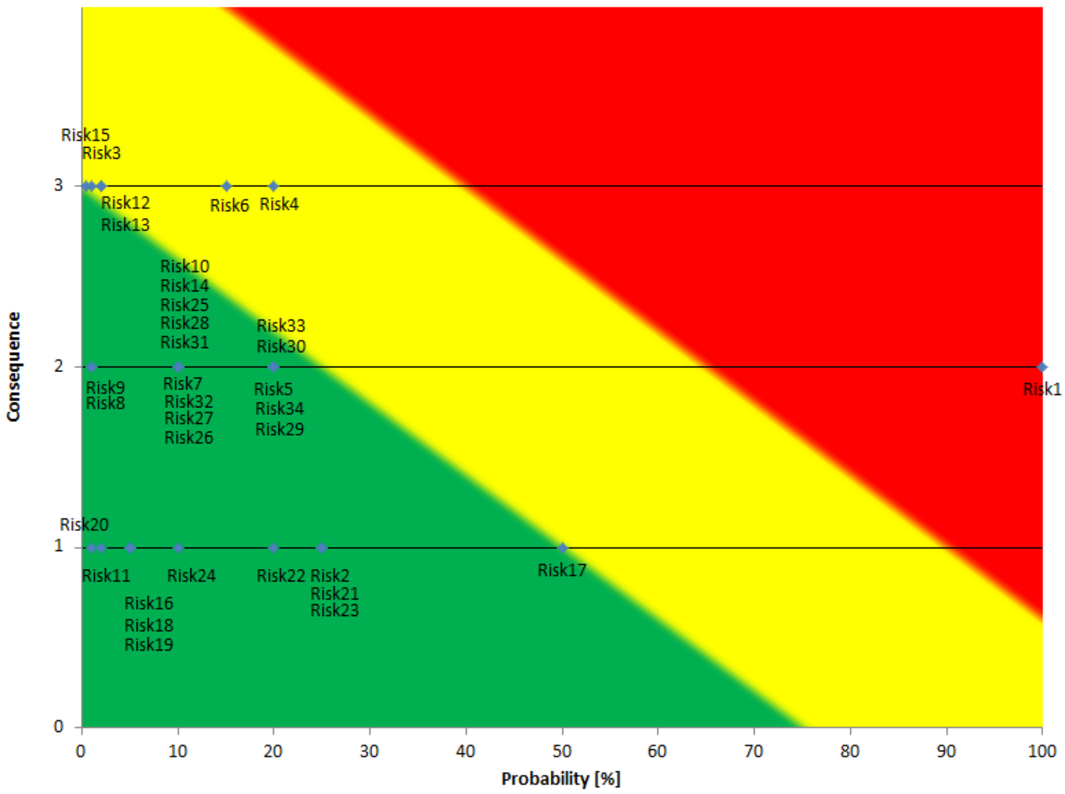

Figure 13: Semi-qualitative/semi-quantitative RAC of the wind turbine

Generally, both charts have the same validity, with the semi-qualitative/semi-quantitative approach being more precise regarding the probability. Other than that, it is just a matter of purpose. Conclusion based on the colored gradation can be made, but should be done with caution. This, as well as the purpose and reasoning behind the chosen gradation, was explained in the methodology. One aspect of the reasoning for the specific placement of the non-fluent gradation of the semi-qualitative/semi-quantitative approach confirms itself now. In contrast to the risk assessment chart that was proposed there, the probability is quantitatively available and the consequence needs a qualitative number. But it was mentioned that if this is the case, it becomes even more relevant that the yellow gradation, the gradation that indicates to take a closer look into the risk, starts in the top left corner (see chapter 2.5.4 Recommended approach for the evaluation). Otherwise the importance of the mentioned „tower segment" risk might be overlooked as it might get lost between the other „green" risks. Every risk with a high consequence is placed within the yellow gradation and should get an appropriate treatment that lowers the probability to occur to a minimum. Apart from that, by looking at this chart it becomes clear that many risks have a relatively low probability on a scale from 0 to 100 %, which is a positive aspect with regard to technical reliability and functionality. Even though this applies to all risks, specific measures and their execution should be especially planned in advance for the risks that have the highest probability, like risk 1 and 17, as they are most likely to appear and the right preparation guarantees that the impact of the consequence does not exceed the planned impact. The risks near to the yellow gradation should also be considered to have another review regarding their handling, as proposed in the methodology.

The qualitative risk assessment chart provides a similar interpretation:

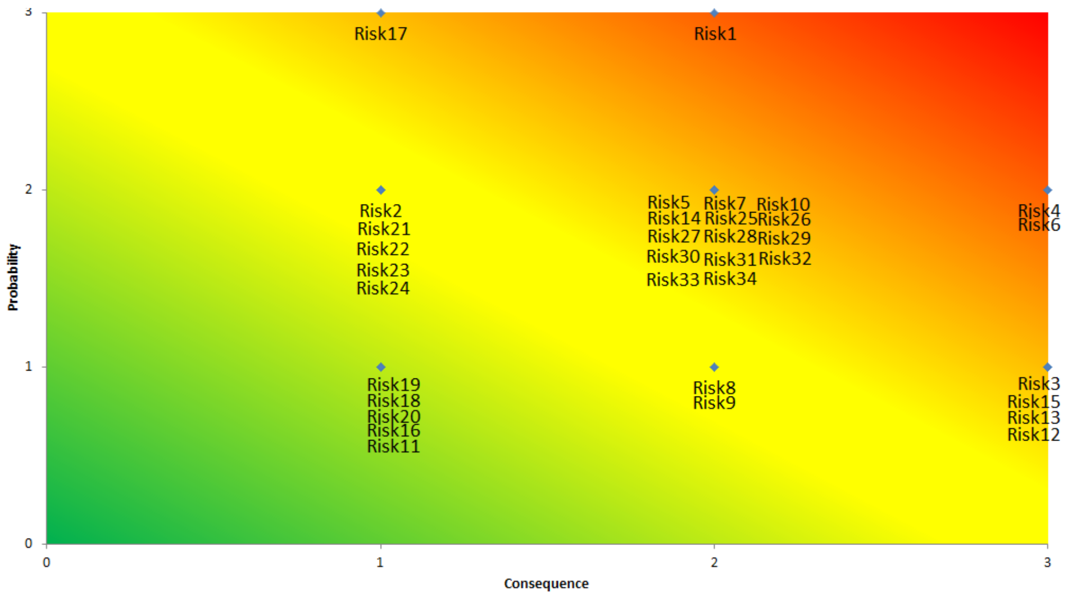

Figure 14: Qualitative RAC of the wind turbine

The reasoning of a fluent gradation was explained in the methodology. Generally, all risks that are located in a slightly red gradation should be taken into consideration for special treatment. The danger of this representation lies in the overlooking of risks that are like the several times mentioned „tower segment" risk, because they are located in the bottom right corner, where they seem to be not that important, even though their occurrence can have a critical impact in reality. Based on this, it is always important to find a special treatment for the risks that have the highest value, no matter regarding the probability or the consequence. This is also proven by the determination of an impact value (by multiplying the qualitative probability and consequence value), as this also does not show the critical impact of some risks. For clarity reasons, the red-yellow-green gradation is applied for the impact values.

Risk#	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
Impact value	6	2	3	6	4	6	4	2	2	4	1	3	3	4	3	1	3	1	1	1	2	2	2	2	4	4	4	4	4	4	4	4	4	4

Figure 15: Impact value of the risks of the wind turbine

The needed special treatment of risk 15 does not become clear in this presentation. For a general prioritization this presentation works, but this evaluation is also about addressing the different probabilities and consequences directly, which do not become clear in a combined value. That is why the presentation of an impact value will not be further used in this case study and the evaluation and the derived treatment will and always should be done with the data of the risk analysis in mind. The measures that will be defined for the appropriate treatment of the evaluated risks come down to the mitigation of probability and/or consequence as well as the preparation for the case of occurrence. How this could be handled will be discussed in the next chapter.

3.2.3 Risk treatment for the wind turbine

It is important to give (or at least consider) a treatment for all risks to balance the overall risk situation. Obviously, every risk needs a special treatment when they occur, because they all differentiate from each other and affect different components and not every component is repaired the same way. To formulate the measure for each risk is out of the scope of this case study and is up to the experts that provided the risk table. But with regard to an overall treatment approach, it is possible to formulate measures that affect a group of similar risks or a group of components. Some of them are solely reactive to the occurrence of the risk, for example, there is no preventive measure against a bird strike into the blades. Other measures aim to define, how much attention needs to be paid to the risks, for example in form of maintenance, a proactive measure. As there are differences regarding consequence and probability, there are also similarities. On one hand, it was already mentioned that there are risks that share the extreme consequence of replacing the component or even reconstructing the whole wind turbine. The resulting costs are very high (assuming the manufacturing costs of the affected component are also high), therefore they can be grouped and the affected component is serviced more often to prevent the occurrence. On the other hand, risks with a low consequence that result in low costs and also might have a rather low probability can be grouped, because it is cheaper and takes less time to repair the damage when it appears, than having enormous personnel costs, while there is no need for such frequent maintenance. In between these more or less frequently occurring maintenances for the different components, there should be a defined time for recurring maintenance for components, that are affected by risks, where the extent of the consequence can vary from low to high.

Based on those thoughts and the previously done evaluation, each risk will be assigned with a time interval for recurring maintenance that results from the probability, consequence and overall type of risk. If there is no time interval, then this is because of the type of risk that only allows for reactive measures and no maintenance.

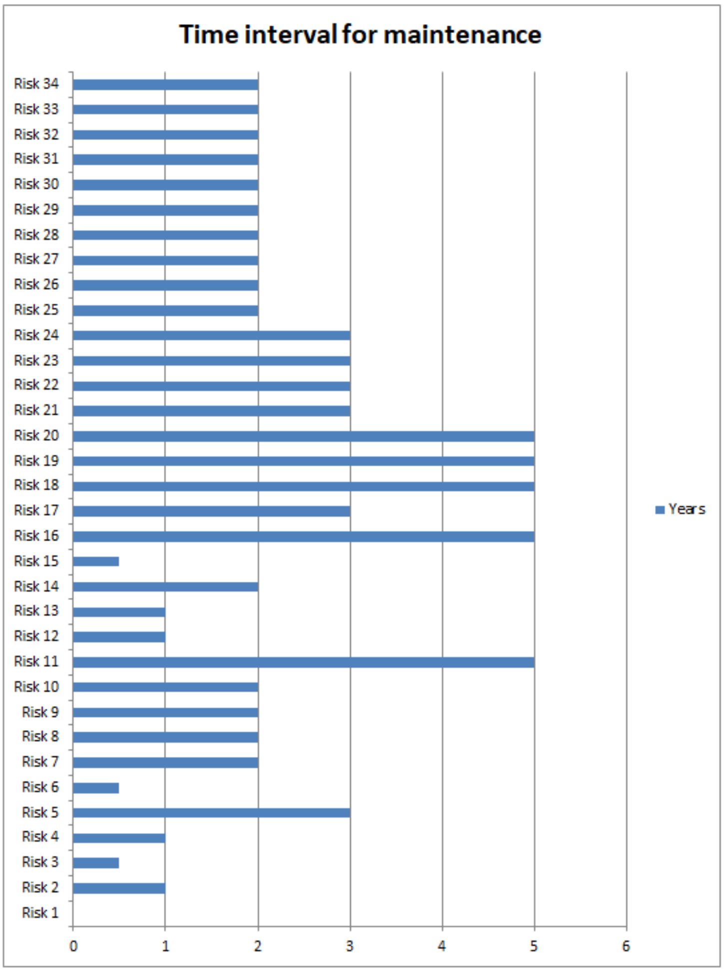

Figure 16: Time interval for maintenance resulting from the risks of the wind turbine

From this presentation, it will be derived, which components or component groups need more or less maintenance and which time interval for recurring maintenance is appropriate. This also acts as an indirect explanation to why the different time intervals were chosen and which risks cause a lower or higher amount of maintenance.

Table 11: Amount of maintenance for the components of the wind turbine

Amount of maintenance needed	**Component**
High (Time interval of **0.5** to **1 year**)	**Tower**: The structural integrity of the tower is required for the overall long term functionality of the whole wind turbine, as affecting risks could cause the total loss of it. That is why maintenance activities should be done every **0.5 year**, despite a low probability that the risks might occur. **Rotor** and **hub**: Both, especially the hub, have a rather high probability (in comparison to the tower) that cracks might appear that could result in the total loss of the whole wind turbine. That is why a frequent maintenance of every **0.5 year** should be in place to keep the probability at its value, maybe even decrease it. Such time interval for the overall rotor is also needed with

	regard to associated subcomponents like the rotor lock brake and the emergency brake, of which the functionality is crucial for the overall functionality of the wind turbine, as a broken brake might result in external damages apart from the rotor itself. **Generator**: The generator is subject to risks, of which the consequences are difficult to estimate. It is possible that the whole generator needs to be changed and personnel are needed for more than a week. As there is no risk regarding the generator that could cause the total loss of the wind turbine though, a maintenance interval of **1 year** should be in place, instead of every 0.5 year. **Blades**: Most risks that affect the blades, like blade separation due to a lightning strike or a bird strike, need to be handled reactive, when they occur, as they can not be prevented by maintenance. The blades could still be serviced in a time interval of **1 year**, as they are affected by risks that are more likely to occur in certain seasons (winter), like ice accretion, which is why a yearly maintenance in this season might decrease the probability of occurrence.
Medium (Time interval of **2 years**)	**Azimuth system**: Generally, all risks affecting the subcomponents of the azimuth system have a rather low consequence of damages. These are repairable. Also, the azimuth system itself has low manufacturing costs in comparison to other main components. However, the occurrence of risks to those subcomponents can result in taking down other components (rotor and nacelle), which results in high costs. To prevent these high costs, maintenance should be done at least every **2 years**. **Bolts**: Even though bolts are not a component with regard to the previously used meaning of components, the risk analysis and evaluation made clear, that many risks occur because of loose or broken bolts, which affect all sort of components in the proper sense. Because broken bolts can result in the total loss of the whole wind turbine, they need to be checked frequently. As bolts are designed for long term use, but the probability of the occurrence of a loose or even broken bolt is rather significant compared to other risks, a time interval of **2 years** should be appropriate.
Low (Time interval of **3** to **5 years**)	**Electrical system**: The consequences of all risks that affect the components of the electrical system were estimated as low, which is why reactive measures are cheaper than too frequent maintenance activities. As the manufacturing costs of the electrical system are high in comparison to the other main components, there still should be maintenance activities every **3 years**, to keep the overall quality of this expensive system. **Nacelle**: None of the mentioned risks affect the nacelle itself, but the components inside and next to it. With regard to those components and the overall rotor nacelle assembly, a time interval of **3 years** for the hull of the

	nacelle should be justified. The components inside and next to it are treated differently. **Foundation**: As there are no risks that directly and solely affect the foundation apart from the already covered broken or loose bolts, general maintenance activities every **5 years** are justified. **Anchor** and **mooring lines**: A very frequent diving to check for damages of the mooring lines or a displacement of the anchoring would be very expensive. Mooring lines and the anchoring should be designed for long term use and the probability of occurring risks is low. Also, the consequence, if a risk occurs, does not affect the functionality of the wind turbine. That is why, from the point of view of the wind turbine, a time interval of **5 years** is justified.

3.3 WP6: EnergyHub@Sea – Photovoltaic System

3.3.1 Technological background of the photovoltaic system

The photovoltaic system technology converts solar radiation directly into electrical energy using the photoelectric effect. Generally, its main components are:

- Solar modules
- Inverter
- Cables
- Mounting system

Inside the modules, photovoltaic cells convert the solar radiation energy into electrical energy respectively direct current. An inverter transforms this into alternating current to make it usable in the electricity grid. The connection between the electricity from the modules and the electricity grid is created by the mentioned cables. A mounting system enables the mounting of the photovoltaic system on a surface and the adjustment of the angle of the modules to the direction of the solar radiation. Photovoltaic modules consist of several interconnected photovoltaic cells. Based on the used cells and their material, the photovoltaic system can be further classified, if needed [14]. Regarding the scope of this report, it is not needed. Instead, the risks of the mentioned main components will be identified and analyzed.

3.3.2 Risk identification and analysis for the photovoltaic system

For the risk identification and risk analysis, the same experts of WP6, that provided the risk table for the wind turbine, shared their knowledge to provide another table that includes all risks that can be expected, when using the photovoltaic system at Space@Sea. Therefore, the same approach to identification and analysis was done and will not be explained again. The table can be found in the annex. All identified risks are given a number again, which will be used for the evaluation. The table includes far less risks though, which is most noticeable, when taking a look at it. Even though that means that there are fewer components affected, the approach of identifying the manufacturing costs will not be taken, to secure an overall comprehensive approach for all technologies that are assessed. The assessment of the risks that were identified for the wind turbine showed that it is often difficult to apply the manufacturing costs, which is due to the type of risks. This has implications on the evaluation in the next chapter.

3.3.3 Risk evaluation for the photovoltaic system

Without a quantitative value for the consequence, it is impossible to create a quantitative risk assessment chart. Also, the sole quantitative approach for the wind turbine showed that it is not possible to get an overview of the overall risk situation of the technology with it, which is needed for this assessment though. That is why the following evaluations will focus on a semi-qualitative/semi-quantitative and a qualitative approach. The same qualitative numbers and their meanings for the probability and consequence as for the wind turbine are applied, but this time they relate to the photovoltaic system and its components. Therefore they relate to different actions and efforts that are taken in order to handle the risk, which also take a different amount of time. Some of them do not take a long time to handle, but still include the replacement of modules. Those risks are assigned the highest number, because it is assumed that there is no worse case than replacing a component, even though it only takes a few days. Repairable damages of the component get a lower qualitative number in comparison.

With this in mind, the following risk assessment charts are created:

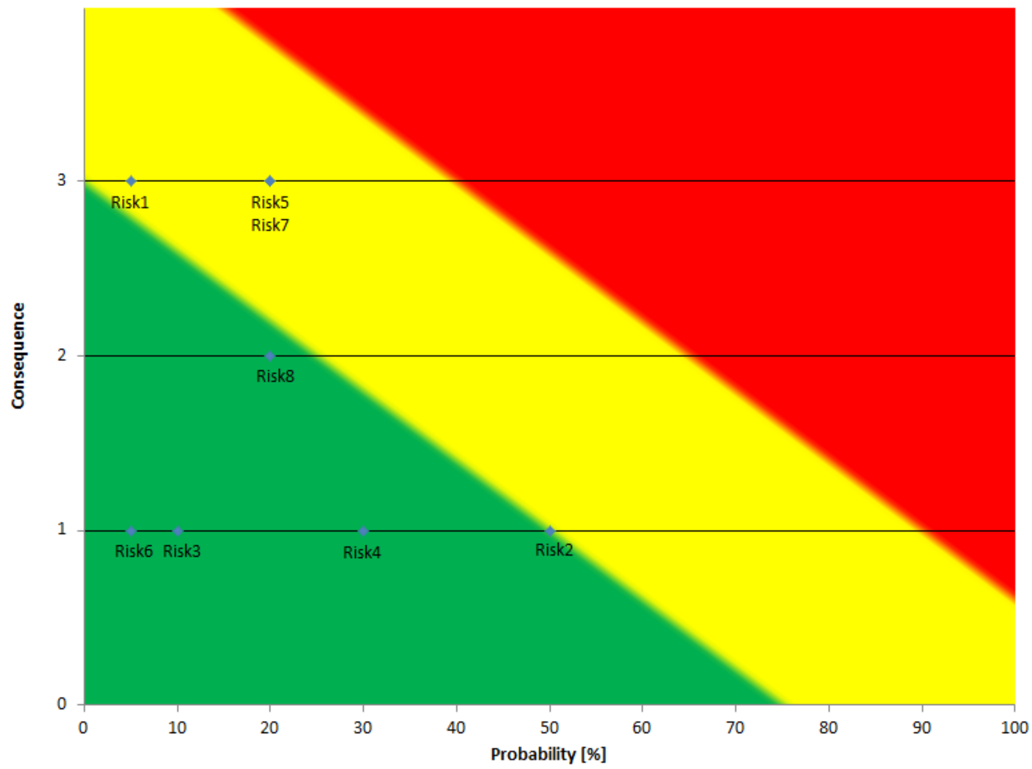

Figure 17: Semi-qualitative/semi-quantitative RAC of the photovoltaic system

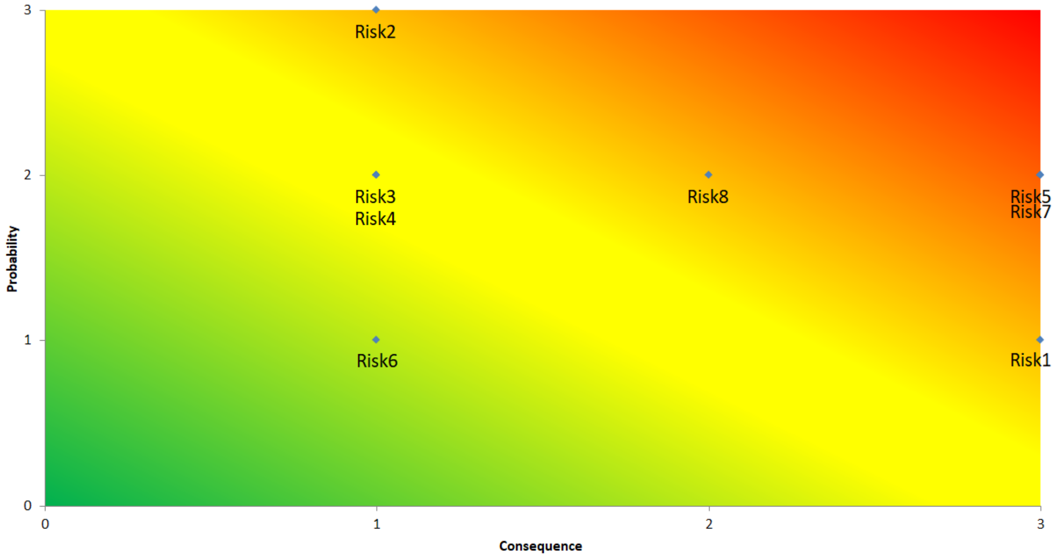

Figure 18: Qualitative RAC of the photovoltaic system

It becomes clear that there are relatively many risks that have an extreme consequence, because they are handled by the mentioned replacement of the component. Where it is possible, they should be prioritized. The color gradation allows for the same conclusion.

There are no risks that could result in losing the whole photovoltaic system with the result of reconstructing it though. Other damages that can be repaired have a lower qualitative number, because a repairable damage is a lower consequence than the change of the whole component. In comparison to the wind turbine, there are no probabilities that are around 1 %. Instead, most of them are noticeable with regard to the defined qualitative range of probabilities, which is why it is difficult to prioritize solely on this aspect. This is why the prioritization should be done with regard to the consequence as well as the sources that cause the risk.

3.3.4 Risk treatment for the photovoltaic system

As the photovoltaic system faces different risks than the wind turbine, its risk treatment needs to be adjusted to those specific risks. They mostly result from inappropriate weather conditions respectively natural influences that are difficult to prevent, because these influences are mostly uncontrollable, they either occur or do not. That is why the treatment mostly results in rather reactive measures than proactive measures and there will not be any chart regarding the maintenance. Instead, the risks will be sorted into types of treatment as well as specific treatment for specific risks:

Table 12: Types of treatment for the risks of the photovoltaic system

Type	**Description**	**Associated risks and affected components**
Type 1	Maintenance activities are done, when there is the season and the location, that give rise to those activities (time interval of **1 year**, predominantly in winter).	Risk 2 (**mounting system**) Risk 5 (**PV modules**)

Type 2	Risks that result from natural influences that are not necessarily related to a certain season, like wind, water (waves) and lightning strikes. A possible proactive measure is the usage of breakwaters, wind protection or lightning rods. If those do not help or are not applicable, reactive measures are needed. Proactive measures should also relate to preventive measures regarding corrosion, as there is the constant influence of water, because of the offshore location.	Risk 1 (**mounting system**) Risk 3 (**junction box**) Risk 4 (**solar glass**) Risk 7 (**inverter**) Risk 8 (**overvoltage protection**)
Type 3	This type solely covers the risk of torn cables or damaged cables. For the sake of saving costs, maintenance activities could be combined with the activities of type 1 as torn cables might be easy to identify and the personnel for the maintenance is already in place. Other than that, the existence of a low probability, the low expected costs and the few days to repair the damage justify checking for those damages every **5 years**.	Risk 6 (**cables**)

3.4 WP7: Living@Sea – Core systems

3.4.1 Risk identification and risk analysis for the core systems

Previously in this case study, the technology's components and the risks, which affect them, were assessed. By that, the risk situation regarding the functionality of the technology was presented. In contrast to that, the following assessment will take a look at the impact of risks of technologies, with regard to the functionality of the Working Package as a whole. Thus, the risk situation of all core systems of Living@Sea will be identified and presented. The applicability of the methodology will be shown from this point of view.

As this is the goal of the WP7 Case Study and there are many core systems, the risks and their effect will not be listed in a detailed way, unlike the case study of WP6. Instead, the consequence of occurring risks of a core system will be defined as the impact of the risk situation respectively a failure of the core system on the functionality of Living@Sea. This is because it would be out of the scope of this report to assess the effect of every risk affecting the individual components of the many core systems. Also, the applicability of the methodology to the risk assessment of technologies and their components has already been shown. The consequence as well as the probability will be qualitatively assigned with a term, because the estimation of the values is solely based on literature and the knowledge of the author and it already became clear in the case study that a quantitative approach needs a lot of data, which is why such an approach will not be used this time.

The identification and analysis of the risks the core systems of Living@Sea were based on the usage of such systems for cruise liners, as the concept of cruise liners comes close to the Living@Sea concept, with them somehow enabling the living and working on the sea for human beings. With regard to this aspect, the following core systems were identified. Where external information for the assessment is gathered by literature, the source is mentioned behind the core component.

- Electricity supply/ battery storage
- Air conditioning/ ventilation
- Lifeboat
- Deck crane [15]
- Panes/ glazing - outer shell
- Cooling chamber (food)
- Helicopter deck
- Elevator (persons and transport) [16]
- Sewage treatment plant [17]
- Water treatment

Based on the mentioned reasons for an qualitative approach, the probability, a core system will fail and this failure will have an noticeable impact on the functionality of the Living@Sea concept, and the consequence, being the description of this impact and its cause, are assigned a qualitative term.

Table 13: Core systems and their values for the risk elements

Core System	Probability of failure	Causes and consequences of failure (impact)
Electricity supply/ battery storage	**Medium** In this case study, it was already mentioned that the electrical conception of offshore-systems is more complex than onshore. Due to complexity there are more risks that arise from it, which in sum lead to a higher probability that a risk might occur, even though the risks on their own might have a low probability. That is why a	**High** The electricity supply is crucial for the overall functionality of Living@Sea and all its related core systems. Therefore, a failure has a high impact on Living@Sea. Failures can occur due to hazards like a short circuit.

	medium probability is justified.	
Air conditioning/ ventilation	**High** Because of many small subcomponents, damages and failures occur relatively often in comparison to the other core systems.	**Low** Damages and failures that occur can be repaired with 5 – 10% of the acquisition costs of the air conditioning/ventilation. Also, the failure of this system does not critically affect the functionality of Living@Sea.
Lifeboat	**Low** Lifeboats are not frequently used, which is why they are not frequently exposed to risks.	**Medium** This value is chosen, because the consequence varies from different point of views. On one hand, the expected damages are low, easy and not expansive to repair as these boots are not used frequently, but just in case of emergency. On the other hand, the risks can have a crucial impact, as a non-functional lifeboat can endanger the life of human beings, which is why its risks need special attention.
Deck crane	**Low** The probability of a failure and the occurrence of risks with the consequences explained are rather unlikely in comparison to the other core components.	**High** The high value was assigned, because the potential failure of cranes can have fatal consequences. Those relate to the health of human beings, as the failure of the crane can result in damages of the surroundings, but also in high costs. They are caused by errors in the identification and interpretation of symptoms and lack of information and training of the personnel. The functionality of the deck crane is also essential for the working activities of Living@Sea, which is why a failure also affects the working flow heavily.

Panes/ glazing - outer shell	**High** The probability of occurrence of the risks is high, because most of them frequently and naturally appear, because of the offshore location.	**Low** Risks are primarily caused by natural influences like wind, water (waves), lightning strikes and bird strikes. Also, seasons influence the amount of risks (therefore the amount of consequences), for example ice accretion is more likely to appear in winter. The consequence is low in comparison to the other risks though, as the risks predominantly result in repairable damage and are not crucial for the functionality of Living@Sea.
Cooling chamber (food)	**Medium** As the cooling chamber is not exposed to any external influences other than the electricity supply, the probability for its failure is similar to the probability of that system. The cooling chamber might fail due to the failure of its own subcomponents, but that does not increase the overall probability significantly. That is why a medium probability is justified.	**Medium** As everybody living or working at Living@Sea is affected by the failure of this core system, the consequence is significant. It does not endanger the life of human beings though, as there should be enough food to survive, which does not need to be cooled. Also, in comparison to the consequence of other core systems it should not be very expensive.
Helicopter deck	**Low** Depending on where the helicopter deck is located on the module, it is more or less exposed to natural influences. A total loss of this component is very unlikely. In comparison to the other systems, the probability is rather low.	**Low** Generally, it is most affected by risks due to natural influences, especially water. Other than that, the robust construction of the helicopter deck should guarantee low consequences, as the occurrence of risks should be recognized at an early stage and a failure of the system should be compensated by the usage of ships, until the

		helicopter deck is reconstructed or repaired.
Elevator (persons and transport)	**Medium** With regard to the mentioned source of information and in relative comparison to the other risks, a medium value for the probability of a failure is justified.	**Medium** Elevator breakdowns due to changed adjustment parts, looseness, transformation, destruction and damage account for almost two third of all elevator breakdown cases. The other occurrences result from contact badness, contamination, user carelessness, malfunction and snapping of a wire, while abnormal sound or vibration, life excess, component aging and abrasion have the largest share of this rest. Those damages can be repaired in many cases, some require the change of subcomponents. As the failure of an elevator has a noticeable impact on the working flow of Living@Sea, a medium value is justified with regard to the consequences that are listed for the other core systems.
Sewage treatment plant	**Medium** The complexity of the system causes a medium probability for the failure of the system.	**High** Because of space reasons, Sewage treatment plants are built with a compact design, while also taking the swell into account. For cruise liners, they are permanently installed in the ship. Once installed, such systems can only be modified or extended at great expense. In view of the wastewater conditions, even modern systems can have significant operating problems or performance losses. Risks cause failure of individual aggregates such as the drainage systems. Also, failures in the measurement technology can lead to a shutdown of parts of the entire plant. As the system is essential for the living, a failure has

		a high impact that also results from high costs for the repair.
Water treatment	**Medium** The complexity of the system causes a medium probability for the failure of the system.	**High** As the water treatment functions with chemical processes just like the sewage treatment plant and the state of the art of both technologies is similar and the system is also crucial for the people living and working at Living@Sea, the same impact of the consequences for the Living@Sea concept apply.

3.4.2 Risk evaluation for the core systems

The previously done estimation of the values will now be evaluated with regard to the impact on Living@Sea and graphically presented in comparison to each core system. The qualitative terms are transformed into qualitative numbers:

- Low = 1
- Medium = 2
- High = 3

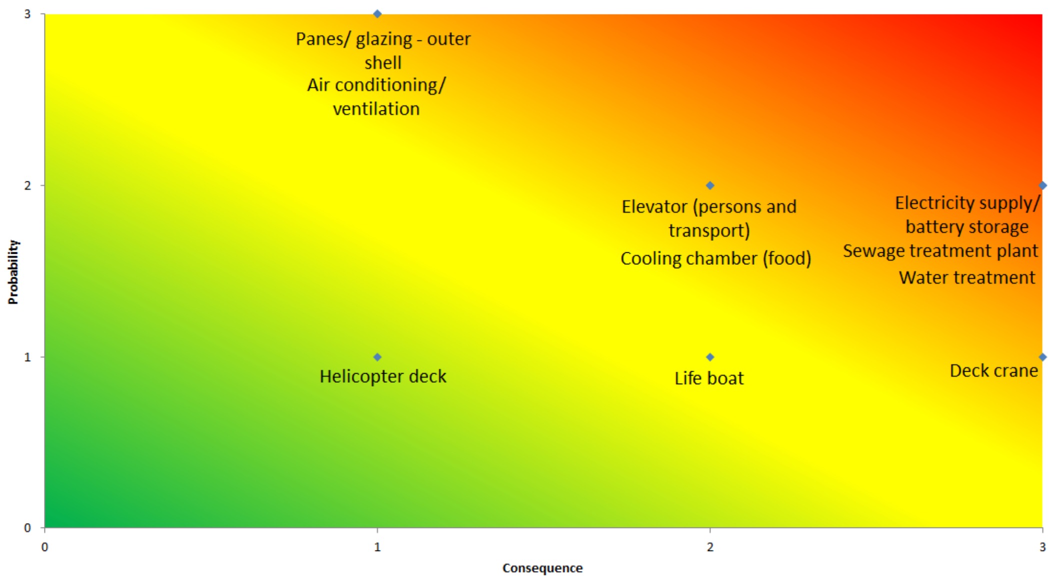

Figure 19: Qualitative RAC of the core systems

As previously, the risks of technologies with a possibly high consequence need a special prioritization and treatment. They have a crucial impact on the functionality of Living@Sea. The electricity supply, the sewage treatment plant and the water treatment secure the basic needs for the living aspect of the Working Package. The deck crane is essential for the working flow and its failure can have a heavy impact on the well-being of the people working and living there as well as on the infrastructure of the whole module. That is why their risks need to be prioritized. The risks of the lifeboats also need to be prioritized, because of the mentioned reason that its risks can possibly have high consequence on the well-being of persons. This is in accordance with the recommended approach for the evaluation that was proposed in the methodology, where it was stated that the evaluation, prioritization and following treatment should be directed to the health of humans respectively the endangerment of human life first. The implementation of technology in this case study, of which the purpose is directly and primarily aimed towards the well-being of persons on site, illustrates that aspect more significantly in comparison to the technologies of WP6, of which the purpose is also aimed towards people outside of the Space@Sea concept. Core systems like the helicopter deck do not primarily serve for the health of human beings and its risks do not equally affect the functionality of Living@Sea, which is why they can be less prioritized, when defining measures.

3.4.3 Risk treatment for the core systems

Based on the risk evaluation and the aspects stated in the risk identification and risk analysis, the amount of maintenance will be derived for each core system, using the same approach as for the wind turbine. It becomes clear that the amount of maintenance needed is overall higher, than for the components of the WP6. This was defined to cover and even emphasize the circumstance that most of the risks of the technologies of WP7 directly affect the well-being of the people at Space@Sea, while also affecting the life and working flow of the persons, of which the flawless course of the processes is the basis for an overall working Space@Sea concept.

Table 14: Amount of maintenance for the core systems

Amount of maintenance needed	**Core system**
High (Time interval of **0.5** to **1 year**)	**Electricity supply/ battery storage**: Because of the importance of this core system for Living@Sea as a whole, frequent maintenance activities every **0.5 year** are necessary. **Sewage treatment plant** and **water treatment**: Very good technical knowledge of wastewater is necessary for the personnel handling the sewage treatment plant, especially to maintain the efficiency of the biological system, which is why the treatment should primarily focus on the appropriate training for the personnel in the first place. The same applies for the water treatment with its chemical processes. Besides that, the importance of the system justifies a time interval of **0.5 year**. **Deck crane**: It was already mentioned in this case study that risks with a low probability, but an extreme consequence, always need special treatment in form of frequent maintenance activities, because reactive actions to the occurrence of the risk only consist of reconstructing the whole system, which is the most expansive case. In this case, the occurrence of such risk also endangers the health of human beings. That is why a time interval of **0.5 year**

	is appropriate. Also, failures may be prevented by promoting training and control in the construction and usage of the system. **Lifeboat**: To prevent damages, it is important to have frequent maintenance activities, so the lifeboats are available, when they are needed in emergency situations. That is why maintenance activities or at least checks every **0.5 year** are justified. **Cooling chamber (food)**: As the failure of this core system affects every person at Living@Sea, maintenance activities every **1 year** should be in place. **Elevator**: Without a scientific management and maintenance, the elevators could lose not only their original functions but also have low performance and safety accidents. That is why preventive checks in accordance with the regular substitution period are needed. That allows for the early detection of damages. The source [16] proposed maintenance activities with a time interval of 1 month to 2 years, depending on the subcomponent. Generally, a short time interval is appropriate as the health and life of human beings could be endangered, which why maintenance activities at least every **1 year** are appropriate. A more detailed approach for the risk treatment of the subcomponents and the overall risk situation of elevators can be taken from the source.
Medium (Time interval of **2 years**)	**Panes/ glazing - outer shell**: Maintenance activities are done, when there is the season and the location that give rise to those activities. The seasonal influence requires yearly maintenance (predominantly in winter). If there is no seasonal influence, a time interval of **2 years** should be appropriate as the constant influence of the weather conditions and waves on the outer shell will have an impact on this core system at some time, which might be prevented with a medium amount of maintenance. A possible proactive measure is the usage of breakwaters, wind protection or lightning rods. If those do not help or are not applicable, reactive measures are needed. Proactive measures should also relate to preventive measures regarding corrosion, as there is the constant influence of water, because of the offshore location.
Low (Time interval of **3** to **5 years**)	**Air conditioning/ ventilation**: Because of the low costs that are expected from the damage, if risks occur, reactive measures are cheaper than too frequent maintenance activities. That is why a general maintenance every **3 years** is justified. **Helicopter deck**: As both risk elements have a low value, maintenance activities every **5 years** should be appropriate.

4 Conclusion and outlook

If there is one main conclusion that can be drawn from all the research on risk management and risk assessment, it is the fact, that every risk assessment heavily depends on the situation and scope, the assessment is facing. If risks are more related to technical aspects, the consideration of standards and norms becomes more relevant as they are often related to the health of human beings, therefore there has to be a standardized approach to assure every risk is identified and analyzed to the needed extent. Practical experience has shown that business aspects of risks are derived by the consideration of costs. It can be derived, that the occurrence of a risk results in some form of cost, e.g. for physical risks in form of repairing costs or for temporal risks in form of costs resulting from the delay. If those can be identified for every risk, there is a foundation for a quantitative comparison of the risks in later steps, which allows for a more detailed approach for the overall assessment. It has to be decided in the beginning, if there is a need for the quantification. This depends on the purpose for which the assessment serves. Is it just for an overview of the risk situation? Is it about the level of each risk to prioritize them in terms of mitigation and general treatment? Or is it about a value that will be used in further calculations, for example the project's budget planning? It also depends on the resources available for the risk assessment, like time, knowledge and personnel, as they affect the whole process respectively define the extent of detail. Based on all those factors, the whole process will be in a qualitative or quantitative manner or a mix of both.

As all these aspects show the dependency on the particularities of the project, those particularities should be kept in mind for all steps of the risk assessment. Approaches should not solely be based on assumptions of old similar projects, but emphasize the differences and therefore identify the risks that come from it, instead of only using already existing checklists. Nonetheless it is important to follow along the predefined steps of a proper assessment and their aspects included, to assure an accurate and correct approach for the handling of risks, as those have a crucial impact on the achievement of the project's or company's goals. For the specific case of the Space@Sea project and based on the approach that was defined for this report, those aspects have been explained in the "Recommended approach for…" chapters. The methodology in this report, which includes these chapters, allows an assessment of risks associated to the technologies used within the project and their business impact. Therefore it is overall possible to create links from risks of technologies to the business case. This framework being created and customized for the needs of the Space@Sea project is the final result of this report.

The definitions of the elements of risk were kept simple. For example, the consequence was simply defined as costs that occur, when damage is done. It was assumed that the manufacturing costs of each component damaged and their proportion to each other are representative for the consequence. In reality, there are far more factors to be considered for risks, especially temporal ones. For further research on this topic, it is recommended to take the temporal dimension into consideration, as such approaches were also identified in this report, when taking a look at the practical experience of another company. There are also approaches in science that include this aspect into the risk-matrix-method that was explained in this report. This method is further developed to a so called "risk cube" that introduces a three-dimensional approach to the assessment. An illustration is taken from [12] and customized for this report.

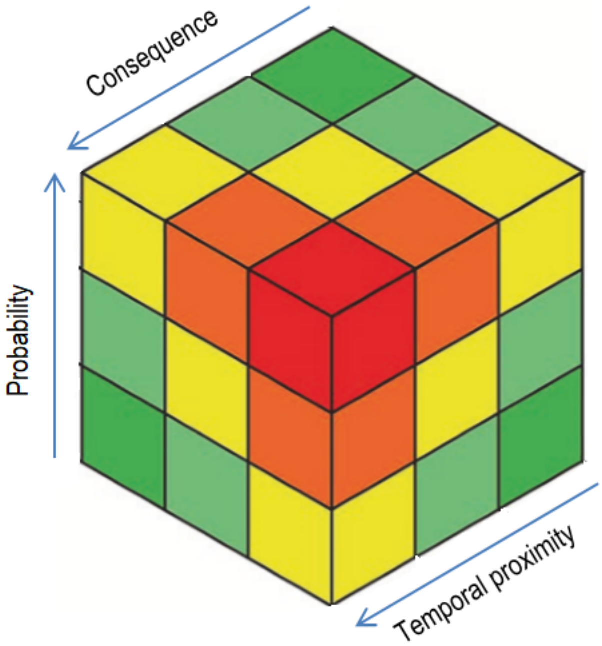

Figure 20: Risk cube (example)

This third dimension is not limited to temporal factors, but can also be defined as the human factor, as risks often occur due to the behavior of humans in regard to the technology being used. Also, besides the probability of occurrence as a main factor, there are many other factors that can be more emphasized on in the calculation of a risk value, for example the vulnerability of a technology, the exposure of a technology to a risk, the frequency of the risk occurring and if the risk of a technology can be mitigated or not.

Further research should consider these factors, as they all influence the risk to be expected. By this, a calculated risk value can be even more detailed and comparable as it portrays the reality more accurate. For now, the usage of the methodology in a case study showed that it is already difficult to assign the two chosen factors, probability and consequence, with quantitative values. Even the proposed simplified approach of using the manufacturing costs as the consequence was not fully applicable, because of missing resources. That is why the qualitative approach of the methodology is more practical to use, as it was possible to illustrate the risk situation of the technologies and core systems of the Working Packages with it, also from a business point of view with regard to saving maintenance costs versus saving repairing costs.

5 Bibliography

[1] Ganz, Christian: Risikoanalysen im internationalen Vergleich. http://elpub.bib.uni-wuppertal.de/edocs/dokumente/fbd/maschinenbau/publikationen/cganz/002/cganz002.pdf

[2] Meier, D.; Rietz, S.: Projektmanagement in der Windenergie, Springer Gabler, 2019; page 120-127.

[3] Dali, A.; Lajtha, C.: ISO 31000 Risk Management— "The Gold Standard", In: EDPACS the EDP audit, control and security newsletter, May 2012.

[4] Gjerdrum, D.; Peter, M.: The New International Standard on the Practice of Risk Management – A Comparison of ISO 31000:2009 and the COSO ERM Framework. In: Risk management, March 2011.

[5] International Standard Organization: Risk management - Guidelines (ISO 31000:2018), 2018.

[6] International Standard Organization: Safety of machinery - General principles for design - Risk assessment and risk reduction (ISO 12100:2010); German version EN ISO 12100:2010, 2011.

[7] Hofmann, M.: Risikomanagement für Offshore-Windparkprojekte. Thomas Martin Verlagsgesellschaft, 2009; page 38-44.

[8] Ganz, Christian: Die Risikoanalyse mittels Konsequenz und Eintrittswahrscheinlichkeit – Methodik am Beispiel des Druckbehälterversagens im Erdgasfahrzeug. http://elpub.bib.uni-wuppertal.de/edocs/dokumente/fbd/maschinenbau/publikationen/cganz/001/cganz001.pdf

[9] Franks, A.; Whitehead, R.; Crossthwaite, P.; Smail, L.: Application of QRA in operational safety issues. Crown copyright, 2002.

[10] Queensland Government: Analyse and evaluate the impact of risks. https://www.business.qld.gov.au/running-business/protecting-business/risk-management/preparing-plan/analyse

[11] Böttcher, J.: Handbuch Offshore – Windenergie. Oldenbourg Wissenschaftsverlag, 2013; page 217-224, page 455-463.

[12] Brauweiler, H.: Risikomanagement in Unternehmen. Springer Gabler, 2019.

[13] International Standard Organization: Safety of machinery - Safety-related parts of control systems - Part 1: General principles for design (ISO 13849-1:2015); German version EN ISO 13849-1:2015, 2016.

[14] Wietschel, M.; Ullrich, S.; Markewitz, P.; Schulte, F.; Genoese, F.: Energietechnologien der Zukunft. Springer Vieweg, 2015; page 103-106, page 123.

[15] Marquez, A.; Venturino, P.; Otegui, J.: Common root causes in recent failures of cranes. In: Engineering Failure Analysis 39 (2014) 55–64, 2014.

[16] Park, S.; Yang, B.: An implementation of risk-based inspection for elevator maintenance. In: Journal of Mechanical Science and Technology 24 (12) (2010) 2367~2376, 2010.

[17] Köster, S.; Westhof, L.; Keller, L.: Stand der Technik der Abwasserreinigung an Bord von Kreuzfahrtschiffen. In: KA Korrespondenz Abwasser, Abfall 5/2016, 2016. https://www.gwf-wasser.de/fileadmin/GWF/01_fb_Koester.pdf

[18] Berberich, J.: Optimierung einer mittelgroßen Windenergieanlage im Hinblick auf Stromgestehungskosten, 2018.

6 Annex

Table 15: Risk table of the wind turbine

Assembly	**Component**	**Hazard**	**Source**	**Risk#**	**Probability of occurrence in 25 years per wind turbine**	**Costs due to…**	**Comments**
Rotor nacelle assembly	Blades	Blade separation	Lightning strike, bird strike	1	100%	Downtime, repair with industrial climbers	Repairable damage at blades; no lost of blades
	Blades and wind turbine	Ice accretion	Freezing rain, freezing spray	2	25%	Downtime	Occurrence depends on the location (Mediterranean Sea 0%; North Sea every year)
	Rotor nacelle Interface	Broken or loose bolts	Poor quality bolts, Overload	3	1%	Demolition, rebuilding	Total loss
	Generator and blades	Operating noise	Damaged generator parts, cracks in the blade tip	4	20%	Repair	Costs are difficult to estimate: 1 to 10 days for personnel; costs of material range from the replacement of a bolt to the replacement of the generator
	Azimuth drive	Potential leakage	Damaged housing of the drive, leaking drain plug	5	20%	Downtime, repair	1-2 days for personnel
	Rotor hub	Cracks	-	6	15%	-	If the rotor hub breaks, there may be damages up to total loss of the wind turbine

	Rotor and generator	Downtime due to excessive vibration	Unbalanced blades, broken windings	7	10%	Downtime, repair	Fall to the ground unlikely, wind turbine shutdown probable
	Main bearing	Backlash on the blades	Broken main bearing	8	1%	Downtime, repair	Fall to the ground unlikely, wind turbine shutdown probable
Control and protection system	Rotor lock brake	Overspeed	Inaccurate information from the meteorological unit	9	1%	Downtime, repair	Unlikely scenario
	Emergency brake	Overspeed	Inaccurate information from the meteorological unit	10	10%	Downtime, repair	Overheated brake because of brake pad wear or setting error or control error
Azimuth system and machine frame	Machine Frame	Fatigue cracks	Excessive local stress concentration	11	2%	Downtime, repair	Re-welding
	Azimuth bearing	Damaged rollers	Increased bearing friction	12	2%	Downtime, repair	Repair is expensive because of taking down the rotor and nacelle
	Azimuth brake disk	-	Ice on disk, disk interface rough due to sand or other environment	13	2%	Downtime, repair	Repair is expensive because of taking down the rotor and nacelle
	Azimuth brake	Hydraulic leakage		14	10%	Downtime, repair	A preloaded brake should be in place
Nacelle & support structure	Tower segment	Structural failure	Loss of stability due to buckling	15	0,5%	Demolition, rebuilding	Very unlikely
	Tower door	Door opening during operation	Mechanical failure of hinges	16	5%	Repair	

	Control cabinet	Breakdown of digital infrastructure	Insufficient skills of personnel	17	50%	Downtime, repair	Happens occasionally, low damage
Position keeping	Anchoring	Permanent change in seabed condition	Flow change	18	5%	None	Offset by a few meters, damage affects the nearest S@S-modules but not the wind turbine
	Anchor	Undesirable dynamic behavior	Degradation of material stiffness	19	5%	None	Offset by a few meters, damage affects the nearest S@S-modules but not the wind turbine
	Mooring lines	Loosening or rupture of mooring lines	-	20	1%	None	Offset by many meters, damage affects the nearest S@S-modules but not the wind turbine
Electrical system	Transformer	Voltage surges	Overvoltage	21	25%	Downtime, repair	Happens occasionally, low damage
	Transformer, switchgear	Leakage of transformer oil		22	20%	Downtime, repair	Low damage
	Converter	High load peak	Electrical overload and low insulation level	23	25%	Downtime, repair	Happens occasionally, low damage
	Medium-voltage switchgear	Technical failure	-	24	10%	Downtime, repair	Low damage
Structural integrity	Hub-rotor generator	Broken or loose bolts	-	26	10%	Depends on the damage: from Downtime/ Repair to Demolition/ rebuilding	Depends on the finding; during maintenance some lose or broken bolts are found occasionally, which will then be adjusted or replaced; but generally, the total loss of the wind

							turbine can occur because of broken bolts
	Rotor generator-main bearing	Broken or loose bolts	-	27	10%		
	Stator generator-main bearing	Broken or loose bolts	-	28	10%		
	Stator generator-machine house	Broken or loose bolts	-	29	20%		
	Rotor brake-stator generator	Broken or loose bolts	-	30	20%		
	Azimuth drive-machine house	Broken or loose bolts	-	31	10%		
	Machine house-azimuth bearing	Broken or loose bolts	-	32	10%		
	Tower top segment-tower bottom segment	Broken or loose bolts	-	33	20%		
	Tower bottom segment-foundation block	Broken or loose bolts	-	34	20%		

Table 16: Risk table of the photovoltaic system

Assembly	**Component**	**Hazard**	**Source**	**Risk#**	**Probability of occurrence in 25 years per PV-system**	**Costs due to…**	**Comments**
Structural connection between the platform and PV modules	Mounting system	Loss of components; undesirable dynamic behavior	Storm, swell, big breaking waves	1	5%	Downtime, repair, replacement of modules	Damage of 2-3 affected modules conceivable; everything else would be a design error
		Ice deposit on the mounting system	Inappropriate weather conditions	2	50%	Downtime	Occurrence depends on the location (Mediterranean Sea 0%; North Sea every year); ice may fall to the ground
Pv modules	Junction box	Short circuit	Entering salt water	3	10%	Failure, Repair	1-2 days for personnel
	Broken solar glass	Pieces of glass	Bird strike, big breaking waves	4	30%	Change of modules	1-2 days for personnel
	Ice or snow deposit on the modules	Slipping ice or snow pieces	Inappropriate weather conditions	5	20%	Downtime	Occurrence depends on the location
Cables/ cable connection	cable	Torn cables, damaged isolation	Insufficient skills of personnel, undesirable	6	5%	Failure, Repair	1-2 days for personnel

			dynamic behavior, storm (separate flying heavy sharp components)				
Inverter	-	Short circuit	Diffusing water, undesirable dynamic behavior, lightning strike	7	20%	Change of modules	1-2 days for personnel
Overvoltage protection	-	Malfunction while lightning strike, high voltages in the board grid	Lightning strike	8	20%	None	Fall to the ground unlikely, system shutdown probable