Towards a Low Emission Port: Development of a decision making tool for technologies for the reduction of the shore-related emission footprint of existing ports in respect to the stakeholders' values.

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Executive summary

Energy-related and environmental issues are getting more attention and are becoming more important over the years. Currently, they are considered as one of the greatest challenges worldwide. The widespread use of fossil fuels causes the increase of the harmful emissions which are associated with significant health and environmental issues. Ports are no exception to this problem as they are considered as major contributors. Although there are some measures available, the high majority of them focus only on technologies that can reduce the vessel emissions. The focus of this research study is on the development of a decision making tool for technologies that can be used for the reduction of the emission footprint of the ports' shore-operations. The decision making for such technologies is not an easy process. The large number of stakeholders, the environmental concerns as well as the fast changing business environment create a complicated decision making scheme. This scheme represents specific practical and theoretical issues. These issues consist the development criteria of the tool.

The practical issues describe both societal issues and problems that should be taken into account. They refer to the port's emission footprint reduction and the use of port and port area's energy or material waste in order to tackle the emission footprint issue. Apart from that, they refer also to issues related to the stakeholders' participation in the decision making. The involvement of all the stakeholders is important in order to make more responsible decisions. As the stakeholders may have conflicting values regarding the technology selection and operation, these possible value conflicts should be addressed. The last practical issue is the increase of the stakeholders' acceptance for the technology to be applied. The theoretical issues arise from the lack of literature information that solves specific issues. Firstly, there is no theoretical tool available that can address the possible value conflicts that are related to the technology choice. Moreover, there is a theoretical gap regarding the waste-use technologies that can reduce the emission footprint. Finally, there is no specific information that refer to how to choose the most appropriate technology based on the stakeholders' point of view by taking into account the port's complex and fast changing business environment.

For the development of the tool, a list of theories was used. These theories were developed in order to solve each of the aforementioned issues. More specifically, the building up of the tool is based on the combination of the following theories: Responsible Innovation, Low Emission Port strategies, Circular Economy, Stakeholder Analysis and Technology Impact Assessment. The developed decision making tool consists of a ten step-by-step approach that provides specific instructions and sub-tools for the assessment of the port's situation and the technologies until the final technology selection. Considering the diverse character of ports, their fast changing business environment as well as the innovations concerning the low emission technologies, this tool has no static data-input. It reacts with the business environment and provides with the best technology choice related to the values of the stakeholders at a specific moment of time. The ten steps are the following:

Step 1: Set specific vision based on the categories of the Low Emission Port Technologies

Step 2: Identification of all the relevant stakeholders

Step 3: Identification of their value objectives

Step 4: Use of AHP sub-tool to identify the importance of the values

Step 5: Creation of emission footprint inventory for the relevant to the vision emission sources

Step 6: Identification of the Low Emission Port Technologies that can be applied

Step 7: Satisficing

Step 8: Use of Pugh's matrix sub-tool in order to perform the Technology Impact Assessment

Step 9: Use of TOPSIS sub-tool for the final decision

Step 10: Emission footprint projection

The developed tool was applied as an illustration study to the port of Piraeus. This port was chosen due to its high economic importance on a European and international level and due to the fact that there is large room for improvement as far as its environmental performance is concerned. To facilitate the analysis, the data about the current situation of the port was first examined. Also, a detailed stakeholder analysis took place with 11 members of the stakeholders to participate in the survey. The application of the method led to some significant remarks. The overall remarks for the tool are based on both the author's remarks and the comments of four interviewees. As far as the author is concerned, the remarks refer to the overall process, to the usefulness and consistency of the data and to the responsible character of the tool. The interviewees replied to specific questions regarding their ideas about the usefulness of the tool, the advantages and disadvantages of its use as well as the fields of improvement.

The developed tool consists of a complicated process but the individual steps are simple to be executed and important in order to solve the practical issues. The final output as well as the intermediate output between the steps are also easy to be realized. It can cope well with both small and large number of technologies and values as decision criteria. The value-based approach that is used by the tool for the selection of the best compromise technology can minimize the value conflicts. The application of the tool proved that it is particularly efficient for gradually identifying the values and their importance as decision criteria. The idea of dynamic input of data provides the flexibility to possible changes which consists an important aspect for making responsible decisions. The main advantage of the tool is the quantification of the decision making process. It can provide a "common language" for understanding the current situation in terms of decision criteria importance and technology opportunities. This can save time from long duration meetings. On the other hand there are some issues identified. The main issues are related to the risk of biased input data for the Pugh's matrix (technology evaluation) as well as the fact that some stakeholders may be unwilling to reveal their values as decision criteria.

The decision making tool can be used by port authorities either as the main decision tool or as supplementary tool that provides port authorities with an indication. The tool can be applied to all the types of ports without restrictions such as the size or the economic activity. The main factors of successful application are the transparent participation of the stakeholders, the inclusion of all the stakeholders, the absence of biased input data and the selection of one of the specific categories of Low Emission Port Technologies to be examined. Finally, this research study concludes with remarks about the method of development and with suggestions about a number of interesting areas for future work; these areas are mainly associated with the limitations of the theories and tools that were used for the development process.

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“Δεν υπάρχει ούριος άνεμος αν δεν ξέρεις προς σε ποιο λιμάνι πλέεις”

- Σενέκας, Στωικός Φιλόσοφος

“If a man knows not to which port he sails, no wind is favorable”

— **Seneca**, Stoic Philosopher

Chapter 1: Introduction to the problem

This chapter consists an exploration of the existing situation in seaports related to the emissions' reduction. It is divided into three parts. In the first part is presented the main reasons that set as important the development of a decision making tool for technical solutions. These solutions can be applied for the reduction of the emission footprint of a port's shore-operations. Also, this part describes the practical issues that need to be addressed. The second part includes a brief analysis of the existing approaches that can be found in the literature today. Based on their shortcomings, it provides the theoretical issues. The results of this analysis together with the information found in the first part led to the formulation of the problem description and the research questions. The third part of the chapter describes the scientific approach that is used for this research study.

1.1 Introduction and motivation

Nowadays, there is a high concern regarding the climate change and the increase of the emissions. Due to the economic and population growth, the influence of the human factor on ecosystem has grown rapidly and that can be observed on the concentrations of CO_2, SO_x, NO_x and PM in the atmospheric air, which are measured at record values since the last 800,000 years. It is extremely likely that the effects of the climate change which can be noticed have as main source this anthropogenic pollution. (IPCC, 2014) According to the Climate Summit of United Nations, the humanity has to take urgent action to limit the consequences of the "dirty" growth on the environment. More than 70 Nations and 1,000 enterprises endorsed the development of mechanisms that would help towards the minimization of the problem of climate change. Furthermore, in this summit, a plan of action of more than $300 trillion was announced which shows that the global society aims to stimulate actions towards emission reduction. (United Nations, 2014)

In order to deal with the climate change problem, there are two main solutions that have been proposed, the mitigation and the adaptation. The mitigation action describes the excessively reduction of emissions and the adaptation action describes the effort to minimize the unfavourable effects by adapting to the climate changes. Nonetheless, the adaptation action cannot be considered as a sustainable solution. There is a negative loop on the application of such measures: the worst the effects of the climate change are becoming, the stricter adaptation action will be needed. (IPCC, 2014) For the case of this research study, the focus will be only on the mitigation actions.

One important factor that contributes negatively to the climate change and more specifically to the increase of emissions is the sea transport and the seaport sector. Both sectors are considered as pillars for the international economy. Even during the period of the global economic crisis, the international trade through waterways has increased in absolute numbers, leading to an increase of the cargo transportation and of the port activities. (World Ocean Review, 2016) Today, 80% of the world's raw, processed and manufactured materials are transported by the maritime sector. The marine sector is considered as a major contributor to the climate change as, since 1990, the emission of greenhouse gasses from vessels has increased by 85% and the emission of shipping activities of the global gross emission per year are at the levels of 3% (Jian Li, 2011) According to International Maritime Organization (IMO), as the environmental damage that is produced by the emissions of the ships and port activities rises significantly, there is a need for measures to be taken. (International Marine Organisation, 2009) A research study from OECD shows the importance to address the emission issues: by 2030 the premature deaths in port cities due to emissions from port activities, and more specifically from particle matter, are going to rise dramatically in case no actions are taken. Figure 1 represents this situation.

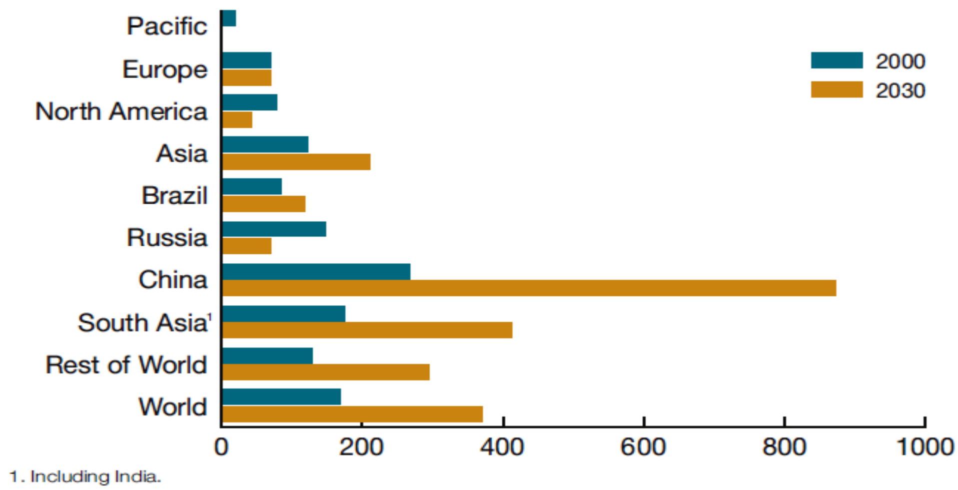

Figure 1 Pre-mature deaths caused by air pollution from port activities per million of capita (OECD, 2011)

The existing global transportation system should be further developed in order to meet this growing transportation demand. This development will also affect the ports. The ports can be characterized by the geographical concentration of high energy demand and supply activities due to their function as central hubs in the transportation of raw materials. Nowadays, busy ports have plans of expansion to accommodate the increased cargo demand and new ports will be developed for the same reason. (Meersman, 2009). As a result, the emissions from cargo-handling equipment, harbor craft and trains or heavy vehicles within or near the port are expected to rise (Vujicic, 2012). In addition, the higher energy consumption will lead to the increase of the overall emissions, as the production energy mix of the countries is still mostly based on fossil fuels. According to the World Bank, 66% of the total energy produced comes from the fossil fuels (TSP, 2016).

The emission mitigation actions at a port level focus on two different categories of measures, the vessel related measures and the port related measures. As far as the vessel related measures are concerned, until now, there are two different types of action plans that are applied in order to achieve emission reduction. The first action plan is the vessel based emission reduction measures. This plan includes the introduction of measures that are applied at vessel level such as the use of cleaner fuels, more sustainable processes and compliance with the marine emission limitations (MARPOL convention). (CNSS, 2016) The other vessel related action plan is the onshore power supply, where shore-side electric power is provided to the ships while they are docked in the port. (Kohli, 2014)

On the other hand, the port related measures regarding land activities vary and cannot be specified from the literature. For instance, the replacement of the diesel engines of the heavy trucks that are operating in the port by electric engines is such a measure. Or even the installation of an energy production technology that is based on sustainable sources such as photovoltaics or wind turbines. Although there are several theoretical approaches related to the reduction of the emissions at a port level such as the Green port or the Sustainable port, they do not focus only on this aspect. Low emission measures are usually part of a general and complex framework which includes usually a lot of information and it makes it difficult to focus only on such a crucial pollutant as the emissions are. This observation led Meersman to state the following regarding the sustainable ports: "although the research for sustainable ports has been going for some time, there is a considerable misunderstanding regarding the term "sustainable". This term appears to consist a difficult and complex concept as people may understand it in different ways". (Meersman, 2009)

The emission measures that mentioned above are divided into three main categories: the policy measures, the management measures and the technical measures. Examples of policy measures that can be used in order to tackle the emission issues are the introduction of incentives for terminal users to use technologies that reduce emissions or the introduction of emission standards in order to control the emission performance. Examples of management measures are the creation and update of a database regarding port's operations related emissions and their impact on air quality levels. Another example could be the organization of workshops with experts with topic related to the reduction of emissions. Finally, the last category of measures are the technical measures. Such an example is the introduction of renewable energy sources for electricity generation in the port area or the transformation of the fleet into (vehicles and vessels) into low emission and fuel efficient. (ESPO, About ESPO and EcoPorts, 2015) For the purpose of this research study, the focus will be on the technical solutions as they are relevant to the context of the MSc. Sustainable Energy Technology.

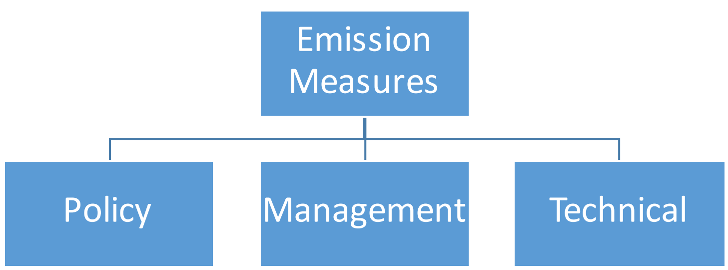

Figure 2 Categories of port emission measures

Another important aspect regarding the emissions is how they should be analysed. The following example can help to have an insight. The relocation of a petrochemical power plant from the port area may have a positive impact on the reduction of port's emission levels but the problem will be transferred to another area. This fact represents an unwilling situation. Therefore, it is important to focus on the emission footprint of the port activities and not only on the emissions. Another reason that enhances this opinion, is that the ports are usually close to port cities and industrial areas which means that the level of emissions that can be measured in the air is affected by factors that may have no relation to the port activities. (San Pedro Bay Ports, 2007)

The impact of the decisions concerning the introduction of technologies that reduce the emission footprint should be analyzed not only from a prospect of economic and environmental performance, but also in terms of stakeholder acceptance including the public. In the complex socio-economic environment of the ports, the implementation of emission reduction solutions interacts with the society and the other relative stakeholders such as the port users. This fact introduces new parameters to the problem that should be taken into account. These parameters can be expressed by taking into account the stakeholder values. Also, the diverging interests and goals that can be met among the stakeholders impose an additional challenge. The values of the stakeholders are important to be met in order to minimize the possibility of possible conflicts regarding the implementation of a chosen technology. The acceptance and dedication of the stakeholders is one of the most important parts of the technology implementation. (van den Hoven, 2013)

Finally, a topic with growing importance in ports is the minimization of the waste and in parallel, gain in terms of emission reduction. As energy is highly related to the emissions (energy mix), the energy waste leads to the increase of the overall emissions. According to the study that made for the ports in Baltic sea region, a large amount of emissions is produced by the fuel waste produced by cargo handling equipment, energy waste in the buildings and lights etc. (Hippinen I., 2014) Another source of waste is the material. There are a lot of materials that end up in the rubbish. However, these materials could be used in combined cycles (energy-heat) and thus, reduce the emissions that alternatively would have produced by fossil fuels. A characteristic example is the port of Rotterdam where 40% of the composition of the industrial material waste (port area) and 38% of the municipal residual waste (port city) are biomaterials that can be reused. (Rotterdam Partners, 2013)

To sum up, it can be concluded that there are many opportunities for improvement. To begin with, the reduction of the port's emission footprint consist a problem that needs to be addressed. Today there are already a lot of measures taken but their focus is mostly on vessels and not on shore-related port operations. Another important issue is associated with the decision making process. There is a literature gap related to the participation of all the stakeholders in the decision making process and a lack of a standardized approach to address their possible value conflicts. In addition, it is essential to explore ways to use technologies in order to reduce the waste and at the same time tackle the emission issues. All the above factors could be fulfilled by proposing an approach of selecting the most appropriate technology that takes into account all these issues. Finally, the existing port concepts should be studied in order to identify whether they tackle the above issues and whether they can provide any theoretical background for the structuring of the decision making approach.

1.2 Existing port concepts

At this subchapter, the exploration of the current port concepts takes place. Also, it is highlighted if and how they address the issues of the reduction of emissions in the port area as described above. The concepts of Sustainable Port, Green Port and Low Carbon Port consist the theoretical tools that can be found in the literature today and are applied in ports worldwide. With the exception of the Low Carbon port, the other concepts do not focus only on emissions but on all the forms of pollution such as water, ground etc. However, the focus of this analysis will be on the emissions.

1.2.1 Sustainable Port

The first and most known concept that can be found in the literature is the Sustainable Port. It describes the situation where port development is happening under the "sustainable development" guidelines. These guidelines are also known as "triple bottom line" and refer to the three parameters "people", "profit" and "planet". Profit is referred to the economic variables that deal with the flow of money. Such values are income, taxes, expenditures, business climate factors etc. People, is referred to the social variables of a community or region, such as access to social resources, health and well-being, quality of life, social capital, education etc. Finally, planet is referred to environmental variables that deal with current or potential influences to the environment and representation of measurements of natural resources. These variables help to analyze the impact that a project or policy would have on an area. (Slaper T., 2010)

The most developed concept found in the literature that follows the sustainable development guidelines is the "Ecoport". The Ecoport concept was developed by European Seaport Organization (ESPO). An Ecoport can be defined as the port that is part of the ESPO network that serves the "ports-helping-ports" in the field of port environmental management. These ports should follow the policy and guidelines that were presented by ESPO and give feedback to other ports and ESPO itself in order to be used as good practices. In order for a port to be characterized as Ecoport, it needs to have a broad ESPO membership and complete a Self-Diagnosis Method (SDM) checklist. In the end, port members will be certified with Ports Environmental Review System (PERS) and ISO 14001 (ESPO, About ESPO and EcoPorts, 2015). This information can be found in Appendix A.

The main principles that are conducted by European Port authorities and can be found in the core of Ecoport definition that express the whole initiative can be contained in five different categories. The first one has to do with the self-regulation which can raise the standards beyond existing regulations. The second category includes the cooperation in the sharing of knowledge between the ports involved. In addition, another category consists of the approach of serving both business and local communities' interests, the enabling of the approach of continuous improvement in the environmental management structure. Finally, the last category is the transparency to third parties in terms of the progress in environmental performance (ESPO, Green Guide, 2012). In respect to these main principles, the framework of five E's was produced, which represents the five pillars for guidance that EcoPort should follow in order to progress towards better environmental performance. The five pillars are the following:

- *Exemplifying*

Ports set a good example to the wider port community by demonstrating excellence in managing the environmental performance of their own operations.

- *Enabling*

Ports provide the infrastructural and operational conditions that facilitate port users and enhance improved environmental performance within the port area.

- *Encouraging*

Ports provide subsidies to the port users in order to improve their environmental performance and become more sensitive to the problems related to the environment.

- *Engaging*

Port authorities should engage with stakeholders and port users in sharing knowledge, means and skills towards joint projects with common goal the reduction of the environmental footprint of the operations.

- *Enforcing*

Ports develop and make use of mechanisms that enforce good environmental practice by port users where they can be applied and ensure compliance.

According to ESPO, the top three environmental priorities that port authorities need to focus are the air quality, the waste and the energy consumption (table in Appendix A). As mentioned in the first subchapter not only air quality but also waste and energy consumption are related to the emission footprint of a port. The aforementioned pillars (5 E's) are applied for the air quality, the waste and the energy consumption with a goal to provide guidelines in order to tackle these issues. This information can be found in Appendix A. The main result from the application of the 5 E's in port cases related to air quality, energy consumption and waste management is that the Ecoport's framework provides mostly general management and policy recommendations that are based on the good practises of the ports involved in the ESPO. There are no specific instructions related to the emission reduction technologies and how they should be chosen.

Except from the 5 E's framework, the Ecoport concept contain guidelines related to the social integration of the port. According to ESPO's report "Code of Practice on Societal Integration of Ports", the port should optimise the relations between the port and its surrounding societal environment and focus on the human factor on ports. Indeed, that is one of the P's (people) included in the sustainable development theory. The same report presents recommended practises related to the societal integration of the port which are analytically presented in appendix A. (ESPO, Code of Practise, 1994) Although the public acceptance is an important issue when it has to do with decisions related to the port activities and development, there is an example that the public opinion was not taken into account in the evaluation of energy efficiency technologies for the port of Gothenburg. The main criteria for the selection of the technologies for the port of Gothenburg (part of Ecoports network) were the CO_2 emissions reduction, the affordability, the payback time of the investment, the needed capacity and the barriers that current port organisation may exist for the implementation of the technology. It can be concluded that the criteria for the decision do not include other factors such as interests of the stakeholders and focus only on emission reduction of CO_2 and not to other which according to the first subchapter are considered important. (Hippinen I., 2014) Finally, Ecoport concept promotes the idea of continuous improvement with the establishment of the process "plan – do – check – act" in order to continue to improve through standardization. More information can be found in Appendix A.

1.2.2 Green Port

One of the most common approaches that is repeatedly found in the literature is the "Green Port". Tiedo Vellinga explains in his report that although it is a common concept, the description of what a Green Port is can be confusing (Vellinga T., A guidance for Port Authorities, 2013). In the same report, he also explains that there are studies that try to provide a single definition which can combine all separate measures that include climate change adaptation and mitigation measures. These studies say that Green Port development is based on "Green Growth" as a driver of its operational and commercial activities (Vellinga T., Green Ports - Fiction, condition or foregone conclusion?, 2011). According to OECD, Green Growth's main target is to improve the resource management, bust productivity, use the economic activity with response to society over long term design and finally, use new innovative technologies to fulfil this purpose. It explains that it is important to be ready to abandon one approach if a better alternative is presented. Green Growth is expressed in different countries by different master plan (China, South Korea, Ireland, Rwanda etc.). (OECD, 2011)

PIANC, known also as World Association for Waterborne Transport Infrastructure, is an international organization founded in 1885. PIANC gives the definition of Green Port: "A Green Port is one in which the port authorities together with port users, proactively and responsibly develop and operate, based on an economic green growth strategy, on the working with nature philosophy and on stakeholder participation, starting from a long term vision on the area in which it is located and from its privileged position within the logistic chain, thus assuring development that anticipates on the needs of future generations, for their own benefit and the prosperity of the region that it serves." (Envicom Working Group 150, 2014) These four dimensions of the above definition are explained below:

- *Economic green growth*

It is important for the port development that the economic progress to be achieved by taking into account the environmental protection. Ports growth should be realized in harmony with the surroundings where space is limited and development is the desired result as an economic driver.

- *Working with nature philosophy*

Working with nature is a process which identifies and utilizes win-win solutions for both project proponents and environmental stakeholders. This process contains the establishment of the project needs and objective, understanding of the environment, potential engagement of stakeholders to identify win-win opportunities and finally preparations of final project proposals and designs.

- *Stakeholder's participation*

The aim of stakeholders' participation in the operational, construction and growth strategies is to gain knowledge about the values of the social environment. This could lead into a successful co-operation between the social environment and local society which, in that way can facilitate a more smooth port development process.

- *Long-term vision*

Long term vision is a way to relate the port development with increasing environmental concern regarding climate change. It emphasizes the importance to think about the future today. The long-term period can be determined by the project type or situation but it should not be more than twenty years.

There was not a lot of information that could be found in the literature regarding Green Port. Also, Green Port provides no specific guidelines related to the emission reduction measures and they are even less specified than Ecoport concept. It is a relatively new concept under development which explains the lack of information. Furthermore, one of the main things that should be reconsidered is the win-win opportunities which according to the concept, should be engaged among the stakeholders. It is difficult to be achieved as the environment of actors that participate in ports' activities is complex. The most developed Green Port that was found in the literature is the Port of Long Beach, California. (Port of Long Beach, 2016) The port authorities of the Port of Long Beach have developed their own plan (Clean Air Action Plan – CAAP) which they use since 2006 in order to improve the environmental performance. The main dimensions of this plan are the environmental responsibility, the fiscal responsibility and the social responsibility. However, there are no specific plans for the participation in the decision making of all the actors involved and still it can be concluded that this framework also give general guidelines. When examining also the implementation strategies of the CAAP, it is clear that it is referred mostly related to control measures and policy recommendations and does not give guidelines related to the technology implementation and how to decide on them. The only part of the report that is related to the technologies analyses what technologies were used and their results based on the monitoring process. (The port of Long Beach, 2006)

1.2.3 Low Carbon Port

One concept that is the least developed in comparison with the Sustainable port and Green port but is highly accepted by scientists in Asia and United Kingdom is the Low Carbon Port. There is an extended analysis of the Low Carbon port approach at the paper of Jian Li, Xaio Liu and Bao Jiang "An explanatory study on Low – Carbon ports development strategy in China". The origin of the Low Carbon port as an approach came out from the need of China to achieve a more environmental friendly economic development. It is based on the "low carbon economy" which describes an economic model that relies on low energy consumption and low pollution. (Li J., 2011)

The Chinese Academy of sciences translated the "low carbon economy" approach into three main objectives: the efficient use of energy, the development of clean strategies and the pursuit of "green" GDP. These objectives should be accompanied by technology innovation strategies, emission reduction measures, and fundamental institutional innovation (Chinese Academy of Sciences, 2009). Finally, the definition of low carbon port can be conducted by the above approaches in Jian Li 's paper: "Low carbon port can be interpreted as a new mode of development of ports through the increase of energy efficiency, large-scale utilisation of renewable energy and the application of carbon elimination technologies."

In the literature there were not a lot of information regarding the Low Carbon port. The main representatives are the ports of Qingdao and Cao Feidian. The main goal of these two ports is to reduce the use of fossil fuels in the port's main operations. Although the development of Low Carbon ports has presented some achievements, it is considered that it is still in its infancy. (Jian Li, 2011) Their low carbon development was based on specific general guidelines that should be followed and are presented below:

- *Promote and improve the low carbon consciousness*

The low carbon development should be enhanced by the contribution of the public towards a "low carbon revolution" by means that not only ports but also the government and other industries should be involved in this development.

- *Set standards of low carbon emission*

There is a high need of scientific and reasonable standards to be set for the achievement of low carbon port development, standards that will be derived with a reference to other ports and organisations standards.

- *Exploit clean energy, introduce low carbon technologies*

Another urgent need to be exploited is the introducing clean technologies to tackle the problems of high energy consumption and high pollution of port logistics and handling equipment. For example, onshore power supply for the ships, wind energy and electric vehicles use could contain a part of this solution.

- *Increase the support of policy and financial to the low carbon ports by government*

The total transformation towards a low carbon port cannot rely only on the efforts of Port authority but also on the support of government. It is needed a series of incentives and regulations to promote such a development.

Concerning the Low Carbon port concept, it can be concluded that is still in the development phase. Although the main focus is on the emissions and mostly on carbon emissions, there is no extensive framework on how to apply the guidelines. Moreover, another important parameter that is not included in the guidelines is related to the stakeholders and how their interests are taken into account. Finally, there are no specific information found in the literature related to waste solutions that can help the reduction of the emissions.

1.2.4 Shortcomings of the existing concepts

To begin with, it is important to be mentioned that the cases of Green port and Low Carbon port are still under development. Also, the guidelines that the three concepts provide are based on the good practises of the participating ports. Due to the diverse and complicated stakeholder environment of ports, there might be cases that the good practises that have been used at one port may not lead to the expected results at another port. Finally, the existing concepts are complicated and difficult to be understood according to the research studies of Meersman and Villenga (mentioned in the previous subchapter).

By examining in depth the guidelines of all the concepts, it can be concluded that the emissions' reduction consists a strategical goal. However, the guidelines provided are related mostly to policy and management recommendations and less on technical solutions. Moreover, they all lack of a specific decision making approach associated with the technologies that can reduce the emissions of the shore-related operations and are the best choice for implementation at a specific moment of time based on certain stakeholder conditions. Also, there are no guidelines in the existing concepts related to the waste use in order to tackle the emissions. The only reference of Ecoport 5 E's does not provide a clear plan and is not related to technologies.

The last issue refers to the stakeholder involvement and the resolution of their possible value conflicts. Again there is no cumulative framework that explains how the port authorities could solve such kind of conflicts. More specifically, the Ecoport concept provides with advice regarding the engagement and encouragement of the stakeholders to reduce the emissions but not on the ways of addressing the issues that may arise among them. In addition, the Green port concept explains the importance of minimizing the issues but mostly through win-win situations which cannot always be the case when a lot of stakeholders with different interests are involved. Finally, the Low Carbon port contains no information related to the stakeholders.

The main conclusion that can be drawn from the literature review is that there is a theoretical gap related to the ways of addressing the emission footprint of the shore-related operations of the port with the use of technical solutions. Moreover, the port authorities should take into account the interests and goals of the stakeholders when deciding on such solutions. It seems that there is a lack of theoretical background as the concepts are developed based on the general strategies of their relevant development theories (Ecoport on the sustainable development, Green port on the Green Growth etc) and on the general good practises that have been already developed and applied. Finally, there was nothing found in the existing concepts related to the use of waste in order to tackle the emissions.

1.3 Criteria for a new solution

By taking into account the results of the subchapters 1.1 and 1.2 it can be concluded that during the decision making process of a technology considering the stakeholders' values, the following practical and theoretical issues should be taken into account as requirements for a new solution.

Practical issues

- Port's emission footprint reduction
- Involvement of all the stakeholders in the decision making that can lead to a more responsible decision
- Addressing of possible value conflicts among the stakeholders related to technologies selection and operation
- Increasing of stakeholders' acceptance for the technology to be applied (including the public)
- Use of energy/material waste in order to tackle the emission footprint issue

Theoretical issues

- Due to ports' complex and fast changing business environment, the current situation should be taken into account and the flexibility to changes should be provided
- Lack of theoretical tool to address the stakeholders' value conflicts
- Lack of literature information related to the waste-use technologies that can reduce the emission footprint
- Lack of literature information regarding how to choose the most appropriate technology based on the stakeholders' point of view as a cumulative decision making approach that solves the practical issues

The theories that seem to address these issues are the Low Emission Development strategies (LEDs), the Responsible Innovation, the Stakeholders Analysis, the Technology Impact Assessment and the Circular Economy. The LEDs is a development theory proposed by OECD and applied in several countries that can provide the foundations for the development of the actions that governments should do in order to reduce the emission footprint. The Stakeholders Analysis and the Responsible Innovation can help on the addressing of the issues associated with the involvement of all the port actors and the addressing of their possible conflicts. The Technology Impact Assessment can provide important theoretical input for the decision making approach related to the technologies. Finally, the Circular Economy can provide the theoretical background regarding how to decide on technologies that can use waste in order to tackle the emission issue.

The aforementioned theories are very popular today in the circles of the Sustainable Energy Technology MSc. The Low Emission Development strategies is the only theory found in the literature that provides a framework related only to emissions. It is considered as a validated theoretical framework as it has been already used in several countries. The use of Responsible Innovation and Stakeholder Analysis theories can be explained by the high effort to minimize the risk of resistance of sustainable energy technologies so as the energy transition towards lower emission technological use can be enhanced. Finally, the Technology Impact Assessment can provide the theoretical background for the evaluation of the technologies concerning their technical and economic characteristics.

1.4 Problem description and research objectives

Based on the aforementioned information it can be concluded that the serious issues that are caused by the emissions of the ports' shore related activities call for action. The emission reduction can be achieved by the introduction of solutions which refer to policy, management and technical measures. For the purpose of this research study and based on the relevance with the MSc. Sustainable Energy Technology, the focus will be only on the shore-related technical measures of existing seaports. In order to deal with the emission footprint issue, the port authorities should decide which of the technical measures are the most appropriate to be implemented. The technology to be selected should have the acceptance of all the stakeholders. Also, during the decision process, the practical and theoretical issues that presented above should be taken into account. Thus, it is important to design a decision making tool that can help port authorities to select the most appropriate technology that reduces the emission footprint of an existing port's shore-related activities.

Given the problem description, the research goals of this study can be expressed in the following points:

- Exploration of the above theoretical background that can help to address the issues mentioned
- Based on the theoretical background, development of the actions that port authorities should do in order to tackle the aforementioned issues
- Development of a brief planning cycle for technologies. This planning cycle will be based on the information found in the literature. The parts of the planning cycle that are related to the decision making will be used as the main framework for the development of the decision making tool
- Development of a step-by-step decision making tool as an approach for the selection of the most appropriate low emission port technologies that can be applied in shore-related port operations
- Application of the tool into Piraeus port in order to extract useful remarks

There are also other significant targets which are mainly associated with the theoretical background information. It should be explored which technologies can be considered as low emission port technologies, how they can be categorized and what important information should be known in order to provide help to the Technology Impact Assessment process. Another relevant target is to propose effective tools for the data acquisition and processing as part of the decision making tool.

The port of Piraeus is selected for the application of the tool for the following reasons. To begin with, it consists a fast growing port with high economic importance on a European and international level. It is considered as one of the main ports that is used for the network of the new silk-road which connects the Chinese market with the European one. In addition, as far as its environmental performance is concerned, there is large room for improvement. (PPA, 2016)

1.5 Research Questions

In order to achieve the aforementioned goals, specific research steps will be followed. These steps can be expressed by the main research question and the affiliated sub-questions.

<u>Main research question</u>

- ✓ *How can port authorities take informed and stakeholder-based decisions on technologies aimed at reducing the emission footprint of the shore-related port operations?*

In order to be able to answer the main research the following sub-question are formulated:

Sub – questions

- *Which stakeholders are involved in port decisions on technologies and what are their values?*
- *How can a planning cycle for technologies address these issues? What would such a planning cycle look like?*
- *How can we select the most appropriate low emission port technology that can be applied in shore-related port operations? Can we develop a tool to assist the decision-making? What would that tool like?*
- *Is an application of the developed tool to the Piraeus port possible and what do we learn from it?*

1.6 Scientific approach

The goal of this research study is to propose a decision making tool that can help the port authorities to select the most suitable technology that can contribute in the minimization of the emission footprint of the ports' shore-related activities. The development criteria for the tool are the practical and theoretical issues. In order to address these issues, the information from the following theories should be explored: Low Emission Development strategies, Responsible Innovation, Circular Economy, Stakeholder Analysis and Technology Impact Assessment. The explanation of the approach used in order to develop such a tool is divided into two main parts so it can be easily understood: the overall approach and the approach per phase.

1.6.1 Overall approach

This section describes the overall design of the research approach. As a lot of parameters should be taken into account, the main target of the method of development is to provide the simplest possible decision making tool. The development of the tool contains four different phases. During the first phase, all the important theories are explored. The second phase describes the development of the planning cycle. The planning cycle consists an intermediate step between the theoretical exploration and the final development. It translates the theories into guidelines for port authorities and puts these guidelines in a sequence. These guidelines will be used as the framework for the building of the decision making tool. During the final phase, the main gaps identified in the developed framework will be filled. Finally, the last phase contains the application of the tool in Piraeus port in order to conclude in useful remarks.

1.6.2 Approach per phase

Theoretical exploration

The theoretical exploration contains the extended analysis of the following theories: Responsible Innovation, Low Emission Development strategies, Circular Economy, Stakeholder Involvement and Technology Impact Assessment. Based on the content, the analysis is divided in two main categories. The theoretical information regarding the substantive and the process matters. Some theories participate in both categories.

- Substantive matters

The information that is provided by the theories related to substantive matters helps the understanding of what should be taken into account by the port authorities for the decision making. It provides the picture of what general facts are important to be considered. The theories involved are the Responsible Innovation, the Low Emission Development strategies and the Circular Economy.

- Process matters

The theories related to process matters describe ways in order to achieve these facts. The theories involved are the Responsible Innovation (values methodological framework), the Low Emission Development strategies, the Stakeholder Analysis and the Technology Impact Assessment.

With an exception of the Technology Impact Assessment and the Stakeholder Involvement theories, the rest of the theories do not contain information regarding the technologies and they do not focus at port-level. Thus, they are deeper explored in the next phase.

<u>Planning cycle</u>

The planning cycle consists the combination of the results of the theoretical exploration and the presentation of them in a structured way. Based on the information found in the previous phase, the development of the planning cycle is divided into two main steps. The first step refers to the identification of the actions for the port authorities coming from the theory of substantive matters. It explains what port authorities should do. The second step involves the combination of the theories presented in the process matters category based on the actions. It explains how the actions can be achieved.

- Actions for port authorities

For this step, the relevant theories of Responsible Innovation, Low Emission Development strategies and Circular Economy are used. The identification of the actions is based on the combination of the above theories. The theories describe guidelines with focus on the regional or national level. Thus, they are “downscaled” at port-level with focus on technologies. For this procedure, the port information found in literature is taken into account. A table of the main actions as well as their elements is produced.

- Planning cycle development

The strategy for the development of the planning cycle is inspired by the software development theory and more specifically on the strategy that is related to the development of algorithms. The strategy divides the design into two main development stages, the high-level design and the low-level design. The high-level design (also known as architectural design) provides the overview of the entire system (plan) by identifying its main stages. The low-level design (also known as detailed design) analyses each stage in detail. (Bell D., 1997) There are similarities between the algorithms’ development and the planning cycle development as both contain main stages that are further analyzed. For the planning cycle, not only the theories of process matters (Responsible Innovation, Low Emission Development strategies, Stakeholder Analysis and Technology Impact Assessment) but also the actions for port authorities are used.

The planning cycle describes both the guidelines regarding the decision making and the guidelines that refer to the implementation of the technology and evaluation of its performance. It can be considered as a total project cycle. The main result of the planning cycle phase is an extended framework (stages and specific steps to be followed) that can be used as the basis for the development of the decision making tool.

- High level design

The high level design defines the main stages of the planning cycle as well as their sequence. For this procedure, the planning cycle of the Low Emission Development strategies is used as inspiration. The reason behind this choice is that it is the only theoretical tool that focuses on steps and the sequence of the actions that should be followed in order to gain emission reduction. The goal of the high level design is to substitute the steps of the LEDs planning cycle with the actions identified. The steps of this cycle are related to policy measures. A modification is performed in order to substitute these steps with the actions which are related to technologies. The simplest way to design this modification is by comparing the content of the characteristics with the content of the actions. The basis of this comparison is the relevance of the content of one action with one of the steps of LEDs. If there is a relevance that can be found, then the characteristic is substituted by the action which forms the new stage. In other case, the content of the action is examined individually. It is examined how it is reasonable to spread its content among the stages that have been already identified. This process is based on reasoning as there is no relevant tool found in the literature. It ensures that the result is as close as possible to the original cycle (LEDs) which is a validated and has been already used in several cases.

- Low level design

The step of low level design contains the detailed analysis of the stages identified in the high level design and the exploration of the steps that should be followed for each one of these stages. The detailing of the high level design refers to the classification of all the information retrieved during the theoretical exploration into detailed steps that port authorities should follow. The low level design is performed on the basis of a combination. The combination includes the content of the actions for port authorities with the relevant process matters theories. Specifically, these theories are the Stakeholder Analysis, the Responsible Innovation (values) and the Technology Impact Assessment. The information of each of these theories is assigned to a specific stage of the high level design. This assignment is based on the content of the theory related to the content of the stage. For instance, the information from the Stakeholder Analysis theory should be assigned to the relevant stage that refers to the stakeholders. The stage should have a clear start and finish and should deliver an output that can be used as an input to the following stage.

The following table represents which theoretical information is used in the high level and low level design process.

Theory	High-level design	Low-level design
Actions for port authorities	✓	✓
LEDs – planning cycle	✓	
Stakeholder Analysis		✓
Responsible Innovation - Values		✓
Technology Impact Assessment		✓

Table 1 Contribution of the theory to the development of the planning cycle for the technology choice and implementation

Development of the decision making tool

This phase explains the final development of the decision making tool. The main criterion that is used as a building block for the tool is the framework developed in the previous phase. Although the aforementioned framework provides detailed guidelines, it does not include instructions on how to put these guidelines into practise. There is a lack of information regarding which technologies should be explored and evaluated. Also, the framework does not specify the ways of dealing with values as well as the tools that can be used for the processing of the relevant data. Thus, the exploration of the low emission port technologies takes part in this phase. Also, the methods of optimal design and non-optimal design that deal with values are analysed. The analysis of these methods consists the background for the selection of the tools that are going to be used for data processing. The adjustment of the new information on the developed framework is performed on the basis of the following idea: the output of the previous step should be input for the next step. Also, each of the methods / tools should be assigned to the relevant stage. For instance, the tool to be used for the extracting data from the stakeholders should be assigned to the relevant with the stakeholders' stage. The following figure represents the situation.

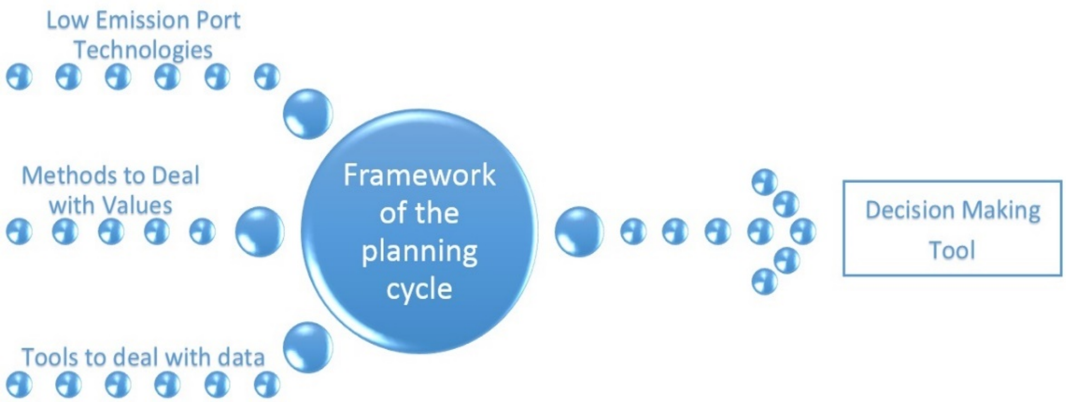

Figure 3 Explanation of the development of the decision making tool

<u>Application of the tool to Piraeus port and remarks</u>

The last phase of the approach is the application of the decision making tool to Piraeus port as an illustration study. The application of the developed tool was made with the support of participants as representatives of the stakeholders. The criteria used for the selection of these participants are related to their involvement in the decision making process concerning the port of Piraeus regarding the technology choice or their current level of knowledge regarding the strategic plans. In order to collect the data, three different questionnaires were used. The first two questionnaires refer to the identification of the values as well as their importance. The first questionnaire is used for the identification of the values that are important for each of the stakeholders when taking decisions regarding technology choice. The second questionnaire uses the data input from the first questionnaire in order to assign a weight (importance) to each of the values identified. The development of the second questionnaire was made according to the AHP tool which is selected as a tool that can deal with data. Each of the representatives replied to both these questionnaires. The third questionnaire was used for the comparison of the technologies. One expert that is chosen based on his knowledge on the technologies and its involvement in the port of Piraeus. For the comparison, qualitative data about the technologies were provided. In fact, this third questionnaire is the Pugh's matrix, a tool to perform comparisons based on specific criteria. The results of this comparison consist the input of the TOPSIS tool which provides with the final result. The remarks of the application came as a result of both the interpretation of the author as a reaction to the theoretical information and the comments of four of the participants in the survey. The information about the participants, the questionnaires as well as the results can be found in chapter 6 and Appendix E.

1.6.3 Scheme

The following figure represents the phases and steps of the overall research approach.

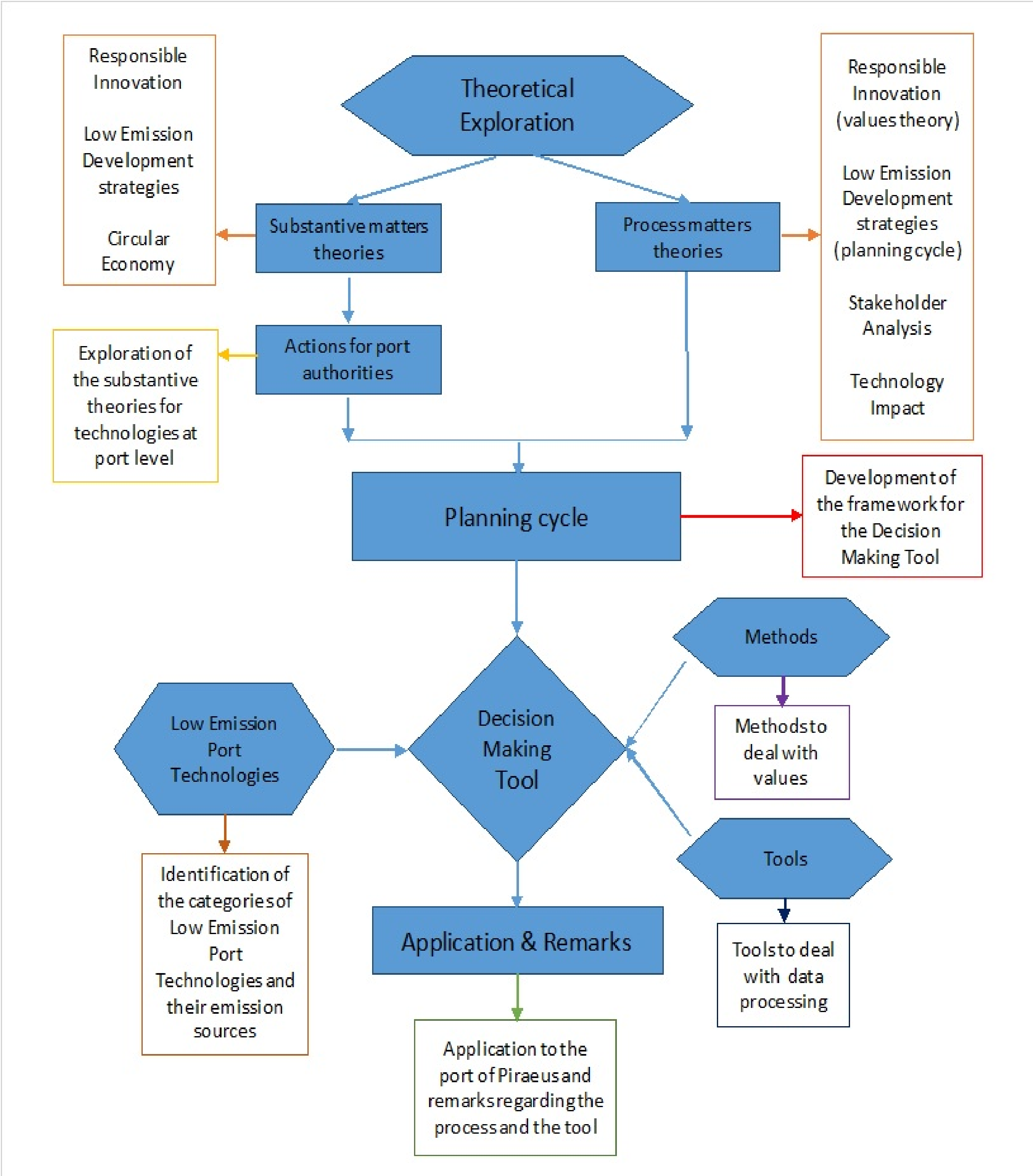

Figure 4 Scientific approach

Chapter 2: Theoretical exploration

The second chapter contains the theory that can contribute in the development of the actions that port authorities should do in order to solve the practical and theoretical issues. The theories explored are: the Responsible Innovation, the Circular Economy, the Low Emission Development strategies, the Stakeholder Analysis and the Technology Impact Assessment. The chapter is divided into two main parts. The first part includes the theory that is related to the substantive issues which can provide the general guidelines that can be followed by port authorities in order to tackle the issues identified. The second part of the theoretical exploration describes the process matters that can provide ways of achieving these guidelines. As Responsible Innovation and Low Emission Development strategies contain both substantive and process information, they are examined in both parts. In the last section of this chapter are presented the overall results.

2.1 Theories related to substantive issues

The first part of the chapter contains the theory that provides information regarding the substantive issues. This information can contribute in the realisation of the important parts that should be included as the main actions that port authorities should do in order to reduce the emission footprint. The theories analysed are the Responsible Innovation, the Circular Economy and the Low Emission Development strategies.

2.1.1 Responsible Innovation

There are scientific sources today that describe their concern regarding how technology and innovations are being used and how they should be used. Technology should not be only a mean to create economic resources but also mean to create social and environmental value. The engineering projects and mostly the technological artefacts included in these projects should not only have a materialistic approach and serve specific interests of the dominant values. The holistic approach of an engineering project is a necessity, as it should serve at the same time the economic and moral values and create space for new intellectual creation based on these values. Therefore, responsible innovation is an approach that tries to balance between the value conflicts, increase the auto-correction between the stakeholders and respect the public. (Stilgoe J., 2013)

Science and innovation, except from value and knowledge, produce also questions, dilemmas and unintended impacts which sometimes may be undesirable. The attempt to manage these undesirable innovation “externalities” led the academic community to explore methods and theoretical approaches in order to understand better the reasons that produce these factors and ways of predicting their impacts. Responsible Innovation or, as it is also known in literature, Responsible Research and Innovation is a concept that consists of already used methods with focus on technological development with an ethical perspective (van de Hoeven, 2013). In general, the concept of Responsible Innovation has emerged as a result of various concerns regarding the innovative products and the purposes of the innovation activity among civil sector, scientists, politicians and the public (Blasko, 2014). The importance of Responsible Research and Innovation has been recognized by European Commission and countries such as UK, Germany, France and Netherlands are participating in Horizon2020 programs (van den Hoven, 2013).

In order to understand better the idea of the concept, we should define what the meaning of the word “Responsible” is. By this word, it is meant that the values of some actors in the development or selection of a technological artefact should not be sacrificed in order to ensure that the values of other actors are completely satisfied. Consequently, in order to perform the most acceptable technological choice, both meeting the criteria set and making trade-offs are necessary (Owen R., 2013). Also, responsibility, as an important aspect of research and innovation, is greatly affected by the dynamic environment, such as change of interests of the actors, location and time (Stilgoe J., 2013).

The definition of Responsible Innovation concept consists a debate since there is no widely accepted definition. Von Schomberg gives a generally accepted definition which reflects a vision where science and society are mutual responsive to each other with an upper goal of social acceptability, sustainability and social desirability of the technological innovation. More specifically: “Responsible Research and Innovation is a transparent, interactive process by which societal actors and innovators become mutually responsive to each other with a view on the ethical acceptability, sustainability and societal desirability of the innovation process and its marketable products in order to achieve the objective of embedding scientific and technological advances in our society” (von Schomberg, 2011)

According to the aforementioned definition, the main goal is to achieve the highest possible degree of social acceptance and at the same time ensuring sustainability to a project. That could be possible only when the stakeholders’ interests (social, technological and governmental actors) have better alignment between the fundamental values and the actual outcomes. Therefore, stakeholders’ analysis and involvement is one of the principal characteristics of the Responsible Innovation concept, for achieving the integration of ethical reasoning and moral values in research and projects and enhancing in parallel the collaboration between the actors (Owen R., 2013).

In addition, a factor that affects this integration is the dynamic environment of a complex social and technical interaction which affects the unpredictability of the innovations’ impacts. Therefore, the continuous assessment of technologies and evaluation of the current situation of stakeholders’ interaction should be done at every stage in order to fulfil the scope of Responsible Innovation (Stilgoe J., 2013). In order to minimize the negative effect of the externalities, it is important that the Responsible Innovation concept is applied in the beginning of the planning of a project, with special attention to the stakeholders’ values. By taking into account both of these factors, the risk of resistance and possible barriers can be minimized. It is a fact that promising technological projects failed to achieve social acceptance which was their reason of failure (Stilgoe J., 2013).

A very enlightening example is the case of the port development of the town Shatian in China. The port area of the town was included in a national program to stimulate port development. It attracted companies occupied in the fields of marine industry, manufacturing and tourism. The local government sold to them land and marine areas. However, despite the initial plans, the development was not successful as the planning did not take into account the local fishermen that they were not allowed to live off finishing anymore as they did for many generations. These villagers were relocated in an area that the marine resources were scarcer. As a results, they tried to prevent the business activities of the new industries. This situation led to violent incidents (Ravesteijn W., 2014). Some examples that also create a lot of debate regarding their public acceptance are nuclear technology, geo-engineering, genetically modified organisms etc.

The above example enhances the importance of stakeholders' values analysis in the beginning of the planning phase and the identification of possible value conflicts. The value conflicts represent a situation where two or more values evaluate different options as best when considered in isolation. (van de Poel I., Values in engineering design, 2009). For instance, a project plan that is economically preferable may be undesirable from an environmental or societal point of view. If those value conflicts were identified in the beginning for the case of Shatian, the unwilling situation may be obviated.

One theoretical framework that can help to have a more structured insight of the Responsible Innovation theory is the Stilgoe's four dimensions (Stilgoe J., 2013): the Anticipation, the Reflexivity, the Inclusion and the Responsiveness. Anticipation is associated with the fact that negative impacts of new technologies cannot always be predicted. Therefore, possible effects that may arise from a technology should be analysed and described. These intended or unintended effects can be of economic, social or environmental nature.

Reflexivity, refers to the regular evaluation of the technology to be applied, in other words the self-assessment of this technology which is necessary to achieve the desired results. Towards the road of responsibility, reflexivity on the part of actors and institutions involved is important as they should assess their activities, commitments and assumptions by always taking into account the available knowledge and considering carefully the universal validity of any chosen approach to deal with issues.

The third dimension of the Stilgoe's framework is inclusion. Inclusion can be described as the process of deliberating through dialogue, engagement, and debate the visions, purposes, questions and dilemmas in order to increase the degree of legitimacy and stimulate the stakeholder engagement including the public. It is considered as the initial attempt to explore the wider perspectives from public and diverse stakeholders that allows to reframe issues.

The fourth and final dimension I the responsiveness. Responsiveness is associated with the dimension of reflexivity. When circumstances, interests and values of the stakeholders involved change, Responsible Innovation should provide the capacity of adjusting the course of action and new knowledge to the new situation. In order to achieve this, the participation and anticipation mechanisms are important. (Stilgoe J., 2013)

2.1.2 Circular Economy

Another important aspect that should be considered for the actions of port authorities is the Circular Economy (CE). Circular Economy is attracting a lot of attention as a way to overcome the existing linear models of production and consumption based on continuous growth. The main goal of this economic model is to increase the efficiency of the resource use by achieving a balance between economy, environment and society. This may occur by promoting the adoption of closing the loop production patterns, where the input resource consists of waste produced by the economic activity. (Ghisellini P., 2014)

Before getting deeper into the circular economy, it is important to distinguish between circular and linear economy. Both models are considered as models of production and consumption. The linear economy is an economic model that ignores the environmental externalities linked to the extraction of a virgin resource and the generation of waste and pollution. On the other hand, as mentioned above, the circular economy is based on production and consumption of goods through closed loop material flows, that internalize environmental externalities linked to extraction and generation of waste. In such a case, the economy takes place in a loop (Sauve S., 2015). Both models are presented graphically in the figure 5.

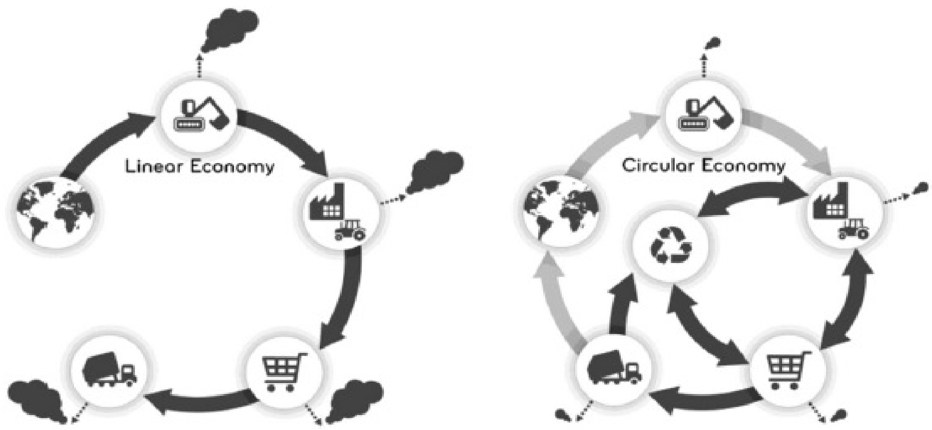

Figure 5 Linear and circular economy (Sauve S., 2015)

In the literature (Ghisellini P., 2014), the circular economy is described by three main “actions”. These actions are defined as 3 R’s and consist the basic principles of circular economy: reduction, reuse and recycle. The reduction principle’s aim is to minimize the input of primary energy, raw materials and waste through the improvement of efficiency in production and consumption processes such as introducing new technologies, more efficient appliances etc. The reuse principle represents the reuse of products and materials for the same purpose for which they were conceived. Finally, the recycle principle refers to a recovery operation during which waste materials are reprocessed into substances or materials that can be used for new products. The recycle process does not include energy recovery and the reprocessing of materials that are to be used as fuels (Ghisellini P., 2014).

But there are limitations and challenges in the application of these principles for the transition to circular economy (Ghisellini P., 2014). These challenges and limitations refer to factors such as design of more durable and efficient products, design for disassembly, reuse and recycle, new business models, development of take-back mechanisms and taxation on use of non-renewable energy. Furthermore, it is important to take into account factors such as the scarcity of rare materials, the ensuring of repair and secondary use of products after the first use, further transformations of food and plastic waste and the increase of renewables (Ghisellini P., 2014).

The aforementioned challenges are categorized by Luscuere in the table 2 by taking into account the ecological, economic and equity (social) terms (Luscuere P., 2015). The ecological challenges consist of the biodiversity, climate change and health effects. The economic challenges contain the scarcity of raw materials and natural resources. Finally, the social challenges are related to equity, with the issues of unfair distribution of resources and the dumping of toxic waste in countries with little regulations to be on the top of the dialogue. The resources are categorized into energy, water, materials and top soil.

Values / Re-cources	Ecology				Economy		Equity		
	Biodiversity	Health Effects	Climate Change	Scarcity	Cost / Benefits	PR Metaphor	Social Responsibility	Fairness	
Energy	SO_2, Acid rain	NOx, PM 2.5	CO_2	Fossil fuels	Pay Back Time ******* Life Cycle Analysis ******* Total Cost of Ownership ******* Life Cycle Costing ******* Hard & Soft Costs and Benefits	'Net Positive'	Energy Positive Buildings	'Supergrid'	Coal Powered Electricity ************ Child Labor *********** Resource Depletion ************* 'Externalising' Costs ************* Rampant Environmental Pollution
	Solar-, Wind-, Environmental-, Geothermal Energy and Highly Productive Biofuels (Algae)								
Water	Contaminated Water	Hormones & Medicines	Rising Sea Level	Fresh Water		'Clean'	Cleaner Discharge as Intake	Geo-Political Governance (lack of)	
	Local Cleaning (Reed filters), use of Algae, Nutrition Regeneration								
Materials	Waste *)	Hazardous Emissions	Chlorofluorocarbons	Virgin Materials		'Healthy'	Actively Cleaning Buildings	'Securing' Resources	
	Non-Toxic, -Carcinogenic or –Mutagenic Substances, From Down- to Re- and UpCycling								
Top Soil	Loss & Degradation	Contamination	CH_4 - Emissions	Phosphate		'Fertile'	Positive Contribution to Top Soil Production	Displacing Arable Land by BioFuels	
	Apply Green Roofs & Walls, Close Cycles, Recovery of Nutrients, Large Scale Eco-Rehabilitation Projects								
*) Toxic-, Carcinogenic-, Mutagenic, etc.			Environmental Challenges / Solutions / model v11, PG Luscuere , December 2015						

Table 2 Resources and values of Circular Economy (Luscuere P., 2015)

At the ecology part, every category of resource (energy, water, materials and top soil) is divided into two lists. The upper list contains the main issues that are referred to the resource and the lower list contains some solutions to tackle the issues mentioned. At the economy and equity part, the lists include the "strategic goal" of the circular economy and the final vertical list presents some issues regarding fairness that need to be tackled down.

2.1.3 Low Emission Development strategies

The term "Low Emission Development strategies" (LEDs) was first emerged under the United Nations Framework Convention on Climate change (UNFFCCC) in 2008 and it is used to describe national economic development plans or strategies that contain low emission economic growth. In the beginning there was a debate regarding Low Emission Development strategies' role in a future climate framework. But over the years a lot of countries have accepted the approach of LEDs with the most important recognition to be the acceptance of LEDS as indispensable part of sustainable development by the Copenhagen Accord (2010) (OECD I. , November 2010). Nowadays, LEDs consists one of the most popular programs running by U.S. Global Climate Change Initiative in collaboration with twenty countries around the world including Mexico, Peru, Indonesia, South Africa, Serbia etc. (EC-LEDS, 2016).

The main purpose of LEDs is the integration of the economic development with the climate change planning. The main factors that help defining the LEDs in order to answer critical questions regarding policymaking priorities, development plans and funding are the economic development priorities, the identification of the major emitters, the vulnerability to the impacts of climate change and the resources available for the preparation of the LEDs.

More analytically, LEDs can serve a range of purposes for government, public sector, the private sector and international community. The main purpose of the government is to set up the policy framework by taking into account the priorities, the barriers and carriers and the assessment of the current situation. The public sector should provide with information regarding considerations and possible conflicts of the development plan. The private sector's focus is on the identification of the priorities and communication with the actions of the government. Finally, the international community which consists of research institutions and universities provides the knowledge and the build-implementation capacity. The general purpose of the LED strategy is conducted by this range of purposes.

The report of OECD also describes the importance of the communication and co-ordination between the four different groups of stakeholders. This co-ordination should be enhanced across different ministries, stakeholders' groups and increase public awareness of climate change and policy. Except from the communication and co-ordination, other important aspects of realising the LEDs' purposes are the implementation costs and the identified actions. LEDs should indicate the total level of funding required and how much of this is available domestically. It is favorable for a LED strategy to prioritise programs and policies for implementation by considering principles of implementation costs.

Another aspect that must be taken into account is the timeframe of the designation of the actions and priorities. In order to build up a political consensus and help to achieve domestic funding, it is significant to agree on a long-term vision on the development plan of the LED strategies. Furthermore, the addition of clear mitigation and adaptation action will help to engage more the domestic stakeholders.

According to OECD, there is no single formula regarding Low Emissions Development strategies (LEDs) can be used for all the countries. However, by studying a lot of existing strategies related to the environmental protection and economic development such as National Climate Change Actions or National Development strategies, OECD concluded in the main objectives that are presented below. According to OECD, the application of these elements contribute to the revealing on the opportunities to achieve a more environmental friendly economic development with the reduction of the emissions. (OECD I. , November 2010)

LEDs' main objectives

- Vision:
  A vision can help by guiding the policy development decisions.
- Assessment of current situation:
  Evaluation of the current state of emissions and socio-economic indicators.
- Mitigation potential and costs:
  Mitigation potential and costs should help to identify the initial actions.
- Vulnerability assessment:
  Indications of how a country may be influenced by air pollution, could help towards the engagement of various stakeholders including general public.
- Priority programs and policies:
  Indication of priorities for mitigation and adaptation which can be combined with economic development strategy in order to identify synergies.
- Finance:
  Alignment of policies with budget and an indication of financing needs.
- Institutional arrangements:
  Explanation of which institutions are responsible for implementing actions and contribute to effective implementation.

The key areas that express the content of LED strategies and are driven by the general purpose of the development plan can be divided into four categories: the long term emissions pathway, the strategy to achieve this pathway, the potential environmental impacts and the description of the mitigation and associated actions. The first category of the long term emissions pathway is divided into two themes, "the national economic development and climate objectives" and the "Emissions levels and objectives". Table 3 describes the overview of the themes, main objectives, functions and time frames of the LEDs. These elements consist a deeper insight of the main objectives as presented above.

Theme	**Elements**	**Function**	**Time Frame**
National economic development and climate objectives	Vision	Goal of strategy	Mid- to Long-term
	Identification of priority programmes	Identify actions and policy priorities	Short- to Long-term
Emissions levels and objectives	Emissions inventory (national or sectoral)	Identify main sources of emissions	Historic and current
	Emission projections	Identify potential emission trajectory	Forward Looking
Mitigation actions	Emission reduction potential	Identify emission reduction potential	Short- to Mid-term
	Mitigation costs	Estimate potential costs of mitigation actions	Short-to Mid-term
Adaptation Actions	Vulnerability Assessment	Explain how country or sector could be affected by climate change	Mid- to Long-term
	Costs of adaptation actions	Estimate potential costs of adaptation actions	Short- to Mid-term
Finance and Technology	Technology & Institutions	Available Technology that can be used and Institutions that are responsible for implementing actions	Short- to Mid-term
	Financial	Identify how the costs of the actions could be financed	Current and forward looking

Table 3 Overview of objectives of LEDs (OECD I. , November 2010)

2.2 Theories related to process matters

This second part of the chapter contains the theoretical exploration concerning the process matters. The results of this exploration should provide an insight regarding how the actions for port authorities can be achieved and contribute in the development of the planning cycle as a framework for the decision making tool. The theories analysed below are the Low Emission Development strategies – the planning cycle, the Responsible Innovation – values methodological framework, the Stakeholder Analysis and the Technology Impact Assessment.

2.2.1 Low Emission Development strategies - the planning cycle

The Low Emission Development strategies report by OECD provide important guidelines concerning the preparation of coherent and co-ordinated strategies with a goal to improve the economic activity by reducing the emissions. This information is the planning cycle of LEDs, a project based cycle which is presented in figure 6. It is developed based on observation and experience from the application of LEDs in countries such as UK, Mexico, Thailand, Israel etc. It is divided into five steps, the formulating goals, the institutional framework, the prioritising policies, the implementation and the monitoring. The first step of formulating goals includes the assessment of the current situation of a country and alignment of the development with the climate policies. The second step includes the institutional arrangement regarding the clear roles and the co-ordination among the relevant stakeholders by taking into account their main expectations. The third step explains the final selection prioritisation of the national policies with the identification of the barriers and ways to address them by considering synergies and trade-offs. The fourth step is the implementation of the policy by identifying potential sources of financing in order to boost the implementation. The last step is monitoring the progress made towards the goals, with the knowledge acquired to be used as feedback for the evolving over time. (OECD I. , November 2010)

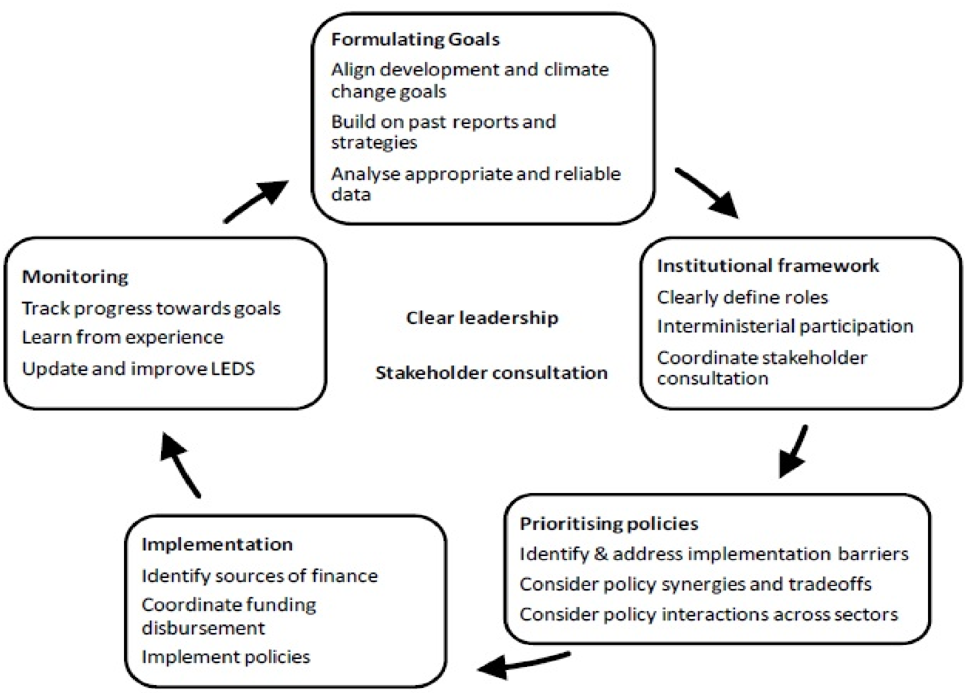

Figure 6 Planning cycle for low emission development strategies (OECD I. , November 2010)

2.2.2 Responsible Innovation – values methodological framework

One of the main aspects of this research study is the existence of multiple values involved in the port. These values will be used to set part of certain criteria in order to evaluate possible solutions and at the same time to help resolving possible value conflicts in a responsible way. Keeney on his "value-focused thinking" highlights the importance of values in the decision making problems, design process and in general, in technological artefacts. With the use of values, the risk of asset management decisions can be minimized. The value analysis provides important information as it determines the context of a company / organization / institution / society etc. (Keeney R., 1996). It is necessary that the values identified in the analysis to be structured using a hierarchy of values or objectives hierarchy, known also as values' tree. In this tree the lowest level includes the values that can be measurable and / or quantifiable (Key Performance Indicators). The upper level is the central value which is defined by the lower values (van der Lei,2012).

The value-based reasoning described above will be achieved by the integration of the values related to the port into the management and design phase for the successful decision making. Despite the diverge character of ports, which have significant differences in all levels and categories, some fundamental values are common for all the stakeholders. This can be explained by taking into account the globalization of port practises that affect at a certain degree the ambitions of the port-related actors. By digging deeper in ports' business environment in order to get a better understanding analysing their features and interests, it is clear that the main focus is on the economic, social and environmental issues. Apart from these values, also the safety and the accessibility should be considered as important. These values are met in analysis that refer to the port of Rotterdam, port of Los Angeles, port of Long Beach and port of Piraeus. (van den Hoven, 2013)

But in order to be able to understand better the complicated context of ports interests, ambitions and development plans, it is important to identify more values than the fundamental ones that are related to ports' operation. For instance, figure 7 explains the values tree of the Port of Rotterdam, which is concluded from an analysis based on Keeney's theory for "value-focused thinking". In this values' tree, it is presented the "technical values" of the port, as they are based mostly on the vision of how the port of Rotterdam can become a global hub and Europe's Industrial cluster (van der Lei TE).

As far as safety is concerned, it includes various aspects such as environmental, nautical and structural safety. Another aspect of the safety is considered the health risk of the people both inside and outside the port. The value of sustainability includes the "cleanness" of port's operation, the related transport activities and the activities of its clients (processes). The fundamental value accessibility describes the flow of goods in the port area where shipping, rail, roads and pipelines need to have sufficient capacity and be available as much as possible. Last but not least, another value is the reputation. Reputation describes the combination of aesthetics and a positive image among the actors involved. In addition, good reputation is linked with the recognition of the port as an entrepreneurial developer. Finally, the creation of societal value includes the broader goal of a port to create value for its clients, the surrounding region and the relevant stakeholders. (van der Lei TE) Other values that were identified in the literature are the economic growth, competitiveness, profitability, circularity, employment, social stability, livability and energy security. (Liagkouras A., 2015)

For the case of resolving value conflicts that arise, the decision makers usually try to compromise them by using the “common sense” reasoning (Liagkouras A., 2015). However, there is no “single” way to achieve these compromises but often is a process that is based on the decision maker’s experiences without relying on a theoretical method. Therefore, some established methods are available in the literature.

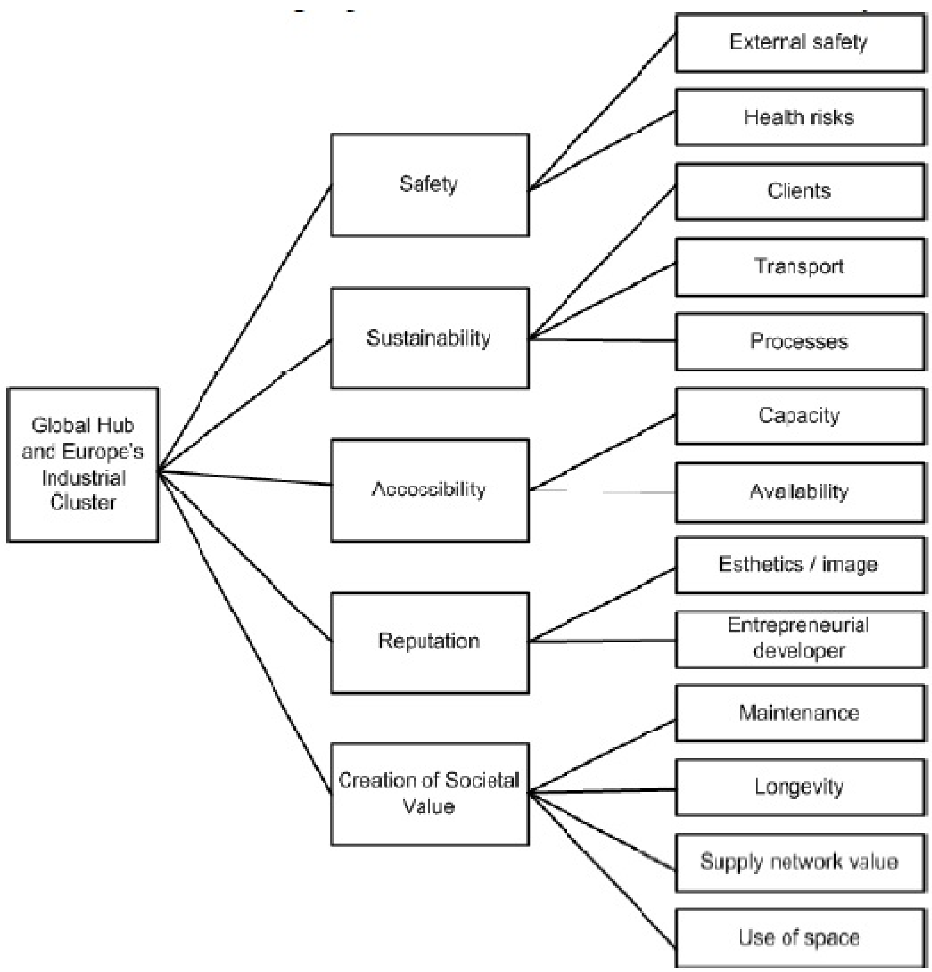

Figure 7 Values- tree of the port of Rotterdam (van der Lei TE)

The first and most known approach is the dominant value. The main characteristic of this approach is that the decision maker takes its decision between two or more values based on the determination of which value is the most important one. The second method is the trade-offs between values. In that case, the decision to be made includes the upside and downside of certain conflicting values in order to improve the value-based performance. The third method is the compensation scheme, where the decision maker provides compensation to the value that is not fulfilled by the decision. The fourth method is the win-win situation where the main goal is the achievement of cooperation between two or more actors in order to accommodate the disputants and improve their performances. The main assumption in that case is that the actors’ conflicting values are equally important (Roberts S., 2015). Finally, the last method is the Value Sensitive Design (VSD). VSD’s aim is to develop new technological artefacts that through them is possible to resolve the conflicting values (van de Poel I., Values in engineering design, 2009). A very nice example is the “not in my backyard” effect of wind turbines installation which is countered by the efforts of various companies to create a system with led screen and cameras that will make the wind turbine invisible by projecting the back view of the wind turbine on the front side and vice versa.

For the case of this research study, the method to be chosen should be in line with the Responsible Innovation theory. The dominant value approach supports the decision making that selects the most important value and does not take into account the rest of the values. Therefore, it is not a preferable method to use for this thesis as all the values should be included according to Responsible Innovation. The compensation scheme is another approach that selects the most important value but provides a compensation to the values that are negatively affected. In some cases such as the safety or environmental protection this would not be a responsible approach. The win-win situation is an optimized method to achieve cooperation and at the same time fulfil the values of the relevant actors. In case of ports with multiple actors and their multiple values is complicated to achieve win-win situations and needs a lot of effort. Maybe this method is appropriate for simplified cases but it cannot always fit to the decisions in more complicated problems. Another issue is the assumption that the actors involved are equally important, which is not true for a port. One more method that has been examined is the VSD method. Again VSD could be used in order to solve specific conflicts but it cannot fulfil more difficult decision making problems for the same reasons as the win-win case. Finally, the trade-offs method follows the ideas of responsible innovation by taking into account all the values identified and by making trade-offs that can enhance the collaboration between the different actors. (Liagkouras A., 2015)

One methodological framework that helps to deal with values is the “step-by-step” approach as it is described in the scientific paper “Responsible innovation and stakeholder management in infrastructures: The Nansha Port Railway project” by Wim Ravesteijn. This framework consists of a method where the value conflicts are revealed by contrasting the impacts with the stakeholder values. It will be used partly as an inspiration for the structuring of the decision making tool in order to achieve the broadest support base of the stakeholders and thus less implementation resistance of the technology. (Ravesteijn W., 2014)

The steps referred are the following:

- Step1: Identification of relevant stakeholders
- Step2: Identification of stakeholders’ goals, interests and values
- Step3: Impact Assessment in respect to economic, social and environmental impacts with regard to the stakeholders
- Step4: Identification of value conflicts and analysis
- Step5: Formation of a policy plan to deal with value conflicts
- Step6: Measures for successful implementation

2.2.3 Stakeholder analysis

Another important theoretical part is the stakeholder analysis. To begin with, it is important to define who is a stakeholder. As stakeholders can be defined the individuals or groups that are directly taking part in a project or can be affected by this project in a positive or negative way as a result of the project execution or completion (Babou S., 2008). In fact, the stakeholders are actors such as individuals / organisations or networks of individuals / organisations that have interest or can influence a project. For the purpose of this research study the stakeholders’ analysis is significant in the decision making of a technology. As explained in the first chapter, the chosen technology should have the general acceptance of the stakeholders so as they will not provide any resistance for its implementation.

There are three steps to be followed in order to perform the analysis. These steps describe the identification of the stakeholders, the analysis of their behaviour, the influence and their interaction and relations. Regarding the identification, the stakeholders can be divided into two different categories. The first one consists of the primary stakeholders which, as actors, directly participate in the decision making process. The second category includes the secondary stakeholders that are not directly involved in the decision making but are affected by the decisions. An example of such a case is the public or parties that their participation is necessary in order to achieve the goals of the project (Babou S., 2008). According to the scientific research of Naniopoulos, the main port-stakeholder categories are the following: the shareholders, the administration, the port users, the suppliers, the government organisations, the scientific institutions, the local authorities and the national regulators (Naniopoulos, 2012).

The next step of the stakeholder analysis is the identification of the possible behaviour of each of the stakeholders. The possible behaviour is highly affected by the values that each stakeholder has. Also, the importance of these values is significant when taking a decision. Thus, the process of identification of the behaviour contains the exploration of the values and the importance that these values have in the decision making for each one of the stakeholders. According to Mitchell, the importance of each one of the values should be explored as it can also provide an insight regarding the dedication of the stakeholders regarding the project. (Mitchell R. K., 1997) Another aspect that should be considered when analysing the involvement of the stakeholders in a project is the dedication. The dedicated stakeholders are eager to mobilize resources for meeting the targets of a project. On the other hand, the non-dedicated are not. Finally, although the influence, the interaction and the relation between the stakeholders consist also important factors, they will not be examined as it is out of the research scope and it would make the decision making process much more complicated. However, it is highly recommended to be examined as part of future work.

2.2.4 Technology Impact Assessment

The last theory related to process matters is the one that examines the impact assessment of the technical solutions that can contribute to the reduction of the environmental footprint in the port area. The impact assessment, as a method, predicts and estimates the likely impacts of a project and aims to reveal effects at a second level, apart from the easily observable direct ones. The impact assessment can be applied based on the use of two types of data. The quantitative or statistical data can measure the order of magnitude of an impact. The qualitative data are useful when the impacts cannot be easily measured such as social impacts (The Impact Assessment Research Center, 2015). This research study will examine both cases for the technical solutions that reduce the emission footprint in the port.

The quantitative data can be used as the criteria that can help the evaluation of the performance of the technical solutions. The performance refers to both the technical and economic characteristics of the technical solutions. According to the research of Azelvarde and the results of the Low Emission Development strategies (subchapter 2.1.3), the main performance criteria are the economic criteria, the mitigation potential data (regarding the emission footprint), the long term vision and the use of space. Also, in his research study he reveals the main factors that should be taken into account during the analysis of these performance criteria. (Azelvarde J., 2004)

Economic Criteria

The economic criteria are considered as the initial capital cost, the maintenance and operation cost (M&O) as well as the payback time. However, in the case of low-emission electricity production, the criterion of levelised cost of electricity (LCOE) should also be adjusted to the aforementioned economic criteria (Appendix B).

Mitigation Potential

The mitigation potential is considered as the environmental impact reduction potential that a technical solution provides. For the case of emissions as part of this research study, the mitigation potential is how much it reduces the emissions.

Long-term vision

The long-term vision is considered as the overall lifetime of the system to be implemented.

Use of space

The use of space can be considered as the area that is needed for the technology in order to be installed. However, there are differences in the scale of area that is needed by various technologies as some technologies can be applied in less space and others need more area. Therefore two criteria were identified in the literature, the minimum area needed for a small installation (applied to all the technical solutions) and energy generation per area which is applied mostly to renewable technologies (Moskovitz D., 1999)

Except from the quantitative data, also the qualitative data are important in order to assess a technology and have an overall view on the impacts it may produce when it will be implemented. As ports consist difficult and complex decision environments, these values should also be taken into account in order to ensure the maximum technology acceptance by the stakeholders. Therefore, a method should be proposed to retrieve data and the evaluation of all the alternatives that may present. This method is described in chapter 4 and it is part of the decision making tool.

2.3 Theoretical exploration's main results

The two following tables highlight the main information found in the theoretical exploration. The first table represents the substantive related information and the second the process related information.

Theories	What is it?	Main information
Responsible Innovation	Transparent & interactive process of embedding technological artefacts in our society with a view on ethical acceptability, sustainability and societal desirability	Values should not be sacrificed in order to ensure that other actor's values are completely satisfied
		Dynamic environment: changes of interests, location and time should be taken into account

		Identification of the possible impact – should be applied in the beginning of a project cycle
		Four dimensions of Stilgoe (Anticipation, Reflexivity, Inclusion and Responsiveness)
Circular Economy	Economic model that suggests to close the loop of processes – internalize the environmental externalities	3R principles (Reuse-Reduce-Recycle)
		Resources to focus: Energy, Materials, Water, Top Soil
Low Emission Development strategies	Integration of economic development with the reduction of emissions	Table 3

Table 4 Overview of the main results of the substantive related information

Theories	What is it?	Main information
Low Emission Development strategies – the planning cycle	Project cycle with guidelines related to policy implementation	Explanation in 5 steps how to implement policies (formulating goals – institutional framework – prioritizing policies – Implementation – Monitoring)
Responsible Innovation – values methodological framework	Information about the treatment of values	Values-tree design and fundamental values
		Trade-offs method
		Ravesteijn's methodological framework
Stakeholder analysis	Information about the identification of stakeholders and their possible behavior	Identification of the stakeholders on the basis of participation in the decision making or influenced by the decisions to be taken
		Identification of their possible behavior (based on the values they use for decision making and the level of importance of these values for them)
Technology Impact Assessment	Criteria to identify the impact of the technologies	Quantitative (can be measured) (Economic – Mitigation potential – Long term vision – Use of Space)
		Qualitative (cannot be measured)

Table 5 Overview of the main results of the process related information

Chapter 3: Development of the planning cycle: a framework for the decision making tool

The third chapter contains the development of the planning cycle. It is divided into two main parts. The first part includes the analysis of the Low Emission Development strategies, the Circular Economy and the Responsible Innovation which are combined into the "actions for port authorities". The second part describes the development of the planning cycle as a project cycle for the low emission technology selection and implementation. Specific stages of the planning cycle are used for the framework that will be used for the building of the Decision Making Tool.

3.1 Application of the substantive theories at port level

The first part of this chapter includes the analysis of the theoretical background as it is identified in subchapter 2.1 (substantive issues). The theories of Low Emission Development strategies, Circular Economy and Responsible Innovation are downscaled to port level with focus on the technical solutions related to the port's shore operations. The main goal of this analysis is to reveal the actions that should be performed by the port authorities in order to tackle the emission footprint issues.

3.1.1 Low Emission Development strategies at port level

To begin with, it is important to be mentioned that although the main purpose of the Low Emission Development is the economic development by setting at the same time environmental goals related to emissions, it should serve in parallel a range of purposes which are linked with four different groups of stakeholders. According to the analysis of chapter two, these stakeholders are the government, the public sector, the private sector, and the international community. For the case of ports, as government should be considered the port authorities because they are the decision makers and the ones that set also the policy plans, give incentives and arrange the actions that port follows. The term "public sector" could be used also to describe the situation at port level with the focus to be on the groups of people who are that affected or affect the port operations. Such example could be the citizens of the port cities, the passengers etc. The term "private sector" refers to companies that operate in the port and could be used again for the port level. Finally, the international community which refers to the research organisations and institutions again can be used for the port level. (Naniopoulos A., 2012) These four categories of stakeholders are important to be included in the planning cycle.

According to the theory, the Low Emission Development strategies have five main themes that are based on. These themes are the national economic development and climate objectives, the emission levels and objectives, the mitigation actions, the adaptation actions and the finance and technology. However, not all the themes are relevant with this research study. According to the subchapter 1.1, the focus of this thesis is on mitigation and not adaptation and therefore the adaptation theme should be excluded from the actions. The reason behind this is that adaptation does not consist a sustainable measure. The pollution can be continued and the adaptation actions can help to the adjustment of our society on this environmental damage without taking any measures to minimize it.

The themes are divided into elements and the elements to their related functions and time frame, as presented in table 3 (chapter 2). However, as the initial focus of this table is on policy formulation, the focus should be turned on the port level and more specifically on the technical solutions that can be applied in ports. Thus, some changes on the original themes should be performed in order to cover more spherical the topic of technical solutions. One main change should be to distinguish among technology and institutions, or better, institutional arrangement. The technology should be connected with the theme of mitigation actions, as the only proposed way of mitigating the emission footprint issues for this research study is through technologies. Finally, the finance theme should become more general and include all the economic parameters and the institutional arrangements. This theme can provide information about the costs, the funding opportunities and the arrangement of the funding among the institutions. To sum up, the new themes that can be used as categories of actions are the port's economic development and emission reduction, the emission levels and objectives, the technology and mitigation potential and the economic and institutional arrangements.

Based on the changes of the themes, the relevant elements and functions should also change in order to accommodate this difference on the themes. The theme of port's economic development is related to the vision. According to table 3, in the first theme of Low Emission Development strategies is the element of identification of policy priority programmes. That should be excluded as it refer to policy measures and for the purpose of this thesis the focus in on technical solutions. The second theme and its elements can remain the same as they describe the creation of emissions inventory based on the main sources of emissions that can be identified in the port operations and the emission projection in the future. At this point it is important to mention that the projection is referred to the emissions in the future after the implementation of the technical solutions. The third theme is the Technology and Mitigation potential. This theme is focused on the technical solutions and is divided into two elements. The first element is the Low Emission Port Technologies (LEPT) as a category of solutions that can be applied in the shore-operations of the port in order to reduce the emission footprint. The identification of the Low Emission Port Technologies is examined in the fourth chapter. The second element is the emission reduction potential from the relevant Low Emission Port Technologies. Finally, the last theme Economic and Institutional arrangements contains three elements, the mitigation cost which is the overall cost from the implementation of the Low Emission Technologies, the institutions which includes, the responsibilities for the implementation among the institutions involved and the financial which is related to the funding of the implementation. The new situation is presented in table 6. Based on the new formulation, the characteristics of the table are more related to the technical solutions rather than on the policy planning.

Theme	**Element**	**Function**	**Time-frame**
Port's Economic Development and emission reduction	Vision	Goal: development and emissions reduction through technical solutions	Mid- to Long-term
Emission levels and objectives	Emissions inventory (port's shore-level)	Main sources of emission (port operations)	Historic and current

	Emission projection in the future	Potential emission trajectory after the implementation	Forward Looking
Technology and Mitigation potential	Low Emission Port Technologies (LEPT)	Available technologies that can be used	Short- to Mid-term
	Emission reduction	Emission reduction potential	Short- to Mid-term
	Mitigation actions cost	Overall cost of the technologies	Short- to Mid-term
Economic and Institutional arrangements	Institutions	Responsibilities of Institutions for the implementation of technologies	Short- to Mid-term
	Financial	Funding to support the implementation	Current and forward looking

Table 6 Low Emission Development strategies at port level

3.1.2 Circular Economy at port level

The second theory that is used for the development of the actions is the Circular Economy. Currently this theory is gaining a lot of attention and there are examples of some ports that begin to explore how they can implement the circular economy to the port ecosystem. Such cases are the port of Amsterdam and port of Antwerp. The port of Amsterdam has as a strategic plan to reduce the dependence on fossil fuels and at the same time explore the opportunities on producing energy based on processes that contain organic material. The idea behind it is to use the solid organic waste that can be found in excess in the Amsterdam metropolitan area, in order to create business cases and gain economic benefits from energy production. More specifically, there are several initiatives which are related to the emission reduction such as Orgaworld, which uses organic wastes in order to provide biogas, electricity, heat and agricultural fertilizes and INB Sustainable which uses biomass in order to supply electricity and hot stream to the neighbouring process industries. Based on the theoretical information of subchapter 2.1.2, the main actions that are identified in the port of Amsterdam are the “recycle” as the input material is the waste from another operation and the “reuse” as the by-products of the processes are used as an input to other processes. (Port of Amsterdam, 2016)

Another port that explores the potential of circular economy is the Antwerp. Antwerp shares vision with port of Amsterdam by means of reducing the dependency on fossil fuels. Their initial focus is on the energy recovery systems that will increase the efficiency of the petro-chemical industry in the Churchill Industrial zone by analysing the energy flows and using them so as to boost the productivity of the sector. Furthermore, port authorities realised due to its position that the port can attract recycling activities and reuse the by-products of the industrial activities as sources of chemical feedstock. Except from that, port of Antwerp has developed initiatives in order to significantly minimize the use of electricity in the main port area. The theoretical actions behind all the aforementioned strategic goals are the “recycle”, “reuse” and “reduce”. (Port of Antwerp, 2016)

As ports are turning their attention more and more into circularity, the main characteristics of circular economy should be introduced also to the actions. The diverse character of ports with its complicated business ecosystem and the relevant industries that are located in the port area make it difficult to set a specific plan regarding the introduction of circularity in the port environment. Based on the theoretical exploration and the information described above, the three main goals (3 R’s) can contribute towards this direction as they can be used for the identification of the circularity opportunities in the port area and explore whether there are technical solutions that could be applied in the port. In fact, the main focus of these goals should be on proposing technical solutions that focus on the port’s shore-operations and can tackle the issues of emissions. Based on the above information, a new element should be used under the theme of Technology and Mitigation potential. This new element can be called circularity and its main function should be the exploration of the port’s circularity opportunities by the application of the 3 R’s.

3.1.3 Responsible Innovation at port level

Ports are areas where a lot of diverse processes of technical, economic and social nature are taking place. Also, by taking into account the international nature of modern marine transportation, it is easy to understand the high number of actors involved in comparison with more localized business sectors. Furthermore, the ethnic diversity makes the analysis of stakeholders’ values and interests more complex. These factors explain why Responsible Innovation theory is an appropriate approach for dealing with the conflicting values in port related problems.

The development of port projects is of great interest from the point of Responsible Innovation as they combine a dual goal, inherent to their public character. The first one is the entrepreneurial goal which describes the attractiveness of the port to users and investments. Moreover, part of the entrepreneurial goal is to provide competitive supply of services to the customers of the port. The second goal is the social aim which describes the raise of citizens’ welfare, in terms of income, health, employment rates and environment aspects (van de Hoven, 2012). Therefore, the case of introduction and implementation of low emission port technologies should fulfil both goals, the entrepreneurial and the social.

In various cases, port authorities are facing dilemmas when making a decision due to the complex decision environment. That situation arises from the fact that they should use strategies for economic growth in order to improve the income and employment levels (entrepreneurial goal development). On the other hand, they should guarantee and develop the social aspects for the citizens (social aim) (Ravesteijn W., 2014). Thus, there is a risk that the economic development may act as a dominant value. This encloses the possibility of negative effects to some actors from the externalities of such decision. Examples of such negative effects are the emissions from the new activities, the conflict for the new use of land etc. As a result, the technical projects should no longer be developed without consideration of the all stakeholders’ values. The values of some actors should not be sacrificed in order to ensure that other actors’ values are completely satisfied. Hence, Responsible Innovation theory is important for the investigation of all the relevant stakeholder values in order to meet the goal of achieving the highest possible acceptance for the technology implementation by trying to satisfy the values of the stakeholders at the maximum possible level.

Another important aspect that should be taken into account is the inclusion of the four dimensions of Stilgoe's in the actions so as to ensure the responsible character of the technical solutions implementation in terms of the impacts on the stakeholders. The first dimension (anticipation) explains that the negative impacts of the technologies cannot always be easily predicted and therefore an analysis with the possible impacts of the technologies should be done. The second dimension (reflexivity) refers to the self-assessment and reconsidering of the main interests of the stakeholders involved through the process of exchanging data. The third dimension (inclusion) is referred to the stimulation of participation of the stakeholders in the decision and implementation phase of the technical solution. Finally, the last dimension (responsiveness) explains the flexibility to adjust to new the circumstances when the importance of the interests of the stakeholders, and thus values, change.

The Responsible Innovation can contribute to the context of the table 6. To begin with, the theme of Port's economic development and emission reduction should preserve not only the social values (LEDs) but all the stakeholders' values. Thus, the current theme should be substituted by the term port's economic development with respect to air quality and stakeholders' values. The vision now covers the goal of this research study which is to satisfy as much as possible the values of all the stakeholders with the decision about a technology implementation. In addition, a new theme should be introduced which is related to the stakeholders, the Stakeholder Involvement. This theme is divided into two main elements, the stakeholder values. All the stakeholders' values should be satisfied as much as possible. At the same time no sacrifices of values of one or more actors should occur. The second element includes the stakeholder participation which should be enhanced in order to achieve the highest possible acceptance of the technologies. Regarding the Stilgoe's dimensions, the Inclusion and Reflexivity refer to the stakeholders and thus, they can be included in the context of the Stakeholder Involvement action. The Anticipation and Inclusion should be added as general information to be taken into account.

3.2 Main actions for port authorities

In this subchapter the information that was retrieved from the subchapter 3.1 is used for the development of the actions for port authorities. The requirements of these actions are also presented. The elements, functions and the time frame are considered as the requirements of each of the main actions (specification of the actions).

Port economic development with respect to air quality and stakeholders' values

The first action describes that the economic development of a port should take place with respect to air quality and stakeholders' values. In order to achieve this, the port authorities should set a specific vision relevant to this principle. This vision should contain the implementation of technologies in order to minimize the emission footprint of the port's shore-operations. The vision should also describe the minimization of the risk of acceptance of the technologies by the stakeholders. Finally, the vision should focus on a long-term time period in order to achieve better dedication from the stakeholders.

Emission levels and objectives

The second action explains that port authorities need to collect data concerning the emission footprint of their shore-related operations. The creation of an emission footprint inventory is important so as the authorities can keep track and measure the success of the technology implementation or, on the other hand, the issues that may appear. In order to create this inventory, the port authorities need to identify the main emission sources of the shore-operations. The emissions inventory should be based on current data. Finally, the authorities need to explore the possible future emissions. This emission footprint projection should also contain the emission results of the technologies to be implemented.

Technology and Mitigation potential

Another action is the Technology and Mitigation potential. The port authorities need to identify what are the available technologies that can be implemented in the shore-related operations and can contribute in the emission footprint reduction. The authorities can search for already applied technologies in ports, innovative technologies that were designed to be applied in the port or technologies that may fit to be applied in the port but are not related to the port operations. In addition, the authorities need to examine whether there are technologies that can contribute to the introduction or improvement of the circularity. For this procedure, the research can focus in the port and port area following the 3 R principles (reuse – reduce – recycle).

Stakeholder involvement

The port authorities need to recognise the importance of the involvement of all the stakeholders in the decision making related to the technical solutions. The stakeholders consist one of the most important factors of the decision making process as they can affect the technology implementation by accepting or rejecting it. Their values should be taken into account in the designing phase of a project. The port authorities should have mechanisms for the identification of these values. The high level of participation among the stakeholders can contribute in the minimization of the risk of technology resistance. Participation can be achieved by the stimulation of synergies among the stakeholders as well as by the minimization of the possible value conflicts that may appear (inclusion dimension). Finally, according to subchapter 3.1.1 the groups of stakeholders should be divided into four categories, the port authorities, the private sector, the public sector and the institutions and organisations. The analysis of the values of the stakeholders through the process of exchanging data can help the authorities to achieve both the highest degree of acceptability of the technical solutions (reflexivity dimension).

Economic and Institutional arrangement

The last action for port authorities is the Economic and Institutional arrangement. The first requirement is related to the cost of the mitigation actions. As the mitigation is performed through the implementation of the technologies, the relevant cost is the one of the technologies proposed. Another important aspect of this action is the financial support. The financial support describes the goal of acquiring the necessary funding to support the implementation and operation of the technologies. Finally, at this action it is important for the port authorities to define specific roles for the institutions that are related to the implementation. The clear roles can contribute in the absence of confusion or lack of communication among the institutes as well as the distribution of the relevant funding.

At this point, in order to avoid any conflicts, it is important to distinguish the use of terms institutions and stakeholders. According to Low Emission Development strategies theory, the institutions refer to the research institutions, organisations that provide knowledge to the project. Such examples are the universities, the NGOs or the ESPO organisation. The stakeholders refer to all the relevant actors in the port area including the institutions.

Also some supplementary information should be presented regarding the Stilgoe's dimensions. The action of stakeholder involvement includes two dimensions which are relevant to its content: the Inclusion and the Reflexivity. The dimensions of Anticipation and Responsiveness should also be taken into account. Based on the subchapter's 3.1.3 analysis, the port authorities should provide the tools of assessing the impact of the technical solutions before the start of the project in order to avoid any undesirable situations (anticipation dimension). Furthermore, in case that the current socioeconomic situation changes, the port authorities should provide the mechanisms to adjust the design to the new circumstances (responsiveness dimension).

The table below represents the summary of the actions for port authorities.

Actions	**Element**	**Function**	**Time-frame**
Port's Economic Development with respect to air quality and stakeholders' values	Vision	Goal: development, emissions reduction and preservation of stakeholders' values through technical solutions	Mid- to Long-term
Emission levels and objectives	Emissions inventory	Main sources of emission	Historic and Current
	Emission projection	Potential emission trajectory	Forward Looking
Technology and Mitigation potential	Low Emission Port Technologies (LEPT)	Available technologies that can be used	Short- to Mid-term
	Emission reduction	Emission reduction potential of the LEPT	Short- to Mid-term
	Circularity	Exploration of technologies with focus on opportunities	Short- to Mid-term
Stakeholder involvement	Stakeholder values	Maximum possible satisfaction of the stakeholders' values	Short- to Mid-term

	Stakeholder participation	Enhance participation	Forward Looking
	Mitigation actions cost	Overall cost of the implementation of the LEPT	Short- to Mid-term
Finance and Institutional arrangements	Financial support	Funds to support the implementation	Current and forward looking
	Institutions	Responsibilities of Institutions for the implementing technologies	Short- to Mid-term

Table 7 Synopsis of the main actions and their analysis

3.3 The planning cycle

This subchapter contains information about the planning cycle. The planning cycle is a project cycle providing guidelines for technologies that reduce the emission footprint. It is developed by the combination of the substantive and process theories explored. It consists an intermediate step between the theoretical exploration and the final decision making tool. However, not all of its stages are related to the decision making and thus, it is examined which of them are useful for the development of the tool. The relevant ones will compose the framework as a building block of the tool.

The development of the planning cycle is analytically presented in Appendix C. According to the subchapter 1.6, the development is divided into two main steps, the high level design and the low level design. The high level design uses the information of the subchapter 2.1 and 3.2. It describes the main stages as well as their sequence. The main stages that were found are the Vision, the Stakeholder Involvement, the Technology and Mitigation, the Finance and Implementation and finally the Monitoring. The sequence of the stages is the one presented. The Monitoring stage provides the Vision stage with the important feedback. Thus, it can be considered as a closed loop project cycle. Finally, the low level design describes the detailing of each of these stages in terms of guidelines. The information found in the process matters theories (subchapter 2.2) as well as the content of the actions for port authorities are combined in this step. The results of the development are presented below.

3.3.1 Stages and their content

<u>Vision</u>

The first stage is the Vision. The Vision descries the process of formulating the strategic goal by the port authorities. The strategic goal includes the implementation of technologies that can help in the reduction of the emission footprint of the shore-operations. They could be more general such as “reduce by 10% the emission footprint of the shore-operations” or more specific such as “decrease the emission footprint at the terminals and offices by focusing on the technologies that can enhance the circularity factor”. By taking into account the diverse character of ports, it is difficult to set a specific vision for all the ports and thus, the selection of such goals should be based on the past reports and strategies based on the opportunities that are present at a specific moment of time.

Stakeholder Involvement

The next stage of the planning cycle is the Stakeholder Involvement. This stage includes all the relevant information concerning the stakeholders that were met in the theoretical exploration. First of all, the stakeholders that are related to the technology implementation should be identified. Usually, because of the large number of stakeholders acting in the port environment, the analysis should focus not on every stakeholder separately but on groups of stakeholders which have similar interests. The process can become simpler when dividing the stakeholders into four big groups, the port authorities, the public sector, the private sector and the organisations & institutions. In such a way it becomes easier to identify which are the stakeholders by assigning them to one of these four groups. Examples of stakeholders are the shareholders, the administration, the port users, the scientific institutions, the government organisation, the local authorities, the national regulators etc. The next step is to categorise the stakeholders based on their involvement in the technology choice. The direct stakeholders are the stakeholders that participate in the decision making process and conclude in the most appropriate technology to be implemented. The indirect stakeholders are the ones that is expected to be influenced by the technology implementation. The next step is to identify the values of the stakeholders (both fundamental values and their relevant value objectives). According to Keeney, these values should be structured into a values-tree (dendrogram) so the decision makers can have a visual perspective of the situation. The final part is the identification of the importance of the values.

The main goal of this stage is to enhance the technology acceptance by putting into the decision making table the values with their relevant importance as decision criteria. The satisfaction of the values at the maximum possible level can enhance the dedication and thus, the participation of the stakeholders in the technology selection, implementation and operation. In addition, this process may reveal possible value conflicts among the stakeholders. That can be achieved by the possible absence of indirect stakeholders’ values in the decision making process or the large differences in the importance of the values as decision criteria. These conflicts can be minimized by the use of trade-offs and synergies.

Technology and Mitigation

The next stage of the planning cycle is the Technology and Mitigation. This stage describes the information that are related to the technologies and their mitigation potential. To begin with, the port authorities need to identify the circularity opportunities not only in the port but also in the port area. Specifically, the authorities should perform research in order to find the available resources that can be used by technologies that reduce the emission footprint of the shore-operations. This research should follow the 3 R principles (reuse – reduce – recycle) as described in the subchapter 3.1. Another aspect of this stage is the identification of the emission footprint based on the emissions related to the vision set. The current emission footprint can help the port authorities to realise the reduction impact of the technologies to be implemented.

Another aspect of this stage is the identification of the Low Emission Port Technologies. Three main criteria should be used by the port authorities in order to identify these technologies. Firstly, they should contribute in the vision set as described in the first stage. Secondly, they should contribute in the emission footprint reduction of the shore-operations. Thirdly, if possible, to contribute in the circularity opportunities identified. Moreover, the assessment of the impact that these technologies have on the values identified is important to be examined. For that assessment, the qualitative of each of the technologies can be used. Finally, based on the technologies found, the final evaluation should take place which results in the selection of the most appropriate technologies. The evaluation should have as decision criteria the stakeholders' values assigned with a weight based on their importance. Finally, the emission footprint projection can reveal the mitigation expectations from the implementation of the chosen technology.

Finance and Implementation

This stage is divided into two main parts, the finance and the implementation. The finance contains the extended economic analysis of the overall cost of the actions that need to be taken in order to meet the goals (e.g. technology installation, maintenance etc). Another important aspect of this pillar is to identify possible sources of financing. The funding will be used for the implementation actions. The implementation actions can be divided into three main parts, the preparation for the implementation (analysis of the existing situation in sociotechnical terms), the installation of the technology chosen, and the testing of the operation should be according to the standards that describe the technology (Painuly J.P., 2002).

Monitoring

Monitoring is the last stage of the loop. It describes the observation and analysis of the results of the technology implementation not only in terms of its performance but also in terms of acceptance and issues related to its operation. During the evaluation, also the finance and implementation issues should be examined. Through the monitoring, it becomes clear whether the initial vision and its relevant targets have been achieved or a new effort is needed.

Additional Information

There are some information that do not refer to specific stagets but on the overall process and thus, they should be presented separately as additional information. This information concerns the dimensions of Stilgoe. The inclusion dimension (minimization of value conflicts) is already described in the Stakeholder Involvement content. The other three dimensions should be taken into account when applying the planning cycle. Specifically, according to the Reflexivity, the stakeholders should exchange the data for their values as decision criteria and their importance. Regarding the Anticipation dimension, the analysis of the impacts should be examined before any decision made. Finally, based on the Responsiveness dimension, if any change in the current situation concerning the vision, the stakeholders, their values or the available technologies is occurred, then the situation should be reassessed by starting from the relevant with the changes stage.

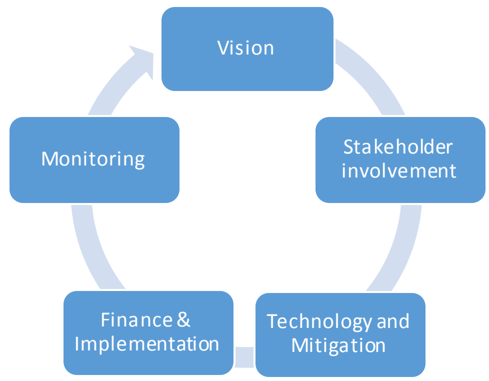

Figure 8 Architecture of the Planning Cycle

As indicated by the previous analysis, the main guidelines of each of the stages is presented below:

<u>Vision</u>

Formulating goals related to technologies selection and implementation that:

- reduce the emission footprint of the shore-related port operations
- respect the stakeholders' values

<u>Stakeholder involvement</u>

- Identification of the relevant stakeholders
- Categorization of them according to their involvement (direct or indirect)
- Identification of stakeholders' values
- Identification of the level of importance for these values
- Identification of possible value conflicts
- Dealing with these value conflicts in order to enhance participation

<u>Technology and Mitigation potential</u>

- Identification of circularity opportunities
- Identification of current emission footprint
- Identification of the available Low Emission Port Technologies
- Assessment of the impact of these technologies
- Comparison and evaluation of the technologies and selection of the most appropriate
- Emission footprint projection

<u>Finance & Implementation</u>

- Identification of the overall cost
- Identification of the sources of funding
- Preparation for the installation of the technology chosen (sociotechnical)
- Installation of the technology chosen
- Testing of the operation of the installation

Monitoring

- Evaluation on the results of the implementation (whether the main goals of the vision have been achieved)
- Assessment feedback to help the formulation of new strategic goals

3.3.2 Practical and theoretical issues

At this subchapter it is examined whether the planning cycle can address the practical and theoretical issues that are mentioned in the first chapter. These issues refer to the decision making process.

Practical issues

- Port's emission footprint reduction

The solution for this issue is indicated by the Vision and Technology & Mitigation stages. The strategic goal describes the use of technologies in order to reduce the emission footprint of the ports' shore operations. Moreover, the selection of the available technologies that can participate in the evaluation phase is based on their capacity to reduce the emission footprint. The operation of the chosen technology can address the issue.

- Involvement of all the stakeholders in the decision making which can lead to a more responsible decision

The involvement of the stakeholders in the decision making is described by the Stakeholder Involvement stage. This stage highlights the importance of the participation of all stakeholders in the process. The involvement is achieved by the inclusion of all the values of all the stakeholders in the decision making process. Finally, the responsible decision is ensured by the presence of the four dimensions of Stilgoe that are taken into account in the whole planning cycle process.

- Addressing of possible value conflicts among the stakeholders related to technologies selection and operation

This issue is solved by the content of the Stakeholder Involvement stage. Specifically, in order for this issue to be addressed, the use of trade-offs based on values is proposed.

- Increasing of stakeholders' acceptance for the technology to be applied (including the public)

The goal of the planning cycle is to evaluate and choose the technology that satisfies the most the values of the all the stakeholders without sacrificing any of them. In this way, the values satisfaction leads to the increase the acceptance of technology.

- Use of energy/material waste in order to tackle the emission footprint issue

The use of waste in order to reduce the emission footprint is described by the content of the Technology and Mitigation stage. The circularity opportunities in the port and port area are taken into account when deciding on the technologies. However, this may not always be the case as there might be no circularity opportunities.

Theoretical issues

- Due to ports' complex and fast changing business environment, the current situation should be taken into account and the flexibility to changes should be provided

The decision making process may provide with unreliable results in case that the complex and fast changing business environment of ports are not taken into account. Thus, the input data should be up to date. That can only be achieved by re-examining the situation every time a change occurs and by avoiding the static input of data in terms of stakeholders, values and technologies that are used every time the analysis is performed.

- Lack of theoretical tool to address the stakeholders' value conflicts

The theory that is used for the addressing of the possible value conflicts is the Responsible Innovation. It proposes the trade-offs as the best way to achieve this. However, the theory does not provide a specific tool that can perform these trade-offs. That is something to be further explored. According to Keeney, the most common tool is a multi-criteria tool.

- Lack of literature information related to the waste-use by technologies in order to reduce the emission footprint

This theoretical information is provided by the Circular Economy and more specifically from the 3 R principles (reuse – reduce – recycle). Based on these principles, the available technologies that contribute to the waste-use and the reduction of the emission footprint can be identified.

- Lack of literature information regarding how to choose the most appropriate technology based on the stakeholders' point of view as a cumulative decision making approach that solves the practical issues

Based on the information presented above, the following stages of the planning cycle contribute in addressing this theoretical issue: the Vision, the Stakeholder Involvement and the Technology and Mitigation. The guidelines that are included in these stages can be used for the final selection of the most appropriate technology that reduces the emission footprint by taking into account all the stakeholders' values, by minimizing the value conflicts, increasing the technology acceptance by the public and minimizing the waste if possible.

3.4 Building block for the Decision Making Tool

Not all the stages of the planning cycle can be used in the decision making process. Specifically, the stages of "Finance and Implementation" and "Monitoring" are not relevant with the selection of the most appropriate Low Emission Port Technology. They refer to stages such as the funding of the chosen technology, guidelines regarding its installation etc. Thus, only the guidelines of the Vision, Stakeholder Involvement and Technology and Mitigation stages can be used. For the shake of simplicity, the stage

Technology the Mitigation is divided into more clear steps, the identification of the emission footprint and the Low Emission Technologies and the Assessment and Final Decision. The framework is presented below.

Vision	Stakeholder Involvemnt	Identification of emission and LEPT	Assessment and final decision
• reduce the emission footprint of the shore-related port operations • respect the stakeholders' values	• Identification of the relevant stakeholders • Categorization of them according to their involvement • Identification of stakeholders' values • Identification of the level of importance of these values • Identification of possible value conflicts • Dealing with these value conflicts in order to enhance participation	• Identification of circularity opportunities • Identification of current emission footprint • Identification of the available Low Emission Port Technologies	• Assessment of the impact of these technologies • Comparison and evaluation of the technologies and selection of the most appropriate • Emission footprint projection

Table 8 Framework for the development of the Decision Making Tool

The development of the planning cycle led to the identification of the absence of specific theoretical information that should be used for the development of the decision making tool. The questions that arose are the following:

- Which are the technologies (LEPT) that port authorities should examine and decide on the most appropriate to be implemented?
- What methods can be used for dealing with stakeholders' value conflicts?
- What tools can be used in order to help with data acquisition and processing?

The technologies are the mean to tackle the emission issues. The methods to deal with the value conflicts are associated with the decision making process. The tools to deal with the data are related both to the technologies and the stakeholder involvement. The categories of technologies will be defined in the next chapter. Regarding the methods to be used, they should contribute towards the minimization of the stakeholders' values conflicts by performing trade-offs. Finally, the tools should be used for the input of the data (importance of the values), the technology comparisons / assessment and the final decision. The criteria for their selection are analyzed in the following chapter.

Chapter 4: Decision Making Tool: Technologies, Methods, Tools and Structure

The fourth chapter describes the development of the Decision Making Tool. The results of the previous chapter (framework) revealed the need for further exploration in three fields: one related to the technologies to be evaluated, one to the methods for dealing with values and one to the tools for data processing. Thus, this chapter is divided into four parts. The first part contains the identification of the Low Emission Port Technologies. The second part refers to the selection of the methods that are able to deal with value conflicts. The third part is related to the selection of the tools that can be used for the data acquisition and processing. Finally, the last part explains the decision making tool.

4.1 Low Emission Port Technologies

In this subchapter the specification of the Low Emission Port Technologies takes place. This exploration is divided into three steps. In the first step, the general information about the low emission technologies will be examined based on the information available in the literature. The second step includes the identification of the emission sources of the ports' shore-operations and based on them the relevant categories of technologies that can tackle these emission sources. The selection of categories instead of specific technologies can be explained by the following argument. The decision making tool should be a dynamic tool. By setting specific technologies, it is not taken into account the innovations that may arise and the diverse character of ports with the changing business environment. The final step of this exploration of the Low Emission Port Technologies contains the assignment of the quantitative criteria of the Technology Impact Assessment theory to categories of the Low Emission Port Technologies.

To begin with, in the literature as low emission technologies are considered the technologies that significantly reduce not only the greenhouse gases, but also the air-borne pollutants such as particle matter. These technologies should not be related strictly with renewable energy as their main source. They can also use fossil fuels such as gas but they should include a range of key advance features that contribute to the reduction of the emissions in comparison with similar existing technologies. Examples of such technologies could be in the field of electricity and power the supercritical pulverised fuel, the waste heat recovery, the hydrogen production and use of it in combined cycle and in the field of vehicles the electric, hybrid, propane and hydrogen engines. (Australian Government - Department of Industry and Innovation, 2016)

However, not all the low emission technologies can be applied at port level. Therefore, it is necessary to analyse briefly the emission sources that can be identified in the port's shore operations which can provide an insight regarding what technologies can be used. According to the research study of the Green Port of Long Beach, the main sources of emissions are identified in the operations of the ships, trucks, trains, cargo-handling equipment, harbour craft and energy use. However, the ships and harbour craft as vessels are not part of this research study as they are not related with shore-related port operations. On the other hand, the port of Long Beach does not have any passenger operations and therefore it does not include the terminals as emission sources. (Port of Long Beach, Clean air action plan,

2016) Another emission source that should be taken into account is the dry bulk operations. These operations that take place in the port contribute to the emissions with particles and affect the air quality (e.g. industrial minerals). (ESPO, Green Guide, 2012) Until now, the main sources of emissions identified are the trucks, the trains, the cargo handling equipment, the terminals and the energy use. The trucks and trains that are used in the ports for the transportation of goods usually use fossil fuels. The cargo handling equipment such as yard tractors and cranes belong to the same category as they are also used for the transportation of goods. The terminals and the offices consume fossil fuels for their heating and use electricity from the country's electricity grid. As the energy mix of the electricity generation at a national level is linked with fossil fuels, the increase of consumption leads to the increase of the emissions. Even though the results of it may not be realised in the air quality of the port area, however, it is conflicting with the low emission footprint idea (should not decrease the quality of air at another area) as described in the first chapter.

The Low Emission Port Technologies that can be applied for the aforementioned emission sources vary. The categorization of the technologies is based on the emission source that needs to be tackled. In order to connect the technologies with the emission sources, the information found in the literature will be used. According to Ecoport's Green Guide, the main categories of technologies refer to the dry bulk, energy efficiency and energy production. (ESPO, Green Guide, 2012) In addition, Norsworthy in his research study mentions also the use of low emission (or even zero-emission in some cases) machinery for the port operations in order to reduce the emission footprint. The term machinery encompasses all types of machines that are used for the port operations and use fossil fuels, even if they produce motion or energy (heat / cooling / electricity). Such machineries could be the cranes, trucks, trains, cars, cargo-handling equipment etc. (Norsworthy M., 2015)

At this point it is important to connect these technology categories with the emission sources. The categories of dry bulk obviously are related to the dry bulk operations which cause dust depression. Usually dust contains thick particle matter (PM_{10}) which is considered as an emission. (ESPO, Green Guide, 2012) Examples of dry bulk that can be met in the port operations are the coal, the iron ore, industrial minerals etc. (Port of Rotterdam, Dry bulk cargo, 2017). The category of low emission machinery is related to the emission sources of trucks, trains, cargo handling equipment and terminal. The energy efficiency category refers to technologies that help the minimization of the energy waste by improving their efficiency and thus, emissions are avoided to be produced. This category is associated with the terminals and offices. Finally, the increasing need for energy in the port could be covered by the energy production. The energy should be generated by renewable energy sources. An indication of these technologies per category is provided in the appendix D.

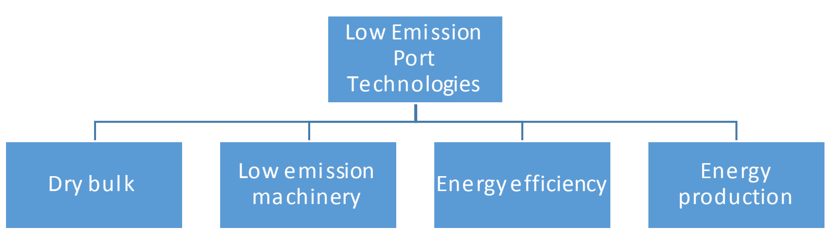

Figure 9 Categories of Low Emission Port Technologies

The last step contains the application of the quantitative criteria as they have been identified in the subchapter 2.2.4 to the categories of Low Emission Port Technologies. The criteria refer to the economic criteria, the mitigation potential, the long term vision and the use of space. The economic criteria contain information about the initial capital cost, the maintenance and operation cost (M&O cost) and the payback time. However, payback time cannot be used in the dry bulk category as there is no economic compensation from the application. For the case of technologies that belong to the energy production category, the levelised cost of electricity (LCOE) should be adjusted as an indication of the cost of the electricity generation. The mitigation potential criteria are related to the potential of the emission footprint reduction from the technology operation. However, there are cases that it might not be applied as a general rule. Specifically, in cases of low emission machinery and energy production categories, there might be low levels of emissions to be emitted locally. However, these emissions should be at low level and the overall emissions should be reduced in terms of footprint and the technologies do not contribute at a high level. Therefore, for both categories it should be mentioned what are the levels of emissions that are emitted. The use of space is related to the minimum area needed for the technology to be implemented. For the case of energy production, one more quantitative criterion should be adjusted which is the energy generation per area. Finally, the last criterion is the long-term vision as overall lifetime of the technologies and can be applied to all the technologies. The information related to the quantitative criteria is presented in the following table 9.

	Dry Bulk	**Low Emission Machinery**	**Energy Efficiency**	**Energy Production**
Economic criteria	Initial capital cost, M&O cost	Initial capital cost, M&O cost, payback time	Initial capital cost, M&O cost, payback time	Initial capital cost, M&O cost, payback time, LCOE
Mitigation potential	Emission reduction	Emission reduction, Emission levels emitted (if)	Emission reduction	Emission reduction, Emission levels emitted (if)
Long-term vision	Lifetime	Lifetime	Lifetime	Lifetime
Use of space	Minimum area needed	Minimum area needed	Minimum area needed	Minimum area needed, energy generation per area

Table 9 Quantitative criteria per category of Low Emission Port Technologies in port

4.2 Methods for dealing with values

As mentioned in the previous chapters, the value conflicts in the planning and design phase consist a major issue that in some cases can cancel the technological artefact development or create a lot of unwanted interactions from stakeholders that believe they are affected in a negative way by the technology development. Same wise, in ports, port industrial areas and port cities where there usually are a lot of different stakeholders with conflicting values, it is important to understand from the planning phase what the situation is and ways that these conflicts can enhance the development of the technological artefact without creating any kind of "resistance".

There are several ways to deal with conflicting values in order to solve possible conflicts that may arise which may cancel the project itself or need a lot of effort from the various stakeholders until the achievement of the final implementation. In subchapter 2.2.2 are mentioned some methods that deal with value tensions such as win-win situation, trade-offs, dominant value approach etc. In addition, it was explained why the method of trade-offs is the most appropriate for the purpose of this thesis.

There are two ways of dealing with value conflicts regarding engineering design, the optimal design and the non-optimizing design. The optimal design refers to the cases where the decision makers tend to find the best or optimal design solution. Non-optimizing design is based on the argument that is not always possible to optimize in the engineering design. As mentioned in the van de Poel's paper, the impossibility of optimizing in engineering is connected with the problematic definition of the design problems that need to be solved. Both optimal design and non-optimizing design should focus on the case of multiple criteria value based problems as in the port area there are a lot of actors representing different values. (van de Poel I., Values in engineering design, 2009)

4.2.1 Optimal Design

The optimal design approaches that deal with multiple criteria can be categorised in three main methods, the efficiency and effectiveness, the cost benefit analysis and the multi criteria design analysis. The efficiency and effectiveness is a method that uses these two measures in order to explore if the design can fulfil its function. Being a measurement tool, the efficiency is defined as the ratio that an artefact fulfils a function based on the effort required. More simply, it is the ratio of the output result in relation to the input effort. The effectiveness is defined as the degree that the artefact can achieve the desired result. Based on this approach the optimal design is the one that fulfils both the criteria of efficiency and effectiveness. However, this method is not the most appropriate to be used for the research goal of this thesis as both the criteria are difficult to be measured and sometimes there might be conflicts among them. Furthermore, this method focuses on technical and economic aspects of the design and is difficult to define the efficiency and effectiveness of qualitative data. (van de Poel I., Values in engineering design, 2009)

The second method is the cost benefit analysis. It is considered as a technique that determines the evaluation criteria for the selection between different alternatives expressed in a common unit such as a monetary unit, labour use, time etc. The alternatives to be chosen should have expected benefits greater than the costs needed (Rodreck D., 2013). Moreover, with this technique it is possible to introduce qualitative criteria such as social values and ethical criteria but they should be expressed into a common unit, for instance a monetary unit. However, this process may be proved controversial as it contains the danger of subjective decision on the criteria to translate these qualitative values into a specific unit. Another disadvantage of this technique is the lack of optimization in regards to multiple criteria as this technique supports the design to be made based on a certain criterion. By taking into consideration a port, the multiple stakeholders that are present express multiple criteria that need to be fulfilled in the highest level. Thus, this method seems to be insufficient to deal with complex socio-technical problems. (van de Poel I., Values in engineering design, 2009)

The final optimal design method is the Multi-Criteria Design Analysis. According to this method, several alternatives are directly compared to each other on several criteria. For instance, different models of cars can be compared based on some criteria such as cost, safety, fuel consumption etc. Usually this method examines firstly the relative importance of the criteria and a weight is awarded to each of the individual criteria. The issues that may arise by this technique are related with the ethical and social values that, even though they can be included in the design, it is difficult to measure them with analytical tools and therefore the calculation cannot be accurate and objective. (van de Poel I., Values in engineering design, 2009)

Based on the aforementioned analysis, it can be concluded that all the methods are facing some issues such as incapability to cope with multiple criteria (efficiency and effectiveness) or the absence of tools to measure qualitative criteria. However, the method of Multi-Criteria Design Analysis can contribute to the decision making tool even though the results may not be absolutely accurate. Furthermore, it is not always possible to use optimal design in order to deal with multi-criteria value based problems. In addition, optimality cannot be reached as some problems do not match to Simon's criteria of a well-defined problem (Simon H. A., 1973). Another aspect why optimality cannot be always achieved is that by nature some values are conflicting, for instance, the economic values concerning the installation of on-shore wind turbine systems and the value of aesthetics of the local residents or the economic value expansion of a port and the value of environmental protection. In such cases, it may be inevitable to perform trade-offs so the method cannot be characterised as optimal. Therefore it is important to explore the non-optimizing design methods.

4.2.2 Non-optimal Design

As it was mentioned before, optimality cannot always be achieved. Thus, it is important to explore also non-optimizing design methods. There are three popular non-optimizing methods to be followed in order to deal with conflicting values, the satisficing, the reasoning about values and the value sensitive design.

The value sensitive design method was briefly analysed in the second chapter (subchapter 2.2.2) and was rejected as an option. The method reasoning about values is a non-calculative process where a philosophical analysis takes place and questions with relevant argumentation are created in order to get a deeper understanding on the values. It is divided in three steps where at the first one the decision maker judges the value conflicts so as these values to be understood better. The second step includes the argumentation for specific conceptualization of these values. The third step the identification of whether there is common ground between the conflicting values that might help to solve the conflict. This strategy of reasoning is not the optimum to be used in the case of a decision making approach as it needs a lot of time and effort to create argumentation and it is difficult to be realised at a more complex stakeholders' environment which is the case of a port.

The last method is the satisficing. According to this strategy, the alternative chosen from a list of possible solutions should be the one that is "good enough" for a particular case even if it is not the optimal. The decision maker becomes a "satisficer" by setting threshold values and accepting any possible solution that exceeds these thresholds. The threshold represents the minimum level that is good enough for the specific value and any alternative that scores more than this will be accepted. Satisficing can be used both for technical requirements and values. (van de Poel I., Values in engineering design, 2009)

For the case of this research study, the satisficing technique can be applied on the values of the stakeholders which are used as decision criteria. Specifically, the technique can contribute to the evaluation of the technologies by setting thresholds to the weighted values of the stakeholders. So the technologies that score less than the threshold on specific criteria will be rejected. Apart from that approach, the technique provides with the possibility of performing trade-offs. The trade-offs can be achieved when one of the two conflicting values exceeds the threshold and the other one does not. In that case, the score of the value that scores better can be reduced to the limit in order to improve the score of the second value. However, this process would have as a result a more complicated tool which needs more intervention by the stakeholders and the decision maker. Thus, the first approach will be used. The trade-offs will be examined in the tools exploration in the following subchapter.

Finally, after having described the most popular methods to deal with conflicting values for multi-criteria value based problems, it is important to explain which of them will be used for this research study. For the decision making approach, the satisficing technique will be used in order to set thresholds for the technologies that can be accepted by the decision maker based on the weights of the values-criteria. The method of multi-criteria analysis of the optimizing strategy will be used in order to evaluate the technologies based on the specific values-criteria. The use of both strategies will be explained in the next chapters.

4.3 Tools

The multi-criteria design analysis is the most appropriate option to be used for the decision making tool and therefore the relevant theoretical tools will be explored in this subchapter. Although there are several multi-criteria tool that can be found in the literature, not all of them are suitable to be used. Some of them represent highly specialized tools that solve very specific problems and are not related to the purposes of this research study as they do not provide any flexibility to be adjusted on guidelines of the planning cycle. Such tools are the Architecture Trade off Analysis Method (ATAM) and the Nonstructural Fuzzy Decision Support System (NFDSS) that are used only for software development. Other tools such as Value Engineering (VE) are used only for solving industrial engineering problems. Some other tools use algorithms that are not publicly available. Finally, some multi-criteria methods describe general guidelines that are not related with the focus of this research study. (Weistroffer H.R., 2005) All the methods found in the literature are presented in the appendix D.

Before analysing the tools that seems to be the most appropriate to be used for the development of the Decision Making Tool, it is important to categorize them based on the criteria that found during the theoretical exploration and in the subchapter 3.4. The first category refers to the tool that is needed for the identification of the relative importance of the stakeholders' values, known also as prioritisation tools. The second category describes the evaluation of the technologies that can be implemented in the port area. This evaluation should be able to judge the technologies based on both qualitative and quantitative information associated with the alternatives. Finally, the last category of multi-criteria tools is related to the multi-criteria optimization tools that will be used for the process of selecting the best alternative that is more suitable to be implemented at the specific moment of time. The optimization tool should be able to perform trade-offs based on the weighted values as criteria.

Regarding the relative importance of the values (prioritisation methods) there are three suitable tools that could be used, the Analytic Hierarchy Process (AHP), the Analytic Network Process (ANP) and the Dominance-based Rough Set Approach (DRSA). The AHP tool describes the process where a set of criteria (values) are compared pair wise in order to find the relative importance and thus the weight of each of the criteria separately. The main advantages of this method are its flexibility, intuitive appeal to the decision makers and its ability to check inconsistencies. However, there are some cases that ranking irregularities can occur when two of the criteria that are compared have similarities in the context they describe. (Ramanathan R., 2001) The ANP tool is a more general form of the AHP where both use a system of pairwise comparisons to measure the weights. The main difference between them is that in AHP all the criteria are considered to be independent but ANP does not require independence among elements. The main advantage is that it can describe better the real world situation. On the other hand, this makes the process much more complicated to be used because it uses complicated stochastic super-matrices, difficult vector and sensitivity analysis and as a result it becomes more difficult to be communicated to the relevant parties that are going to use it. It consists a time-costly tool. (Saaty T., Theory and applications of the Analytic Network Process: Decision Making with Benefits, Opportunities, Costs and Risks, 2005) The final tool, DRSA, can be used also to rate the weights of the criteria and is based on the dominance relations which, as described, is not the case of this thesis as it conflicts with the idea of responsibility. (Greco S., 2001) Furthermore, this tool is the most complicated among the three and needs a lot of time resources in order to be applied. Based on all the above information, AHP seems to be the best tool to be used for the prioritisation of the values criteria as it is simple to be used, easy to be communicated and provides flexibility.

Regarding the evaluation of the technologies based on certain criteria, there are three suitable tools found in the literature, the Pugh's matrix, the Evidential Reasoning Approach (ERS) and the Weighted Sum Model (WSM) tool. The Pugh's matrix compares different alternatives with a datum alternative on the basis of some predefined criteria. The datum represents the average or the most common alternative (technologies). The main advantage of this tool is that it reduces the influence of the subjective opinions as the comparisons of one alternative versus another creates more objective results. Furthermore, another advantage is that the tool is appropriate for complex decision making problems that contain a lot information as there is no limitation on the number of the criteria and alternatives to be evaluated. Finally, the Pugh's matrix method requires no training and it is easy understandable. The only disadvantage is that in some cases there is a need for assumptions to be made related to the independence of the criteria used for the comparison. (Burge S., 2009) The second tool is the Evidential Reasoning Approach. This tool does not use the comparison for the evaluation but represents an alternative option on a criterion. The matrix that it is used is called belief decision matrix and every value on the table represents a belief distribution (good, average, bad etc). The main difference with the Pugh's matrix is that it does not compare the alternatives but it evaluates each of them separately. That increases the risk of subjective opinions. Also, in case that the results of the belief distribution have the similar values, the results of the optimisation tools may not be helpful for the decision making. (Wang Y.M., 2004) Finally, the last method is the Weighted Sum Model. This method should be applied only in the case that all the data are expressed in the same unit. The model should contain only quantitative information and therefore is not an option for the purposes of this research study. (Triantafyllou E., 2000) The Pugh's tool seems to be the most appropriate tool to be used because of the advantages of flexibility, better objectivity and the possibility to use a larger number of criteria and alternatives in cases that it is needed.

Finally, the last category is the multi-criteria optimisation tools, known also as ranking methods. The main tools found are the VIKOR, the Technique for the Order of Prioritisation by Similarity to Ideal Solution (TOPSIS), the ELECTRE and the Preference Ranking Organisation Method for Enrichment of Evaluations (PROMETHEE). All these tools are used in order to select the most appropriate alternative based on certain weighted criteria and are associated with the compromise for conflict resolution by allowing trade-offs which consists an important aspect of this research study. In all the methods, the input criteria could be conflicting and non-commensurable (different units). Furthermore, there is no restriction to the number of criteria and alternatives to be used. Finally, all the methods are using similar algorithms and are having similar advantages and disadvantages. Based on research made by the Opricovic for the comparison of these four tools, it is concluded that the VIKOR, ELECTRE, PROMETHEE gave identical results and TOPSIS slightly different in the case of using stochastic data (randomness) which is not the case for this research study. On the other hand, TOPSIS is considered as the most commonly used method because of its simplicity related to the other tools and its flexibility to apply a number of criteria even during the decision phase. (Opricovic S., 2005)

The tools (AHP, Pugh's matrix, TOPSIS) for decision making that will be used for the decision making process of this research are known in the literature as the "Triptych". They are used in different stages of the decision making process. There is also an interaction between the tools as the output of one tool is the input to another. The triptych was developed in 2000 and is widely used to support methodologies for product development (Chollar G. W., 2010). In order to avoid any confusion with decision making tool which consists the main product of this research study, these tools will be referred as sub-tools.

4.3.1 Analytic Hierarchy Process (AHP)

The AHP is a structured multi-criteria analysis technique for complex decisions and is widely used around the world in fields such as government, industry, healthcare, universities etc. It was developed by Thomas Saaty in 1970s. It is divided into four steps. The first step contains the decomposition of the decision making problem into a hierarchy and identification of the criteria. For this research study, the criteria are the values of the stakeholders. The second step describes the pair-wise comparisons for each criterion and the creation of a matrix based on the judgements made by the stakeholders. For this step a scale should be selected that explains the degree of preference. The third step includes the normalization of the resulting matrix and the calculation of the weighted average rating for each criterion. The fourth and final step is the evaluation of the consistency of the judgements in order to ensure that the original preference ratings that have used for the weights were consistent. This step is based on calculations that are made in order to measure the eigenvalue, the deviation from the Consistency Index (CI), Random Index (RI) and finally the Consistency Ratio (Cr). According to Saaty the Cr factor should be smaller than 0.10 with 0.12 to be the higher value to be accepted. In case the price is higher than 0.12, a new research regarding the judgments made should be performed. (Saaty N.L., 1991) More information is presented in Appendix D.

4.3.2 Pugh's matrix

The Pugh's matrix, also known as Pugh method or Pugh analysis or decision matrix tool, is a decision making sub-tool that helps to determine which potential solutions are better than others related to a problem and based on certain criteria. It was developed by Stuart Pugh in 1985 and is considered as a qualitative technique that help engineers to obtain stakeholders' input, to identify the ranking of these solutions and quantitate the qualitative judgements. The criteria that are used for the ranking can also contain weights. (Burge S., 2009) This sub-tool is based on the preparation of a matrix with rows to represent the criteria (values) and columns to represent the different alternatives (technologies) to be evaluated. One of the alternatives is chosen as a datum against which all the other alternatives will be compared and judged. The datum represents the most commonly used alternative. The scale that indicates whether an alternative is better, equivalent or worse is the "+", s, "-", which is proposed by Pugh. So, in case one alternative is better than the datum, it takes the "+" symbol. The sub-tool is considered to be time-efficient when a number of 12 alternatives are compared based on 22 criteria. It can cope well with larger numbers, but it is more time consuming and there is an undermined risk of confusion.

According to Pugh, it is important to be mentioned that "the matrix does not make the decisions but it is a procedure for controlled convergence onto the best possible concept (alternative), and is not composed for absolutes in mathematical sense" (Commitee on Theoretical Foundations for Decision Making in Engineering Design, 2001). Finally, Pugh's matrix is considered a tool that presents weaknesses and is not always appropriate for taking final decisions. Therefore, the optimisation sub-tool should be used which will also contain the execution of trade-offs. (Burge S., 2009) The step by step procedure of the sub-tool is presented in Appendix D.

4.3.3 Technique for Order of Prioritisation by Similarity to Ideal Solution (TOPSIS)

The TOPSIS was introduced in 1993 by Hwang, Lai and Liu. It is an algorithm that was developed in order to solve goal based multi-objective decision making problems. It compares a list of alternatives based on certain weighted criteria, by normalising the scores of the alternatives for each of the criteria and then calculating their geometrical distance from the possible ideal solution and negative ideal solution. The main idea behind this algorithm is that the chosen solution should be close to the possible ideal solution and away from the negative solution. This method provides a compromised solution for problems that have multiple objectives which cannot be optimized easily because of conflicts between these objectives. Simply, it allows trade-offs. The criteria's goal are analysed based on two dimensions, the maximization or the minimization depending on the nature of the criteria what the goals of the research study. For the use of this method the criteria of evaluation of the alternatives should be considered independent. According to the TOPSIS theory, a statistical significant difference is considered the 0.025. In cases that the difference of the score between the first two technologies is less than 0.025, then both of the technologies can be used and the decision maker can choose which one of them. (Hwang C.L. L. Y., 1993) The steps of the sub-tool are explained in detail in Appendix D.

4.4 Decision Making Tool for Low Emission Port Technologies

This subchapter contains information about the decision making tool. The decision making tool is a ten-step approach that provides specific guidelines and sub-tools that can assist port authorities to decide on a technology among various alternatives. As decision criteria are used all the values of the stakeholders. The technology chosen can reduce the emission footprint of the shore-operations of the port. It consists a dynamic tool. Considering the diverse character of the ports, their fast changing business environment as well as the innovations concerning the low emission technologies, this tool has no static data-input. It reacts with the business environment and provides with the best technology choice related to the values of the stakeholders at a specific moment of time. The chosen technology is the one that satisfies the most all the stakeholders' values. This fact minimizes the risk of technology "resistance" and enhances the participation of the stakeholders during the implementation and operation phases. In addition, it consists a flexible tool as the change at a stakeholder's values, change of the importance of the values or the introduction of a new technology can be introduced to the tool without affecting the rest of the data retrieved. Finally, it gives the port authorities the opportunity to focus on specific among various emission sources.

The development of the decision making tool is analytically presented in Appendix D. The guidelines of the developed framework that is presented in subchapter 3.4 are used are used as the main building block. Moreover the theoretical gaps of the framework are covered by the information found in this chapter (LEPT, methods for dealing with values and sub-tools). Regarding the technologies, the categories of technologies with their relevant emission sources are presented in the first step. The methods chosen are the multi-criteria design analysis and the satisficing. The sub-tools are the AHP, the Pugh's matrix and the TOPSIS which performs the trade-offs. The sequence of the steps was developed based on the following idea: the output of the previous step is the input to the next. However, the process of identification of the stakeholders and values and the LEPT can be performed in parallel. Concerning the sub-tools, a five point scale was selected to be used. This scale is proposed by Pugh for the cases of qualitative-data input. Finally, the AHP and Pugh's matrix sub-tools are using Excel for their calculations. The TOPSIS algorithm was developed in python (code can be found in Appendix E).

4.4.1 Ten-steps decision making tool

The ten step-by-step approach of the Decision Making Tool is the following:

Step 1: Set specific vision based on the categories of the Low Emission Port Technologies

Step 2: Identification of all the relevant stakeholders

Step 3: Identification of their value objectives

Step 4: Use of AHP sub-tool to identify the importance of the values

Step 5: Creation of emission footprint inventory for the relevant to the vision emission sources

Step 6: Identification of the Low Emission Port Technologies that can be applied

Step 7: Satisficing

Step 8: Use of Pugh's matrix sub-tool in order to perform the Technology Impact Assessment

Step 9: Use of TOPSIS sub-tool for the final decision

Step 10: Emission footprint projection

4.4.2 Explanation of the steps of the tool

Step 1: Set specific vision based on the categories of the Low Emission Port Technologies

The vision to be set by the port authorities should be based on the categories of Low Emission Port Technologies. The categories of these technologies address different emission sources. The table represents the situation.

Low Emission Port Technologies	Emission sources
Dry Bulk	Dust dispersion (coal, iron ore, industrial minerals etc)
Low Emission Machinery	vehicles, trains, cargo-handling equipment, terminals
Energy Efficiency	Terminals, Offices
Energy (electricity) Production	Electricity produced from fossil fuels (combustion in the port or grid (energy mix))

Table 10 Architecture of the Planning Cycle

Step 2: Identification of all the relevant stakeholders

This step contains the identification of the stakeholders that either influence or get affected by the decision concerning the technology. Based on their participation, the stakeholders should be divided into direct and indirect. The direct are the ones that participate directly in the decision making process and usually are shareholders. The indirect are the ones that do not participate in the decision making process but are affected by the decision. An example of such situation is the following. The port authorities decide on the selection of the technology (profit, reduction of emissions), the users of the port as well as the residents are affected by the technology implementation and operation (use of land, employment). By dividing the results into these two categories (direct and indirect), it is possible to understand better the possible conflicts in the next steps, where the weights of the values will be revealed.

Information that can help the stakeholders' identification:

- The process can become simpler when dividing the stakeholders into four big groups, the port authorities, the public sector, the private sector and the organisations & institutions
- Then divide into more specific groups such as: shareholders, administration, port users, scientific institutions, government organisations, local authorities, national regulator etc.

Step 3: Identification of the value objectives

This step describes the identification of the value objectives. As far as the fundamental values is concerned, their identification is provided by the literature. Such values can be found in the analysis of the ports of Rotterdam, Long Beach, Los Angeles and Piraeus. The basic fundamental values found are the economic growth, the environmental protection, the society improvement, the accessibility and the safety. Regarding the value objectives, they should be identified by the stakeholders based on the idea of dynamic input of data. The value objectives consist the decision criteria that the stakeholders use for the technology selection. A questionnaire is used in order to take as input these values. A list of value objectives found in the literature is provided to them. In addition, they are free to reply to this questionnaire with the value objectives that they use when deciding on a technology even if it is not included in the list given. Finally, the value- tree should be designed. An example is the following figure with three fundamental values and their relevant value objectives.

List of Value-objectives
income, profitability, productivity, efficiency, competitiveness, circularity, employment, synergies, external safety, health risks, emissions, livability, social stability, energy security, capacity, availability, aesthetics, longevity, use of space, entrepreneurship

Table 11 List of value objectives provided

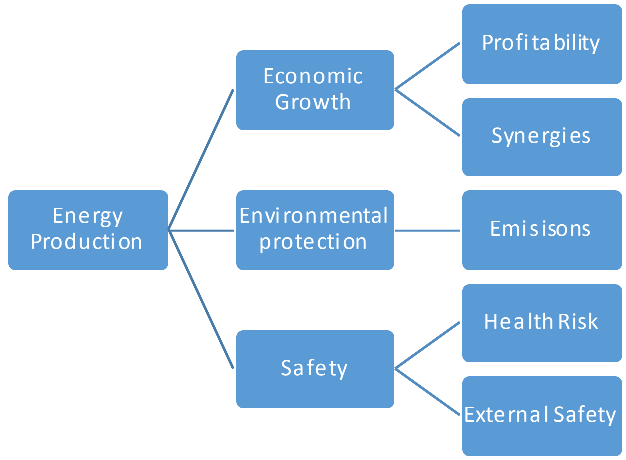

Figure 10 Example of a values-tree

Step 4: Use of AHP sub-tool to identify the importance of the values

The AHP contributes in the identification of the weights of the relevant fundamental values. These weights express the importance that the fundamental values have as criteria for decision making for each of the stakeholders. A questionnaire is used in order to collect the data from the stakeholders. This questionnaire contains the comparisons among the fundamental values that the stakeholders have to reply. When all the stakeholders reply this questionnaire, the method will provide the weights of the fundamental values. According to AHP, a 5 point scale should be used. An example of a question and the relevant scale is presented below:

Question:
Do you believe that economic growth is more important than environmental protection?

- Much less important
- Less important
- Same importance
- More important
- Much more important

Scale:

Much less important: $\frac{1}{10}$

Less important: $\frac{1}{5}$

Equal importance: 1

More important: 5

Much more important: 10

An example of the reply of all the questions for each of the stakeholders is presented below:

	Economic growth	Environmental protection	Safety
Economic growth	1	5	0.2
Environmental protection	0.2	1	1
Safety	5	1	1

Table 12 Example of an AHP table

Then, by using the averages of all the stakeholders' replies, the process as explained in Appendix D leads to the final results (weights). An example of weights is the following:

Fundamental values	Overall weights
Economic growth	2.38
Environmental protection	1.85
Safety	2.82

Table 13 Example of weights of fundamental values

Then the weights are assigned to the value objectives according to the method presented in Appendix D.

Value objectives	Overall	Direct participation	Indirect participation
Profitability	1.19	1.44	0.87
Synergies	1.19	1.44	0.87
Emissions	1.85	0.94	0.67
Health Risk	1.48	1.50	1.46
External Safety	1.48	1.50	1.46

Table 14 Example of weights of value objectives

Step 5: Creation of emission footprint inventory for the relevant to the vision emission sources

In this step the emission inventory is built related to the emission sources of the chosen category of technologies. For instance, in the case that the chosen LEPTs are related with the energy (electricity) production (covering part of the consumption of the shore-related operations), the emissions inventory will be based on the energy mix of the grid which is usually the provider of electricity. Other case is the emissions of the machines that are used when exploring the technologies related to Low Emission Machinery etc. Such an inventory could be the following.

Emission type	Type A (g/kWh)	Type B (g/kWh)	Annual Type A (tn/year)	Annual Type B (tn/year)	Total (tn/year)
SO_2	35	12	2,800	960	3,760
CO_2	1200	520	96,000	41,600	137,600
NO_x	3	1.2	240	96	336
PM	0.2	0.6	16	48	64

Table 15 Example of emission footprint inventory

Step 6: Identification of the Low Emission Port Technologies that can be applied

Regarding this step, two main analysis should take place. The first one refers to identification of the circularity opportunities in the port area based on the Low Emission Port Technology category chosen. The literature or field research should take place in order to explore whether there are technologies that can be used in order to realise one of the three R's (reuse – reduce – recycle).

Reuse: technologies that use energy / materials for the same purpose for which they were conceived and reduce emissions (e.g. Heat exchangers, batteries to store excess of electricity (energy recovery))

Reduce: technologies that reduce the energy / material use and at the same time reduce the emissions (e.g. more efficient appliances in the terminals, more efficient low sulphur engines in the trucks etc)

Recycle: technologies that use energy / material in reprocessing in order to reduce emissions (e.g biogas, biomass)

Based on the available technologies in the market and on the results of the research for circularity opportunities, the final list of technologies that can be implemented is provided. The quantitative criteria of these technologies with the relevant available legislation are important to be identified. The following table provides with the data that should be examined per category of Low Emission Port Technologies.

	Dry Bulk	**Low Emission Machinery**	**Energy Efficiency**	**Energy Production**
Economic criteria	Initial capital cost, M&O cost	Initial capital cost, M&O cost, payback time	Initial capital cost, M&O cost, payback time	Initial capital cost, M&O cost, payback time, LCOE
Mitigation potential	Emission reduction	Emission reduction, Emission levels emitted (if)	Emission reduction	Emission reduction, Emission levels emitted (if any)
Long-term vision	Lifetime	Lifetime	Lifetime	Lifetime
Use of space	Minimum area needed	Minimum area needed	Minimum area needed	Minimum area needed, energy generation per area

Table 16 Quantitative criteria per LEPT category

Step 7: Satisficing

The satisficing technique consists the preparation for the final comparison and evaluation of the technologies. It takes into account the results concerning the importance of the values (weights) as found in step 4. Based on these weights, the decision maker sets thresholds. These thresholds refer to the minimum score acceptance that a technology should have in the Pugh's matrix table. In case that the score is lower, then it is not accepted. For the scores, a scale is used, usually the following: "- -", "-", "s", "+", "++". The judgement is performed by the decision maker on the fundamental values and affects the value objectives. At this step the different scores between the direct and indirect stakeholders are taken into account. An example of such thresholds is presented in the following table.

	Overall weights	Direct stakeholders	Indirect stakeholders	Thresholds
Economic growth	2.38	2.84	2.01	“-“
Environmental protection	1.85	1.75	1.93	no
Safety	2.96	3	2.92	‘’-‘’

Table 17 Example of Satisficing table

Step 8: Use of Pugh’s matrix sub-tool in order to perform the Technology Impact Assessment

This step contains the evaluation of the technologies compared with a datum technology with the use of the value objectives as decision criteria. As datum usually is selected the most widely used technology. The evaluation uses the same scale with the Satisficing method of step 7 and the qualitative data found in step 6. The column impact refers to the value objective. It can be either positive or negative. For instance the profitability is desirable and therefore has a positive impact. On the other hand the emissions is undesirable and has a negative impact. The impact will be included in the TOPSIS (next step). In case the impact is negative, the input in the table is inverted (e.g. “-“ becomes “+”). An example is presented below. Also, at this step the thresholds set in the previous step are applied. There might be technologies that are rejected as they do not pass the previous score.

	PV	wind turbines	biomass	impact
Profitability		“+”	s	positive
Synergies		s	"+"	positive
Emissions		s	"+”	negative
Health Risk		“+”	“+”	negative
External safety		“-“	“-“	positive

Table 18 Example of Pugh’s matrix

Step 9: Use of TOPSIS sub-tool for the final decision

In this step takes place the final evaluation and decision of the technologies. The TOPSIS sub-tool performs trade-offs and has as an output the solution that satisfies at the maximum possible level the decision criteria (value objectives) including their weight. The input of the tool is a number and therefore the above scale should be translated:

“- -“ → 1

“-“ → 3

S → 5

“+” → 7

“++” → 9

The tool input for the above example is presented in the following table with random numbers.

Criteria Name	Weights	Impact	PV	Wind Turbines	Biomass
Profitability	1.19	positive	5	7	5
Synergies	1.19	positive	5	5	7
Emissions	1.85	negative	5	5	3
Health Risk	1.48	negative	5	7	7
External Safety	1.48	positive	5	3	3

Table 19 Example of input in the TOPSIS tool

An example of results could be the following.

Technology	Score
PV	0.488
Wind turbines	0.433
Biomass power plant	0.412

Table 20 Example of results of the TOPSIS tool

Step 10: Emissions projection

Finally, the last step contains the emission projection of the most appropriate technology. In order to calculate the emission projection, the contribution of the new technology is extracted from the existing emission footprint inventory identified in the step 5.

Emission type	Existing situation (tn/year)	Future situation (tn/year)	Reduction annually (%)	Overall reduction at lifetime (tn/20 years)
SO_2	3,760	3,370	10.3%	7,800
CO_2	137,600	115,000	16.4%	452,000
NO_x	336	297	13.1%	780
PM	64	53	17.2%	220

Table 21 Example of Emission projection table

4.4.3 Main assumptions

The non-deterministic nature of socio-technical value based problems explains why the developed tool may not be the only possible one or the most efficient. The application of the decision making tool is influenced by the assumptions that have been made during the development phase. At this section the assumptions are presented so as the future researchers can analyse how these assumptions are influencing the results of the tool and whether possible replacements / adjustments to the tool can be made in order to improve the reliability and the decision making accuracy.

Assumptions:

- The stakeholders to be found are considered to be completely independent
- The stakeholders' power of intervention in the decision making process is considered to be equal
- Fundamental values and value objectives are assumed to be independent from each other
- Value objectives are treated equally (compared to their relevant fundamental value)

4.4.4 Decisions scheme for each step

The following figure shows the steps of the decision making tool, what decisions are taken, how and by whom.

step 1	Set specific vision based on the categories of the Low Emission Port Technologies
What	Selection of a LEPT category to be examined (out of 4 categories)
How	Shore-related emission sources that need to be addressed
Who	Port Authorities
step 2	Identification of all the relevant stakeholders
What	Identification of the stakeholders and categorization of them into direct and indirect
How	Find the stakeholders that are participating in the decision making process and those that are affected by the technology implementation. Focus on groups of stakeholders
Who	Port Authorities
step 3	Identification of the the value objectives
What	No decisions to be made (procedural step)
How	Use of questionnaire for data input
Who	Port Authorities, Stakeholders
step 4	Use of AHP sub-tool to identify the importance of the values
What	No decision to be made (procedural step)
How	Application of the AHP sub-tool
Who	Port Authorities
step 5	Creation of emission footprint inventory for the relevant to the vision emission sources
What	No decision to be made (procedural step)
How	Emission sources analysis related to the chosen LEPT category and creation of the inventory
Who	Port authroties - organisations / institutions / companies that provide knowlegde
step 6	Identification of the Low Emission Port Technologies that can be applied
What	LEPT available in the market (with analysis of their quantitative data)
How	Exploration of good practises / technologies that reduce the footprint of the chosen emission sources
Who	Port authroties - organisations / institutions / companies that provide knowlegde
step 7	Satisficing
What	Thresholds as preparation for the evaluation of the LEPT
How	Based on the weights of the values provided by the AHP analysis
Who	Port Authorities
step 8	Use of Pugh's matrix sub-tool in order to perform the Technology Impact Assessment
What	Evaluation of the LEPTs through comparison
How	Expert(s) with the use of the Pugh's matrix (quantitative data found in step 6 are taken into account)
Who	Experts - organisations / institutions / companies that provide knowlegde
step 9	Use of TOPSIS sub-tool for the final decision
What	Selection of the most appropriate LEPT
How	Results of the TOPSIS tool (based on the scores of each LEPT)
Who	Port authroties - organisations / institutions / companies that provide knowlegde
step 10	Emission footprint projection
What	No decision to be made (procedural step)
How	Calculations on the impact of the chosen technology to the emission footprint
Who	Port authroties - organisations / institutions / companies that provide knowlegde

Table 22 Ten-steps decision analysis

Chapter 5: Application of the Decision Making Tool to Piraeus port

In this chapter takes place the application of the developed Decision Making Tool to Piraeus port. Specifically, this chapter contains the information found during the application of the tool for each of the ten steps of the tool. Also, the information regarding the Piraeus port and the stakeholders that are involved are presented. The main goal of this application is to provide an insight to the processes and the possible issues of understanding.

5.1 Vision, assumptions and data management

The first step of the Decision Making Tool to be applied is the vision. Also, the main assumptions used and the data management are mentioned in this subchapter. Although the research on the port of Piraeus and the port area was deep, it cannot be considered as a case study but as an illustration study because of the assumptions that were made regarding the stakeholders' analysis and the randomness of the selection of the participants in the survey that helped with the data gathering and processing.

5.1.1 Step 1: Vision for the case of Piraeus port

To begin with, the Decision Making Tool should be applied for a specific vision. This vision should be based on the categories of Low Emission Port Technologies (dry bulk, low emission machinery, energy efficiency, energy production). In order to meet the scientific content of the MSc Sustainable Energy Technology, the vision of this illustration focuses on the energy production category. It is set as "Implementation of renewable technologies for electricity generation that can reduce the emission footprint of the Piraeus' shore-operations". The renewable technologies that generate electricity are included in the category of solutions referred as "energy production" as part of the Low Emission Port Technologies.

Currently, the port of Piraeus with an exception of a small PV system, uses the energy from the energy mix of the country which depends on fossil fuels at a level of 50%. The low-emission energy generation is not going to affect directly the emission levels of the port area, but it can help reduce the overall impact as described in the first chapter by the term "emission footprint". Also, the port of Piraeus has plans to implement on-shore based measures so as ships could use electricity in the port instead of their engines which will increase the electricity consumption. (Piraeuspress, 2016) The renewable technologies can provide part of this energy needed.

5.1.2 Data management

The data are retrieved by the use of two methods, the information published online and the questionnaires. The online information can be found not only from the original website of the port, but also from numerous additional websites related to administrative, technical and economic features. This information helps in the identification of the relevant with the vision stakeholders. As far as the questionnaires are concerned, three different questionnaires are used: for the identification of the values objectives (values-tree), for the weighting of the values (AHP sub-tool) and for the evaluation of the technologies (Pugh's matrix). The participants, their role and the relevance with the research topic as well the questionnaires themselves can be found in the appendix E with the reference of this information to be called during the different stages of the process in this chapter.

5.2 General information of Piraeus Port

The port of Piraeus is the biggest port in Greece and one of the biggest in Mediterranean. The port has a continuous history as its establishment can be tracked back in 2600 B.C. Piraeus acted as the main port of ancient Athens which was an important commercial centre of all the Greek regions of the ancient times. The end of the Greek era led the port activities to be reduced for a period of 15 centuries. The port was used only sporadically during the Byzantine and Ottoman periods and it was often occupied by pirates. During the 19th century and after the liberation of the Greek state, the proximity to Athens which was the capital of the newly liberated state played again a significant role. The infrastructures such as railroad and the industrial development made the port a national transportation hub. (Hadjimanolakis Y., 1997)

By the beginning of the 20th century, the increased need of independent management of the port development led to the establishment of the Administration Committee of the Piraeus port. The electrical connection led into an increase of factories and small industries that were located around the port area which traded their products through the port. In 1911, the port authorities were allowed to management autonomy with a special governmental agreement that established a new administrative entity, the Port Committee. The Port Committee had the autonomy to decide on topics related to planning, funding, maintenance and general development. But with the increase of the port traffic, there were a lot of conflicts because third parties had control on several processes that were taking place in the port. That was solved in 1930 with the establishment of the Port of Piraeus Authority, known also as PPA, which granted broader jurisdiction to the public administrative body of the Piraeus port. The decision to centralize all the responsibilities of management into the PPA was the reason behind the rapid development of the port. (Hadjimanolakis Y., 1997)

Today, the port of Piraeus consists a major commercial and transportation hub. The relatively short distance from Suez Canal explains the increase of the import of large amount of Asian cargo in Europe. The cargo is mostly is related to cars or electronic devices which are exported from China and Japan and use Piraeus as the gateway of Europe. For instance, around 500.000 new cars (land area 180,000 m2) from Asian countries arrive each year in the port facilities with more than 75% of them to be shipped to other Mediterranean countries (OLP, 2016). Annually, 47,000 vessels of all kinds are served in total with 1.100 personnel to be employed by the PPA. The passenger's hub can serve approximately 20 million passengers every year including cruise-ship facilities which can serve up to 11 large cruise-ships and they include two passenger terminals. Piraeus port is ranked third worldwide in passenger traffic. The cargo facilities is ranging over three berths (Pier I, Pier II and Pier III) which together have storage capacity at the levels of 190,000 m2. The cargo handling equipment includes 60 transport vehicles and 14 cranes. (PPA, Strategy and Vision, 2016)

It is also important to be mentioned the new situation that arised in 2014 after the agreement of the PPA with the China Ocean Shipping Company (COSCO). COSCO is a state company of the People's Republic of China and is based in Beijing. It is the owner of more than 130 ships and it is active in more than 100 major ports worldwide. It participates in the Piraeus port with two sister companies COSCO Hellas and Piraeus Container Terminal, known also as PCT. COSCO is active in the fields of cargo transport, ship building, port terminal infrastructure and operation (COSCO, COSCO group container lines, 2015). The agreement of Piraeus and COSCO was in the region of 368m € which started in January 2015. The company will also take the 67% of the PPA shares (now has 51%) (Stamouli N., 2016). The company will invest in the Piraeus port 558m € in the fields of shipbuilding and cruising industry as well as in the field of shipping container facilities and transportation of oil products (Smith H., 2016). The agreement also defines that the PPA will receive through dividends an estimated amount of 109m € by the end of 2021. Moreover, the investment of COSCO enhances the collaboration between the PPA and the Chinese market which benefits the global port status and are going to be major source of income for the port in the future (Paris C., 2016).

The port city that surrounds the port is the Piraeus municipality. The mayor of the Piraeus is also member of the board of directors which consists of 11 members, 7 representing the Chinese interests and 4 representing the Greek interests including the major. Piraeus city was developed in parallel with the port. It is a metropolis of around 500,000 residents. Piraeus economic activity is related to the hub and a lot of companies (headquarters of ship-owners) that can be found in the street "Akti Miaouli" have large shipping activities worldwide (Hellenic Statistical Authority, 2011). In the past there were a lot of small and medium sized industries in the port area but now due to legislation that was applied in 1984, only very small factories were allowed and the rest should be relocated outside the region of Attica. Moreover, according to the legislation, there could be only petrochemical activities related to the refineries and shipbuilding industries (Christodoulakis A., 1999).

At this point it important to be mentioned that Piraeus port is following an environmental policy. It is member of the Ecoports network since 2004. Also, in the framework of the corporate social responsibility of the port authorities, the port participates in the Port Environmental Port System, known as PERS (environmental management scheme from ESPO) since 2011 and has been certified on four consecutive occasions (last was in March 2014). Piraeus uses also the Self Diagnosis Method (SDM) which was also initiated by ESPO. The method's assessment criteria are based on the international standard ISO 14001. Both PERS and SDM have been analysed in the third chapter. Finally, the organization and monitoring of the port's performance was established by Lloyd's. Based on all the above information, it can be clearly defined that port keeps a record with the parameters associated with the environment impact of the port operations and tries to apply a more environmental friendly agenda. (OLP, 2016)

Moreover, the port administration is developing twelve domestic environmental programs in collaboration with universities, domestic institutions and independent scientists. One of these programs is related with the measurements of the air quality. More specifically, a monitoring station was installed in the central area of the port and its results are analyzed by the National Technical University of Athens (NTUA). The measurements refer to CO, CO_2, NO_x, SO_2, O_3, $PM_{2.5}$ and PM_{10}. Furthermore, although there is only one photovoltaic (PV) installation in the port area, there are plans for future projects. The power of the existing installation is 430 kWp which is installed in the container terminal (OLP, 2016). Although the future plans include the installation of large PV power plants (3.5 MWp), the plans are not running yet because of discussions regarding relevant technologies that may be used instead of PVs. The reason is that PV power plants need more space than other solutions and the space is important for the port as a transportation hub (Goudis N., 2016). Apart from the PV power plant, there is one more project that should be mentioned and that is electricity generation by the use of bio-fuels. In a distance of 2km from the Piraeus port there is a small island which is used for black and grey water treatment that is originated from the Piraeus municipality. During the treatment and more specifically during a process that is called anaerobic digestion, which has a by-products biogas, methane and CO_2. The biogas is used for a combined cycle generation of electricity which covers the electricity needs of the processes and the excess is injected back to the grid. This process is associated with the idea of circularity as from waste there is production of electricity and heat. Finally, although the introduction of on-shore electricity supply for the cruise ships as a first step is on the plans of the PPA and COSCO, still there is no infrastructure to allow such a connection. According to PPA, the main problems of such an investment right now is the economic feasibility and lack of standardization. But as more and more ports worldwide invest in such technologies, the onshore power supply becomes attractive solution for the lowering of the emissions in the port (EYDAP, 2015).

5.3 Step 2: Identification of the stakeholders

In this section, the identification and analysis of the stakeholders that are related to the vision will take place. Firstly, as not all the stakeholders participate in the decision making process, it is important to divide them into two different categories. Those who are directly involved in the decision making process and those who are indirectly involved by means that they may influence the decision or may be affected by the decision (positively or negatively) regarding the technologies that are going to be implemented in the port area. The number of stakeholders that is identified depends on the judgement of the author.

5.3.1 Stakeholders directly involved in the decision making

At this part of the sub-chapter the stakeholders that are responsible for the decision making and are relevant with the energy production technologies will be analysed. All of them consist the main stakeholders of the Piraeus port. These stakeholders are the Piraeus Port Authority, the COSCO, the ship owners, the municipality of Piraeus and the Regulatory Authority for ports.

Piraeus Port Authority (PPA)

The Piraeus Port Authority is the most important stakeholder related to the port of Piraeus. It is responsible for the administration of the port and as mentioned in the previous subchapter, since 1930 it is completely autonomous for the taking decisions related to the port area and port operation. Also, PPA consists a for-profit organisation and its shares are traded in the Greek stock market exchange. Since August 2016, it is decided that COSCO will buy the 67% of the shares. Moreover, 26% of the PPA shares belong to ship owners and 7% of the shares belong to the municipality of Piraeus. (OLP, 2016) Based on these information it is clear that the PPA goals and interests are influenced by these stakeholders.

The main goal of the PPA is the economic growth. However, the economic growth should not come at the cost of other values related to social and environmental factors. To begin with, the port uses advanced environmental management systems in collaboration with ESPO at the Ecoports program. Apart from that, the port has plans to enhance the green energy production and reduction of the pollution (with focus on emissions, noise and water) in the port area (PPA, Strategy - Vision, 2016). Another important goal that PPA has set, is to improve the social responsibility factor. Except for the environmental measures the plan contains the increase of the number of job positions that will be available in the port area, support humanitarian and cultural activities and support vulnerable social groups that are located in the port city. (PPA, Social Responsibility, 2016)

COSCO

As mentioned above, COSCO's involvement in 2015 and 2016 in the Piraeus port as the largest shareholder is one of the most important events in the history of the port since 1930. The agreement between PPA and COSCO is expected to boost the profitability of both COSCO and PPA as the company's plan is to increase the cargo capacity and invest in the infrastructures of the port so as to use Piraeus port as a transportation hub in order to promote the Asian products in the eastern and central Europe. Furthermore, another main goal of COSCO for the Piraeus port is to create synergies. The privatization of the port created a lot of demonstrations and the employees of the PPA with the companies that have business activities related to the port expressed their concerns regarding the agreement. The synergies could help the minimization of the negative opinion and help the domestic economic growth. (Kollias F., 2016) Furthermore, COSCO with its framework of social responsibility sets as important factor of the port development the environmental protection. The company develops green energy projects in the port infrastructures and has also as a goal to minimize the environmental impact of the ports by achieving emission reduction in a number of its terminal worldwide (mostly in China). (COSCO, 2007) The same interest regarding environmental responsibility the company has for the port of Piraeus where it believes that it can benefit also from the good reputation regarding such actions. (COSCO, COSCO group container lines, 2015)

Ship Owners

The ship owners' stakeholder group includes the owners of all types of ships that are active within the commercial port of Piraeus. For example the owners of the cargo ships, ferries, cruise ships etc. The vast majority of the ship owners participate in the decision making process as their association contains 26% of the shares of the PPA. Their goals are mostly related to the economic growth, accessibility and availability of the port area for their ships. (Liagkouras, 2015) Regarding the environmental goals, their main concern is to follow MARPOL protocol and be compliant with the upper allowed limits of SO_x and NO_x emissions (International Maritime Organisation, 2016). Complying with the compulsory regulation contributes to the companies' social responsibility. Moreover, although the onshore green energy projects do not directly affect any of their economic activities, they can benefit from the good reputation that the port will gain by taking actions in order to reduce the environmental impact and from the dividends, as green energy projects will help the profitability of the PPA.

Municipality of Piraeus

The municipality of Piraeus consists a major stakeholder as it is affected directly from the port policies and interacts with the majority of the stakeholders. As mentioned above, the municipality of Piraeus has the 7 % of the PPA shares and participates in the decision making process. The municipality has multiple goals regarding the port operation and the decisions regarding it. To begin with, the economic growth of the port will affect not only the income of the municipality but also the income of the residents of the port city. From a social point of view, the main interests of the municipality are the safety and health of the residents from the port operations or the expansion of the port and the minimization of the possibility of accidents. Accessibility is also of a great importance for the residents when refers to the traffic that can be observed in the port city that is related to the port activities. Another social aspects that are important for the municipality are the use of space in the port city and the employment opportunities that are presented in the port area. Finally, the improvement of the air quality and the noise from the port operations are important issues that should be satisfied. (Municipallity of Piraeus, 2016)

Regulatory Authority for Ports

The regulatory authority for ports is a new organisation that was established in April 2014. The main responsibilities of this organisation is to monitor the implementation of public-private agreements in the Greek ports and to ensure the compliance with the agreed service levels. These agreements contain specific performance levels, job creation, compliance with environmental agreements etc. Moreover, the organisation consults the port authorities by expressing the governments' interests but cannot intervene in the decision making. However, the regulatory authority for ports acts as a control mechanism and it should approve the decisions made e.g. in order to avoid market manipulation. (Raports, 2014)

5.3.2 Stakeholders indirectly involved in the decision making process

In the second part of the stakeholders analysis are included the stakeholders that are indirectly involved in the decision making process. These stakeholders are the Residents, the Public Power Corporation, the Ecoports network, the Passengers, the Fossil Fuel companies and the Transportation companies.

Residents

The residents of the Piraeus port consist a major stakeholder. Although they do not participate in the decision making, they are directly affected by the port's operation and therefore their opinion should be taken into account. There are cases that the residents threatened the development of projects. Such a case is the marina of Zea, where was supposed to become a park with tree and in the end there were plans to be used for yachts (AMPE, 2013). From a socio-economic point of view, the residents of the port city consider the value of employment of high importance due to the high unemployment rates of Greece. The implementation of renewable technologies in the port area could contribute towards the reduction of these rates during the construction and maintenance phase. Furthermore, the environmental impact of the port activities is an important factor that residents demand to be minimized. Another factor that should be eliminated according to the residents is the health risk.

Public Power Corporation (PPC)

The Public Power Corporation is a group of companies that are responsible for the generation and the distribution of electrical energy and the maintenance of the existing infrastructures. The PPC is the greatest energy producer in Greece (13.2 GW) and the only distributor. In addition, PPC is responsible for the evaluation and approval of the electricity generation related project designs and of the connection of these projects to the electricity grid. PPC strategic aim is to promote the integration of the renewables in the energy mix of the country. Also, it has developed business plans for developing collaboration between individuals or organisations such as PPA in order to help financing renewables' projects. (Ministry of Environment and Energy, 2016)

Ecoports Network

Ecoports network was initiated by ESPO and PPA is a member since 2004. The main goal of the Ecoports network is to achieve the best possible environmental performance by applying environmental management and following the good practices as they have developed in the network (subchapter 1.2 and appendix A). According to the information found in the strategic documents, the Ecoports are interesting for the development of the triptych "people" – "profit" – "planet" which can be translated into the society improvement, economic development and environmental protection. (ESPO, 2012)

Passengers

As mentioned above, the port of Piraeus is a major hub for passengers that travel to the islands or visiting Piraeus and Athens from cruise ships. Passengers are associated with the value of accessibility as they do not want to experience traffic jams and any kind of delays. Another topic that is considered important by the passengers is the aesthetics of the port. Although aesthetics factor is difficult to be measured (subjective factor), it expresses the general feeling of the open space around the port. Finally, the time that the passengers will stay at the port, they are influenced by the environmental factors such as the air quality. (Liagkouras, 2015)

Technology suppliers

The technology suppliers include the companies that are responsible for the renewable technology solutions that are going to be implemented in the port area. The main goal of this group of stakeholders is the economic growth. Also, most of the companies care about the creation of societal value and it can be found as a main value in their strategic planning. The societal value is mostly related to the employment because of the economic crisis effect of high unemployment rates. Another important aspect is the safety of the products they deliver. (Liagkouras, 2015)

5.4 Step 3: Identification of the value objectives

The third step of the tool explores the value objectives that are related to the fundamental values (as found in chapter 2) as decision criteria for the stakeholders. The participants have chosen specific value objectives and have assigned them to these fundamental values. The questionnaire and the reply of each of the representatives of the stakeholders can be found in appendix E. Also, during the process the stakeholders were free to propose other values except for the ones presented. The value objective of "noise" was identified. At this point it is important to be mentioned that the value-objectives "entrepreneurship" and "synergies" was decided to be put together as a values group. The reason behind that is the high possibility for dependency between these two values. They both explain the effort towards economic development, through individual effort (entrepreneurship) or combined effort (synergies). Moreover, the formulation of a values group contained by the aforementioned values was proposed by Mr. Bantias, vice-presindent of the Regulatory Authorities of Ports. The value objectives that were identified are the presented in the following values-tree figure.

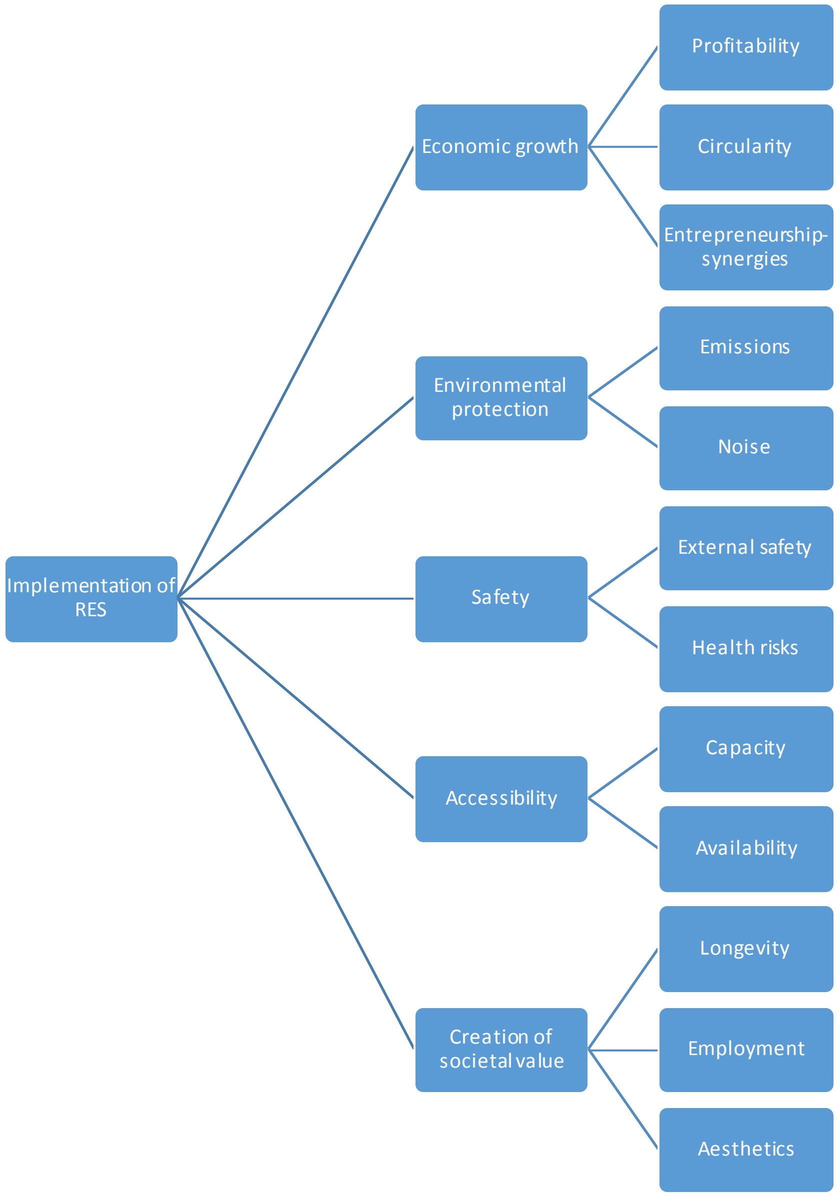

Figure 11 Piraeus values-tree

5.5 Step 4: AHP sub-tool analysis

According to the tool, the fundamental values that are presented in the values tree table are the input of the AHP analysis. The pair-wise comparison of these values was made based on the stakeholders' opinion and expresses the importance that these values have for the decision making regarding technological artefacts. The consistency factor was in all cases under 0.10 so there was no need answers to be excluded. More information regarding the questionnaire used and the analytical answers of each of the stakeholders is presented in the appendix E. The results of the AHP analysis are the following:

Fundamental values	Overall weights
Economic growth	2.38
Environmental protection	1.85
Safety	2.96
Accessibility	1.89
Creation of societal value	2.85

Table 23 Overall weights of the fundamental values

	Economic growth	Environmental protection	Safety	Accessibility	Creation of societal value
COSCO	3.5	1	3.5	4	1.69
Ship owners	4	1	2.49	2.49	1.34
Municipality of Piraeus	1.03	1	2.04	1.43	4
Regulatory authorities of ports	2.83	4	4	1	2.66
Residents	1	1	2.89	1.12	4
PPC	1.25	2.01	3.28	1	4
Ecoports	2.83	4	3.23	1	4
Passengers	1	1.07	2.12	4	1.77
Technology suppliers	4	1.57	3.11	1	2.18

Table 24 Individual weights of the stakeholders

Apart from the overall weights of the fundamental values and the weights for each of the stakeholders separately, it is also important to present the weights divided into direct and indirect stakeholders. Based on the following table some remarks can be drawn. Firstly, safety is considered the most important value for both categories. The biggest differences are noticed in the values creation of societal value and economic growth.

Fundamental values	Weights of stakeholders' values	
	Direct participation	Indirect participation
Economic growth	2.84	2.01
Environmental protection	1.75	1.93
Safety	3	2.92
Accessibility	2.23	1.62
Creation of societal value	2.42	3.19

Table 25 Weights of fundamental values based on participation in the decision making process

The following table represents the overall result on the value objectives.

Values objectives	Overall	Direct participation	Indirect participation
Profitability	0.78	0.94	0.67
Circularity	0.78	0.94	0.67
Entrepreneurship-synergies	0.78	0.94	0.67
Emissions	0.93	0.88	0.97
Noise	0.93	0.88	0.97
External Safety	1.48	1.50	1.46
Health Risks	1.48	1.50	1.46
Capacity	0.95	1.12	0.81
Availability	0.95	1.12	0.81
Longevity	0.95	0.80	1.05
Employment	0.95	0.80	1.05
Aesthetics	0.95	0.80	1.05

Table 26 Weights of values objectives based on participation in the decision making process

5.6 Step 5: Creation of emission footprint inventory

According to the subchapter 4.4.2, before creating an emissions inventory, it has to be examined what the main emission sources related to the vision are. The vision is related to the electricity generation from renewable sources in the port area. The goal is to produce a part of the electricity consumption of the port from low emission electricity generation. Thus, based on the information provided in the subchapter 4.1, the electricity consumption is main emission source. Based on that, the emissions footprint of the port is related to the electricity consumption. The port operations are electrified from the national electricity grid (national energy mix). So, in order to create the emissions inventory two important values need to be examined, the electricity consumption of the port and its relevant energy mix emissions.

To begin with, in the literature there were no data available regarding the overall energy consumption of the Piraeus port shore-operations. Thus, the data of a port that has relatively similar size, traffic and operations (cargo and passenger activities) should be used. Such a case is the port of Los Angeles. The data from the port of Los Angeles will be used in order to define the electricity consumption. The port of Los Angeles consumed in 2012 200,000 MWh of electricity and this number will be used also for the illustration. (Port of Los Angeles, Energy Management Action Plan, 2014)

The next step is to define the emissions from the national energy mix. According to the Hellenic Electricity Distribution Network Operator (HEDNO), the lignite accounted for 49% of electricity generation in the interconnected system, natural gas for 20.2%, and RES (including large hydro-power) for 30.5% (Greek Ministry of Energy, 2017). Thus, the 30.5% of the 140,000 MWh should be excluded as the rest is produced from emitting technologies. In addition the, the port authorities have already installed a PV system which contributes to the lowering of the emissions. The electricity produced by this should be reduced from the overall consumption. The 430 kWp PV installation produces around 730 MWh annually (PVgis, 2016). So, the new consumption can be estimated to be 139,000 MWh. The annual electricity that comes to the port from lignite is 68,000 kWh and from natural gas is 28,000 kWh. In addition, according to a study for combustion power plants, the emissions from the lignite electricity production are the following: SO_2 = 32.85 g /kWh, CO_2 = 1085 g / kWh, NO_x = 2.42 g / kWh and PM = 0.24 g / kWh. According to the same study, the natural gas emissions are the following: SO_2 = 0.006 g /kWh, CO_2 = 631 g / kWh, NO_x = 0.83 g / kWh and PM = 0.035 g / kWh. (Argonne, 2012) Based on the above data the following table explains the annual emissions of the port.

Emission type	**Lignite (g/kWh)**	**Natural Gas (g/kWh)**	**Annual Lignite (tn)**	**Annual Natural Gas (tn)**	**Total (tn/year)**
SO_2	32.85	0.006	2,233	0.168	2,233
CO_2	1085	631	73,780	17,668	98,448
NO_x	2.42	0.83	164	23.24	187.24
PM	0.24	0.035	16.32	0.98	17.3

Table 27 Emission footprint for port of Piraeus (from electricity consumption)

5.7 Step 6: Identification of the Low Emission Port Technologies that can be applied

This step describes the identification of the technologies that can be applied. First, the circularity opportunities are explored in the port and port area and then the available low-emission renewable technologies are explored.

5.7.1 Circularity opportunities in the port area

The results from this process helps in the exploration of the available renewable technologies that can contribute in the circularity. For this step the field research is important. However, for the cases of this illustration study, a literature exploration takes place. According to the subchapter 4.4.2, the 3 R principles (reuse-reduce-recycle) are explored. Regarding the renewable technologies, the principles of reuse and recycle were identified in the port area. (SEV, 2016) In the port area, there are a lot of petrochemical industries and refineries. (OLP, 2016) The use of the hydrogen (by-product of the refineries) in order to generate electricity consists a circularity opportunity (reuse). Moreover, the waste from other processes that take place in the Piraeus city and port area can be used for electricity generation. Such use of waste could be the biomaterials from the city waste or even agricultural residues from the agricultural areas close to the Piraeus port. (SEV, 2016)

5.7.2 Available Low Emission Port Technologies related to energy (electricity) production

The next step of the tool is the identification of the technological artefacts that are related to the vision that was set for the illustration of the Piraeus port. In this subchapter, the technologies will be briefly described and the quantitative data will be presented. However, all the detailed numbers are indications based on information retrieved from literature analysis based on specific sized systems. The legislation related to the renewables and low emission technologies is the paper 4414 / 2016 FEK 149/A/09-08-2016 and it includes all the technologies except for the tidal energy (Ministry of energy, 2016). Finally, the technologies that are selected to be examined are mainly used by ports or planned to be used by ports. More information for each of the technologies can be found in the appendix E.

Photovoltaics

The photovoltaic technology is one of the most common technologies that is applied in a lot of ports already for example in Piraeus, Barcelona, Stockholm, Los Angeles, Tenerife, a lot of ports in India etc. The working principle of such a system is simple. The conversion of light energy into electrical energy based on a phenomenon called photovoltaic effect. The system contains the photovoltaic modules, the inverter(s), cables, meters and safety devices. The photovoltaic system can be installed not only on the roofs but also on the field. The roof installation is considered to be more expensive (around 15 € / MWh) in comparison with field installations (8 € / MWh). The expected lifetime is high and the maintenance costs are low.

For the port of Piraeus, the photovoltaic technology is considered as a suitable technology mostly because of its low initial cost and of the high irradiance levels at an average of 1950 kWh /m2 (appendix E). As mentioned also in the previous chapter, there is a photovoltaic installation of 430 kWp and a plan for a project of total power 3.5 MWp. On the other hand, the application of this technology created debates regarding how much power should be installed. Due to its low production per square meter rate, the need to cover a significant amount of energy consumption of the port activities means that there is high need to install not only on the roofs of the existing buildings in the port but also on field areas in or around the port. The problem with the land use is that it competes with the economic activity of the port. In addition, the location of the photovoltaic installation should be not shaded, and by taking into account the fact that the port side is facing south, there are also restrictions of land use in front of the installation. Another problem that should be considered is the aesthetics. There are some debates in Greece whether the photovoltaic installation should be used in large scale in dense populated areas because of their dark colour and their industrial view. (Goudis N., 2016)

Quantitative data of the technology

LCOE: 105 euros / MWh (Fraunhofer ISE, 2014)

Initial Capital Cost: Low (Parida B., 2011)

Electricity generation: 270 kWh / m2 (PVgis, 2016)

Emissions: No emissions

Lifetime: 25 years (Parida B., 2011)

Maintenance & Operation cost: Low (Parida B., 2011)

Minimum area required: 15m2 (Parida B., 2011)

Legislation available: Yes

Wind turbines (> 800 kW)

Apart from the photovoltaic technology, another technology that is often used by port authorities in order to generate “green” electricity is the wind turbines. Wind turbine application can be divided into two categories, onshore and offshore. Onshore wind turbines are installed on land and offshore are using foundations in order to be installed in the sea. Both can be connected via the grid directly with the Piraeus port electric substation which lies in the port area. There are already a lot of ports worldwide that are using the energy produced by onshore wind turbines and there are plans for the development of offshore wind turbines. There is a difference in the levelized cost of electricity because of the foundations and the cable connection via underwater cable. (CRES, 2016)

The port authorities of the Piraeus port never examined the case of wind turbines installation due to its high initial capital cost. However, after August and the announcement of COSCO's acquisition of 67% and its plans to further develop the port operations with an increase in the cycle of operation, there are some considerations regarding if they should examine the case of wind turbines due. The reason behind that is the new available capital for such investments from COSCO, its vision to reduce the environmental footprint of the port and the good wind conditions that are observed in the area. The main concerns regarding the wind turbines technology are mostly focused on two issues. The "not in my backyard effect" that may create conflicts with the local residents as the wind turbines can be installed in the port area, on the top of the hills that lie north to the port or to the island of Salamina that lies opposite to the port. In all the places there are houses with permanent residents. The second is referred to the offshore wind turbines and sea traffic that may be created after their installation. Moreover, for the maintenance of the offshore wind turbines, there would be needed space for the maintenance materials and vessels. Finally, another issue that may become a problem for the installation of this technology is the sound is produced when the long blades are rotating. (CRES, 2016)

<u>Quantitative data of the technology</u>

LCOE: 45 euros / MWh onshore (Fraunhofer ISE, 2014)

145 euros / MWh offshore (Fraunhofer ISE, 2014)

Initial Capital Cost: High

Electricity generation: 2,000 kWh / m2 (CRES, 2016)

Emissions: No emissions

Lifetime: 20 years (Signe Gry Braad D., 2015)

Maintenance & Operation cost: High (Signe Gry Braad D., 2015)

Minimum area required: 400m2 (Signe Gry Braad D., 2015)

Legislation available: Yes

<u>Small Wind turbines (<10kW)</u>

Except for the high-power wind turbines, there are wind turbines with power less than 10 kW and can be placed both on the roofs of buildings and on field. Also, there are several types of such wind turbines with some of them to have vertical axis. Although there was no example found in literature of ports that have installed small wind turbines, it is considered as a good solution for cases because of its medium initial capital cost and the simplicity of installation in the case of buildings. The annual production of the system is good compared to the space needed (3 m2 for wind turbines that are installed on the buildings and around 10 m2 for wind turbines installed in the field). It is considered as a relatively new technology in the field of wind turbines.

Regarding Piraeus port authorities, the small wind turbines technology has been proposed to be installed by some companies (e.g. AigeanElectric) but it is not considered as an option right now. The main concerns are referred to the maintenance level needed due to the turbulent flows that may arrive on the blades from the tall buildings in the area and the high possibility of repowering at less than 20 years of lifetime as this technology is not applied for a period that ensures the lifetime expectancy. (CRES, 2016)

<u>Quantitative data of the technology</u>

Initial Capital Cost: Medium

LCOE: 120 euros / MWh (Fraunhofer ISE, 2014)

Electricity generation: 375 kWh / m2 (CRES, 2016)

Emissions: No emissions

Lifetime: 20 years (Signe Gry Braad D., 2015)

Maintenance & Operation cost: Medium (Signe Gry Braad D., 2015)

Minimum area required: 5m2 (Signe Gry Braad D., 2015)

Legislation available: Yes

<u>Biomass power plant</u>

Another technology that is widely used in ports is the biomass power plant. This plant consists of several parts including the storage facilities, the pre-treatment facilities, the water boiler, the steam generator, and in case the system is designed to provide heat (combined heat and power) the heat exchanger with the heating network. The biomass power plant is considered as carbon neutral although it emits SO_2, NO_x and PM but in really low levels. The input of the biomass plant could be energy crops or forest products. However, the cultivation of energy crops such as eucalyptus, poplar and willow compete with the food production and therefore should not be the main source of biomass. The forest products constitute the majority of the biomass today and they are pellets and briquettes that are manufactured by compressing by-products of the forest industry such as bark or small diameter roundwood. (International Renewable Energy Agency, 2012)

For the case of Piraeus port, the biomass power plant could be a good solution due to its medium initial capital cost and the high energy production in respect to the area needed. Also, another advantage is the employment as there are job positions regarding the operation, transportation of the biomass and production. The main concerns of this technology are about the competition between the biomass and food production and the emissions that are production during the thermo-chemical process of combustion that may burden the effect of high emissions that is present in the Piraeus port area. Furthermore, in case that the pre-treatment of the biomass is not successful, the emission levels at the exhaust gases will rise at high levels. (International Renewable Energy Agency, 2012)

<u>Qualitative data of the technology</u>

LCOE: 110 euros / MWh (Fraunhofer ISE, 2014)

Initial Capital Cost: Medium (Fraunhofer ISE, 2014)

Electricity generation: 7,000 kWh / m2 (PPC., 2012)

Emissions:

CO_2: 14.3 g / kWh (Pennise D., 2014)

SO_2: 0.04 g / kWh (Pennise D., 2014)

NO_x: 0.42 g / kWh (Pennise D., 2014)

PM: 0.036 g / kWh (Pennise D., 2014)

Lifetime: 35 years (Pennise D., 2014)

Maintenance & Operation cost: High (Pennise D., 2014)

Minimum area needed: 2800m2 (Cuellar A. D., 2012)

Legislation available: Yes

Biogas power plant

The next technology that can be applied in the port of Piraeus is the biogas power plant. The biomass material that can be used as an input could be bio-waste, agricultural residues and degradable wastes. The biogas is produced by the anaerobic digestion process where the input material is decomposed under specific conditions and produces biogas and fertilizer. The combustion of the biogas takes place in the combustion chamber in order to generate electricity or both electricity and heat (CHP). The main difference with the biomass power plant and, at the same time, the main advantage of this technology is the use of waste material that cannot be burned in order to produce energy. Again, this type of power plants are considered as carbon neutral technology. (International Renewable Energy Agency, 2012)

The main concern regarding this type of power plant is the space that it is needed in order to store the bio-waste or residues that will produce the biogas / biodiesel. Another important issue is the higher levels of emissions that are presented in comparison with the biomass power plant. On the other hand, the possibility to use waste organic material is a high advantage for this technology as the waste from the residential area around the port city or the residues from the agriculture activities that take place in the plain of Kopaida (close distance to Athens) can be used for the production of the biogas. Finally, this technology can be considered as the recycling process of bio-waste as it creates fertilizer that can be used for growing plants.

Qualitative data of the technology

LCOE: 170 euros / MWh (Fraunhofer ISE, 2014)

Initial Capital Cost: Medium (Fraunhofer ISE, 2014)

Electricity generation: 5,300 kWh / m2 (Linke B., 2015)

Emissions:

CO_2: 10.8 g / kWh (Linke B., 2015)

SO_2: 0.36 g / kWh (Linke B., 2015)

NO_x: 0.79 kg / kWh (Linke B., 2015)

PM: 0.02 g / kWh (Linke B., 2015)

Lifetime: 35 years (Linke B., 2015)

Maintenance & Operation cost: High (Pennise D., 2014)Maintenance & Operation cost: High (Pennise D., 2014)

Minimum area required: 2000m2 (Samer M., 2013)

Legislation available: Yes

Hydrogen from refineries / Solid Oxide Fuel Cell – Gas Turbine

The next technology to be examined is the solid oxide fuel cell (SOFC) combined cycle with gas turbine (GT) with the hydrogen input to be produced from the refineries. The hydrogen can be economically extracted from the off-gases of the refineries by using cryogenic separation through a combination of plate-fin heat exchangers and phase separators (Linde Group, 2014). The hydrogen extracted and stored can be used to power the fuel cell combined cycle and produce electricity and heat. The SOFC works at a range of temperatures 750^o C to 1000^o C and the port can benefit from these temperatures in order to provide heat for specific port operations, district heating or the heat can be given back to the refinery. There are already market products related to the system described but the technology cannot be considered as mature enough. (Brandon N., 2014)

One of the main advantages of this technology is its high efficiency (only 10% losses). Another important advantage is that the SOFC – GT system has fuel flexibility and can use bio-gas or syngas (Brandon N., 2014). So, due to unexpected factors such as the relocation of the refinery, the system can still operate but with the use of different fuel. The main issues related to the hydrogen production is that the hydrogen is needed to the refineries in order to lower the sulphur content of diesel fuel. Therefore, there might be a conflict related to the amounts of hydrogen that are available for the SOFC- GT system. Moreover, the hydrogen is very flammable and when stored under high pressure, it is very dangerous for explosions. (Crowl D., 2007)

<u>Qualitative data of the technology</u>

LCOE: 427 euros / MWh (Romeri M. V., 2015)

Initial Capital Cost: High (Brandon N., 2014)

Electricity generation: 5,800 kWh / m2 (Brandon N., 2014)

Emissions: No emissions

Lifetime: 7 years (of the SOFC) (Brandon N., 2014)

Maintenance cost: High (Brandon N., 2014)

Minimum area required: 1500m2 (Brandon N., 2014)

Legislation available: Yes

Tidal Energy

The last technology that is chosen to be examined is the tidal energy. The tidal energy describes the extraction of the energy that comes from the flows that can be found undersea. The technology has been tested during the past 5 years and currently there are development plans from the ports of Milford and Dover. Although it is an already developed technology, it was impossible to find realistic data with an exception of the LCOE and the initial capital cost. Furthermore, there is no legislation available that can cover the tidal energy development in Greece and therefore this technology cannot be considered as an alternative among the technologies described above. Last concern regarding the technology is the absence of current flow data around the area of Piraeus.

Qualitative data of the technology

LCOE: 280 euros / MWh (International Energy Agency, 2015)

Initial Capital Cost: High

Electricity generation: n/a kWh / m2

Emissions: n/a

Lifetime: n/a

Maintenance cost: High

Minimum area required: n/a

Legislation available: No

5.8 Step 7: Satisficing

The next step is the application of the satisficing method. For the satisficing method the results of the AHP method (step 4). According to the opinion of the stakeholders concerning the importance of the fundamental values in the decision making, three thresholds should be placed. Specifically, on the economic growth, the safety and the creation of societal value. The economic growth is considered important (ranked third) in overall but it is very important for the direct stakeholders. Safety is considered as the most important value in overall and for both categories (direct and indirect). Finally, the creation of societal value is ranked second in overall but first for the indirect stakeholders group.

	Overall weights	**Direct stakeholders**	**Indirect stakeholders**	**Thresholds**
Economic growth	2.38	2.84	2.01	"-"
Environmental protection	1.85	1.75	1.93	no
Safety	2.96	3	2.92	"-"
Accessibility	1.89	2.23	1.62	no
Creation of societal value	2.85	2.42	3.19	"-"

Table 28 Thresholds

The thresholds set by the author are “-“ which means that when the comparison of the technologies will take place, the solutions that will score “--“ compared to the datum technology should be rejected as a non-suitable alternative. In addition, the rejection should be applied even when only one of the value objectives scores is lower than the threshold.

5.9 Step 8: Pugh’s matrix

The next step of the tool is the Pugh’s matrix. The matrix is used for the comparison of the technologies with the datum technology on the basis of thee values objectives as comparison criteria. The technologies’ comparison have been evaluated by an expert based on his experience with the specific field of occupation The expert that did the evaluation is Mr. Konstantinos Mavroudis, founder of Aigaioelektrike S.A., consultant and developer of energy projects since 1980 and consultant of the Greek Ministry of Energy for topics related to sustainable energy. He participated also in various business schemes regarding the improvement of the environmental footprint in Piraeus port. The qualitative data that found in step 6 were provided to Mr. Mavroudis in order to perform the comparisons. The datum technology that was chosen by the expert was the PV technology (it has been implemented in the port area). The results of the comparison are presented in the following table.

The last column presents the idea of the impact. The impact is related to the value objectives and more specifically with its attribute to be desirable or not by the stakeholders. The impact consists a preparation for the use of the TOPSIS as it explains the goal-based reasoning of the sub-tool. For the negative impact the, value objective should be minimized by the algorithm of TOPSIS and for the positive the opposite. For instance, in the case of profitability, the “+” on the wind turbines means that they are more profitable in comparison with PV but in case of emissions, the “+” means higher emissions in comparison with PV and therefore should be minimized.

	PV	wind turbines (>800kW)	small wind turbines (<10kW)	biomass power plant	biogas power plant	hydrogen – SOFC / GT	impact
profitability		"+"	"-"	s	s	"--"	positive
circularity		s	s	"+"	"++"	"+"	positive
entrepreneurial-synergies		s	s	"+"	"++"	"-"	positive
emissions		s	s	"+"	"+"	s	negative
noise		"++"	"+"	"+"	"+"	s	negative
external safety		"-"	s	"-"	"-"	"--"	positive
health risks		s	s	"+"	"+"	"++"	negative
capacity		"++"	"++"	"+"	"+"	"-"	positive
availability		"+"	"+"	"--"	"--"	"-"	positive
longevity		"-"	"-"	"+"	"+"	"--"	positive
employment		"+"	"+"	"++"	"++"	"+"	positive
aesthetics		"-"	"-"	s	"+"	s	positive

Table 29 Pugh's matrix

At this point, the results of the satisficing method should be applied. As mentioned in the previous subchapter, the economic growth, the safety and the creation of societal value have as thresholds the "-". In the case of hydrogen / SOFC GT, the scores in the critical values objectives are less than those that are considered "good enough" and therefore should be eliminated as an input for the TOPSIS. Regarding the safety issues that were scored as "--", although there are regulations regarding the safety of the hydrogen technology, still there are risks due to the high pressured storage and transportation. Finally, the rest of the technologies will be compared in the TOPSIS.

5.10 Step 9: TOPSIS

The TOPSIS tool is used for the final decision of the technology that is the most suitable to be implemented in the Piraeus port at the specific moment of time, under the specific stakeholders' conditions and under the specific assumptions. The input of the TOPSIS table is presented in the appendix D. and the results are presented in the following tables. It is important to be mentioned that some of the values objectives use the minimization algorithm and the rest use the maximization algorithm. This is related to the impact presented.

Technology	Score
PV	0.496
Wind turbines	0.427
Small wind turbines	0.466
Biomass power plant	0.472
Biogas power plant	0.544

Table 30 Overall results of the TOPSIS sub-tool

According to the results of the TOPSIS sub-tool, the biogas power plant is the most appropriate technology to be implemented in the port of Piraeus at this moment. The second technology in the ranking is the PV, third the biomass power plant, fourth the small wind turbines and fifth the wind turbines. The difference in the score among Biogas and PV seems to be high enough in order to conclude that there is no need for further examination and comparison. At this point it is important to see also the results of the wo categories of the stakeholders separately.

Technology	Score	
	Direct Stakeholders	Indirect Stakeholders
PV	0.484	0.503
Wind turbines	0.468	0.393
Small wind turbines	0.487	0.466
Biomass power plant	0.435	0.500
Biogas power plant	0.514	0.569

Table 31 Results per category of stakeholder of the TOPSIS sub-tool

In both cases, the biogas power plant is considered as the most suitable solution to be applied. However, in both cases the score of some technologies has changed compared to the overall results table. In the case of direct stakeholders, the small wind turbines are evaluated as second in the ranking.

5.11 Step 10: Emission footprint projection

The last step of the tool is the emission footprint projection considering the impact of the technology to be implemented. In order to define the emissions of the technology chosen, the power to be installed should be identified or even better the annual electricity production should be known. Based on the qualitative data provided in the subchapter 5.7, the annual electricity generation per area for the biogas power plant is 5,300 kWh / m2. However, the estimation of the energy production includes a lot of uncertainties because it is difficult to examine how much the area is available. Based on the report of Samer, an average biogas power plant for large scale applications is estimated to be at the levels of 500 kWp that covers an area of 1200m2 and thus, the electricity that be generated is at the levels of 8,400 MWh annually (Samer M., 2013).

Emission Type	Levels (g/kWh)	Overall (tn)
SO_2	0.36	3
CO_2	10.8	90.7
NO_x	0.79	6.6
PM	0.02	0.1

Table 32 Emissions from the biogas power plant

The new situation should be presented for the case that the biogas power plant is going to be implemented. Based on the analysis of the subchapter 5.6, the consumption should be divided into three parts, lignite, natural gas (grid emitting) and biogas (low emitting). The energy produced by lignite is now 49% of the 139.000 MWh minus the 8,400 MWh of the biogas power plant equals to 63,990 MWh and likewise, natural gas (20.2%) will contribute with 26,380 MWh annually.

Emission type	Lignite (g/kWh)	Natural Gas (g/kWh)	Biogas (g/kWh)	Annual Lignite (tn/year)	Annual Natural Gas (tn/year)	Annual Biogas (tn/year)	Total (tn/year)
SO_2	32.85	0.006	0.36	2,100	0.15	3	2,103.15
CO_2	1085	631	10.8	69,429	16,645	90.7	86,164.7
NO_x	2.42	0.83	0.79	154	21.8	6.6	182.4
PM	0.24	0.035	0.02	15.35	0.92	0.1	16.37

Table 33 Emissions projection annually

The following table explains the annual reduction of the emission footprint (%) and the overall reduction of emission footprint (tn) after the lifetime of the biogas power plant (35 years) by taking into account the existing emission's inventory as presented in the subchapter 5.6. After the implementation of the biogas power plant, it seems that there is a reduction of the annual emissions at an average total level of 6%. The important thing to be mentioned is the high reduction of the CO_2 emissions after the lifetime which is at the levels of 429,940 tonnes.

Emission type	Existing situation (tn/year)	Future situation (tn/year)	Reduction annually (%)	Overall reduction at lifetime (tn/35 years)
SO_2	2,233	2,103	6%	4,550
CO_2	98,448	86,164	12.5%	429,940
NO_x	187.24	182.4	2.7%	169.4
PM	17.3	16.4	5.6%	31.5

Table 34 Emission footprint projection

Chapter 6: Remarks from the application

The sixth chapter refers to the remarks from the application of the developed decision making tool to Piraeus port. It is divided into two sections. The first section describes the remarks that are coming from the author's interpretation. The remarks of this section are based on the analysis of specific performance criteria found in literature. The second section includes the remarks of four interviewees that participated in the application. The remarks of this section refer to the replies of the interviewees regarding the understanding of the process and the applicability of the tool.

6.1 Author's interpretation

The evaluation of the performance of a multi-criteria decision making tool regarding its application consists a complicated task. There is no cumulative method that can support such an analysis and can provide unified data for such tools. The main reasons behind that are related to significant differences among the decision problems (characteristics of the problem, size of the alternatives and decision criteria etc), the differences between the tools (focus on different aspects e.g. optimizing compared to non-optimizing),the existence or not of qualitative data (difficult to be expressed in numbers) etc. Moreover, comparisons between such tools cannot be achieved for the same reasons. Thus, Hwang proposed a qualitative method of evaluation based on specific criteria known as "measures of multi-criteria decision tool performance". These measures are divided into two main categories, the overall process and the crossing of the data and provide an overview of the performance of the tool. They are used in order to provide with important remarks for the application of the developed tool. (Hwang C.L. M. A., 2012)

<u>Overall process</u>

- <u>Time resources</u>

The overall time needed for the execution of all the steps of the decision making tool for Piraeus port was 322 hours. It is important to highlight that the vision was set by the author based on the relevance with the MSc Sustainable Energy Technology and not based on the current interests of the port authorities of Piraeus. The time resources per step are presented below:

Step 1 (Vision): 0 hours

Step 2 (Identification of the stakeholders): 90 hours

Step 3 (Identification of the value objectives): 72 hours

Step 4 (AHP analysis): 16 hours

Step 5 (Emission footprint inventory): 24 hours

Step 6 (Identification of the LEPT): 88 hours

Step 7 (Satisficing): 8 hours

Step 8 (Pugh's matrix): 8 hours

Step 9: (TOPSIS): 8 hours

Step 10: (Emission footprint projection): 8 hours

By taking into account the availability of the data and the willingness for participation, the time resources are affected by two important points: the number of the participants and the time needed to communicate the decision making tool (Hwang C.L. M. A., 2012). Regarding the participants, their number affects mostly the step 8 in case that more than one experts do the evaluation of the LEPT, and not the step 3 which uses questionnaires in order to extract the data. Regarding the communication of the tool, the experience of the application showed that an estimated time of 8 or 16 hours should be enough. Finally, an estimated 20% should be added in the calculations of the overall time resources needed (information from Mr. K. Mavroudis). This extra time refers to the decision about the vision (specific category of solutions). The overall time estimated time resources for the application of the tool should be around 380 to 420 hours. Although a comparison cannot provide with important results, an estimation for the application time of a random multi-criteria decision making tool for a transportation planning problem with 11 alternatives and 13 decision criteria is provided by Hwang in his book (around 390 hours) (Hwang C.L. M. A., 2012).

<u>Size of the problem (dimensions) and possible constraints</u>

According to Hwang, the size of the problem refers to the number of the dimensions (alternatives and the decision criteria) the tool can process and the possible constraints if there are any. Regarding the dimensions, the main limitations refer to the potential of the AHP, Pugh's matrix and TOPSIS sub-tools. According to the theory, all the aforementioned sub-tools can have unlimited inputs in terms of alternatives (technologies) and decision criteria. Also, they can be used for the evaluation of only two alternatives but that may be not efficient in terms of time consuming. The most sensitive sub-tool is considered to be the Pugh's matrix. The expert(s) have to perform the evaluation through comparisons. According to Pugh's research, the tool is considered as efficient when a number of less than 12 alternatives and 22 decision criteria is used. That consists the only constrain. However, the sub-tool can be used for larger dimensions but with possible issues in terms of reliability of the output data.

- <u>Simplicity of use</u>

The next factor is the simplicity of use of the tool. Although the developed tool as a whole can be considered as complicated, their separate steps seems to be simple and easy to be executed. This fact is enhanced by the results of the interviews which are presented in the following part of the subchapter. However, it is important to examine more carefully two specific steps. The first step is the vision and refers to the difficulties that may arise in the choice of a specific category of Low Emission Port Technologies. The second step is the identification of the technologies that can contribute in the circularity. Although it is one of the important topics worldwide related to sustainability, still there are not specific guidelines that can help the decision maker to find the circularity opportunities. Thus, the decision maker has to do field research in order to explore all the possibilities.

- Ease of understanding the logic of the method

In general terms the main logic of the method is simple and it can be expressed in the following sentence: "The port authorities decide on the most appropriate Low Emission Port Technology that decreases the emission footprint of the shore-operations with the use of the values of the all the stakeholders as decision criteria". It was fully understood by the participants in the survey. Also, there were no issues related to the differences between the term emission footprint and actual emissions. The sequence of the steps provided no problems in understanding and communicating as the output of the previous step consists the input to the next.

- Information availability

The last parameter is the information availability. As information availability can be considered the information regarding the port, the stakeholders, their values, the technologies as input data to the tool. The information that refer to the port usually can be found easily from websites, reports and scientific articles as well as by the participation of relevant actors in a survey that uses questionnaires and interviews. The input data for this tool are the stakeholders, their values and the available Low Emission Port Technologies. There are two cases that data may be difficult to be attained. The first refers to the circularity opportunities. There is not a lot of research going on in ports and port areas related to the opportunities to use specific LEPTs to achieve circularity. The second refers to the unwillingness of some stakeholders to discuss policy matters concerning the use of specific values as decision criteria as well as their importance.

Crossing of the data

- Simplicity and usefulness of the output data

This factor refers to the easiness of understanding and the usefulness of the output data of the developed tool. The main output are the results of the TOPSIS and the emission footprint projection tables. Except for that, also the output tables of the intermediate steps are discussed (the AHP analysis, the satisficing and the Pugh's matrix). To begin with, the main output is the table of the TOPSIS (step 9). The table assigns a score to each of the LEPTs. The highest the score, the more it satisfies the value objectives. As a result the technology with the highest score is the most appropriate to be used. According to the TOPSIS theory, a statistical significant difference is considered the 0.025. In cases that the difference of the score between the first two technologies is less than 0.025, then both of the technologies can be used and the decision maker can choose which one of them. It can be considered that the table provides with clear results the decision maker for the selection of the best technology. Regarding the emission footprint projection, the output table as shown in subchapter 5.11 presents the expected emission footprint after the implementation and operation of the technology. This information is useful in the monitoring phase (evaluation and feedback) where the port authorities compare the theoretical results with the real case.

Apart from the main tool outputs, also the outputs of the intermediate steps should be discussed. Regarding the AHP results, it is important to be highlighted that the tables that represent the weights of the values are divided into the direct and indirect stakeholders' results. This representation can help port authorities to realise from the early stages of the tool application if there are any possible conflicts based on the weights on specific values. The tables provided by the AHP analysis are easy to be understood. As far as the satisficing method (step 7) is concerned, the output of the step is represented in a table that shows the weights of the fundamental values (overall and per category) and the thresholds to be applied. The table is simple and it is easy to understand how it is used for the step 8 (Pugh's matrix). On the other hand, for the case of Pugh's matrix output table, there were some identified during the application. Sometimes, the "impact" which consists an important input for the TOPSIS, created confusions. Specifically, the impact explains what the effect of the value objective is. The desirable effect is described as "positive" and the undesirable as "negative". In the cases that the impact is negative, the signs should be reversed (e.g. "-"becomes "+") which creates a difficulty in the understanding of the table. Finally, it can be considered that with the exception of the Pugh's matrix table, the rest output information provided by the tool are clear and easy to be understood by the decision maker and the participants in the survey.

- Data consistency

Another factor of evaluation of the method concerns the input data consistency. The input data refer to the stakeholders, the value objectives and their importance of the value objectives (input of AHP), the available LEPTs and the evaluation of the Pugh's matrix. Regarding the stakeholders, it is difficult to define what a consistent input is. Following the Keeney's and Nianopoulos proposal regarding the stakeholder analysis (presented in chapter 2), the formulation of groups of stakeholders (e.g. technology providers, residents) as well as the division of the them into direct and indirect contributes in the inclusion of all the possible stakeholders. However, there is always a risk of excluding a stakeholder accidentally or on purpose by the decision maker. The value objectives input is introduced in the tool by the use of questionnaire. There are two risks related to the consistency. The first one refers to the unwillingness of the stakeholders' representatives to reveal their policies in decision making and the second concerns the absence of the deep understanding of their value objectives as decision criteria. The AHP sub-tool provides a consistency check for input that is provided by the questionnaires that are replied by the stakeholders. The inconsistent replies are excluded and the questionnaire should be re-answered. As far as LEPT is concerned, it can be concluded that the data input are consistent (technologies with their quantitative characteristics based on recent analysis). Finally, the Pugh's matrix consists the only step that encloses a high risk of biased data. That is because experts are used in order to complete the evaluation of the LEPTs based on the quantitative data that are delivered to them. However, there are cases that qualitative criteria are used (such as aesthetics). In that case the comparison includes the opinion of one person.

Input data	Consistency
Stakeholders	Possibly yes
Value objectives	Possibly yes
AHP	yes
LEPT	yes
Pugh's matrix	Risk of biased data

Table 35 Input data consistency

- Chosen solution the best compromise?

Another measure of performance that concerns the multi-criteria decision tools explores whether the chosen solution is the best compromise. Based on the TOPSIS theory, the algorithm performs trade-offs based on the weights of each of the value objectives. In such a way, the tool takes into account the importance of the decision criteria of the stakeholders and provides with the solution that satisfies at the maximum degree these criteria. At this point it is essential to be mentioned that the best compromise is highly related to the consistency of the data as mentioned in the previous part. Generally, it can be considered that when the Pugh's matrix data are not biased, then the output of the tool consists the best compromise.

Responsible character of the tool

The last remarks refer to responsible character of the tool. One way to examine it, is by analysing the Stilgoe's four dimensions for the tool. The first dimension is the inclusion. According to that dimension, the port authorities should satisfy as much as possible the values of the stakeholders in order to increase their participation. That is achieved by the selection of the technology which satisfies at the maximum level these values (TOPSIS). The dimension of the responsiveness can be also fulfilled by the re-execution of the steps 2, 3 and 4, as they provide the flexibility to adjust to new circumstances when the number of stakeholders as well as their values and their importance change. Another dimension is the anticipation. The anticipation explains that the negative impacts that may arise should be examined before the implementation of the technology. This can be achieved by the overall application of the developed tool as its main goal is to identify the negative impacts in the beginning. Finally, the last dimension is reflexivity which is related to the self-assessment and examination of the position (values) of the stakeholders through exchanging data. The tables of the sub-tools can provide the data related to the current situation of all the stakeholders' values as well as the impact assessment of the technologies. As a result, it can be considered that the developed tool follows the main dimensions of responsibility provided by Stilgoe.

Summary author's remarks

Based on the above analysis, a summary with the main author's remarks is briefly presented below:

Measures of performance:

- Complicated process but the steps are simple to be executed and important in order to solve all the practical issues
- It needs around 400 hours for all the steps to be executed. However, that is highly dependent on the size of the problem. The time needed for the execution cannot be compared with other tools because of the differences of the problems they solve.
- Can cope well with small and large number of alternatives and decision criteria. The best is 12 alternatives and 22 decision criteria
- The logic of the method as well as the context and the sequence of each of the steps are understandable and easy to be communicated
- The output data are easy to be understood
- Reliable output data in case that there are no biased data in the Pugh's matrix
- The TOPSIS performs the trade-offs optimization so as the chosen technology to be the best compromise
- It can be considered that the tool can contribute in the responsible decision making

All the comments that presented above provide with the factors that affect the successful application of the tool. These factors are the following:

Factors of successful application of the tool:

- Vision should strictly follow one the four categories of LEPT
- Extended analysis for the identification of the stakeholders so as all of them are included in the decision making process
- Willingness for transparent participation from all the stakeholders
- Pugh's matrix qualitative criteria should be treated carefully in order to reduce the risk of biased data

The decision making tool developed for this research project consists an attempt to include in the decision making process of ports all the values of the relevant stakeholders. By taking into account the assumption of equality of power among the stakeholders it can be considered as a more democratic way to approach such kind of problems. According to Mitchel, the satisfaction of these values lead to the increase of technological acceptance and as a result it guarantees the minimum implementation and operation resistance from the stakeholders. The tool is flexible in adjusting to the changing social and business conditions.

6.2 Remarks from interviews

Apart from the author's remarks, there are also remarks based on interviews. Four participants took part in these interviews, namely Mr. Euaggeliou, Mr. Mavroudis, Mr. Oikonomou and Ms. Karvouni. The same people have been replied to the questionnaires during the application of the tool. The total duration of the interview was 1 hour where the analytical presentation of the tool took place in the beginning the specific questions were asked regarding the easiness of understanding, general comments, the advantages and disadvantages and the important adjustments that could improve the tool. The analytical replies of the interviewees as well as information about the interviews are presented in the Appendix F.

To begin with, from the interviews it can be concluded that the participants believe that the scope as well as the steps were clear to them. That enhances the position of the author as explained above. Only one interviewee believes that the tool cannot be used directly mainly because of the absence of the application results. Based on the comments of the interviewees, they believe that the developed tool has the potential to be used in the decision making process mainly as a supplementary tool. It provides the quantification of the process which helps in starting the discussion of the technology selection from a certain basis. Another important aspect is that the tool explores both the technological artefacts and the business situation of the port. Finally, according to Mr. Oikonomou, the weights that have been assigned by the stakeholders to the values represent the current economic and policy situation. The information is presented briefly in the two following tables.

Participants	Clear scope	Clear steps	To be used directly
A Euaggeliou	Yes	Yes	Yes
K Mavroudis	Yes	Yes	Yes
S Oikonomou	Yes	Yes	Yes
D Karvouni	Yes	Yes	No

Table 36 Scope, steps and direct use (interviews)

Participants	Comments on the tool
A Euaggeliou	• Innovative approach to assist the decision making • It is important that it takes into account more criteria than just the economic ones • Gives a “direction” to the decision makers (board members and managers) regarding the complex decision making situation as far as the stakeholders and their values is concerned.
K Mavroudis	• It is an interesting approach that can save time from the meetings. • Dynamic tool that explores both the latest technological artefacts and business situation. • It provides the possibility to start from a certain basis the discussion of choosing a technology. That basis refers to the importance of the values as decision criteria for the stakeholders. • It consists a way to quantify the decision making process which is considered as a qualitative process. • Satisficing method is important in order to reduce the number of the examined technologies.
S Oikonomou	• I believe that is an interesting tool which can have application not only in the port’s but also to other fields that the stakeholder values “work” as decision criteria. • The current ports’ economic and policy situation is expressed through the weighting of the values as decision criteria by the stakeholders. That makes the process less complicated. • The decision maker does not intervene in the process which provides more objective results.
D Karvouni	• It consists an interesting tool that can assist the decision making process • It is important that takes into account the circular economy • It is important that it takes into account the decision criteria of all the stakeholders

Table 37 Comments on the tool (interviews)

As far as the advantages are concerned, the interviewees believe that the tool can substitute the long-duration meetings. The reason behind that is that the tool consists a process where a “common language” is used regarding the realization of the stakeholders’ interests and the technology opportunities. It is an automated process with a lot of flexibility to the changes of the business and social environment of the port. Also, the idea of dynamic input of data leads to the inclusion of all the stakeholders’ values and the available technologies in order to take the most informed decisions. The interviewees reckon as main disadvantages the possible biased output data from the Pugh’s matrix. Also there might be an issue in the accuracy of the results as it underlies a risk of depended values or possible confusion from a high number of criteria and alternatives. In addition, the possible technology implementation issues are not taken into account. Finally, the last disadvantage of the tool refer to the possible issues that may arise from the use of the 5-point scale. The output scores may be close and in such case the final decision might be under question.

Participants	Advantages of the tool
A Euaggeliou	• It can balance the value conflicts and increase the acceptance of the technology to be implemented. • It is less time consuming than the "business as usual". • It takes into account all the important criteria for decision making including the performance criteria of the technologies and the values of the stakeholders.
K Mavroudis	• It quantifies difficult concepts such as the values that are used as decision criteria. • The process can save a lot of time • The tables of the method as well as the final results of the method (most appropriate technology) can set a framework of discussion during the meetings. • Every stakeholder accepts the common language of the "numbers". • Automated process which asks for minimum intervention by the decision makers.
S Oikonomou	• It consists a fast process compared to the issues it solves. • One of the most important assets is that it has dynamic input of data. • The tool provides the capacity of using a lot of criteria for the evaluation of the technologies.
D Karvouni	• It takes into account the public opinion • It takes into account the circularity opportunities • It is good that the stakeholders know what to expect from the technology implementation based on the values table (pugh's matrix results)

Table 38 Advantages of the tool (interviews)

Participants	Disadvantages of the tool
A Euaggeliou	• There might be difficulties in the communication of the emission footprint concept. • Usually the economic growth is the most important decision criterion. • Some stakeholders may not want to openly reveal their values.
K Mavroudis	• There might be an issue of understanding which can lead to confusion in cases that a lot of criteria and technologies are used. • The independence of the values should be explored in order to achieve more reliable results. • The Pugh's matrix may provide with biased data.
S Oikonomou	• Risk of biased results at step 8 (Pugh's matrix). • Absence of sensitivity analysis of the decision criteria. • The use of a 5-point scale may create problems when the scores of the results are close.
D Karvouni	• The number of the criteria should not exceed a specific level. • The automated process for the trade-offs should contain the option of decision maker intervention. • Technology implementation issues are not taken into account.

Table 39 Disadvantages of the tool (interviews)

The last topic of discussion refer to the possible fields of improvement of the developed tool given by the interviewees. The main focus of the participants was on exploring ways to reduce the decision criteria, introduce methods to secure the independence of these criteria and methods to reduce the risk of biased data from Pugh's matrix. Another important aspect for improvement consists the set of specific rules regarding the groups of individuals that participate in the research such as the residents or the port users. Finally, the increase of the scale from 5 to 10 points (e.g. 1,2,3,4.....,10) can contribute in the more accurate scores for the evaluation of the technologies. The following table represents these comments.

Participants	Improvements / Adjustments to the tool
A Euaggeliou	• Explore ways to assign higher weight to the economic growth in comparison to the other values by serving in parallel the rest of the values. The economic growth is the main driver of the technology implementation and operation. • Set of rules and creation of a specific survey for the input data of the groups of individuals such as the residents and the passengers. • Validation with the application of the tool to several ports and studies that refer to the opinion of the stakeholders after the implementation and operation of the technology.
K Mavroudis	• It would be better if the decision criteria could be minimized at a number of 6 or 7 • Independence of the criteria should be secured • Explore methods to produce more objective results for the Pugh's matrix specifically for the qualitative criteria that cannot be measured
S Oikonomou	• Use of 10-point scale in order to provide results with larger differences among the scores. • Sensitivity analysis for the decision criteria should be included. • Explore other methods to replace the Pugh's matrix in order to reduce the risk of biased results.
D Karvouni	• Provide a plan of use of the tool for the case that a change is occurred. • It is preferable the trade – offs to be performed by a combination of the decision makers and the TOPSIS. Thus, flexibility can be achieved. • The implementation issues of the technology should be taken into account during the evaluation of the technologies.

Table 40 Adjustments for the tool (interviews)

7.1 Conclusions

After the analysis of all the previous chapters, the theoretical exploration, the development of the tool, the application and the remarks from it, it is now possible to formally answer the main research question and the sub-questions. Also, this chapter contains the reflections on the development of the decision making tool, comments on the use of the theories and on the assumptions, comments on the applicability of the tool as derived from the remarks and the fields of future research for further improvement of the tool.

7.1 Research sub-questions

- ✓ *Which stakeholders are involved in port decisions on technologies and what are their values?*

The identification of all the stakeholders that are involved in the decision making process related to the low emission port technologies is significant in order to maximize the degree of technology acceptance. By considering the diverse character of the ports worldwide, it is difficult to define specific stakeholders that can be met at all the ports. In order to simplify the process of identification, the stakeholders are divided into two main categories. The first category consists of the stakeholders that directly participate in the decision making process or influence the decisions. The second category refers to the stakeholders that are not directly involved in the decision making but they are affected by the technology operation. The process of identification can become even simpler when dividing the stakeholders into four big groups, namely the port authorities, the public sector, the private sector and the organisations & institutions. The most common groups of stakeholders that can be met in ports are the following: the shareholders, the administration, the port users, the suppliers, the government organisations, the scientific institutions, the local authorities and the national regulators. Based on the theoretical exploration, the fundamental values of the stakeholders are the economic growth, the environmental protection, the safety, the accessibility, and the creation of societal value. To these fundamental values are assigned one or more value objectives which are used as the final decision criteria of the tool. Again based on the diverse character of the ports, it is not reasonable to set specific value objectives. This data are given by the stakeholders so as the real case is always examined. However, a list of the most common value objectives is provided to them. The list is the following:

List of value-objectives
income, profitability, productivity, efficiency, competitiveness, circularity, employment, synergies, external safety, health risks, emissions, livability, social stability, energy security, capacity, availability, aesthetics, longevity, use of space, entrepreneurship

Table 41 List of value objectives

✓ *How can a planning cycle for technologies address these issues? What would such a planning cycle look like?*

The planning cycle for technologies provides the port authorities with general guidelines in order to select the most appropriate technology that its implementation and operation can minimize the emission footprint of a port's shore operations. These guidelines were developed based on the theoretical exploration which involves the following theories: Responsible Innovation, Low Emission Development strategies, Circular Economy, Stakeholder Analysis and Technology Impact Assessment. The guidelines of the planning cycle reveal the ways of addressing the aforementioned practical and theoretical issues. The analytical information is presented in the two following tables:

Practical Issues	Ways of addressing
Port's emission footprint reduction	By implementing a technology that contributes in such a reduction
Involvement of all the stakeholders in the decision making of the technology	By taking into account all the values of all the stakeholders
Addressing of possible value conflicts	By performing trade-offs
Increase of the acceptance of the technology to be applied (including the public)	By satisfying all the values at the maximum possible degree
Use of waste in order to tackle the emission footprint issues.	By exploring circularity opportunities that can be used by technologies in the port and port area

Table 42 Ways of addressing the practical issues

Theoretical Issues	Ways of addressing
Complex and fast changing business environment	Dynamic input of data. The tool should be able to follow possible changes by providing a platform that should always ask for the current input data (stakeholders – their values – technologies)
Lack of theoretical tool to address the stakeholders' value conflicts	Trade-offs through a multi-criteria tool
Lack of literature information related to the waste-use by technologies in order to reduce the emission footprint	Use of 3 R principles (reuse-reduce-recycle) for the identification of circularity opportunities and of relevant technologies
Lack of literature information regarding how to choose the most appropriate technology based on the stakeholders' point of view as a cumulative decision making approach that solves the practical issues	By following the overall guidelines of the planning cycle

Table 43 Ways of addressing the theoretical issues

The planning cycle consists of five different stages, namely the "Vision", the "Stakeholder Involvement", the "Technology and Mitigation", the "Finance and Implementation" and the "Monitoring". Each of these stages contains actions that should be performed by the port authorities and are based on the aforementioned guidelines. The "Vision" refers to the set of a strategy for reducing the emission footprint by implementing a technology without sacrificing the port's economic development. The "Stakeholder Involvement" includes the identification of the relevant with the vision stakeholders as well as their values and ways to deal with possible value conflicts. The "Technology and Mitigation" includes the identification of the technologies that can be implemented as well as the evaluation of them in order to select the most appropriate one that satisfies at the maximum possible degree the stakeholders' values. The "Finance and Implementation" refers to the identification of the overall cost and the preparation for the installation and the "Monitoring" explains the assessment feedback loop. The planning cycle is used as the framework for the development of the decision making tool. But not all its stages are included. The "Finance and Implementation" and the "Monitoring" refer to the phases after the selection of the technology and thus, they are excluded. Thus, only the guidelines from the first three stages are included in the framework. However, these guidelines cannot be considered as a cumulative approach that can solve the issues identified. The development of the planning cycle led to the identification of specific gaps that should be filled in order to achieve a complete decision making tool. These gaps refer to the identification of the technologies to be compared, the methods/tools that can be used for the data gathering and processing and the methods/tools that are suitable to perform the trade-offs.

✓ *How can we select the most appropriate low emission port technology that can be applied in shore-related port operations? Can we develop a tool to assist the decision-making? What would that tool like?*

The selection of the most appropriate technology is based on the values of all the stakeholders. These values are used as decision criteria for the evaluation through comparison of the different low emission port technologies. As the values may have different importance for the stakeholders, it is examined their overall weight which is assigned to the corresponding value. For the comparison phase, the quantitative criteria of each of the technologies (performance criteria) are taken into account, specifically: the economic criteria, the mitigation potential of each of the technologies, the life-time and the use of space. Finally, the most appropriate technology is the one that satisfies better the weighted values-criteria of all the stakeholders (optimized trade-offs).

The main building block of the decision making tool is the aforementioned developed framework based on the planning cycle. It includes the guidelines of the three stages, the Vision, the Stakeholder Involvement and the Technology and Mitigation. Moreover, the lack of information that was identified in the planning cycle concerning the data gathering and processing is fulfilled by specific methods and sub-tools, namely the multi-criteria sub-tools (AHP, Pugh's matrix, TOPSIS) and the Satisficing method. The combination of this information with respect to the sequence of events provided by the planning cycle, leads to a step-by-step approach. As the tool should have dynamic input of data, all the data are always provided for the current situation. Except for the stakeholders and their values, the same rule applies to the low emission port technologies (LEPT). The LEPT are divided into four categories based on the emission source they tackle (Dry Bulk, Low Emission Machinery, Energy Efficiency, Energy (electricity) Production). The steps of the decision making tool are the following:

Step 1: Set specific vision based on the categories of the Low Emission Port Technologies

Step 2: Identification of all the relevant stakeholders

Step 3: Identification of their value objectives

Step 4: Use of AHP sub-tool to identify the importance of the values

Step 5: Creation of emission footprint inventory for the relevant to the vision emission sources

Step 6: Identification of the Low Emission Port Technologies that can be applied

Step 7: Satisficing

Step 8: Use of Pugh's matrix sub-tool in order to perform the Technology Impact Assessment

Step 9: Use of TOPSIS sub-tool for the final decision

Step 10: Emission footprint projection

✓ *Is an application of the developed tool to the Piraeus port possible and what do we learn from it?*

The application of the developed tool was performed for the Piraeus port. The vision that was set is related to the MSc Sustainable Energy Technology which is the following: "Implementation of renewable technologies for electricity generation that can reduce the emission footprint of the Piraeus' shore-operations". The focus of the application was on the process and not on the results as the participants in the survey were not selected by a scientific method but based on their relevance with the decision making process and the topic of examination. The application of the method led to some significant remarks. To begin with, although the tool is considered as a complicated one, the individual steps are simple to be understood and executed. The final output as well as the intermediate output between the steps are also easy to be realized. The technology with the best score at TOPSIS results consists the best compromise. An estimated time of execution of all the steps is around 400 hours. Finally, although it can cope well with both small and large number of alternatives and decision criteria, there is a restriction in terms of time consuming and good understanding. The theoretical number of technologies to be used should be less than 12 and the decision criteria cannot be more than 22. However, some interviewees mentioned that the ideal number of criteria should be less than 10. The main advantage recognised is the quantification of the decision making process. The tool can provide a "common language" for understanding the current situation in terms of decision criteria importance and technology opportunities. This can save time resources from long-duration meetings. Another advantage is the flexibility to adjust to changes relevant to the business and social environment of the port. As far as the disadvantages are concerned, the participants reckon as main disadvantages the risk of biased input data for the Pugh's matrix, the absence of inclusion of the possible technology implementation issues and the fact that some stakeholders may be unwilling to reveal their values as decision criteria. Finally, the remarks concerning the applicability of the tool can be found in the following subchapter 7.5.

7.2 Main research question

✓ *How can port authorities take informed and stakeholder-based decisions on technologies aimed at reducing the emission footprint of the shore-related port operations?*

The reduction of the emission footprint of the port's shore-related operations can be achieved by the implementation of Low Emission Port Technologies. As there are a lot of such technologies available in the market, the port authorities should show preference for one out of four categories identified (Dry Bulk, Low Emission Machinery, Energy Efficiency, Energy (electricity) Production). Each of the categories tackles a specific emission source (table 10 – sub-chapter 4.4.2). In order to achieve stakeholder-based decisions, the port authorities should recognise the stakeholders that are related to the technology implementation and operation. As the historical examples shown us, the exclusion of one stakeholder from the decision making process may create unwilling situations. Thus, the port authorities should take into account not only the stakeholders that take part in the decision making process but also those that are affected by the technology. The stakeholders are taking decisions based on specific values that are used as decision making criteria. These values may have different importance. Therefore, a weight should be assigned to each of the values based on the overall importance they have for the stakeholders. The evaluation of the technologies is performed by comparing their performance based on these values. Following this comparison, the technology to be chosen is the one that satisfies at the maximum possible degree all the weighted values. This technology consists the best compromise based on the importance of the decision criteria of all the stakeholders. Another important aspect for port authorities is the informed decisions. For that reason, the only "static" data that is used is the five categories of fundamental values of the stakeholders (economic growth, environmental protection, safety, accessibility, and creation of societal value). The rest of the data needed for the decision making process (stakeholders, their values, technologies) are taken from a current analysis of the port situation every time a decision is about to be taken. This analysis is achieved by the use of recent online sources, questionnaires for the representatives of the stakeholders and sub-tools. Such sub-tools are the AHP, which assigns the weights to the values and the Pugh' matrix that performs the evaluation of the technologies through comparison. For the final decision, the TOPSIS sub-tool is used, which performs trade-offs' optimization. All the above information is structured in a ten-step decision making tool that was developed for this research study. The main characteristic of this tool is the quantification of the decision making process. Based on this tool, the port authorities can select the Low Emission Port Technology that has the highest degree of acceptance from all the stakeholders. Despite its apparent complexity, the scope and the steps of the tool are clear and easy to be understood. Also, the output is presented in tables where the selection is based on the scores of the technologies. Finally, the process of the tool ends with the creation of the emission footprint projection for the chosen solution. The results of it can contribute in the feedback process of the port authorities through evaluating the real results compared to expected theoretical reduction.

7.3 Reflections on the method of development

The different practical and theoretical issues to be solved created a complicated development scheme which required the combination of completely different theories. The scope of the development method was to provide the simplest possible results without compromising the ability to solve all these issues. In order to simplify and structure the process of development, it was decided to categorise it into three phases: the theoretical exploration, the planning cycle and the final decision making tool. This structured way of development proved to be very useful for the following reasons. To begin with, the exploration of the theories (Responsible Innovation, Low Emission Development strategies, Stakeholder Analysis and Technology Impact Assessment) reveal a lot of "dirty" information that had no relevance with the scope of this research study. Thus, this information was filtered and only the important one was kept as presented in the tables of subchapter 2.3. Also, some of the results of the phase 1 couldn't be used directly as they were not relevant to the technology measures. Specifically, the Low Emission Development strategies and the Responsible Innovation refer to guidelines related to policy measures. The focus of these theories was changed to technology measures. Moreover, some parts of the theory identified to be more relevant with actions that occur after the technology has been chosen. These parts were used in the planning cycle so as future research can have an overall insight but were excluded from the framework (e.g. Monitoring). Finally, the structuring of all the information into concrete guidelines contributed in the realisation of the main gaps of the framework that were filled in the third face. These gaps refer to the sub-tools / methods and the categories of technologies that the port authorities should focus on.

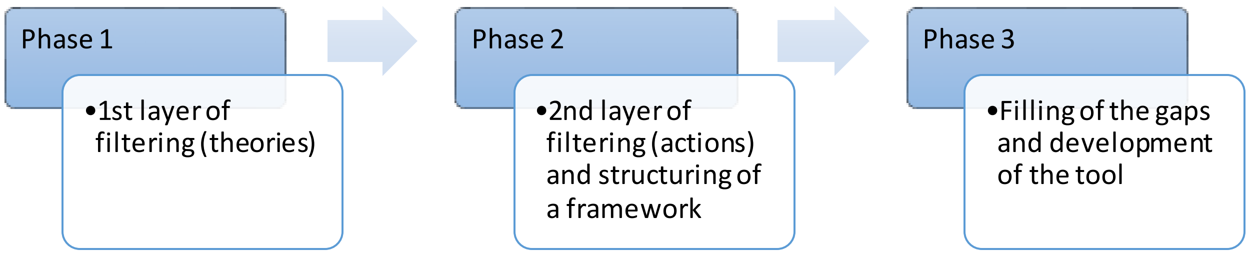

Figure 12 Phases of development

The main issue identified during the development process was the difficulty to find information regarding the technology measures in the ports. The vast majority of the scientific research focus mainly on policy and management measures. Another issue was the absence of theoretical information regarding the ways the decisions are taken at a port level. These facts enhance the scientific importance of this research study. In addition, there were no examples in the literature that describe a method of development of a multi-criteria decision making tool that quantifies the decision making process. Such a development is unique as the tool takes into account all the practical and theoretical issues. The development of the tool was achieved after various "trial and error" efforts. That reason affected highly the time resources spent on this research study. To sum up, the method of development of the tool seem that worked well in terms of the results provided. The double layer of filtering proved to be particularly efficient when comparing the size of the input information (phase 1) and the framework produced (phase 2). The framework, as the main building block of the tool, provided the flexibility of adjusting the multi-criteria sub-tools where the input and processing of data was needed.

7.4 Reflections on the theories, sub-tools and assumptions

As far as the theories is concerned, the below comments refer to the contribution in the development phase and the main limitations identified. To begin with, the Responsible Innovation is one of the most important theories used in the development. The idea of including all the possible stakeholders in the decision making process, satisfying all their values at the maximum possible degree as well as the importance of the dynamic input of data are based on this theory. It introduced to the model the element of trade-offs as the best way of resolving the possible value conflicts. However, it does not provide any guidelines on how to achieve that. The Low Emission Port Development strategies consists the only validated theoretical method that describes guidelines for achieving low emission development. The information retrieved from this theory helped both in the development of the actions of port authorities and in the structuring of the planning cycle. The main limitation from the use of this theory is that its guidelines refer to policy measures and thus it was needed to be further formulated. The Circular Economy contributed in the tool by providing the 3 R (reuse-reduce-recycle) principles that help the identification of the circularity opportunities. However, the theory does not provide any guidelines regarding ways of applying these principles. Another theory that was used is the Stakeholder Analysis. It introduces to the development the way to identify the possible stakeholders. There are two limitations found for this theory. Considering the diverse character of ports, it is difficult to define specific stakeholders as static input to the tool. Secondly, the interactions between the stakeholders as well as the influence is taken into account. The main reason for that is the complexity that it would adjust to the tool. Finally, the Technology Impact Assessment defines the most common performance criteria of the technologies (quantitative data) but it cannot support the cases of qualitative data.

Apart from the theories, also the contribution and the limitations of the sub-tools used are examined. The AHP sub-tool was used for the creation of the questionnaire and the analysis of its results. It contributes in the identification of the weights that are assigned to each of the values. There were no limitations found that are related to the AHP as it produces consistent data. The Pugh's matrix is used for the evaluation of the technologies. The most critical limitations refer to the Pugh's matrix. It includes the risk of biased data because of the comparisons performed by one or more experts and the absence of a consistency check. Moreover, the Pugh's matrix set the only limitation on the number of the alternatives and decision criteria. As mentioned above, it is considered as efficient when a number less than 12 alternatives and 22 decision criteria is used. Finally, the TOPISIS that performs the trade-offs optimization has as limitation the absence of flexibility for intervention by the decision maker.

Regarding the assumptions used for the development of the tool, the following can be pointed out. First of all, the stakeholders have been studied independently during the application of the tool. In order to decrease the sensitivity of the model to the specific choice of stakeholders, it is recommended to focus on groups of stakeholders (subchapter 2.2.3). This will also reduce the complexity of the tool, as it means that fewer stakeholders will have to be studied in total. An additional remark with respect to the stakeholders is the assumption of "equality of power", meaning that no investigation is included in the decision making process regarding the power of intervention of the stakeholders. This is explained by the complexity that it would adjust to the tool. That should be a topic of future research. Furthermore, the fundamental values and the value objectives are assumed to be independent from each other. During the application they have been treated independently and there were no specific comments from the participants of the survey regarding any misunderstanding that is related to the values dependency. In order to increase the accuracy of the results of the tool, a method of investigation of interdependencies can be introduced as an intermediate step between the identification of the values of the stakeholders and the weighting of these values. A method to achieve that is described by Caspin-Wagner and it concerns a table that contains all the values and study whether the increase/decrease of the score of one value applies to the score of the other values (Caspin-Wagner K., 2013). Finally, for the shake of simplicity the value objectives have been treated equally (their importance depends on the importance of the relevant fundamental value). The main reason for that is the avoidance of time consuming processes. In case that the decision maker believes that a more reliable result can be enhanced by taking into account the different importance of the value objectives, he/she can apply the AHP tool to each of the categories of value objectives and adjust the weight of the fundamental value to them.

7.5 Applicability of the tool

The main target of this research study was to provide the port authorities with a responsible decision making tool that can be used for the selection of the most appropriate technology that can lead to substantial emission footprint of the port's shore-operations. This target has surely been ambitious. The economic incentives that are at stake in the ports are large and frequently overshadow the attempts to adopt technical measures that concern protection of the environment. The value-based approach that is used by the tool for the selection of the best compromise technology can minimize the value conflicts. The application of the tool proved that it is particularly efficient for gradually identifying the values and their importance as decision criteria. The idea of dynamic input of data provides the flexibility to possible changes which consists an important aspect for making responsible decisions. Thus, the results refer always to the current port situation. The combination of successful theories and sub-tools for the development provides with the important viability and enhances the credibility of the tool.

The decision making tool can be used by port authorities either as the main decision tool or as supplementary tool that provides port authorities with an indication. The tool can be applied to all the types of ports without restrictions such as the size or the economic activity. However, there are some factors that affect the successful application. Firstly, it is important for the port authorities to follow strictly one of the categories of LEPT as they are explained in subchapter 4.4.2. Otherwise there might be issues concerning the use of the quantitative data for the evaluation (Pugh's matrix). Another important factor is the inclusion of all the relevant stakeholders as well as their values. These stakeholders should show the willingness to participate actively in the process and should communicate transparently their policies regarding their decision criteria for the technology decision. Finally, great emphasis should be given in the execution of the Pugh's matrix step. This step is the most crucial because of the high risk of biased data. It has to be executed carefully. It needs to be ensured that the expert(s) that do the comparisons understand(s) fully the value objectives that used as criteria and can connect these value objectives with the relevant quantitative data. The comparison that includes quantitative criteria (e.g. profitability, lifetime of technology) can be answered easily by the use of the data found during the LEPT identification. For the qualitative criteria that refer to more abstract concepts such as the aesthetics, a questionnaire can be used in order to gather a more spherical view about the comparison by taking into account the opinion of the stakeholders. Finally, the main limitations of the tool refer to the limitations of the involved theories and sub-tools which have been described in the previous subchapter.

7.6 Recommendations for future scientific work

As described before, the set of theories and sub-tools that were chosen produced satisfactory results; still, it would be a good idea to explore different options for the further improvement of the tool. The improvements are based on the limitations of the involved theories and sub-tools and the interviews. To begin with, the first field of improvement of the tool should be the evaluation of the technologies. The reason for that is that the Pugh's matrix may provide with biased data. The Pugh's matrix can be replaced by another multi-criteria tool such as the Evidential Reasoning Approach (ERS) or another tool from the list provided in Appendix D that is relevant to the evaluation of technologies. Another possible issue identified is the absence of a method to deal with possible interdependencies of the value objectives. One method has been already described in the subchapter 7.4 by Caspin-Wagner (sensitivity analysis). Another method is the correlation analysis. In cases that the value objectives have strong correlation between them, they can be included in the same "values group". In addition, an important field of future research is the exploration of methods to be introduced in step 2 and 3 that can investigate the power of intervention of the stakeholders in the decision making process and how much they can influence a decision. The results of this investigation can be included in the weights of the values.

Except for the theoretical improvement, the interviewees contributed in the recommendations for future research that relate mostly to more practical characteristics. The first idea concerns the increase of the size of the scale that is used for the evaluation of the technologies. Instead of a five-point scale, a ten-point scale could be used. The advantage of such a case is the larger differences among the scores of technologies that can decrease the possibility of close scores. Another field of future research that seems to be important is to examine a method that can introduce to the decision making process the possibilities of issues that may appear during the installation phase of the technologies. Furthermore, it could also be a topic of discussion whether the tool should provide the possibility of intervention to the decision maker in specific steps such as the performance of the trade-offs. In that case, the research can be based on the findings of the chapter 3 that refers to the actions for port authorities and the general guidelines of the planning cycle.

The tool should be applied for the rest of the categories of LEPT in order to extract useful remarks. Although the tool is based on validated and credible theories and sub-tools, the reliability of the tool is under discussion as it was never applied for a real case. Therefore, the real case application should be performed by port authorities that are ready to test the tool by implementing the technology and then examining whether it achieved the expected results in terms of emission reduction and stakeholder acceptance. As far as the stakeholder acceptance is concerned, survey methods such as questionnaires and interviews can be used in order to gather data and produce relevant results. Finally, the creation of a neural network for the same problem (same practical issues) and the comparison with the results of the developed decision making tool can provide with an interesting insight regarding the potential of the tool. More information can be found in the work of N. Karayiannis, "Decision Making using neural networks", that explores the setting up of such a network for pollution sources at a river (Karayiannis N., 1993).

7.7 Scientific relevance with MSc Sustainable Energy Technology

One of the main goals of the MSc Sustainable Energy Technology is to propose ways to enhance the economic development and at the same time reduce the environmental impact. This research focuses on that aspect as it describes the development of a decision making tool that can be used by port authorities in order to reduce the emission footprint of ports. This tool examines which sustainable technologies are the most appropriate to be used. The most appropriate technology is the one that apart from the performance criteria, minimizes the risk of "resistance" by the stakeholders. This is directly related to the context of the studies at the MSc Sustainable Energy Technology as it explores ways of promoting the implementation of sustainable technologies and improving the acceptance by the stakeholders.

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Appendix A – Chapter 1

Ecoport information

Process of introducing improved environmental management to EcoPorts

In order to create a more systematic approach on the EcoPorts' pursuit of environmental progress by taking into account their individual priorities and organizational structure, ESPO proposed a toolbox of assisting tools and well established environmental management standards. These can be used by the involved EcoPorts so as to set respective targets, implement measures, monitor and evaluate their impact. In this way, they can achieve a continuous environmental improvement (ESPO, Green Guide, 2012).

Assisting tools

The assisting tools of EcoPorts are referred to the Self-Diagnosis Method (SDM) and Port Environmental Review System (PERS). Both systems were developed to act as a proven overarching framework that assists ports to reduce their environmental footprint. The SDM method is characterized as a cost efficient methodology that provides environmental risk identification and establishes the priorities for action.

In fact, SDM provides a checklist that port authorities have to fill before entering the EcoPorts network. This checklist addresses the fields of environmental personnel training, communication, monitoring environmental policy, management organization etc. After the completion, ESPO sends a report regarding a SWOT analysis of the EcoPort's current environmental management performance, a gap between this performance and requirements of the established systems that are explained belowand an analytical report with expert's recommendations on the current status. From this report it can be identified what next steps for further development based on the environmental performance in comparison with the European benchmark of performance should be (ESPO, How to join the EcoPorts network and use SDM and PERS, 2011).

The second assisting tool "PERS", an Environmental Management System which is designed to deliver to users an actual set up of current environmental management of the port and an overview of the port's activities environmental performance. In addition, this tool enables the compliance with the European environmental legislation and ensures the quality and effectiveness of the management (ESPO, Green Guide, 2012).

Established environmental standards

Except from the tools, in order to evaluate the environmental performance of EcoPorts, two widely recognized by stakeholders and public are used, the ISO 14001 and the Eco-Management and Audit Scheme (EMAS).

The ISO 14001 is a family of standards that is related with providing advices to organizations regarding the minimization of the effect of operations to the environment and at the same time complies with regulations and applicable laws. The main principles can be simplified to be the Plan-Do-Check-Act (or PDCA) cycle, where "Plan" is the establishment of objectives and processes required, "Do" is the implementation of these processes, "Check" is the monitoring of results and finally "Act" is the action to be taken and the final evaluation if the objectives are being met (ISO, 2009). According to ESPO, the EcoPorts should demonstrate conformity with ISO14001 by making a self-declaration or by using external organizations to gain a certification of its environmental management system (ESPO, Green Guide, 2012).

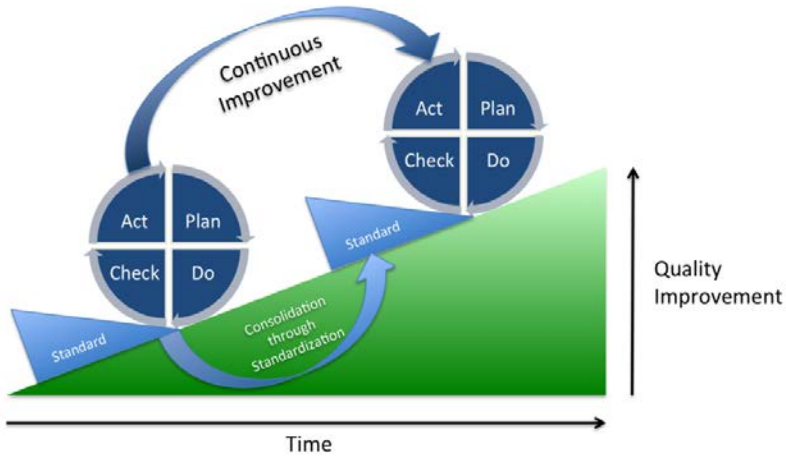

Figure 13 PDCA as basic principle of ISO 14001 (Moen R., 2009)

Top environmental priorities

The top environmental priorities that port authorities need to focus were determined and are presented in the following table. The ranking of these priorities change through time because of political interventions. In 2013 the total ranking mentioned "Air quality" as the most important priority. According to ESPO, this priority was set because of the people working or living around the port area and the attempt of European Union to control the exhaust emissions of air pollutants by vessels (ESPO, Top environmental priorities of European Ports 2013, 2013).

	1996	2004	2009	2013
1	Port Development (water)	Garbage / Port waste	Noise	Air quality
2	Water quality	Dredging: operations	Air quality	Garbage/ Port waste
3	Dredging disposal	Dredging disposal	Garbage / Port waste	Energy Consumption
4	Dredging: operations	Dust	Dredging: operations	Noise
5	Dust	Noise	Dredging: disposal	Ship waste
6	Port Development (land)	Air quality	Relationship with local community	Relationship with local community
7	Contaminated land	Hazardous cargo	Energy consumption	Dredging: operations
8	Habitat loss / degradation	Bunkering	Dust	Dust
9	Traffic volume	Port Development (land)	Port Development (water)	Port development (land)
10	Industrial effluent	Ship discharge (bilge)	Port Development (land)	Water quality

Table 44 Top port environmental priorities (ESPO, Top environmental priorities of European Ports 2013, 2013)

This also can be noticed by European Commission's acts that have to do with the enforcement and implementation of air related legislation 2008/50/EC. Moreover, ports are usually situated in areas with dense population that are affected by air pollution. For these critical areas, it is important for port authorities to apply appropriate control mechanisms and enhance the reduction of port related air pollution.

5 E's framework for air quality

The 5 E's framework is applied in order to solve the air quality issues and the guidelines are presented below:

Exemplifying

- Transform own fleet (vehicles and vessels) into low emission and fuel efficient
- Use state of the art own terminal equipment (movable or not)
- Use of low emission fuels in vessels (sulphur, carbon, PM)
- Monitoring authority achievements
- Invest and introduce new technologies that reduce air pollution

Enabling

- Provide infrastructures for Onshore Power Supply (OPS)
- Suitable space in the port area for LNG bunkering facilities
- Apply techniques to prevent dust dispersion from dry bulk operations/ road traffic, such as wind screens or buffering zones

Encouraging

- Incentives for ship owners and operators that demonstrate an outstanding performance
- Support for the use of Onshore Power Supply to ship owners
- Incentives for terminal users to use technologies that reduce emissions
- Provide awards

Engaging

- Update database regarding port's operations related emissions and their impact on air quality levels
- Organise workshops and hire experts with improvement of air quality as a target
- Organise joint pilots and feasibility studies with port users
- Cooperate with port users for developing OPS and LNG bunkering

Enforcing

- Introduce low emission zones
- Control the performance by introducing emission standards
- Inspections on port users and contractors to check if they follow the rules and agreements

- Incorporating air emissions criteria in procedures linked with concession and lease agreements

5 E's framework for energy conservation

Except from the Air Quality, ESPO sets as a high priority the energy conservation. Ports are often an area that industrial activities take place, which need energy for their production operations. According to European policy (EU Renewable Energy Directive, 2009), a 20% reduction in primary energy use should take place. Therefore, ports should play an important role towards that direction. Same as with Air Quality, the five E's framework is used to give guidance towards Energy Conservation (ESPO, Green Guide, 2012).

Exemplifying

- Managing energy consumption and improving energy efficiency
- Determining reduction targets and carbon neutrality
- Using Renewables wherever is possible

Enabling

- Provide infrastructures for Onshore Power Supply (OPS)
- Provide infrastructures for Renewables and LNG
- Create the facilities and circumstances for stakeholders collaboration regarding energy
- Provide conditions for efficient vessel and handling services

Encouraging

- Rewards to ship owners and operators to follow environmental management plan
- Subsides to terminal operators that use state of the art terminal equipment
- Support for the use of Onshore Power Supply to ship owners
- Incentives for terminal users to use technologies that reduce emissions
- Provide awards

Engaging

- Work together with port users and competent authorities to deploy the right infrastructure for transportation from and to the port
- Organise workshops and hire experts for OPS and LNG development
- Working together with port users in calculating emissions
- Cooperating with terminal operators and port users to find measures to improve energy efficiency

Enforcing

- Control the performance by introducing standards about energy consumption and efficiency into contract documents

- Inspections on port users and contractors to check if they follow the rules and agreements
- Incorporating energy use criteria in procedures linked with concession and lease agreements

5 E's framework for waste management

Finally, the 5 E's framework is applied in order to give guidance to port authorities related to the waste management. The guidelines are the following:

Exemplifying

- Establishing a waste management plan
- Consulting with ship owners, tenants and other port users while planning and designing the port's reception facilities and the waste management plan
- Demonstrating excellence while managing port authority generated waste (offices, fleet, vehicles, own operations)
- Investing in equipment for optimal handling of waste
- Setting targets for reducing amount of port authority generated waste
- Setting targets for increasing recycling and reuse

Enabling

- Building/establishing port reception facilities for different types of waste
- Facilitating port users (vessels, tenants and operators) to separate and deliver their waste in an effective way
- Establishing a simple system for notification information on quantities and types of waste that vessels want to deliver, in order to optimise the reception on arrival
- Providing easily accessible information through the port's web site and through other means (leaflets, newsletters, information meetings)

Encouraging

- Monitoring waste volumes and types and reporting those to the vessels
- Including waste collection fees within the port dues
- Applying an incentive scheme rewarding waste separation
- Applying an incentive scheme rewarding vessels with less water in sludge

Engaging

- Cooperating with agents in view of providing accurate and up-to-date waste related information to ship owners
- Collaborating with other ports and exchanging waste related information (e.g. waste reception facilities)
- Monitoring and communicating the cost reductions due to waste sorting

- Sorting of biological waste (if possible) and monitoring how much green energy it will produce

Enforcing

- Incorporating good waste management practices in tendering procedures associated with concession and lease agreements
- Monitoring and ensuring that port users comply with the rules and agreements

<u>ESPO code of practice on societal port integration</u>

Another important aspect of the Ecoport is the societal integration of the port and its activities. As societal integration is considered the actions of the port authorities to optimize the relations between the port and the surrounding societal environment. The main focus is the human factor such as the employees, the people that live in the general port area and the general public. The report by ESPO "Code of Practice on Societal Integration of Ports" (ESPO, 2010) recommends some guidelines regarding this integration. This focus is divided into three target groups, the general public, the current and future employees, and the people that live in and around the ports. The first group aim for ports is to ensure the public support in a way that the port will continue to operate and to achieve development projects. The second group is related to the need of ports to attract better educated workers. The third group goal for ports is to improve the quality of life of the people living around the port, support attractive business climate and co-operation between cities and ports.

For the three groups, ESPO proposes different guidelines. The first guideline is the general public support and image. The problem that this guideline tries to solve is that ports have become unknown territory for a lot of people and there is an increasing disconnection between ports and their surrounding urban area. Therefore, in order to tackle this problem ESPO suggests to open the port to people so as to experience the port life. As it is nicely mentioned in the report, "the city should breathe port atmosphere".

Another way to increase the reputation and meet the targets of public support is to enhance the connection between the ports and the education and job market. The port job market does not contain only the strictly the direct port jobs but also the port related jobs such as companies and their employees that operate in the port area. ESPO proposes ports to identify the gaps within the port job market, recognize the mismatch between the supply and demand for employees in order to vacant port jobs. Finally, this gap should be bridged by connecting the educational institutes' programs with the job needs related to the port area.

The last guideline that refer to the integration of the port in the society is the improvement of the relationship between the port and the city. According to the report, the first focus should be on minimizing the negative externalities of the port towards the port city. The main factors that should be tackled can be found in the appendix B. In addition, there are a lot of examples regarding how the role of the port can help to minimize separation gap between ports and port cities. The main ESPO's recommendations are referred below:

- To strengthen social cohesion and stimulate employment
- To promote innovative port and urban economic development
- To respect the equilibrium between the port cities and their natural environment

- To respect access to the port areas
- To treat the port as an urban space
- To integrate the port with the cities' port life
- To respect the port heritage and port cities' culture
- To play with flexibility and not to freeze space
- To exploit and benefit from blending
- To prepare for tomorrow's jobs

All the aforementioned guidelines regarding the port integration in the port cities emerged from practical experience. A lot of European ports, that are member of the ESPO network, have participated in this field experiment with the most known ports to be the port of Amsterdam, Antwerp, Hamburg, Rotterdam, Valencia etc. The main objectives of this initiative is to use these guidelines in order to raise awareness to the stakeholders regarding the benefits of the integration of the port in the society and to stimulate such actions.

Appendix B – Chapter 2

Levelized Cost of Electricity

The levelized cost of electricity is measure to compare different methods of electricity generation on a consistent basis. It consists an economic assessment on the average total cost to build and operate a power-generating asset. The result of the following formula provides the minimum cost at which electricity must be sold in order to break even over the lifetime of the project. (Branker K., 2011)

$$LCE = \frac{sum\ of\ costs\ over\ lifetime}{sum\ of\ electrical\ energy\ produced\ over\ lifetime} = \frac{\sum_{t=1}^{n}\frac{I_t+M_t+F_T}{(1+r)^t}}{\sum_{t=1}^{n}\frac{E_t}{(1+r)^t}}$$

Where,

t: year

I_t : investment expenditures in the year t

M_t : O&M expenditures in year t

F_t : fuel expenditures in year t

E_t : electrical energy generated in year t

r : discount rate

n : expected lifetime of the system

Appendix C - Chapter 3

The third part of this chapter contains the development of the planning cycle based on the information found in the subchapter 2.2 and the subchapters 3.1 and 3.2. The planning cycle to be developed will provide an inspiration regarding the guidelines that port authorities can use for the technology choice and implementation in order to tackle the emission issues. That can be achieved only when the main actions as well as their context are included in these guidelines. For the purpose of this research study, only specific parts of the planning cycle that are useful for the development of the decision making approach are going to be used. Therefore, these parts will be examined in detail and the rest that are mostly relevant with the technology implementation will be given as an indication.

High-level design of the planning cycle

The main goal of the high-level design is to create an overview which can describe the main stages as well as the sequence of the planning cycle. These stages should be related to the actions of the port authorities because these actions seem to solve the societal issues as presented in chapter 1. Based on the theoretical exploration of subchapter 2.2, the Low Emission Development strategies is the only validated theory that presents an overview (figure 5) and has as a goal the emissions reduction. Therefore, the high-level design of the planning cycle should be based on the planning cycle of Low Emission Development strategies. The five steps that are included in this cycle (LEDs) are: the formulating goals, the institutional framework, the prioritising policies, the implementation and the monitoring which, all of them are referred to policy and management guidelines with no direct relation to technical solutions. However, the focus of this research study is on technical solutions. Therefore, a modification should be proposed in order to substitute these characteristics related to policy with the actions of port authorities which are related to the technical solutions.

For this modification, there was no theoretical tool found in the literature regarding the high-level design. Therefore, except for the theoretical information of subchapter 2.2, the development of the planning cycle should be based on reasoning. To begin with, the simplest way to design this modification is by relating the context of the steps of the planning cycle of LEDs with the context of the actions based on the table 5. If there is a relevance that can be found, then it can be used as a new stage the relevant action. In case there is no relevance, the step of the planning cycle should be examined individually whether it can contribute to the planning cycle with focus on technical solutions. If there is no contribution it should be excluded. In the end, all the actions presented in subchapter 3.2 with their elements should be included in the final planning cycle. This process is presented below.

<u>Formulating goals</u>

The step of formulating goals is the first of the planning cycle of LEDs. It includes the creation of the vision by representing the main goals that the port authorities want to achieve. The vision should be based on historic information by means of past experiences and should include the main ambitions for the future. By comparing with the action of port's economic development, it seems that a relevance exists because the action explains the main target of the development (reduce emission footprint and at the same time preserve the stakeholder values) which can also be considered as vision. For the sake of simplicity, the stage term that could be used is the "vision" and can be described by the aforementioned action.

Institutional framework

The second step of the planning cycle of LEDs is the institutional framework. In this step takes place the defining of the co-ordination among the institutions and enhancing it through specific policies. Before the relevance examination with the actions of port authorities, it is important to be mentioned that, according to LEDs, the term "institutions" does not cover all the stakeholders in the port area (as explained in the previous subchapter) but only the organisations that provide knowledge to the port related to emissions reduction such as universities or research organisations. However, this research study focuses on all the stakeholders, their interests and how to enhance their participation. The planning cycle to be developed should focus also on these aspects and therefore the characteristic of Stakeholder involvement should substitute the institutional framework as a stage.

Prioritising policies

This step of the planning cycle is referred to the policies and how to prioritize them which consists the main focus for the Low Emission Development strategies. It seems that there is no direct relevance with one of the actions as none of them describes policies, analysis of barriers and policy interactions. Therefore, it should be excluded from the development of the planning cycle related to technologies.

Implementation

This step of the planning cycle of LEDs explains the implementation of the policies in terms of attracting funding and co-ordinating funding disbursement. The planning cycle to be developed should focus on the implementation of technologies, not policies. Although in the beginning it seems that there is no relevance among the implementation step of the LEDs and the actions for port authorities as described above, a relevance can be explained based on the idea that the implementation is related to process matters (how the technology can be implemented). When examining in more detail the action of Economic and Institutional arrangements (table 5), it can be concluded that the element of Economy as finance is included also in the step of the planning cycle (analysis of the cost and funding to support the implementation). An idea could be to break down the action based on the context into two main stages, the "Finance and Implementation" and the "Institutional arrangement". But the context of the institutional arrangement or better the stakeholder arrangement can be included in the action that is related to the stakeholders which is the stakeholder involvement. According to the Stilgoe's dimension Anticipation, the relevant with the stakeholders' analysis and arrangements should be done in the designing phase where decision regarding the technologies are taken based on several criteria and not during the implementation phase. Finally, the new stage of the planning cycle is the "Finance and Implementation".

Monitoring

Finally, the monitoring step explains the importance of keeping track of the results after the implementation. The results can help the port authorities to realise whether the initial goals have been achieved and if further progress is needed. In addition, these results can help port authorities to learn from experience and provide knowledge for the setting of new vision. Although that such an characteristic is missing from the actions for port authorities, it is important to be adjusted to the planning cycle as it contributes towards the continuous improvement idea (as described in chapter 1) by means that the lessons learned by the existing can be used in order to improve the future developing plans through a feedback loop mechanism.

Furthermore, based on the above analysis, the actions of "Technology and Mitigation potential" and "Emission levels and objectives" have no direct relevance with any of the steps of the planning cycle of the Low Emission Development strategies. On the other hand, as actions for port authorities, they should be included in the planning cycle. Regarding the "Technology and Mitigation potential", it seems that there is a relevance with the stages of "Vision" and "Finance and Implementation" based on the sequence of the events. Before the implementation of the technologies, the technologies should be known. Moreover, it seems that the Vision is the first stage that starts the cycle. Therefore, it should be placed between these two stages, but after the stakeholder involvement. However, the "Emission level and objectives" still cannot be related to any of the steps. The inclusion of this action in the planning cycle will be examined in the analysis of the low-level design and its main elements will be included in the most relevant stage.

To sum up, the formulating goals will be substituted by the port's economic development with respect to air quality and stakeholders' values by referring to it as "vision". The institutional framework will be substituted by the "stakeholder involvement", the prioritising policies will be replaced by the "technology and mitigation potential". Instead of the step of implementation it will be used the staget of "finance and implementation" with "monitoring" to close the loop of the cycle. The reasoning behind the sequence of the stages is that the output of the previous stage can be used in the next. In figure 7, the architecture of the methodological framework is presented from the analysis that was carried out above.

Low-level design of the planning cycle

The second part of the development phase of the planning cycle for technology choice and implementation is that the low-level design or better the "detailing". The main stages that were identified in the previous subchapter is analysed in detail based on the information presented in the subchapters 2.2 and 3.2. In addition, the main elements of Emission levels and objectives, which is the only action that had no relevance with the main steps of the planning cycle of LEDs, will be added in the most relevant stages.

<u>Vision</u>

The first stage is the vision. It can be described as the process of formulating the strategic goals by the port authorities. These strategic goals should be built on past reports and strategies and on the opportunities that are present at a specific moment of time. There is no specific process found in the literature regarding how to formulate the vision probably because of the diverse character of ports. The initial targets could be more general such as "reduce by 10% the emissions in the port by increasing the number of job positions", but also more specific as an example "decrease the emissions at a terminal level and increase the circularity factor". The strategic goals should focus on the reduction of the emission footprint with the use of technical solutions. At the same time, they should serve the public needs and minimize the possible conflicts among the stakeholders.

Stakeholder involvement

The next stage, as described from the high-level analysis, is the Stakeholder involvement. The information found in the literature associated with the stakeholders is presented in subchapters 2.2.2 (Responsible Innovation values methodological framework) and 2.2.3 (stakeholder analysis). The sequence of the process is inspired by the Ravesteijn's framework. At this point, all the stakeholders involved should be identified. Usually, as there are a lot of stakeholders acting in the port environment, the analysis should focus not on every stakeholder separately but on groups of stakeholders which have similar interests (categorization of their involvement). As first step of the categorization can be used the groups that have been identified in subchapter 3.1.4: the port authorities, the private sector and public sector and the organizations and institutions which provide knowledge and take part in the research such as universities or ESPO. Based on the results of this analysis, the second step is to form the groups with stakeholders that have similar interests. After the identification of the stakeholders, another step that provides important information regarding their involvement in the technological choice and implementation is the process of dividing them into direct and indirect stakeholders. The direct stakeholders are directly associated with the project (affect) and the indirect are influenced by the project. The next step of the process is the translation of the interests found into values. According to Keeney, these values should be structured into a values-tree (dendrogram) which represents graphically all the values of all the stakeholders. This first part is related to the element of stakeholders' interests (table 5).

According to table 5, the next part is related with the participation of the stakeholders and how to enhance it. According to 2.2.3, the dedication can enhance the participation. The dedication can be achieved when the interests of each of the stakeholders' group can be satisfied. However, the satisfaction of the interests of all the stakeholders is not an easy process because they may realise differently the importance of the interests and in some cases, the interests may be conflicting. Thus, the identification of the importance of each of the interests is essential. By knowing the importance, the possible conflicts can be minimized with the use of trade-offs. Also, better co-ordination can be achieved as the port authorities can realise what are the interests of each of the stakeholders' group which can reveal also opportunities for synergies and clear roles in the participation. In the existing theoretical exploration there is a lack of information regarding the ways of dealing with these value issues. The most common theoretical methods that can address these issues are provided by the multi-criteria tools. In the fourth chapter the relevant methods are explored.

Technology and Mitigation

The next stage is the Technology and Mitigation potential. The information that will be used for the analysis of this stage is the literature related to this stage is the Technology Impact Assessment (subchapter 2.2.4) in and the main elements (with their relevant functions) of the specific action for port authorities (subchapter 3.2). The sequence of the steps that will be presented below is based on the idea that the output of the previous step should be input of the next step. To begin with, the first step should be the identification of the circularity opportunities that are presented in the port area. According to subchapter 3.1.2, the main sources that can be used for the "reuse" and "recycle" principles are the wastes (energy or by-products of biomaterials) of the industries and the port city around the port. The "reduce" principle is related to the reduction of energy use of the shore-related port operations. The next step is the identification of the technologies that can be implemented. These technologies are referred also as Low Emission Port Technologies and will be examined in the next steps of this research study. For the identification of these technologies at a specific moment of time, three main criteria should be used.

Firstly, the technologies should fulfil the vision that was set in the beginning of the process. Secondly, these technologies should be related to specific emission sources of the shore-related port operations. Finally, the circularity opportunities identified in the previous step should be connected with the available technologies. However, there is a lack of information in the theoretical background as presented in chapter 2 regarding the Low Emission Port Technologies. Therefore, the identification of the technologies that can be considered as Low Emission Port Technologies is performed in the following chapter 4.

The next step after the identification is the evaluation of the technologies found. At this point, it is important to examine how the criteria of the technology impact assessment (as they have been analysed in the subchapter 2.2.4) can be used for this evaluation. The main criteria are divided into quantitative and qualitative. The quantitative are the economic criteria, mitigation potential, long-term vision and use of space. The economic criteria contain information about the initial capital cost, maintenance and operation cost (M&O cost) and payback time. The mitigation criteria are related to the amount of the emissions that are reduced by the time the technology is implemented.

The qualitative criteria are difficult to be recognised as they usually represent subjective opinions. However, the stakeholder analysis with the values identification can provide an insight regarding the qualitative values of the relevant stakeholders. The final evaluation should be done based on both the quantitative and qualitative criteria. The Low Emission Port Technology to be selected should be the most satisficing in terms of technical characteristics and the level it contributes towards the addressing of the value conflicts and enhancing the participation of the stakeholders. Also based on the theoretical exploration, the process of taking into account the indirect stakeholders' opinion can minimize the resistance that may appear to the implementation of the technology.

Except for the stages of "vision", "stakeholder involvement" and "technology and mitigation", there are also the stages of "finance and implementation" and "monitoring". Although both of them are related to the technical solutions, they are not relevant with the focus of the general scope of this research study which is to provide a decision making approach. Nonetheless, it is important to be presented for the planning cycle and therefore an indication of their context will be given based on the information found in chapters 1 and 2. These stages need further exploration and should be part of a future research study.

<u>Finance and Implementation</u>

This stage is divided into two main parts, the finance and the implementation. The finance contains the extended economic analysis of the overall cost of the actions that need to be taken in order to meet the goals. Another important aspect of this pillar is to identify possible sources of financing. The funding will be used for the implementation actions. The implementation actions can be divided into three main parts, the preparation for the implementation (analysis of the existing situation in sociotechnical terms), the installation of the technology chosen, and the testing of the operation should be according to the standards that are described by the technology certification and datasheet (Painuly J.P., 2002).

<u>Monitoring</u>

Monitoring is the last stage of the loop and describes the observation and analysis of the results of the implementation. It becomes clear whether the initial vision and its targets have been achieved or a new effort is needed. The evaluation of the results should be occurred with an insight on the technological choice, the results of the stakeholders' participation as well as the finance and implementation processes.

The above information should be used for the set of new vision as a feedback loop which contains recommendations to be used in order to improve further the reduction of emissions with respect to the societal needs.

All the main stages that have been identified in the high-level design phase are related to one of the actions for port authorities as presented in subchapter 3.2. However, as the focus of the planning cycle of LEDs is on policies it was difficult to relate the action of Emission levels and objectives with one the steps of the cycle. Therefore, based on their context, the elements of this action will be connected with the most relevant stage. According to table 5, these elements are the creation of emissions inventory (based on the sources of emissions) and the emission projection (potential emission trajectory after the implementation). Both of the elements can be included in the Technology and Mitigation stage. The emissions inventory should be in the beginning of the process (as assessment of the current situation) and the emission projection should be that last part of the process as it is related to the emission based on the Low Emission Port Technology that was chosen.

Appendix D – Chapter 4

Examples of Low Emission Port Technologies

In this part of the appendix, a list of low emission port technologies that can contribute to the reduction of emissions at the port level are presented. However, due to the limited literature information and the continuous innovation is important to mention that the following list is only an indication and there might be more technologies that were not found.

Dry Bulk (Ecoport, 2012)

- Wind screens
- Buffering zones
- Use of floating cranes

Low emission machinery (or even zero emission) (Port of Los Angeles, Green Bond Series, 2016)

- Electrification of the cranes
- Replacement of engines of the tracks with new ones that have better emission standards
- Installation of electric grid to support electricity driven trains
- Use of vehicles (trucks) in the port that have hybrid, propane or electric engines
- Introduce of bicycle routes for the port's personnel

Energy efficiency (Anttila A., 2014)

- Heat recovery technologies
- Use of heat pumps in the terminals
- Improve the insulation of the walls
- Use of Solar Thermal technology
- Use of district heat technologies

Energy production (from renewable sources) (US Department of Energy, 2007)

- Solar energy technologies
- Wind energy technologies
- Biomass technologies
- Biogas technologies
- Hydrogen technologies
- Wave energy technologies

Multi-Criteria Decision Making tools

The following Multi- Criteria Decision Making methods are available in the literature (Weistroffer H.R., 2005):

- Aggregated Indices Randomization Method (AIRM)
- Analytic hierarchy process (AHP)
- Analytic network process (ANP)
- Architecture tradeoff analysis method (ATAM)
- Characteristic Objects METhod (COMET)
- Choosing By Advantages (CBA)
- Data envelopment analysis
- Decision EXpert (DEX)
- Disaggregation – Aggregation Approaches (UTA*, UTAII, UTADIS)
- Dominance-based rough set approach (DRSA)
- ELECTRE (Outranking)
- Evaluation Based on Distance from Average Solution (EDAS)
- Evidential reasoning approach (ER)
- Goal programming (GP)
- Inner product of vectors (IPV)
- Measuring Attractiveness by a categorical Based Evaluation Technique (MACBETH)
- Multi-Attribute Global Inference of Quality (MAGIQ)
- Multi-attribute utility theory (MAUT)
- Multi-attribute value theory (MAVT)
- New Approach to Appraisal (NATA)
- Nonstructural Fuzzy Decision Support System (NSFDSS)
- Potentially All Pairwise RanKings of all possible Alternatives (PAPRIKA)
- PROMETHEE (Outranking)
- Pugh's matrix
- Stochastic Multicriteria Acceptability Analysis (SMAA)
- Superiority and inferiority ranking method (SIR method)
- Technique for the Order of Prioritiszation by Similarity to Ideal Solution (TOPSIS)
- Value analysis (VA)
- Value engineering (VE)

- VIKOR method
- Weighted sum model (WSM)

Analytic Hierarchy Method (AHP)

The steps of the AHP method are explained in more detail below with the use of a three criteria problem as an example:

Step 1

Analysis of the problem into criteria that the decision maker needs to evaluate in order to take the most responsible decision. Also this step includes the selection of the scale that is going to be used.

Step 2

Consider a matrix of pair-wise elements:

$$\begin{bmatrix} C_{11} & C_{12} & C_{13} \\ C_{21} & C_{22} & C_{23} \\ C_{31} & C_{32} & C_{33} \end{bmatrix}$$

Step 3

Summary of the values in each column of the matrix:

$$C_{ij} = \sum_{i=1}^{n} C_{ij}$$

Divide each element in the matrix by its column total:

$$X_{ij} = \frac{C_{ij}}{\sum_{i=1}^{n} C_{ij}}$$

Which generates the following pair-wise matrix:

$$\begin{bmatrix} X_{11} & X_{12} & X_{13} \\ X_{21} & X_{22} & X_{23} \\ X_{31} & X_{32} & X_{33} \end{bmatrix}$$

Usage of the following formula:

$$W_{ij} = \frac{\sum_{j=1}^{n} X_{ij}}{n}$$

In order to generate the following weighted matrix:

$$\begin{bmatrix} W_{11} \\ W_{12} \\ W_{13} \end{bmatrix}$$

Step 4

The consistency vector is calculating by multiplying the pair-wise matrix with the weighted matrix:

$$\begin{bmatrix} C_{11} & C_{12} & C_{13} \\ C_{21} & C_{22} & C_{23} \\ C_{31} & C_{32} & C_{33} \end{bmatrix} * \begin{bmatrix} W_{11} \\ W_{21} \\ W_{31} \end{bmatrix} = \begin{bmatrix} Cv_{11} \\ Cv_{21} \\ Cv_{31} \end{bmatrix}$$

Where,

$$Cv_{11} = \frac{1}{W_{11}} \left(C_{11}W_{11} + \ C_{12}W_{21} + C_{13}W_{31}\right)$$

$$Cv_{21} = \frac{1}{W_{21}} \left(C_{21}W_{11} + \ C_{22}W_{21} + C_{23}W_{31}\right)$$

$$Cv_{31} = \frac{1}{W_{31}} \left(C_{31}W_{11} + \ C_{32}W_{21} + C_{33}W_{31}\right)$$

Calculation of λ, Consistency Index and finally Consistency Ratio:

$$\lambda = \sum_{i=1}^{n} Cv_{ij} \qquad CI = \frac{\lambda - n}{n-1} \qquad C_r = \frac{CI}{RI}$$

Where RI is selected from the following table:

n	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.68	0.9	1.12	1.24	1.32	1.41	1.46	1.49

Table 45 Random Inconsistency for 1 ≤n ≤ 10 (Saaty T., Decision Making for Leaders: The Analytic Hierarchy Process for Decisions in a Complex World, 2008)

Below is presented an example of an AHP matrix made in excel for 3 criteria. The scale that it is used for the judgments and the analysis of the AHP matrix it is considered as the most common scale. The judgements that need to be made are the C_{21}, C_{31}, and C_{32} which complete also other cells of the matrix as it can be seen below.

factor	C1	C2	C3
C1	1.00	Resulted from the ($1/C_{21}$)	Resulted from the ($1/C_{31}$)
C2	C_{21}	1.00	Resulted from the ($1/C_{32}$)
C3	C_{31}	C_{32}	1.00

Table 46 Example of AHP process matrix with 3 criteria

Scale

The scale that it is used to quantify the qualitative judgements of the pair-wise matrix is presented below.

1/10: much less important

1/5: less important

1: equal importance

5: more important

10: much more important

Pugh's Matrix

The step by step procedure of the tool is analysed below. Also, an example of the matrix that can be used is presented in table 47. (Burge S., 2009)

Step 1

The first step is to list all the criteria as the row labels of the table and the alternatives as the column headings. Then, based on the experience, data or the most common practice, the datum alternative is selected. In addition, the weights of the criteria, if existed, are added to the matrix.

Step 2

This step is connected with the scoring of each alternative for each of the criteria following the comparison between them. As mentioned above the scale varies with the five-point scale 1 to 5 or "- - " to "++" to be the most common. The five-point scale represents the comparison where 1 or "- -" is the "much worse", 2 or "-" is the "worse", 3 or "s" is the "equivalent", 4 or "+" is the "better" and 5 or "++" is the "much better".

Step 3

This step describes the calculation of the weighted scores for each alternative/criterion combination. This can be achieved by the multiplication of the arithmetic values of step 2 and the weights of the criteria that were introduced in the step 1.

Step 4

The final step includes the summary of all the scores that have been calculated in the previous step for each of the alternatives. The alternative that has the best score is the most suitable solution for the problem described by the specific criteria.

The table below represents Pugh's matrix with 3 criteria, weights of importance, and five alternatives to be compared. The comparison is between the datum and each of the alternative based on the specific criterion. For this example a scale with signs has been chosen. In cases where all the alternatives compared with the datum have signs s, + or ++, a new datum among the alternatives 2 to 5 has to be used.

factor	weight	Datum	Alternative 2	Alternative 3	Alternative 4	Alternative 5
C1	5		s	--	++	-
C2	3		-	s	s	+
C3	1		--	s	+	s

Table 47 Example of AHP process matrix with 3 criteria

TOPSIS

The TOPSIS method is applied in seven steps. The first step contains the creation of a matrix with the criteria and alternatives to be evaluated. The second step includes the normalisation of the matrix, the third the calculation of the weighted normalised matrix, the fourth the determination of the worst and best alternative. In the fifth step, it is calculated the geometrical distance between the alternatives and best / worst condition. The final two steps include the calculation of similarity to worst condition and the ranking of the alternatives. The steps are presented in more detail below (Hwang C.L. Yoon K., 1981):

Step 1

Creation of evaluation matrix $\left(x_{ij}\right)_{mxn}$, where m is the number of alternatives, n the number of criteria and x_{ij} the intersection of each alternative and criterion.

Step 2

Normalization of the matrix to form the new matrix $R = \left(r_{ij}\right)_{mxn}$ by using the formula

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \text{ where } i = 1, 2, \ldots, m \text{ and } j = 1, 2, \ldots, n.$$

Step 3

Determination of the weighted normalised decision matrix by using the formula of step 2 where

$$w_j = \frac{W_j}{\sum_{j=1}^{n} W_j} \text{ where } j = 1, 2, \ldots, n \text{ so that } \sum_{j=1}^{n} W_j = 1$$

And W_j is the original weight that is given to the indicator w_j

Step 4

Determination of the best and worst alternative (A_b and A_w)

$$A_b = \{\langle \min(t_{ij} | i = 1, 2, \ldots, m) \mid j \in J_- \rangle, \langle \max(t_{ij} | i = 1, 2, \ldots, m) \mid j \in J_+ \rangle\} \equiv \left(t_{bj} \middle| j = 1, 2, \ldots, n\right)$$

$$A_b = \{\langle \max(t_{ij} | i = 1, 2, \ldots, m) \mid j \in J_- \rangle, \langle \min(t_{ij} | i = 1, 2, \ldots, m) \mid j \in J_+ \rangle\} \equiv \left(t_{wj} \middle| j = 1, 2, \ldots, n\right)$$

Where,

$$J_- = (j = 1, 2, \ldots, n \mid j \text{ related to the criteria that have positive impact})$$ and

$$J_+ = (j = 1, 2, \ldots, n \mid j \text{ related to the criteria that have negative impact})$$

Step 5

Calculation of distances between the target alternative i and the best and worst condition (A_b and A_w)

$$d_{ib} = \sqrt{\sum_{j=1}^{n}\left(t_{ij} - t_{bj}\right)^2}, i = 1, 2, \dots, m \text{ and}$$

$$d_{iw} = \sqrt{\sum_{j=1}^{n}\left(t_{ij} - t_{wj}\right)^2}, i = 1, 2, \dots, m$$

Where d_{ib} and d_{iw} are the target distances to the best and worst conditions from the target i

Step 6

Calculation of the similarity to the worst condition

$$s_{iw} = \frac{d_{iw}}{(d_{iw} + d_{ib})}, 0 \leq s_{iw} \leq 1 \text{ and } i = 1, 2, \dots, m$$

Where

$s_{iw} = 1$ if and only if s_{iw} has the best condition

$s_{iw} = 0$ if and only if s_{iw}has the worst condition

Step 7

Ranking of all the alternatives based on s_{iw} $(i = 1, 2, \dots., m)$

Development of the Decision Making Tool

For the development of the process of the Decision Making Approach, the relevant information of the subchapters 3.3, 3.4, 4.1, 4.2 and 4.3 will be used. The context of the stages of Vision, Stakeholder Involvement and Technology and Mitigation will be used for the sequence of the steps (subchapter 3.3.3) and will be assigned to the relevant four stages, as the "Technology and Mitigation" was broken down into identification and evaluation. In addition to that, the satisficing method should also be included in the context of one of the new stages. It should be placed after the stakeholder involvement and before the final evaluation of the technologies. As described above, the satisficing filters which technologies are good enough to be used based on the results of the Stakeholder Involvement stage. In fact, it consists a preparation for the criteria of the evaluation and therefore should be introduced as a separate step between the identification and evaluation. Except for the methods, also the sub-tools of subchapter 4.3 should be included in the Decision Making Approach. The sub-tool of AHP is associated with the analysis and identification of the values of the stakeholders and it will be placed in the context of the Stakeholder Involvement stage. The sub-tools Pugh's matrix and TOPSIS will be placed in the stage of Evaluation and Final Decision as they both compare the alternatives in order to identify the most appropriate technology. All the aforementioned characteristics will be explained in detail below.

Vision

The main idea of the vision stage is to formulate goals related to the reduction of the emission footprint of the shore-related operations of a port. This can be achieved by the use of the Low Emission Port Technologies. As explained in subchapter 4.1, they represent a variety of different technologies and are associated with the different types of emission sources identified in the shore operations. Therefore, they have been categorized in groups of solutions. These groups of solutions are described by different qualitative characteristics that are used for the comparison of these technologies. Based on the idea that the comparison should contain same criteria, the vision to be set should refer to one of the four categories of technologies: the dry bulk technologies, the low emission machinery technologies, the energy efficiency technologies or the energy production technologies. In such way port authorities can cope with specific emission sources which can make the decision making process less complicated. Finally, it should be clearly explained that the selection of the Low Emission Port Technology should be done according to the stakeholders' values.

Stakeholder involvement

The stakeholder involvement stage is divided into several parts. The first part contains the identification all the relevant with the vision stakeholders, the categorization of them into direct and indirect stakeholders, the identification of their main interests and values. According to Keeney's "values-focused thinking" the values are distinguished into fundamental values or values-criteria (central values) and value objectives (low values). The fundamental values can be identified from the general goals or vision or strategy of the stakeholders and can be found in the documentation (subchapter 2.2.2). For the value objectives, relevant data should be acquired as these are more difficult to be realised in the literature. Also, in order to evaluate the port's current situation, the dynamic input of data is important. Therefore, a method for data gathering with questionnaires or interviews should be used. When all the values are identified, the values-tree should be drawn for a better overview of the situation related to the stakeholders.

The second part of this stage is related to the identification of the importance of the values presented. For this part the first sub-tool AHP will be used. Firstly, the opinion of each of the relevant stakeholders is needed so as to identify the relative importance of each of the fundamental values. Interviews or questionnaires can be used for retrieving the important data. Through these interviews or questionnaires, the stakeholder has to compare how much more important, important, equal, less important or much less important for taking decisions considers a criterion (fundamental value) in comparison to another criterion (another fundamental values). This process reveals the opinion of each of the stakeholders regarding the importance of the fundamental values and the information will be included in several tables. However, these data should be summarized in order to be processed to the AHP matrix. At this point, the first assumption should be made. It is assumed that the power of intervention of the stakeholders is equal. Usually except from the weighting of the values, a weighting system should also be established for the stakeholders by means of investigation of the power of intervention of each stakeholder which should be weighted and introduced in the matrixes. However, for the purpose of this research study, this is not considered the case. The weighting methodology follows the idea of "equity of input" as far as the stakeholders are concerned. Finally, the average score of the judgements will be introduced in the AHP matrix where the overall importance of these values will be concluded. For the AHP matrix procedure, the five-point scale is selected to be used:

Much less important: $\frac{1}{10}$

Less important: $\frac{1}{5}$

Equal: 1

More important: 5

Much more important: 10

The AHP will provide the final overall weights of the fundamental values based on the stakeholders' opinion. However, not only the fundamental values but also the relevant value objectives should be identified. Following the analysis that is described in Appendix C, the score of the values objectives arises by multiplying the weight of the fundamental value with the weight that the value objective has in the related cluster. For this research study, the weight of the value objectives is assumed to be equal in each cluster as it is considered that the value objectives affect equally the fundamental value. Also, another important assumption is that the value objectives are completely independent not only in the same cluster but also in the whole values-tree.

At this point, the output of the process until now is described by two tables which contain the overall weights of the fundamental values and the weights of the relevant value objectives. The results from the data gathering process can reveal if there are any big differences in the scoring on the importance of the fundamental values among the stakeholders. If there are, that could be a sign of possible conflicts. According to the theoretical exploration the values conflicts are solved with trade-offs which are executed with the use of TOPSIS.

Finally, the value objectives will be used as the input of the Pugh's matrix and more specifically as the main criteria for the evaluation of the technologies. There are three main reasons that explain the use. The first one is related to the participation of the stakeholders which can be enhanced through dedication. In order to achieve higher dedication, the values should be fulfilled at the highest possible degree. Therefore, the evaluation should be based on the fulfilment in terms of satisfying the value objectives based on the weights. Moreover, by achieving participation, the risk of "implementation resistance is minimized". The second reason is related to the fulfilment of the societal needs which consist main part of the vision. When the weights of the values of the stakeholder related to the citizens of the port city are represented in the weights of the values, then they are taken into account when the evaluation is based on these values. The third reason is that not only quantitative but also qualitative data can be used for the evaluation and the value objectives may represent some of them.

<u>Identification of Emissions and Technologies</u>

The next stage of the Decision Making Approach is the Identification of Emissions and Technologies. This stage is directly related to the vision as its context is influenced by the categories of the Low Emission Port Technologies. The identification includes four main steps. The first step is related to the exploration of the circularity opportunities in the port area. For this step an analysis based on the three main principles "reuse", "reduce", "recycle" should be done for the port area in order to identify these opportunities. The relevant information that can be used for this step are presented in the subchapter 3.3.

The next step is thethe identification of the emissions based on their sources. Again, the vision affects the context of this step as the Low Emission Port Technologies are related to a specific group of emission sources. For instance, low emission machinery is related to the trucks, cargo handling equipment, trains etc. Based on the emission sources, the relevant emissions inventory should be produced. Finally, the Low Emission Port Technologies that can be applied will be identified based on the good practises of other ports, circularity opportunities results and the research for innovations that may have not been applied yet in the port but it seems to solve the issues of emission reduction. Finally, the main quantitative data according to the criteria of Technology Impact Assessment (table of subchapter 4.3) of these technologies will be provided as well as the available information related to legislation. Otherwise, the technology should be excluded.

Satisficing

The intermediate step between stakeholder involvement and the final evaluation of the technologies is the Satisficing. It can be used in order to set thresholds as a qualitative estimation of what is the minimum score of a criterion that is considered as “good enough”. This estimation comes from the results of the AHP importance analysis of the Stakeholder Involvement. But the thresholds have been set for the fundamental values and not for the values objectives. Although the value objectives are multiplied down to get the corresponding weight, the thresholds shouldn’t change. This argument is based on the following reasoning. When a fundamental value has a specific importance level among the stakeholders, also the value objectives that characterize the fundamental value and were taken into account during the evaluation phase of the importance should have the same importance level considering that they are also independent and equal. Therefore, the same thresholds will be used. The results of the Pugh’s matrix will be filtered and if any of the alternatives is exceeding the thresholds, it should be rejected. In case there is a large number of technologies that are rejected, the threshold limits should be reconsidered.

Evaluation and Final Decision

The final stage of the Decision Making Approach is the Evaluation and Final Decision. It is divided into two steps, the evaluation of the Low Emission Port Technologies (alternatives) and the final decision. According to the results of the subchapter 4.3.2, the Pugh’s matrix will be used for the evaluation of the alternatives. The criteria that are used for the comparison process of this matrix are the values objectives. In order to perform the analysis of the Pugh’s matrix, the opinion of one or more experts should be used. The selection of the expert(s) should be a case for further research but for the sake of simplicity, for this research study an expert who is experienced in the identified Low Emission Port Technologies and knows the port business environment should be selected. By combining the quantitative data of the previous analysis with his knowledge, he/she should select the datum technology and based on that, judge the rest of the alternatives by performing a comparison. The scale that is widely used is a five-point scale which is presented below:

Much worse: - -

Worse: -

Same: s

Better: +

Much better: ++

The final step of this stage is the use of TOPSIS for the final decision. The input of the TOPSIS matrix comes from the output of the Pugh's matrix. However, the scores of each technology from Pugh's matrix should be formulated in order to be introduced to the TOPSIS matrix for the final decision. The aforementioned five-point scale of Pugh's matrix will be translated into "1", "3", "5", "7", "9" for each of the points respectively. Finally, TOPSIS will give the most suitable solution for the existing situation at the port as the sub-tool's algorithm finds the optimized solution based on trade-offs. An important thing to be mentioned is that the final decision is not related with one decision maker but all the stakeholders participate as decision makers with the port authorities to have the overall management of the process. Finally, based on the results, the emission projection should take place with the use of the lifetime of the technology chosen as the time-frame. The emission projection should provide with information regarding the existing situation of emission footprint and the future information about the expected reduction during the operation of the chosen technology. The table that is presented in subchapter 4.4.2 related to the step 10 of the tool is inspired by the Los Angeles Port (Port of Los Angeles, 2012).

Weighting of the value objectives

This part of the appendix explains the weighting of the values-objectives of the values tree. The values-tree (dendogram), as a theoretical approach of data (values) clustering, belongs to the more general theory of hierarchical clustering. The hierarchical clustering is based on the simple idea that some objects are more related to nearby objects than objects that are further away. The objects that are close to each other form a cluster and are usually connected through algorithms that calculate the distance. In the case of values as objects, there is no mathematical connection but a qualitative relation regarding the influence that a value objective has to a fundamental value. (Rokach, 2005)

Based on the theory of Keeny, as explained in the chapter 2, there are two methods for the clustering process of the values tree, the bottom-up where the researcher identifies the first the values-objectives and then creates clusters that are related to a fundamental value, or the top-down where the fundamental values are set and then are filled into clusters based on the values-objectives that are related to each of fundamental values. Whatever the method, the weighting technique remains the same. The following table represents a values-tree with the weight of the fundamental values and of the values objectives. The real weights of the values objectives to a decision making process are resulted after the multiplying down of the weight of the fundamental values and the weights of the values objectives in the cluster that are directly related to the specific fundamental value. (Poyhonen M., 1998)

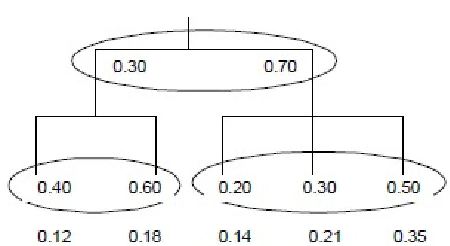

Figure 14 Explanation of weighting of the values-objectives of a values tree (Poyhonen M., 1998)

Appendix E – Chapter 5

Port of Piraeus photos

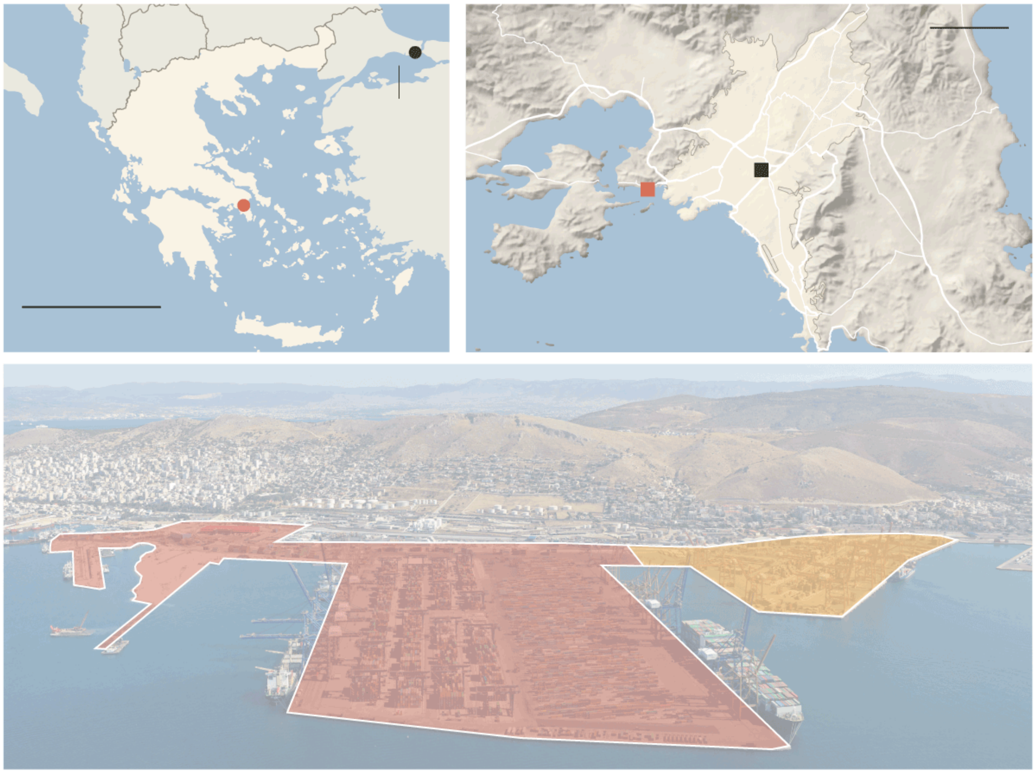

Figure 15 Piraeus' container terminal (New York Times, 2016)

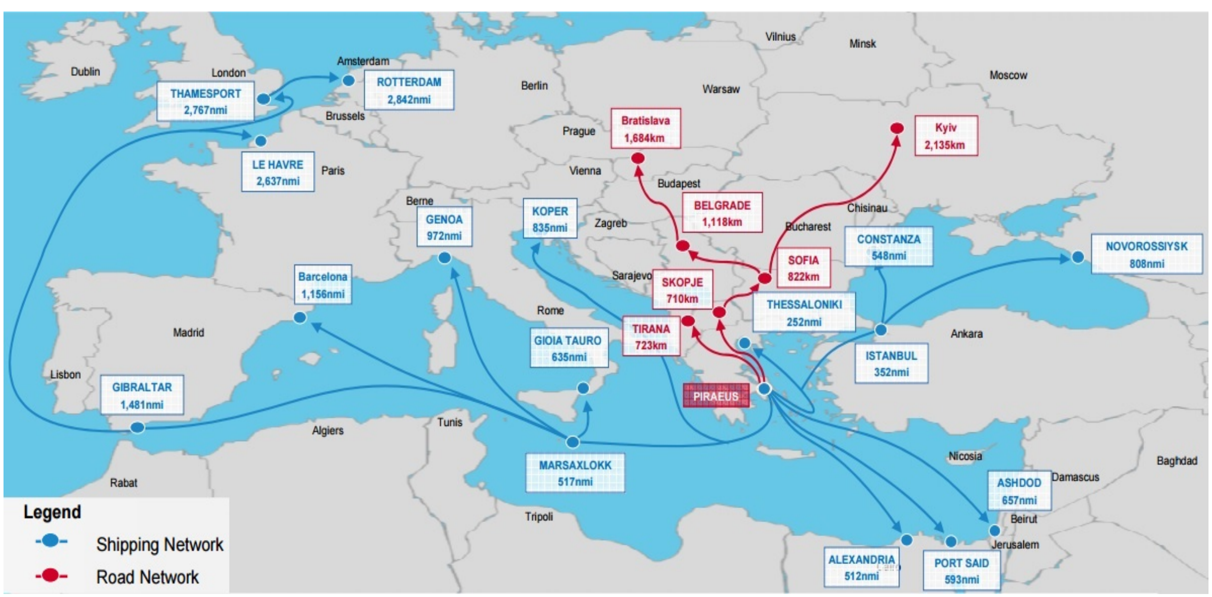

Figure 16 Commercial network of Piraeus (Maritime Logistics, 2015)

Participants in the stakeholder involvement

Participant	Part of research	Role	Relevance
Gloria Li	Values and AHP analysis	On behalf of COSCO	• Phd researcher related to the new silk road (China) • COSCO activities are included in her research
Ioannis Lekkas	Values and AHP analysis	On behalf of Piraeus Port authorities	• Mechanical Engineer • External consultant at Piraeus Bank • Department of port projects
Alexandros Euaggeliou	Values, AHP analysis and interview	On behalf of Ship Owners	• Chartered accountant • Economic consultant of shipping companies • Participates regularly in decision making
Dimitra Karvouni	Values, AHP analysis and interview	On behalf of Municipality of Piraeus	• Recently retired employee of the Municipality • Civil engineer responsible for infrastructures transportation and planning
Dimitris Bantias	Values and AHP analysis	On behalf of Regulatory port Authorities	• Vice President
Georgios Papageorgiou	Values and AHP analysis	On behalf of Residents	• Resident of Piraeus city • Urban engineer
Stavros Oikonomou	Values, AHP analysis and interview	On behalf of Public Power Corporation	• Electrical engineer • Grid stabilization for

			south Attica (includes Piraeus)
Aris Kourepis	Values and AHP analysis	On behalf of Ecoports	• Mechanical Engineer • Participated in the team related to the implementation of Ecoports' good practises
Drosos Makris	Values and AHP analysis	On behalf of Passengers	• Materials engineer • Travels two times per week from Piraeus to Aigina (island)
Makis Togias	Values and AHP analysis	On behalf of Technology Suppliers	• Ex - sales manager of Big Solar S.A.- leading company in the market related to all energy efficiency and energy production technologies

Table 48 Participants in the Stakeholder involvement analysis phase

<u>Questionnaire of value objectives identification</u>

The current questionnaire is related to research that takes place for my MSc thesis and has as a purpose to test through application the decision making approach that was developed for the Low Emission Port concept. It is referred to the decision making regarding technologies that can be applied not only in the port but also in the port area and help reduce the emissions footprint of the port. The case that is examined is the Piraeus port.

<u>Actions</u>

Please complete the following table with the values that you believe that are important for the decision making of the implementation of a Renewable Energy technology in the Piraeus Port. The list of values is the following. You are free to add your own value in case that this value is not included in the list.

income, profitability, efficiency, productivity, competitiveness, circularity, employment, synergies, external safety, health risks, emissions, livability, social stability, energy security, capacity, availability, aesthetics, longevity, use of space, entrepreneurship

Economic growth	Environmental protection	Safety	Accessibility	Creation of Societal value

Table 49 Questionnaire of values objectives

Results of the value objectives questionnaire

	Economic growth	**Environmental protection**	**Safety**	**Accessibility**	**Creation of societal value**
COSCO	Profitability, synergies, entrepreneurship	Emissions, Noise	External safety, Health risks	Capacity, Availability	Longevity, Employment
Ship owners	Profitability	Emissions	External safety, Health risks	Capacity, Availability	Employment
Municipality of Piraeus	Income, synergies	Emissions, Noise	External safety, Health risks	Availability	Employment, Aesthetics
Regulatory authorities of ports	Income, synergies circularity	Emissions, Noise	External safety, Health risks	Capacity, Availability	Longevity, Employment
Residents	Income, synergies, entrepreneurship	Emissions, Noise	External safety, Health risks	Availability	Employment, Aesthetics
PPC	Income, synergies	Emissions	Health risks		
Ecoports	synergies	Emissions, Noise			Longevity, Employment
Passengers		Noise	External safety	Availability	Aesthetics
Technology suppliers	Income, synergies	Emissions, Noise	External safety, Health risks		Longevity

Table 50 Piraeus Stakehoders' values

Questionnaire of AHP analysis

The current questionnaire is related to research that takes place for my MSc thesis and has as a purpose to test through application the decision making tool that was developed for the Low Emission Port concept. It is referred to the decision making regarding technologies that can be applied not only in the port but also in the port area and help reduce the emissions footprint of the port. The case that is examined is the Piraeus port.

Details for better understanding the nature of this questionnaire

1. The questionnaire's goal is to test the AHP method of the approach. Specifically, this method will be used in order to reveal the importance of specific values during the decision making process of the stakeholders of Piraeus port.

2. The main values to be explored are the economic growth, the environmental protection, the safety, the accessibility and the creation of societal value.

3. As economic growth is considered the profitability, the circularity and the entrepreneurship–synergies. Analytically, circularity describes the promotion of greater resource productivity aiming to avoid pollution. For instance, the use of waste from one operation can be regenerated into a product (energy or material) that can be used for another operation. In addition, entrepreneurship-synergies describes the enhancing of entrepreneurship by creating synergies among companies/institutions/organizations.

4. As environmental protection is considered the reduction of emissions and the noise.

5. As safety is considered the external safety and the health risks. The external safety is referred to the safety to people and organizations outside the port and are not related to specific modes of operation. The health risks are referred to people that are both inside and outside the port and port area and are related to the operation (number of injuries or deaths).

6. As accessibility is considered the capacity and the availability. Analytically, it is referred to the shipping, rail, road and pipelines which need to have sufficient capacity and need to be available as much as possible.

7. Finally, as creation of societal value is considered the longevity of the technology, the employment and the aesthetics.

Questions

1. Do you believe that economic growth is more important than environmental protection?
    - Much less important
    - Less important
    - Same importance
    - More important
    - Much more important

2. Do you believe that economic growth is more important than safety?
    - Much less important
    - Less important
    - Same importance
    - More important
    - Much more important

3. Do you believe that economic growth is more important than accessibility?
    - Much less important
    - Less important
    - Same importance
    - More important
    - Much more important

4. Do you believe that economic growth is more important than creation of societal value?
    - Much less important
    - Less important
    - Same importance
    - More important
    - Much more important

5. Do you believe that environmental protection is more important than safety?
    - Much less important
    - Less important
    - Same importance
    - More important
    - Much more important

6. Do you believe that environmental protection is more important than accessibility?
    - Much less important
    - Less important
    - Same importance
    - More important
    - Much more important

7. Do you believe that environmental protection is more important than creation of societal value?
    - Much less important
    - Less important
    - Same importance
    - More important
    - Much more important

8. Do you believe that safety is more important than accessibility?
    - Much less important
    - Less important
    - Same importance
    - More important
    - Much more important

9. Do you believe that safety is more important than creation of societal value?
    - Much less important
    - Less important
    - Same importance
    - More important
    - Much more important

10. Do you believe that safety is more important than creation of societal value?
    - Much less important
    - Less important
    - Same importance
    - More important
    - Much more important

11. Do you believe that accessibility is more important than creation of societal value?
    - Much less important
    - Less important
    - Same importance
    - More important
    - Much more important

12. Did you face a problem in replying these questions?
    - Yes
    - no
13. In case you faced, can you please write down the number of the question(s)? What are the difficulties you faced?
    ____

AHP analysis results

	COSCO	Ship Owners	Municipality	RAP	Residents	PPC	Ecoports	Passengers	Technology suppliers	Total
Economic growth	3.5	4	1.03	2.83	1	1.25	2.83	1	4	2.38
Environmental Protection	1	1	1	4	1	2.01	4	1.07	1.57	1.85
Safety	3.5	2.49	2.04	4	2.89	3.28	3.23	2.12	3.11	2.96
Accessibility	4	2.49	1.43	1	1.12	1	1	4	1	1.89
Creation of societal value	1.69	1.34	4	2.66	4	4.00	4	1.77	2.18	2.85

Table 51 Overall weights of the fundamental values

COSCO

							weight
	Economic growth	Environmental pr.	Safety	Accessibility	Creation of societal value		W
Economic growth	1	5	1	1	1		1.80
Environmental pr.	0.2	1	0.2	1	1		0.68
Safety	1	5	1	1	1		1.80
Accessibility	1	1	1	1	5		1.80
Creation of societal value	1	1	1	0.2	1		0.84
sum	4.2	13	4.2	4.2	9		
							weighted criteria average of row
	Economic growth	Circularity	Safety	Accessibility	Creation of societal value		W
Economic growth	0.238095238	0.384615385	0.238095238	0.238095238	0.111111111		0.242002442
Environmental pr.	0.047619048	0.076923077	0.047619048	0.238095238	0.111111111		0.104273504
Safety	0.238095238	0.384615385	0.238095238	0.238095238	0.111111111		0.242002442
Accessibility	0.238095238	0.076923077	0.238095238	0.238095238	0.555555556		0.269352869
Creation of societal value	0.238095238	0.076923077	0.238095238	0.047619048	0.111111111		0.142368742

Table 52 COSCO AHP – input and weighted criteria

	relative importance	dinstance from the smallest	scaled importance	difference 1st with 5th		step for the "+1"
	RI	differences	SI	difference		δ
Economic growth	24.20%	13.77%	3.50	0.16508		0.055026455
Environmental pr.	10.43%	-13.77%	1.00			5.50%
Safety	24.20%	13.77%	3.50	n-2		
Accessibility	26.94%	16.51%	4.00	3		
Creation of societal value	14.24%	3.81%	1.69			

Table 53 COSCO AHP - scaled importance

	eigenvalues λ						
	Consistancy measure	λmax	n	CI	RI		CR
Economic growth	5.855701312	5.876814988	6	-0.024637002	1.12		-0.021997324
Environmental pr.	5.876814988						
Safety	5.855701312			-0.042979335			-0.038374406
Accessibility	5.826835902						
Creation of societal value	5.510463122						

Table 54 COSCO AHP - consistency factor

Ship Owners

	Economic growth	Environmental pr.	Safety	Accessibility	Creation of societal value		weight W
Economic growth	1	5	1	5	5		3.40
Environmental pr.	0.2	1	0.2	0.2	1		0.52
Safety	1	5	1	1	1		1.80
Accessibility	0.2	5	1	1	5		2.44
Creation of societal value	0.2	1	1	0.2	1		0.68
sum	2.6	17	4.2	7.4	13		
							weighted criteria average of row
	Economic growth	Circularity	Safety	Accessibility	Creation of societal value		W
Economic growth	0.384615385	0.294117647	0.238095238	0.675675676	0.384615385		0.395423866
Environmental pr.	0.076923077	0.058823529	0.047619048	0.027027027	0.076923077		0.057463152
Safety	0.384615385	0.294117647	0.238095238	0.135135135	0.076923077		0.225777296
Accessibility	0.076923077	0.294117647	0.238095238	0.135135135	0.384615385		0.225777296
Creation of societal value	0.076923077	0.058823529	0.238095238	0.027027027	0.076923077		0.09555839

Table 55 Ship Owners AHP – input and weighted criteria

	relative importance	dinstance from the smallest	scaled importance	difference 1st with 5th		step for the "+1"
	RI	differences	SI	difference		δ
Economic growth	39.54%	33.80%	4.00	0.33796		0.112654
Environmental pr.	5.75%	-33.80%	1.00			11.27%
Safety	22.58%	16.83%	2.49	n-2		
Accessibility	22.58%	16.83%	2.49	3		
Creation of societal	9.56%	3.81%	1.34			

Table 56 Ship Owners AHP – scaled importance

	eigenvalues λ						
	Consistancy measure	λmax	n	CI	RI		CR
Economic growth	6.360757574	6.360757574	6	0.072151515	1.12		0.064420995
Environmental pr.	5.610851896						
Safety	5.447193434			-0.063117656			-0.05635505
Accessibility	5.739049466						
Creation of societal value	5.264206228						

Table 57 Ship Owners AHP – consistency factor

Municipality of Piraeus

							weight
	Economic growth	Environmental pr.	Safety	Accessibility	Creation of societal value		W
Economic growth	1	5	0.2	0.2	0.1		1.30
Environmental pr.	0.2	1	1	1	0.2		0.68
Safety	5	1	1	1	1		1.80
Accessibility	5	1	1	1	0.2		1.64
Creation of societal value	10	5	1	5	1		4.40
sum	21.2	13	4.2	8.2	2.5		
							weighted criteria
							average of row
	Economic growth	Circularity	Safety	Accessibility	Creation of societal value		W
Economic growth	0.047169811	0.384615385	0.047619048	0.024390244	0.04		0.108758897
Environmental pr.	0.009433962	0.076923077	0.238095238	0.12195122	0.08		0.105280699
Safety	0.235849057	0.076923077	0.238095238	0.12195122	0.4		0.214563718
Accessibility	0.235849057	0.076923077	0.238095238	0.12195122	0.08		0.150563718
Creation of societal value	0.471698113	0.384615385	0.238095238	0.609756098	0.4		0.420832967

Table 58 Municipality of Piraeus AHP – input and weighted criteria

	relative importance	dinstance from the smallest	scaled importance	difference 1st with 5th		step for the "+1"
	RI	differences	SI	difference		δ
Economic growth	10.88%	0.35%	1.03	0.31555		0.105184
Environmental pr.	10.53%	-0.35%	1.00			10.52%
Safety	21.46%	10.93%	2.04	n-2		
Accessibility	15.06%	4.53%	1.43	3		
Creation of societal value	42.08%	31.56%	4.00			

Table 59 Municipality of Piraeus AHP – scaled importance

	eigenvalues λ						
	Consistancy measure	λmax	n	CI	RI	CR	CR
Economic growth	6.898480911	7.295045776	6	0.099618906	1.12		0.088945452
Environmental pr.	5.474189592						
Safety	6.688155863			0.139593494			0.124637049
Accessibility	7.295045776						
Creation of societal va	7.13396522						

Table 60 Municipality of Piraeus AHP – consistency factor

Regulatory authority of ports

							weight
	Economic growth	Environmental pr.	Safety	Accessibility	Creation of societal value		W
Economic growth	1	1	1	1	1		1.00
Environmental pr.	1	1	1	5	1		1.80
Safety	1	1	1	5	1		1.80
Accessibility	1	0.2	0.2	1	1		0.68
Creation of societal value	1	1	1	1	1		1.00
sum	5	4.2	4.2	13	5		
							weighted criteria
							average of row
	Economic growth	Circularity	Safety	Accessibility	Creation of societal value		W
Economic growth	0.2	0.238095238	0.2380952	0.076923077	0.2		0.190622711
Environmental pr.	0.2	0.238095238	0.2380952	0.384615385	0.2		0.252161172
Safety	0.2	0.238095238	0.2380952	0.384615385	0.2		0.252161172
Accessibility	0.2	0.047619048	0.047619	0.076923077	0.2		0.114432234
Creation of societal value	0.2	0.238095238	0.2380952	0.076923077	0.2		0.190622711

Table 61 Regulatory authority of ports AHP – input and weighted criteria

	relative importance	dinstance from the smallest	scaled importance	difference 1st with 5th		step for the "+1"
	RI	differences	SI	difference		δ
Economic growth	19.06%	7.62%	2.83	0.13773		0.04591
Environmental pr.	25.22%	13.77%	4.00			4.59%
Safety	25.22%	13.77%	4.00	n-2		
Accessibility	11.44%	1	1	3		
Creation of societal value	19.06%	7.62%	2.66			

Table 62 Regulatory authority of ports AHP - scaled importance

	eigenvalues λ						
	Consistancy measure	λmax	n	CI	RI		CR
Economic growth	5.245964643	5.7809413	6	-0.043811737	1.24		-0.035332046
Environmental pr.	5.780941313						
Safety	5.780941313			-0.109325116			-0.088165416
Accessibility	5.213060179						
Creation of societal value	5.245964643						

Table 63 Regulatory authority of ports AHP - consistency factor

Residents

							weight
	Economic growth	Environmental pr.	Safety	Accessibility	Creation of societal value		W
Economic growth	1	1	1	1	0.2		0.84
Environmental pr.	1	1	1	1	0.2		0.84
Safety	1	1	1	5	1		1.80
Accessibility	1	1	0.2	1	1		0.84
Creation of societal value	5	5	1	1	1		2.60
sum	9	9	4.2	9	3.4		
							weighted criteria average of row
	Economic growth	Circularity	Safety	Accessibility	Creation of societal value		W
Economic growth	0.111111111	0.111111111	0.238095238	0.111111111	0.058823529		0.12605042
Environmental pr.	0.111111111	0.111111111	0.238095238	0.111111111	0.058823529		0.12605042
Safety	0.111111111	0.111111111	0.238095238	0.555555556	0.294117647		0.261998133
Accessibility	0.111111111	0.111111111	0.047619048	0.111111111	0.294117647		0.135014006
Creation of societal value	0.555555556	0.555555556	0.238095238	0.111111111	0.294117647		0.350887021

Table 64 Residents AHP – input and weighted criteria

	relative importance	dinstance from the smallest	scaled importance	difference 1st with 5th		step for the "+1"
	RI	differences	SI	difference		δ
Economic growth	12.61%	-0.90%	1.00	0.21587		0.071958
Environmental pr.	12.61%	-0.90%	1.00			7.20%
Safety	26.20%	13.59%	2.89	n-2		
Accessibility	13.50%	0.90%	1.12	3		
Creation of societal value	35.09%	22.48%	4.12			

Table 65 Residents AHP - scaled importance

	eigenvalues λ						
	Consistancy measure	λmax	n	CI	RI		CR
Economic growth	5.70637037	5.878118318	6	-0.024376336	1.12		-0.021764586
Environmental pr.	5.70637037						
Safety	5.878118318			-0.045245326			-0.040397613
Accessibility	5.854218534						
Creation of societal value	5.72378925						

Table 66 Residents AHP - consistency factor

Public Power Corporation

							weight
	Economic growth	Environmental pr.	Safety	Accessibility	Creation of societal value		W
Economic growth	1	1	0.2	1	0.2		0.68
Environmental pr.	1	1	0.2	5	1		1.64
Safety	5	5	1	10	0.2		4.24
Accessibility	1	0.2	0.1	1	0.1		0.48
Creation of societal value	5	1	5	10	1		4.40
sum	13	8.2	6.5	27	2.5		
							weighted criteria average of row
	Economic growth	Circularity	Safety	Accessibility	Creation of societal value		W
Economic growth	0.076923077	0.12195122	0.030769231	0.037037037	0.08		0.069336113
Environmental pr.	0.076923077	0.12195122	0.030769231	0.185185185	0.4		0.162965742
Safety	0.384615385	0.609756098	0.153846154	0.37037037	0.08		0.319717601
Accessibility	0.076923077	0.024390244	0.015384615	0.037037037	0.04		0.038746995
Creation of societal value	0.384615385	0.12195122	0.769230769	0.37037037	0.4		0.409233549

Table 67 Public Power Corporation AHP – input and weighted criteria

	relative importance	dinstance from the smallest	scaled importance	difference 1st with 5th		step for the "+1"
	RI	differences	SI	difference		δ
Economic growth	6.93%	3.06%	1.25	0.37049		0.123495518
Environmental pr.	16.30%	12.42%	2.01			12.35%
Safety	31.97%	28.10%	3.28	n-2		
Accessibility	3.87%	1	1	3		
Creation of societal value	40.92%	37.05%	4.00			

Table 68 Public Power Corporation AHP - scaled importance

	eigenvalues λ						
	Consistancy measure	λmax	n	CI	RI		CR
Economic growth	6.011861105	7.098484025	6	0.109848403	1.12		0.098078931
Environmental pr.	5.51780935						
Safety	6.100832505			0.009637349			0.008604776
Accessibility	5.511946744						
Creation of societal value	7.098484025						

Table 69 Public Power Corporation AHP - consistency factor

<u>Ecoports</u>

	Economic growth	Environmental pr.	Safety	Accessibility	Creation of societal value		weight W
Economic growth	1	0.2	1	1	0.2		0.68
Environmental pr.	5	1	1	5	1		2.60
Safety	1	1	1	5	1		1.80
Accessibility	1	0.2	0.2	1	0.2		0.52
Creation of societal value	5	1	1	5	1		2.60
sum	13	3.4	4.2	17	3.4		
							weighted criteria average of row
	Economic growth	Circularity	Safety	Accessibility	Creation of societal value		W
Economic growth	0.076923077	0.058823529	0.238095238	0.058823529	0.058823529		0.098297781
Environmental pr.	0.384615385	0.294117647	0.238095238	0.294117647	0.294117647		0.301012713
Safety	0.076923077	0.294117647	0.238095238	0.294117647	0.294117647		0.239474251
Accessibility	0.076923077	0.058823529	0.047619048	0.058823529	0.058823529		0.060202543
Creation of societal value	0.384615385	0.294117647	0.238095238	0.294117647	0.294117647		0.301012713

Table 70 Ecoports AHP – input and weighted criteria

	relative importance RI	dinstance from the smallest differences	scaled importance SI	difference 1st with 5th difference		step for the "+1" δ
Economic growth	9.83%	3.81%	2.83	0.24081		0.08027
Environmental pr.	30.10%	24.08%	4.00			8.03%
Safety	23.95%	17.93%	3.23	n-2		
Accessibility	6.02%	1	1	3		
Creation of societal value	30.10%	24.08%	4.00			

Table 71 Ecoports AHP - scaled importance

	eigenvalues λ Consistancy measure	λmax	n	CI	RI		CR
Economic growth	5.273564226	5.428346457	6	-0.095275591	1.12		-0.085067492
Environmental pr.	5.428346457						
Safety	5.181392838			-0.130400143			-0.116428699
Accessibility	5.428346457						
Creation of societal value	5.428346457						

Table 72 Ecoports AHP - consistency factor

Passengers

							weight
	Economic growth	Environmental pr.	Safety	Accessibility	Creation of societal value		W
Economic growth	1	0.2	1	1	0.2		0.68
Environmental pr.	5	1	1	5	1		2.60
Safety	1	1	1	5	1		1.80
Accessibility	1	0.2	0.2	1	0.2		0.52
Creation of societal value	5	1	1	5	1		2.60
sum	13	3.4	4.2	17	3.4		
							weighted criteria average of row
	Economic growth	Circularity	Safety	Accessibility	Creation of societal value		W
Economic growth	0.076923077	0.058823529	0.238095238	0.058823529	0.058823529		0.098297781
Environmental pr.	0.384615385	0.294117647	0.238095238	0.294117647	0.294117647		0.301012713
Safety	0.076923077	0.294117647	0.238095238	0.294117647	0.294117647		0.239474251
Accessibility	0.076923077	0.058823529	0.047619048	0.058823529	0.058823529		0.060202543
Creation of societal value	0.384615385	0.294117647	0.238095238	0.294117647	0.294117647		0.301012713

Table 73 Passengers AHP – input and weighted criteria

	relative importance	dinstance from the smallest	scaled importance	difference 1st with 5th		step for the "+1"
	RI	differences	SI	difference		δ
Economic growth	7.99%	-36.33%	1	0.36327		0.121089397
Environmental pr.	8.79%	0.80%	1.07			12.11%
Safety	21.55%	13.56%	2.12	n-2		
Accessibility	44.32%	36.33%	4.00	3		
Creation of societal v	17.35%	9.36%	1.77			

Table 74 Passengers AHP - scaled importance

	eigenvalues λ						
	Consistancy measure	λmax	n	CI	RI		CR
Economic growth	5.365919998	6.617645219	6	0.088235031	1.12		0.078781278
Environmental pr.	5.381728354						
Safety	6.109693823			-0.030483185			-0.027217129
Accessibility	6.617645219						
Creation of societal value	5.762932985						

Table 75 Passengers AHP - consistency factor

Technology suppliers

							weight
	Economic growth	Environmental pr.	Safety	Accessibility	Creation of societal value		W
Economic growth	1	5	1	10	5		4.40
Environmental pr.	0.2	1	0.2	5	1		1.48
Safety	1	5	1	10	1		3.60
Accessibility	0.1	0.2	0.1	1	0.1		0.30
Creation of societal value	0.2	1	1	10	1		2.64
sum	2.5	12.2	3.3	36	8.1		
							weighted criteria average of row
	Economic growth	Circularity	Safety	Accessibility	Creation of societal value		W
Economic growth	0.4	0.409836066	0.303030303	0.277777778	0.617283951		0.401585619
Environmental pr.	0.08	0.081967213	0.060606061	0.138888889	0.12345679		0.096983791
Safety	0.4	0.409836066	0.303030303	0.277777778	0.12345679		0.302820187
Accessibility	0.04	0.016393443	0.03030303	0.027777778	0.012345679		0.025363986
Creation of societal value	0.08	0.081967213	0.303030303	0.277777778	0.12345679		0.173246417

Table 76 Technology Suppliers AHP – input and weighted criteria

	relative importan ce	dinstance from the smallest	scaled importance	difference 1st with 5th		step for the "+1"
	RI	differences	SI	difference		δ
Economic growth	40.16%	37.62%	4.00	0.37622		0.125407
Environmental pr.	9.70%	7.16%	1.57			12.54%
Safety	30.28%	27.75%	3.21	n-2		
Accessibility	2.54%	-37.62%	1.00	3		
Creation of societal value	17.32%	14.79%	2.18			

Table 77 Technology Suppliers AHP - scaled importance

	eigenvalues λ						
	Consistancy measure	λmax	n	CI	RI		CR
Economic growth	5.750197695	5.750197695	6	-0.049960461	1.12		-0.044607555
Environmental pr.	5.54661037						
Safety	5.337197134			-0.116226745			-0.103773879
Accessibility	5.224966088						
Creation of societal value	5.2353601						

Table 78 Technology Suppliers AHP - consistency factor

Technologies

This part of the appendix is related to the information retrieved from the literature regarding the technologies application in the port and port area. It provides with brief information that help the better understanding of the technologies. In addition, it provides with information regarding how these technologies are related to the ports.

Photovoltaic Technology

The photovoltaic technology is very common for "green" energy port applications. Photovoltaic installations can be found not only in ports with annual high irradiation but also in ports where irradiation is not that high. The following two examples, port of Barcelona and port of Stockholm, represent such a case.

The example of the port of Barcelona

The port of Barcelona authorities have a long term plan to promote medium and long term alternatives to hydrocarbon fuels. Following this vision, they have installed already a lot of PV systems on roofs of warehouses and on special structures (Port of Barcelona, 2014). The example of figure xxx. is such a case where 443 kWp of power has been installed (PolderPV, 2016). Another example is the 3 MWp installation that was installed on the roof of a logistics warehouse and carports (ZAL port, 2016).

Figure 17 Photovoltaic Installation in Barcelona Port

The example of the port of Stockholm

Another example of successful implementation of photovoltaic technology in the port is the Stockholm's port case. Port authorities have installed a 220 kWp system which covers the energy consumption of the terminal building by 15%. Moreover, port authorities have plans to investigate further the implementation of the photovoltaic technology in the port and port area. The following figure shows the specific system installed. (Stockholms stad, 2014)

Figure 18 Photovoltaic Installation in Stockholm Port (Stockholms stad, 2014)

Solar Irradiation Map Greece

The following irradiation map shows the average annual sum of irradiation per square meter of Greece. Piraeus port can be found in the Athens area with an average of around 1950 kWh per square meter annually.

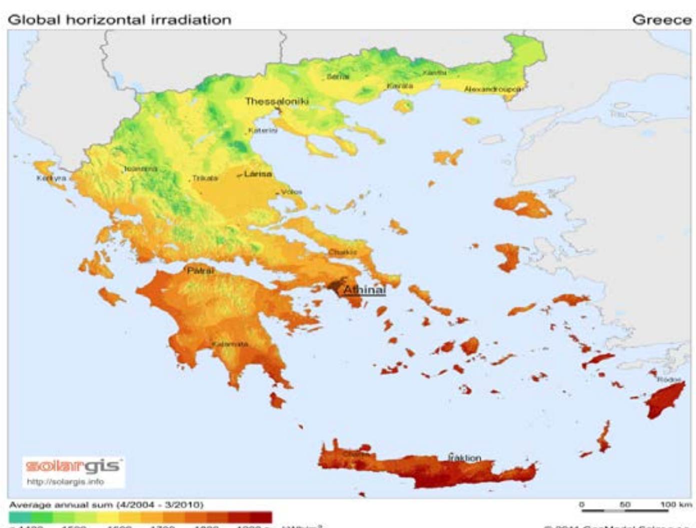

Figure 19 Solar radiation in Greece (solargis, 2016)

Wind turbines technology

The wind turbines technology together with the photovoltaic technology are the two most dominant "green" technologies and contain the biggest share in the renewables market. The working principle of a wind turbine is to harvest, from the covering area of the blades when turning, the wind's kinetic energy and through a generator produce electricity. The usual tower height of a wind turbine is about 50m and the blade length is about 25m. The area needed to support a wind turbine is approximately 400m2. Onshore wind turbines can be found in a lot of ports today and there are also discussions regarding the electrification of ports through offshore wind turbines. Netherlands is one of the countries that wants to explore the offshore wind turbines opportunities in their ports of Den Helder, Amsterdam, and Vlissingen (Holland Pioneers in international business, 2014). An example of an offshore installation can be found in the following figure.

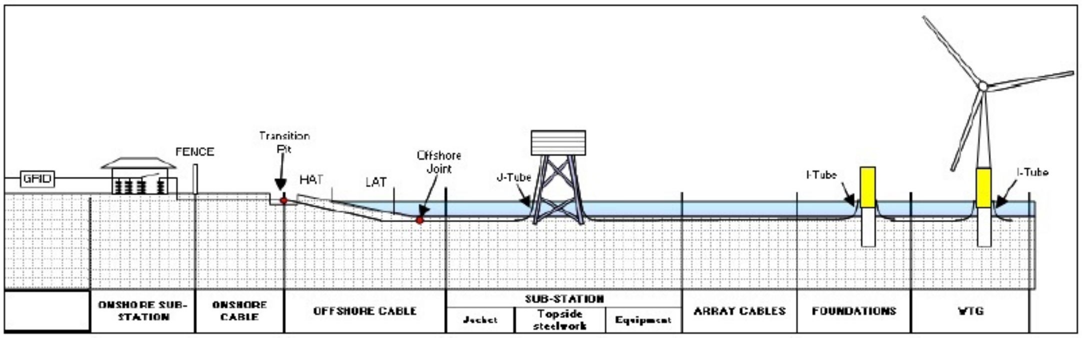

Figure 20 Offshore wind turbine installation configuration (Kaiser M. J., 2012)

The example of the port of Rotterdam

The port of Rotterdam has a master plan that contains the use of wind turbines in the port and port area in order to cover an amount of the electricity consumption of the port. As shown in the figure, the yellow spots are the wind turbines that are already operating and the blue sport are the wind turbines under development. Currently the total capacity of wind power installed in the port area is 200MW and there are plans to increase the power installed to 300 MW by 2020. (Port of Rotterdam, Wind Energy, 2016)

Figure 21 Wind turbine projects in port of Rotterdam (Port of Rotterdam, Wind Energy, 2016)

The example of the port of Shoreham

Another example of wind turbines installation and operation in the port area can be found in the port of Shoreham. The green energy produced by the two 100 kW wind turbines will be used in order to power the pumps that are used in order to replenish the water lost to the sea when the lock gates of the port are opened. Until now, the energy used for these pumps was delivered by the electricity and thus from the energy mix of the UK which contains burning of fossil fuel. (Port of Shoreham, 2016)

Figure 22 Wind turbine projects in the port of Shoreham (Port of Shoreham, 2016)

Small wind turbines technology

Except from the wind turbines with power more than 100 kW (sub-MW and MW) there are also small wind turbines with power less than 10 kW that can be installed in the port area in order to cover part of the electricity needs of the port. The small wind turbines can be installed not only on the field but also on the roofs of the buildings. The tower has a height between 6m and 20m. Also, these wind turbines can have blades not only on the horizontal but also on the vertical axis. An example of such turbines can be found in the following figure. (U.S. Department of energy, 2016)

Figure 23 Small wind turbine projects (TVenergy, 2016)

Biomass power plant

The biomass power plant technology is applied in a lot of ports nowadays. The main process behind the electricity generation (usually combined with heat production) is the thermo-chemical process of combustion of the biomass. There are also cases where biomass is used in combination with coal (co-fired) in order to reduce the use of the fossil fuel. However, the co-firing process should not be examined for the case of Piraeus port as the levels of emissions are high. The usual power installation of biomass power plant is more than 5 MW. (International Renewable Energy Agency, 2012)

Figure 24 Biomass power plant in port of Stockton, USA (DTE Energy, 2016)

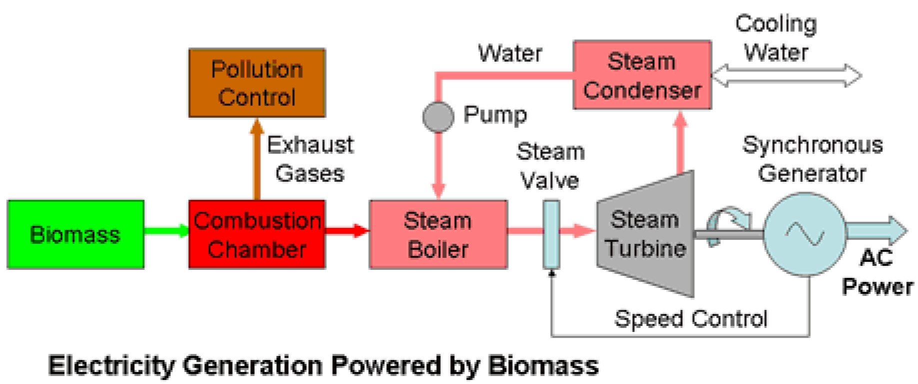

Figure 25 Biomass power plant configuration (DTE Energy, 2016)

The example of the port of Ghent

In the port of Ghent there would be constructed by 2019 the biggest biomass power plant in the world, with power at the levels of 215 MW of electricity and 110 MW of thermal energy. The biomass input will be supplied by woodchips, wood pellets and agro-residues from the area. The overall investment of the power plant will be at the levels of 450m € and the offer 100 new job positions. (Power technology, 2016)

Biogas power plant

As explained in the chapter 8, the biogas production comes from the anaerobic digestion process. The biogas contains methane and carbon oxides which are used for the heat and electricity production. Thus, the exhaust gases of the combustion of the biogas contain carbon emissions. Furthermore, the process produces a low-carbon fertilizer as by-product which can be used in the agriculture sector. The power output of such installations can be usually found at the level of 100 kW up to 5 MW based on the availability of the area and of the resources (Burkard T., 2009). Moreover, there are discussions that are taking place in the Piraeus port nowadays regarding the use of biogas not for energy production, but as a fuel for the local ferries (Piraues chamber of commerce and industry, 2016).

The following figure explains in detail the process and the parts that this process contains:

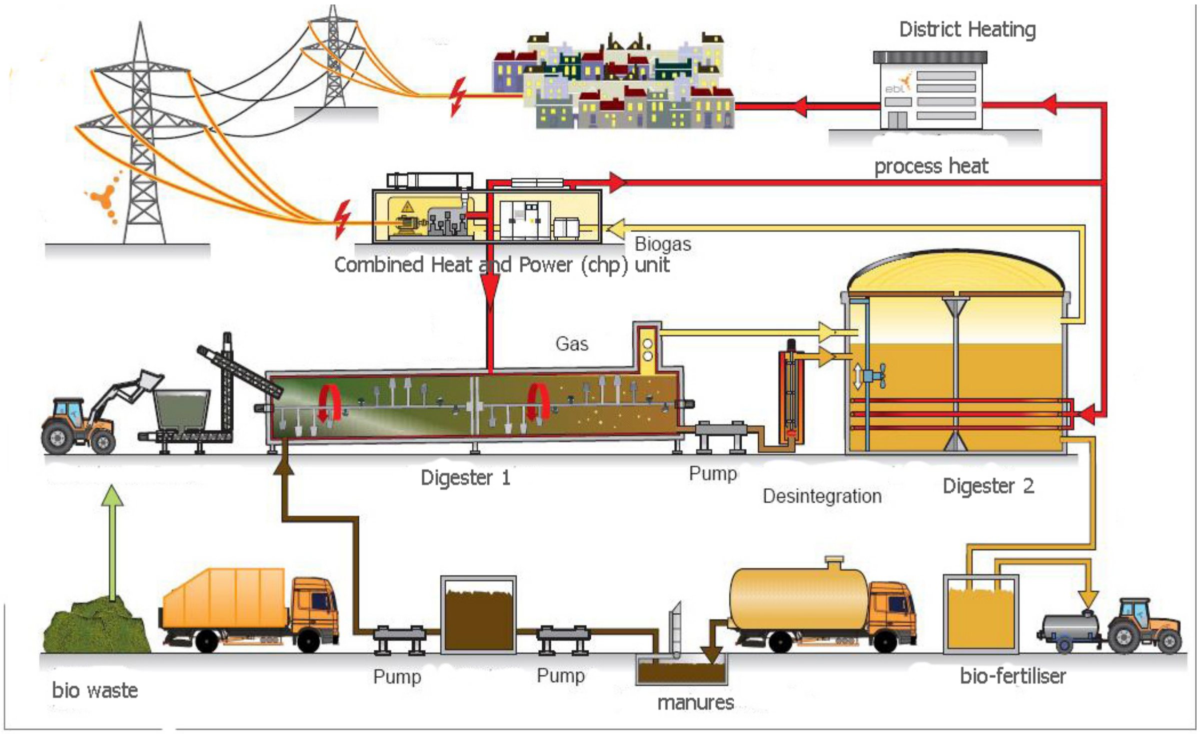

Figure 26 Biomass power plant configuration (Keitel H.V., 2014)

Hydrogen - SOFC / GT

The technology of hydrogen extraction from refineries with a Solid Oxide Fuel Cell – Gas turbine system should be examined separately for its two different steps. Firstly, it is important to define how hydrogen can be extracted from the refinery. In the chemical processes that take place in a refinery, there are products off-gases rich in hydrogen. The most efficient method of extracting the hydrogen from the off-gases is called steam reforming. There are several equipment that perform steam reforming with the most common to be Pressure Swing Adsorption (PSA) which gives high purity hydrogen product (99.9% or higher) which reduces the cost of pre-treatment of the hydrogen before its introduction to the SOFC – GT system. (Rostrup-Nielsen J.R., 2005)

Secondly, it is important to describe the SOFC – GT hybrid system. The hydrogen produced in the steam reforming process will be compressed and stored. It will be used as an input to the SOFC which will produce electricity and heat. Also, in cases when the catalyst used in the fuel cell is nickel, the gases that contain hydrocarbons can be used as input without steam reforming. The reforming takes place on the anode of the fuel cell due to its high temperature. But this method reduces the lifetime of the materials and increases the poisoning risk. The hydrogen – SOFC / GT technology has high efficiency and is recommended in applications combined with refineries that can be found in port areas. (Chinda P., 2012)

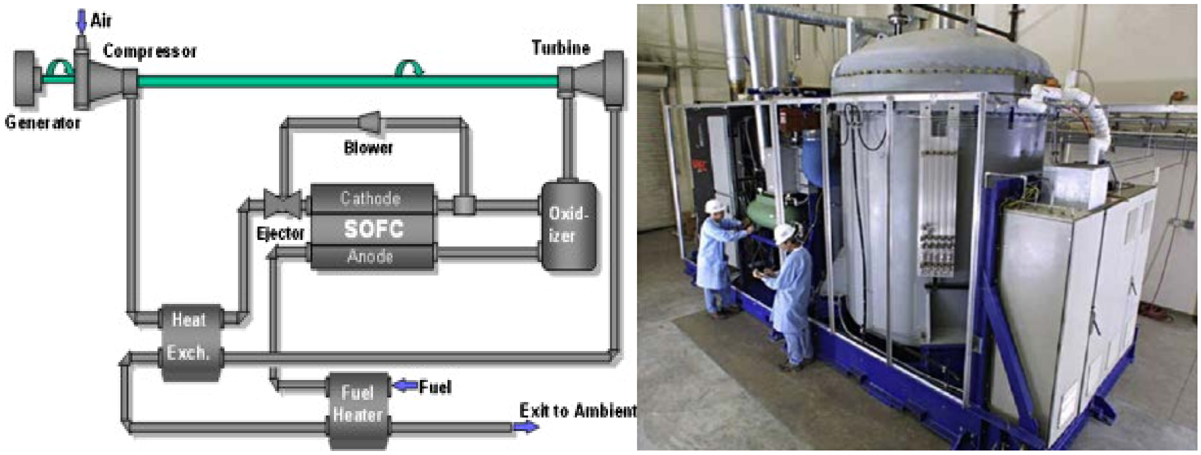

Figure 27 SOFC – GT system 220 kW (Mc Larty D., 2016)

<u>Tidal energy technology</u>

The tidal energy is referred to the harvesting of the energy that can be found in the natural horizontal flow of the sea water in response to the interaction with Moon, Earth and Sun. A the sea water is 832 times denser than the air and currents contain more kinetic energy than wind, a smaller device is required in comparison to wind energy technologies. It is estimated that worldwide there are 50,000 MW of economically exploitable resources. An example of designs of a tidal current turbine is presented below. (MEYGEN, 2016)

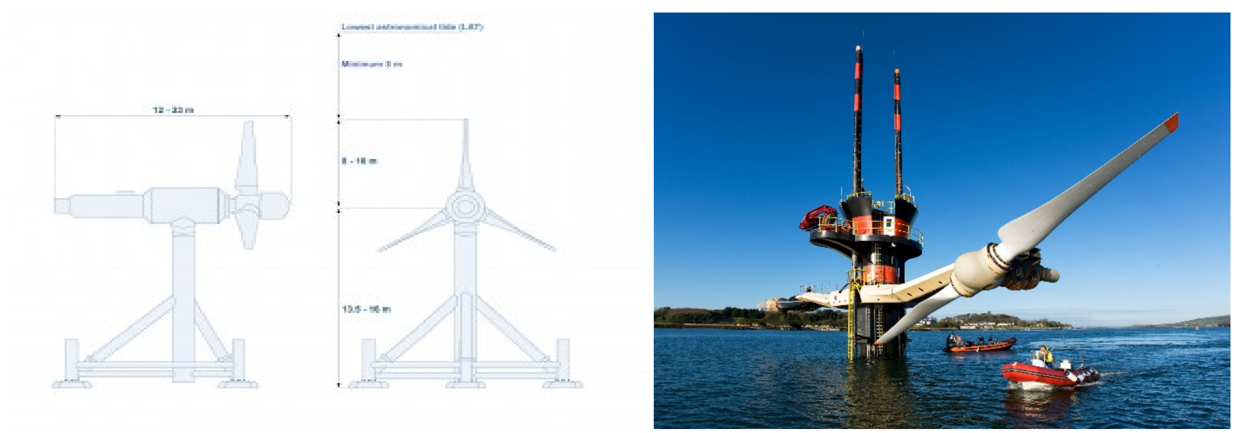

Figure 28 Example of designs of tidal current turbines (Marine Turbines, 2016)

The examples of the port of Dover and Pembroke

Although the technology is not marketable yet, there are some initiatives regarding the installation, monitoring and further development. Such initiatives can be found in two ports of UK, the port of Dover and the port of Pembroke. The port authorities of Dover have set a tidal investigation zone with a total area of 0.45 km2. The investigation about the feasibility study covers economic, environmental and practical aspects of a small scale devices. Based on the results port authorities will decide whether to further invest or not to such technology. (Port of Dover, 2016) Moreover the port of Pembroke created a partnership with companies related to the marine energy and more specifically, tidal current turbines in order to develop their products. The main advantage is the 4 m/s current flow that can be met around the port which makes it capable of extracting 5,600 MW of power. (Port of Pembroke, 2016)

TOPSIS input and results (Python)

The Topsis method is applied for three cases of stakeholders:

- all stakeholders
- only direct stakeholders
- only indirect stakeholders

The Topsis algorithm needs:

- a matrix of scores per criterion and per technological alternative (e.g. for PV, Wind turbines etc.)
- a vector of impacts per criterion, 1 if it has positive impact, -1 if it has negative
- a vector of weights per criterion, derived from the AHP

These are derived from the input data which is read per case.

Code:

```
class topsis:
        def __init__(self,matrix):
                self.rows=len(matrix)
                self.cols=len(matrix[0])
                self.idealPoints=[max(x) for x in zip(*matrix)]
                self.worstPoints=[min(x) for x in zip(*matrix)]
                pass

        def setPoints(self,idealPoints,worstPoints):
                self.idealPoints=idealPoints
                self.worstPoints=worstPoints

        def normMatrix(self,matrix):
                squareMatrix=[[y**2 for y in row] for row in matrix] #elevation square
matrix
```

```
            vectorSumSquare=[sum(x) for x in zip(*squareMatrix)] #get vector of column 
sum og square matrix
            normMatrix=[[z/v for z,v in zip(row,vectorSumSquare)] for row in 
squareMatrix] #normalize Matrix: TOPSIS algorithm: STEP 1
            return normMatrix

        def weightMatrix(self,normMatrix,weight):
            normWeightMatrix=[[ z*w for z,x in zip(row,weight)] for row in normMatrix] 
#weight normalized matrix: TOPSIS algorithm: STEP 2
            return normWeightMatrix

        def idealPointDistance(self,normWeightMatrix,idealPoints): #distance  fro 
idealpoint: TOPSIS algorithm: STEP 4
            mat=[[(x-y)**2 for x,y in zip(row,idealpoints)]for row in normWeightMatrix]
            sumDifferenceVector=[sum(x) for x in zip(*mat)]
            idealPointsDistance=[x**0.5 for x in sumDifferenceVector]
            return idealPointsDistance

        def negativePointDistance(self,normWeightMatrix,worstPoints): #distance  from 
idealpoint: TOPSIS algorithm: STEP 4
            mat=[[(x-y)**2 for x,y in zip(row,worstPoints)]for row in normWeightMatrix]
            sumDifferenceVector=[sum(x) for x in zip(*mat)]
            negativePointDistance=[x**0.5 for x in sumDifferenceVector]
            return negativePointDistance

        def relativeCloseness(self,):  #relative closeness - TOPSIS algorithm STEP 5
            relativeCloseness=[(n/(n+p)) for n,p in 
zip(negativePointDistance,idealPointsDistance)]
            return relativeCloseness

        def runTOPSIS(self,stdMatrix,weight):
            """process the matrix and get the ranking values for each alternative"""
            pass



if __name__ == '__main__':
        main()
```

In [1]:
```
from skcriteria import topsis
import pandas as pd
```

Overall

The input data is read:

In [2]:
```
data = pd.read_csv("topsis_input_overall.csv")
data
```
Out[2]:

	Criteria Name	Weights	Impact	PV	Wind turbines	Small wind turbines	Biomass power plant	Biogas power plant
0	profitability	0.78	positive	5	7	3	5	5
1	circularity	0.78	positive	5	5	5	7	9
2	entrepreneural-synergies	0.78	positive	5	5	5	7	9
3	emissions	0.93	negative	5	5	5	7	7
4	noise	0.93	negative	5	9	7	7	7
5	external safety	1.48	positive	5	3	5	3	3
6	health risks	1.48	negative	5	5	5	7	7
7	capacity	0.95	positive	5	9	9	7	7
8	availability	0.95	positive	5	7	7	3	3
9	longetivity	0.95	positive	5	3	3	9	9
10	employment	0.95	positive	5	7	7	9	9
11	aesthetics	0.95	positive	5	3	3	5	7

In [3]:
```
scores = data.ix[:,3:].astype(float).transpose()
scores
```
Out[3]:

	0	1	2	3	4	5	6	7	8	9	10	11
PV	5	5	5	5	5	5	5	5	5	5	5	5
Wind turbines	7	5	5	5	9	3	5	9	7	3	7	3
Small wind turbines	3	5	5	5	7	5	5	9	7	3	7	3
Biomass power plant	5	7	7	7	7	3	7	7	3	9	9	5
Biogas power plant	5	9	9	7	7	3	7	7	3	9	9	7

In [4]:

```
impacts = data["Impact"].apply(lambda x: 1 if x == "positive" else -1)
impacts
```

Out[4]:

```
0     1
1     1
2     1
3    -1
4    -1
5     1
6    -1
7     1
8     1
9     1
10    1
11    1
Name: Impact, dtype: int64
```

In [5]:

```
weights = data["Weights"]
weights
```

Out[5]:

```
0     0.78
1     0.78
2     0.78
3     0.93
4     0.93
5     1.48
6     1.48
7     0.95
8     0.95
9     0.95
10    0.95
11    0.95
Name: Weights, dtype: float64
```

Applying Topsis:

In [6]:

```
rank, points = topsis.topsis(scores.values.tolist(), impacts.tolist(),
weights.tolist())
```

The `rank` variable contains the ranking of every order alternative and the `points` is the distance of every alternative to the ideal and anti-ideal points.

In [7]:

```
for [r, name, p] in sorted(zip(rank, scores.index.values.tolist(), points)):
    print "{}. {} -> {}".format(r, name, round(p,3))
1. Biogas power plant  -> 0.544
2. PV -> 0.496
3. Biomass power plant -> 0.472
4. Small wind turbines -> 0.466
5. Wind turbines -> 0.427
```

Direct stakeholders

The input data is read:

In [8]:
```
data = pd.read_csv("topsis_input_direct.csv")
data
```
Out[8]:

	Criteria Name	Weights	Impact	PV	Wind turbines	Small wind turbines	Biomass power plant	Biogas power plant
0	profitability	0.94	positive	5	7	3	5	5
1	circularity	0.94	positive	5	5	5	7	9
2	entrepreneural-synergies	0.94	positive	5	5	5	7	9
3	emissions	0.88	negative	5	5	5	7	7
4	noise	0.88	negative	5	9	7	7	7
5	external safety	1.50	positive	5	3	5	3	3
6	health risks	1.50	negative	5	5	5	7	7
7	capacity	1.12	positive	5	9	9	7	7
8	availability	1.12	positive	5	7	7	3	3
9	longetivity	0.80	positive	5	3	3	9	9
10	employment	0.80	positive	5	7	7	9	9
11	aesthetics	0.80	positive	5	3	3	5	7

In [9]:
```
scores = data.ix[:,3:].astype(float).transpose()
scores
```
Out[9]:

	0	1	2	3	4	5	6	7	8	9	10	11
PV	5	5	5	5	5	5	5	5	5	5	5	5
Wind turbines	7	5	5	5	9	3	5	9	7	3	7	3
Small wind turbines	3	5	5	5	7	5	5	9	7	3	7	3
Biomass power plant	5	7	7	7	7	3	7	7	3	9	9	5
Biogas power plant	5	9	9	7	7	3	7	7	3	9	9	7

In [10]:
```
impacts = data["Impact"].apply(lambda x: 1 if x == "positive" else -1)
impacts
```
Out[10]:
```
0     1
1     1
2     1
```

```
3    -1
4    -1
5     1
6    -1
7     1
8     1
9     1
10    1
11    1
Name: Impact, dtype: int64
```

In [11]:

```
weights = data["Weights"]
weights
```

Out[11]:

```
0     0.94
1     0.94
2     0.94
3     0.88
4     0.88
5     1.50
6     1.50
7     1.12
8     1.12
9     0.80
10    0.80
11    0.80
Name: Weights, dtype: float64
```

Applying Topsis:

In [12]:

```
rank, points = topsis.topsis(scores.values.tolist(), impacts.tolist(),
weights.tolist())
```

The `rank` variable contains the ranking of every order alternative and the `points` is the distance of every alternative to the ideal and anti-ideal points.

In [13]:

```
for [r, name, p] in sorted(zip(rank, scores.index.values.tolist(), points)):
    print "{}. {} -> {}".format(r, name, round(p,3))
1. Biogas power plant  -> 0.514
2. Small wind turbines -> 0.487
3. PV -> 0.484
4. Wind turbines -> 0.468
5. Biomass power plant -> 0.435
```

Indirect stakeholders

The input data is read:

In [14]:

```
data = pd.read_csv("topsis_input_indirect.csv")
data
```

Out[14]:

	Criteria Name	Weights	Impact	PV	Wind turbines	Small wind turbines	Biomass power plant	Biogas power plant
0	profitability	0.67	positive	5	7	3	5	5
1	circularity	0.67	positive	5	5	5	7	9
2	entrepreneural-synergies	0.67	positive	5	5	5	7	9
3	emissions	0.97	negative	5	5	5	7	7
4	noise	0.97	negative	5	9	7	7	7
5	external safety	1.46	positive	5	3	5	3	3
6	health risks	1.46	negative	5	5	5	7	7
7	capacity	0.81	positive	5	9	9	7	7
8	availability	0.81	positive	5	7	7	3	3
9	longetivity	1.05	positive	5	3	3	9	9
10	employment	1.05	positive	5	7	7	9	9
11	aesthetics	1.05	positive	5	3	3	5	7

In [15]:

```
scores = data.ix[:,3:].astype(float).transpose()
scores
```

Out[15]:

	0	1	2	3	4	5	6	7	8	9	10	11
PV	5	5	5	5	5	5	5	5	5	5	5	5
Wind turbines	7	5	5	5	9	3	5	9	7	3	7	3
Small wind turbines	3	5	5	5	7	5	5	9	7	3	7	3
Biomass power plant	5	7	7	7	7	3	7	7	3	9	9	5
Biogas power plant	5	9	9	7	7	3	7	7	3	9	9	7

In [16]:

```
impacts = data["Impact"].apply(lambda x: 1 if x == "positive" else -1)
impacts
```

Out[16]:

```
0     1
1     1
2     1
3    -1
4    -1
5     1
6    -1
7     1
8     1
9     1
10    1
11    1
```

```
Name: Impact, dtype: int64
```

In [17]:

```
weights = data["Weights"]
weights
```

Out[17]:

```
0     0.67
1     0.67
2     0.67
3     0.97
4     0.97
5     1.46
6     1.46
7     0.81
8     0.81
9     1.05
10    1.05
11    1.05
Name: Weights, dtype: float64
```

Applying Topsis:

In [18]:

```
rank, points = topsis.topsis(scores.values.tolist(), impacts.tolist(),
weights.tolist())
```

The `rank` variable contains the ranking of every order alternative and the `points` is the distance of every alternative to the ideal and anti-ideal points.

In [19]:

```
for [r, name, p] in sorted(zip(rank, scores.index.values.tolist(), points)):
    print "{}. {} -> {}".format(r, name, round(p,3))
1. Biogas power plant  -> 0.569
2. PV -> 0.503
3. Biomass power plant -> 0.5
4. Small wind turbines -> 0.446
5. Wind turbines -> 0.393
```

Appendix F – Chapter 6

This part of the appendix refers to the interviews and their remarks that are related to the application of the developed decision making tool. The overall duration of the interview was 1 hour. During the first 35 minutes, the explanation of the tool took place. The interviewee had the possibility to intervene with questions. This interaction with the author provided with more reliable remarks. The second part of the interview is the discussion of the specific topics of importance that were set by the author. The interviewees are asked to develop their ideas about the specific topics and the author intervenes with extra questions in order to explore deeper their thoughts. The duration of this part is approximately around 20 minutes. Finally, the last part consists the summary of the discussion part where the most important remarks are highlighted. This part lasts around 5 minutes.

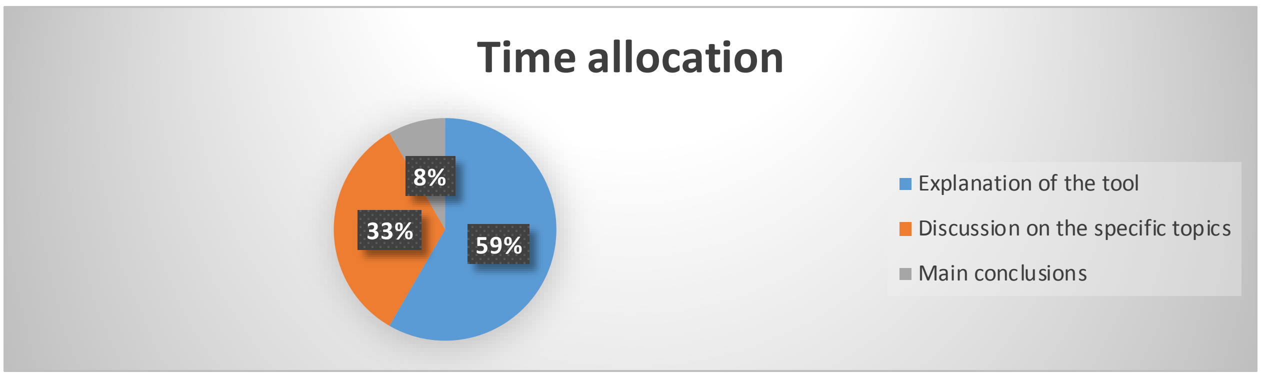

Figure 29 Time allocation - interviews

The four participants that were chosen to be interviewed were chosen based on their relevance with the decision making process in boards that participate different stakeholders. Also, another criterion is the relevance with the port of Piraeus. Finally, all the interviewees have been already participated in the application of the tool which means that they have already the experience of its use. More information about the participants can be found in the appendix E. The topics of importance are expressed by the questions that are presented below.

Topics of Importance - Questions

What is your general idea about the tool? *(Comments)*

Is the general scope of the tool clear? *(Ease of understanding)*

How easily can you understand what is expected to be done when executing the steps of the tool? *(Ease of understanding)*

Do you believe that the tool can be used directly to assist the decision making process? *(Applicability)*

What are the main assets that the developed tool brings to the decision making process? *(Advantages)*

What issues can you identify that may provoke unwilling situations and affect the reliability of the tool? *(Disadvantages)*

Can you recommend specific fields of improvement? *(Future research recommendations)*

Replies of the interviewees

Dimitra Karvouni

1. Do you have experience with decision making tools?

   - No (only analysis of their results)

2. What is your general idea about the tool?

   - It consists an interesting tool that can assist the decision making process
   - It is important that takes into account the circular economy except for only the performance of the technologies. Its importance is highlighted by EU guidelines for the municipalities
   - It is important that it takes into account the decision criteria of all the stakeholders.

3. Is the general scope of the tool clear?

   - I find the scope clear enough

4. How easily can you understand what is expected to be done when executing the steps of the tool?

   - All the steps have specific instructions which contributes in the simplicity of understanding. Also the example of the tables show how the output would be like which helps to realise better the instructions.

5. Do you believe that the tool can be used directly to assist the decision making process?

   - I would not use it directly before the validation and, if possible, verification results. However, it could be a good contribution in the decision making process.

6. What are the main assets that the developed tool brings to the decision making process?

   - It takes into account the public opinion, the residents and the passengers.
   - It takes into account the circularity opportunities.
   - One important advantage is that the stakeholders can have an estimation on what to expect from the technology implementation based on the values as decision criteria. That can be identified by the comparison of the technologies with the use of Pugh's matrix.

7. What issues can you identify that may provoke unwilling situations and affect the reliability of the tool?

   - The number of the criteria should not exceed a specific level. It may become confusing when their number is high. For instance, in case that there are a lot of technologies and more than 20 criteria, that may create an issue in comparing them.

- Should be less automated process for the final selection of technology. The TOPSIS provides the best technology based on optimized trade-offs. It is important for the flexibility of the tool to provide the option of intervention to the decision makers.
- Technology implementation issues are not taken into account.

8. Can you recommend specific fields of improvement?

- It is important to provide a plan of use of the tool for the case that a change is occurred.
- It is preferable the trade – offs to be performed by a combination of the decision makers and the TOPSIS. Thus, flexibility can be achieved.
- The implementation issues of the technology should be taken into account during the evaluation of the technologies.

<u>Konstantinos Mavroudis</u>

1. Experience with decision making tools?

- Yes (TOPSIS and customized preference tools developed in excel for comparison of technologies based on their performance (quantitative data))

2. What is your general idea about the tool?

- It is an interesting approach that can save time from the meetings.
- Dynamic tool that explores both the latest technological artefacts and business situation.
- It provides the possibility to start from a certain basis the discussion of choosing a technology. That basis refers to the importance of the values as decision criteria for the stakeholders.
- It consists a way to quantify the decision making process which is considered as a qualitative process.
- Satisficing method is important in order to reduce the number of the examined technologies.

3. Is the general scope of the tool clear?

- I find the scope of the tool clear and easy to be understood

4. How easily can you understand what is expected to be done when executing the steps of the tool?

- It was easy to understand what is expected by each step, the input asked and the output given.

5. Do you believe that the tool can be used directly to assist the decision making process?

- The tool can be used directly as supplementary tool.

6. What are the main assets that the developed tool brings to the decision making process?

    - It quantifies difficult concepts such as the values that are used as decision criteria.
    - The process saves a lot of time from long meeting with all the presence of all the stakeholders.
    - The tables of the method as well as the final results of the method (most appropriate technology) can set a framework of discussion during the meetings.
    - Every stakeholder accepts the common language of the “numbers”.
    - Automated process which asks for minimum intervention by the decision makers.

7. What issues can you identify that may provoke unwilling situations and affect the reliability of the tool?

    - There might be an issue of understanding which can lead to confusion in cases that a lot of criteria and technologies are used. That may lead to the “loss” of the overall picture regarding the stakeholders’ situation and the technologies.
    - The independence of the values should be explored in order to achieve more reliable results.
    - The Pugh’s matrix may provide with biased data.

8. Can you recommend specific fields of improvement?

    - It would be better if the decision criteria could be minimized at a number of 6 or 7.
    - Independence of the criteria should be secured.
    - Explore methods to produce more objective results for the Pugh’s matrix especially for the qualitative criteria that cannot be measured.

<u>Stavros Oikonomou</u>

1. Experience with decision making tools?

    - Yes (customized tools developed for the Public Power Corporation that concern multi-criteria analysis and neural networks)

2. What is your general idea about the tool?

    - I believe that is an interesting tool which can have application not only in the port’s but also to other fields that the stakeholder values “work” as decision criteria.
    - The current ports’ economic and policy situation is expressed through the weighting of the values as decision criteria by the stakeholders. That makes the process less complicated.
    - The decision maker does not intervene in the process which provides with more objective results.

3. Is the general scope of the tool clear?

    - I believe I fully realised the scope of the tool.

4. How easily can you understand what is expected to be done when executing the steps of the tool?

    - I had no issues to identify the reasoning and the expected outcome of the steps.

5. Do you believe that the tool can be used directly to assist the decision making process?

    - I believe that the tool can used directly as a supplementary tool to support the decision making process.

6. What are the main assets that the developed tool brings to the decision making process?

    - It consists a fast process compared to the issues it solves.
    - One of the most important assets is that it has dynamic input of data. Always the current situation is taken into account in terms of stakeholders' interests and available technologies.
    - The tool provides the capacity of using a lot of criteria for the evaluation of the technologies.

7. What issues can you identify that may provoke unwilling situations and affect the reliability of the tool?

    - Risk of biased results at step 8 (Pugh's matrix).
    - Absence of sensitivity analysis of the decision criteria.
    - The use of a 5-point scale may create problems when the scores of the results are close.

8. Can you recommend specific fields of improvement?

    - Use of 10-point scale in order to provide results with larger differences among the scores.
    - Sensitivity analysis for the decision criteria should be included.
    - Explore other methods to replace the Pugh's matrix in order to reduce the risk of biased results.

Alexandros Euaggeliou

1. Experience with decision making tools?

    - Yes (several tools, mostly customized for economic performance analysis)

2. What is your general idea about the tool?

    - Innovative approach to assist the decision making
    - It is important that it takes into account more criteria than just the economic ones
    - Gives a "direction" to the decision makers (board members and managers) regarding the complex decision making situation as far as the stakeholders and their values is concerned.

3. Is the general scope of the tool clear?

    - I find the scope of the tool clear

4. How easily can you understand what is expected to be done when executing the steps of the tool?

    - I had no problems of understanding the steps.

5. Do you believe that the tool can be used directly to assist the decision making process?

    - The tool has the potential to be used directly. However, in the beginning as a supplementary tool.

6. What are the main assets that the developed tool brings to the decision making process?

    - One of the most important assets is that the chosen technology can balance the value conflicts and increase the acceptance of the technology to be implemented.
    - It is less time consuming than the "business as usual".
    - It takes briefly into account all the important criteria for decision making including the performance criteria of the technologies and the values of the stakeholders.

7. What issues can you identify that may provoke unwilling situations and affect the reliability of the tool?

    - There might be difficulties in the communication of the emission footprint concept.
    - Usually the economic growth is the most important decision criterion. That may not be the case for this tool.
    - Some stakeholders may not want to openly reveal their values as decision criteria.

8. Can you recommend specific fields of improvement?

    - Explore ways to assign higher weight to the economic growth in comparison to the other values by serving in parallel the rest of the values. For instance a percentage increase of the weight which is related to the overall weight identified in the AHP analysis. The economic growth is the main driver of the technology implementation and operation.
    - Set of specific rules regarding the input data of the stakeholders that concern the groups of individuals such as the residents, port users etc. For instance, create a survey for the residents, for the passengers etc.
    - Validation with the application of the tool to several ports and studies that refer to the opinion of the stakeholders after the implementation and operation of the technology.