DAMEN

UNIVERSITY OF TWENTE.

The development of a Green Shipyard concept

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Preface

Before you lies the thesis ”The development of a Green Shipyard concept”, the results of, among others, a survey and case study performed among several shipyards in order to gain insight in the environmental performance. The motivation for this research originates from clients interests in sustainable aspects and regulatory changes seen in the industry.

This research is the final proof of competence for obtaining my Master of Science (MSc) degree in Construction Management and Engineering (CME), from the University of Twente. I was engaged in researching and writing this thesis from May to November 2016. This research was undertaken on behalf of Damen Shipyards and executed in collaboration with the department Civil & Modular Construction (C&MC).

The research was difficult, but conducting extensive investigation allowed me to answer the research questions that were identified. Fortunately, both and ir. A.C. Buchner and ing. M. Omar of Damen Shipyards, and my tutors from the University of Twente, prof. dr. ir. J.I.M. Halman and dr. ir. A.G. Entrop, were always available and willing to answer my queries.

I would like to thank my supervisors for their excellent guidance and support during this process. I also wish to thank all of the respondents, without whose cooperation I would not have been able to conduct this research.

To my other colleagues at Damen Shipyard, and especially Damen Green, I would like to thank you for your wonderful cooperation as well. It was always helpful to spar ideas about my research around with you. I also benefitted from discussing issues with friends and family, especially Lisanne Havinga, who was willing to provide me with specific expertise about Lifecycle Assessments (LCA). I would like to thank my parents and girlfriend, Lisa Mengerink, in particular, for their kind words and support during the whole process. If I ever lost interest, you kept me motivated.

I hope you enjoy your reading

D.I. Janson
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Samenvatting

De wereldwijde scheepvaart industrie heeft een grote impact op het milieu, verbeteringen blijven echter ver achter ten opzichte van de andere industrieën. De toenemende zorg voor het milieu, gedreven door vernieuwende regelgeving en marktfactoren, eist dat de scheepvaart industrie bewust bezig gaat met het verbeteren van de milieuprestatie. De huidige ontwikkelingen zijn voornamelijk gericht op het verbeteren van de schepen zelf, waarbij de focus vooral ligt op het verminderen van het brandstof gebruik. Doordat klanten steeds vaker interesse tonen in de duurzaamheid van productieprocessen en vernieuwende regelgeving direct van invloed is op de scheepswerven zelf, neemt de interesse in duurzame scheepswerven toe.

Dit onderzoek legt de basis voor ontwikkelingen op het gebied van groene scheepswerven. Een uitgebreide literatuur studie maakte het mogelijk om een definitie te formuleren voor een groene scheepswerf. Er is alleen gekeken naar de processen en systemen op een operationele werf, waarbij er geen rekening is gehouden met de duurzaamheid van het geproduceerde schip of de materialen die daarvoor gebruikt worden. Er is vastgesteld dat een operationele scheepswerf groen is als de impact op het milieu bij zowel energiegebruik als vervuiling door afval nul is. De impact op het milieu bij energiegebruik kan worden teruggedrongen door het verminderen van het gebruik, het overstappen op duurzame energiebronnen en het efficiënter gebruiken van energie. De impact op het milieu bij vervuiling door afval kan worden beperkt door minder afval te creëren, het overstappen op duurzame materialen, het hergebruiken en recyclen van afvalstoffen en het efficiënter gebruiken van materialen.

Door het combineren van verschillende beoordelingsmethodieken was het mogelijk om een raamwerk te ontwikkelen die het mogelijk maakt om de milieuprestatie van scheepswerven inzichtelijk te maken. De geformuleerde definitie van een groene scheepswerf en inzicht in een operationele scheepswerf is samengebracht in het Green Performance Framework (GPF), waarin drie kwalitatieve en zes kwantitatieve Environmental Performance Indicators (EPIs) de milieuprestatie van scheepswerven meetbaar maakt. Doordat er relatief weinig literatuur over de milieuprestatie van scheepswerven beschikbaar is, is er data van acht operationele scheepswerven gebruikt om een basis prestatieniveau te formuleren en daardoor passende meetschalen voor de zes kwantitatieve EPIs te formuleren. Uiteindelijk is het raamwerk getest door middel van een case studie, waarbij de milieuprestatie van drie operationele scheepswerven inzichtelijk is gemaakt.

Op basis van de case studie kunnen de volgende conclusies geformuleerd worden. Ten

eerste is het voldoen aan wet- en regelgeving met betrekking op het milieu het belangrijkste doel van een scheepswerf. Het verbeteren van de milieuprestatie van de scheepswerf wordt alleen gedaan als dat wordt voorgeschreven, en verdere ontwikkelingen worden in mindere mate doorgevoerd en niet gestimuleerd door de scheepswerven. Ten tweede is de transparantie en interne communicatie omtrent de milieuprestatie van een scheepswerf minimaal. Scheepswerven hebben weinig tot geen inzicht in hun eigen prestatie en zijn niet in staat om dit daadwerkelijk te monitoren of evalueren. Ten derde zijn de werven verder ontwikkeld en bewuster bezig met de milieu impact van energie dan dat van vervuiling door afval. Dit is bijvoorbeeld terug te zien in de milieudoelstellingen van de scheepswerven, waarbij vaak gerefereerd wordt naar een energievermindering maar niet naar een afvalvermindering. Ten vierde worden de verbeteringen in grote mate beperkt door de grote investeringskosten en lange terug verdientijd. De huidige energieprijs is bijvoorbeeld dermate laag, waardoor er weinig stimulans is om te investeren in duurzame energie bronnen. Uiteindelijk zullen de scheepswerven bereidwilliger moeten zijn om hun milieuprestatie te verbeteren, en daarbij accepteren dat niet alle investeringen op korte termijn winstgevend zijn.

Na de case studie is het ontwikkelde GPF geëvalueerd, en is er geconcludeerd dat het een geschikte methode voor zelf analyse en om de prestatie van verschillende aspecten onderling te vergelijken. Echter blijkt het niet mogelijk om de prestatie terug te brengen naar één score om te kunnen zeggen dat scheepswerf X beter presteert dan scheepswerf Y. Een nieuwbouwwerf verschilt dermate veel van een reparatie & conversie werf, waardoor het niet mogelijk is een betrouwbare vergelijking te maken.

Het uitvoeren van de case studie en het testen van het ontwikkelde raamwerk maakte het mogelijk om aspecten te bepalen die van grote invloed zijn op het milieu. De resultaten van de case studie zijn gebruikt als input voor het formuleren van een drie stap implementatiestrategie voor het ontwerpen van een Groene Scheepswerf. De drie stappen geven aan welke transitie nodig is om een groene scheepswerf te ontwerpen die in de operationele fase groen is. De eerste stap is gericht op het schakelen naar een doelbewuste groene organisatie, waarbij het belangrijk is om verder te kijken dan de huidige wet en regelgeving. De tweede stap is gericht op het optimaliseren van de scheepswerf indeling en het doelbewust ontwerpen van schepen voor een groen productieproces (daarbij denkende aan Lean Manufacturing en Design for Production). De derde stap is gericht op het implementeren van groene civiele werken conform milieu impact verminderende theorieën als Trias Energetica en Waste Hierarchy.

Uiteindelijk biedt dit onderzoek een degelijke basis voor het meetbaar maken van de milieuprestatie van scheepswerven, geeft het inzicht in aspecten die een grote invloed hebben op het milieu en biedt het structuur aan het ontwerpen van een groene scheepswerf. Het ontwikkelde GPF is een valide methode om de eigenprestatie van een scheepswerf meetbaar te maken en de geformuleerde implementatiestrategie biedt structuur om tot een groene scheepswerf te komen.

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List of acronyms

IMO	International Maritime Organization
CSR	Corporate Social Responsibility
WCED	World Commission on Environment and Development
GHG	Greenhouse Gases
EPIs	Energy performance indicators
EED	Energy Efficiency Directive
LCA	Life Cycle Assessment
HSEQ	Health, Safety, Environment and Quality
GPF	Green Performance Framework
GWPs	Global Warming Potentials

Assessing the green performance of shipyards
Developing and testing the GPF

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Abstract

The global shipping industry causes considerable impact on the environment, and its environmental upgrading lags behind on other industries. The increasing environmental concerns, driven by regulations and market factors, requires the shipping industry to reduce their impact on the environment. While there is a comprehensive literature reflecting the sustainability of ships, especially focusing on efficient and effective use of fossil fuels, little work has focused on the sustainability of shipyards. This research is a first attempt to provide a reliable and meaningful set of Environmental Performance Indicators (EPIs) for assessing the performance of an operational shipyard, whereby the indicators are brought together in the Green Performance Framework (GPF). Through the formulation of an appropriate definition of a Green Shipyard and acquiring insight in an operational shipyard, three qualitative EPIs and six quantitative EPIs could be specified. Data from eight operational shipyards is collected to formulate a baseline performance level and define appropriate measurement scales for the EPIs. The GPF is tested and evaluated in a case study, assessing the environmental performance of three operational shipyards. The case results, highlighting aspects that have a high impact on the environment, are used as input for the formulation of a three step implementation strategy for the development of a Green Shipyard concept.

Keywords: Green shipyard, Environmental performance, Environmental performance indicators, Environmental performance assessment, Environmental performance improvements

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1. Introduction

The shipping industry plays a fundamental role in societies and global economy, supporting international trade activities between geographic locations [1]. The increasing environmental concerns, driven by regulations and market factors, requires the shipping industry to change towards becoming more sustainable and environmental friendly [2]. Research performed by the International Maritime Organization (IMO) in 2014 shows that the shipping industry accounts for approximately 2,6% of the total global carbon dioxide (CO_2) emission in 2012 [3]. Various push and pull factors stimulate the shipping industry to go “green”. Regulatory-driven trends, as the obligation to reduce the production of Greenhouse Gases (GHG) by 20% by 2020 (concluded by the European Council on 8 and 9 March 2007) [4], are pushing the market to change. Market driven trends, like increasing the environmental awareness and growing interest in Corporate Social Responsibility (CSR), pulls the market to change [2]. As most impact on the environment is caused in the operational phase of a ship, past research has focused on a more efficient and effective use of fossil fuels to reduce the environmental impact of ships [5].

While there is now a rich literature reflecting the sustainability of ships [1, 6], especially in its operational phase [5], little work of this kind has focused on the sustainability of shipyards. With such a large focus dedicated to increase efficiency and an effective use of fossil fuels during the ships operation, other avenues of avoiding the climate change are apparently often overlooked [6]. Furthermore, the implementation of EU regulations for an energy saving of 20% by 2020 [4] and the formulated objective of IMO to significantly reduce the CO_2 by the shipping industry [3], results in the obligation of shipyards to improve their environmental performance. To our knowledge, this paper is one of the few to examine the environmental performance of shipyards.

Insight in the environmental performance of existing shipyards can be acquired by performing an environmental assessment. Many methods, models, measures and sets of indices have been developed to assess the environmental performance [7] which focus on a specific topic or single instance [8]. However, the available methods are not directly transferable to the shipyard industry, due to the complexity and diversity of shipyards [9], and therefore requires the development of a newly tailored assessment framework.

Therefore, the aim of this paper is to start filling this gap in the literature by developing, testing and evaluating a framework to enable the assessment of the environmental performance of shipyards. The purpose here is not to provide a detailed Lifecycle Assessment (LCA) of a shipyard, but rather to shed light on aspects of an operational shipyard having a high impact on the environment. Through a theoretical definition of a Green Shipyard and selecting specific aspects with appropriate Environmental Performance Indicators (EPIs), a framework for assessing the environmental performance of a shipyard is developed. The developed framework is tested and evaluated by performing a case study, and empirical evidence of aspects having a high impact on the environment is gathered. Furthermore, this paper applies the empirical evidence as input for the formulation of an implementation strategy for a Green Shipyard concept to illustrate the possibilities and boundaries for the development of a sustainable shipyard.

The further outline of this paper is organised in eight sections. Section 2 explains the theoretical background of a Green Shipyard concept and the applicability of environmental assessment methods. In section 3, the research methodology is explained. Section 4 explains the development of the Green Performance Framework (GPF). Section 5 tests the developed GPF, shows the outcome of the individual cases and compares the outcome of each case. Section 6 formulates an implementation strategy for a Green Shipyard concept using the case results as input. Section 7 discusses the scientific contribution, practical implications and research limitations. Finally, Section 8 presents the final conclusions.

2. Literature background

The concept of sustainable development is an attempt to combine the growing concerns about a range of environmental issues with socio-economic issues [10]. Many of todays sustainable developments involve the three separate yet connected dimensions of environment, economy and society [10], where meeting the needs of the present without compromising the ability of future generations to meet their own needs is the most widely known definition of sustainability [3]. Although “green” and “sustainability” are often used interchangeable, the definitions can be interpreted differently and the debate regarding a uniform definition of green is still continuing [11]. This research specifically focuses on the environmental performance of a shipyard, and therefore associates the term green with the environmental dimension of sustainability.

2.1. Shipyard processes

A shipyard can be considered as an industrial production facility, where certain input is used to design, develop, construct, repair or dismantle a ship [5]. The gross input and output of a shipyards processes are visualised in Figure 1 (adapted from the automotive industry [12]). Basically three types of shipyards can be distinguished, namely newbuilding, repair & conversion and dismantling yards [13]. These types of shipyards differ in operations that are performed on the yard, whereby newbuilding processes a significant amount of material to produce new vessels, repair & conversion is labour oriented on the work performed, and dismantling yards focuses on dismantling vessels for the reuse of materials [14]. Each of these yards can be divided into components directly related to the production and repair & conversion of a ship (i.e. welding, cutting, etc.) or components indirectly related to the production of a ship (i.e. financial department, lunch room, etc.) [15]. The input and output can be divided into process and non-process use of (re)sources and leftovers of materials used (sinks). The process use relates to the production processes of a vessel and non-process use to facilities as lighting which cannot directly be related to particular ships account [15, 6].

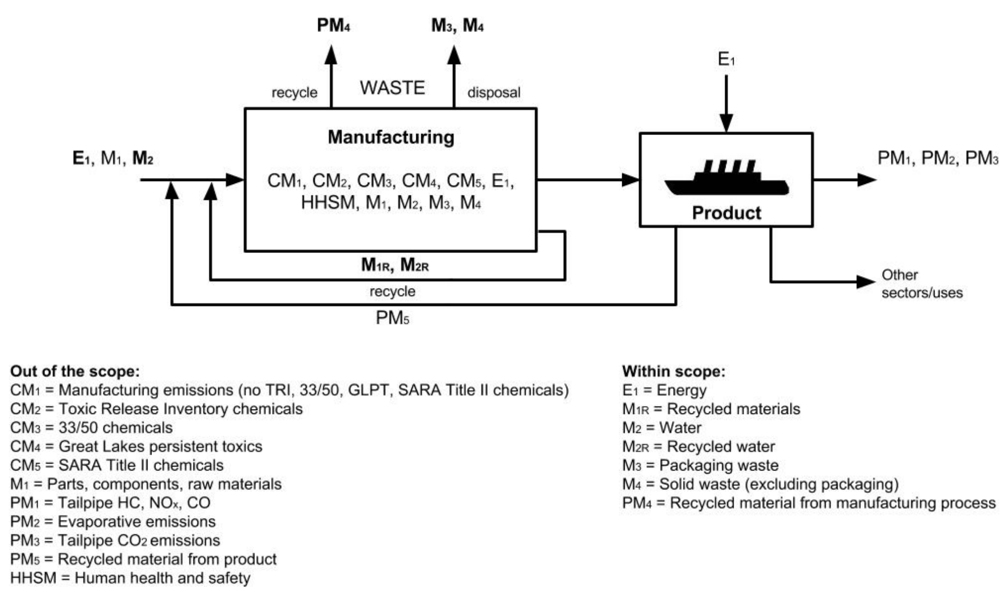

Figure 1: The gross input and output of a shipyards processes (adapted from [12].

Figure 2 visualises the production process of a typical standardised newbuilding shipyard [16]. Newbuilding yards structurally follow these processes in order to develop a vessel. A standard procedure applied by repair & conversion yards is difficult to define in an standard flowchart, due to their unstructured way of working and large variety in processes [14]. Dismantling yards are relatively new and under development, and therefore left outside the scope of this research.

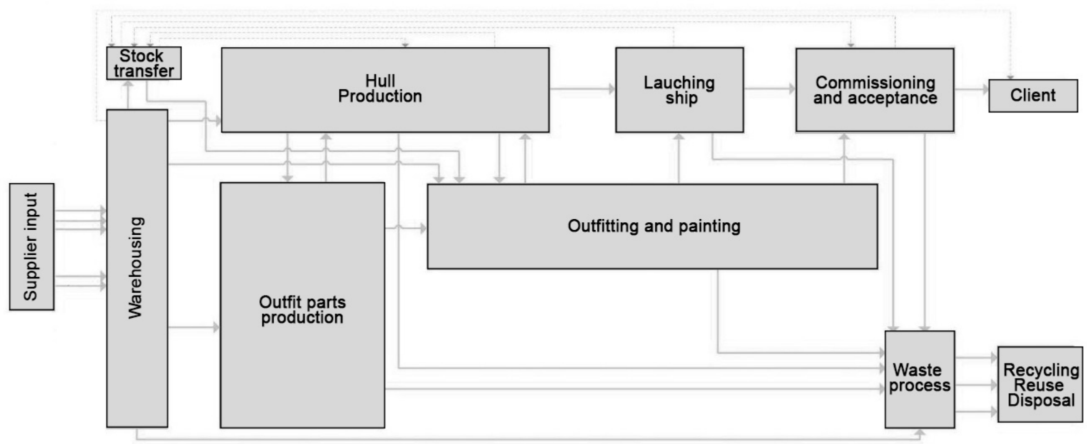

Figure 2: The production process of a typical production shipyard [16].

2.2. Definition of a Green Shipyard

Since the issues surrounding environmental performance are complex and far-reaching, Dangelico and Pontrandolfo [11] combined the environmental impact, environmental focus and the lifecycle phase of a product into an approach to formulate an appropriate definition of green. The three different types of environmental impact acknowledged (and consider a product green) are less negative (meaning that it has a lower impact that conventional products), null impact, or positive contributes to the environment [11]. Corresponding to the theory explained by Dangelico and Pontrandolfo [11], to come to an environmental friendly shipyard, the environmental impact of a Green Shipyard needs to be null. Considering that every product (even a green product) has an impact on the environment, it is important to clarify the environmental focus of an operational shipyard. The environmental focus can be classified into three categories, namely materials (incl. water), energy, and pollution (emissions and toxic waste) [17, 18]. The operational lifecycle phase of a shipyard impacts the environment with the operations that are performed, whereby a distinction can be made between the production processes and building facilities. In order to cover all environmental sustainability components, especially related to the differences between newbuilding and repair & conversion yards [14], the focus of a null impact is on both the categories energy and pollution. The relation between the input and output of the operational shipyard is visualised in figure 3, specifying the activities of both the categories energy and pollution.

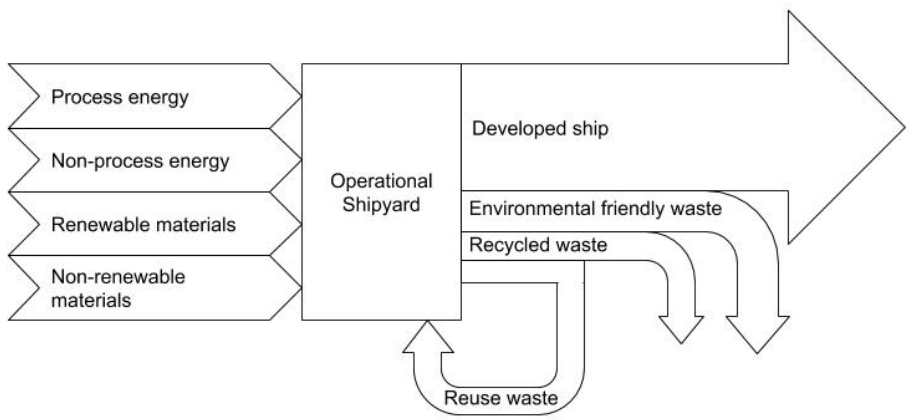

Figure 3: Input and output of an operational Green Shipyard.

The input of an operational shipyard is divided into process and non-process energy, and renewable and non-renewable materials. The use of energy is distinguished between primary and secondary energy sources. Primary energy resources are resources which exist prior to the modification by humans and secondary resources are obtained by the transformation of primary resources [19]. The energy use on an operational shipyard, which is divided into process (direct) and non-process (indirect) use [20], is classified as secondary energy resources [13, 15]. The use of renewable energy resources reduces the negative effects of fossil energy resources and the overall emissions form electricity generation, reduces the GHG and provides the opportunity to actively improve the environment [21]. Both the input of process and non-process energy shown in Figure 3 needs to be produced by renewable resources in order to achieve null impact. Addressing the environmental performance of energy from a wider perspective, a more positive contribution to the environment can be delivered by increasing the energy efficiency of processes and building facilities, and thereby contribute to attain sustainable development [22]. The Trias Energetica approach is a method to ensure that the use of conventional and renewable energy is optimised, by focusing on the following three topics: reduce energy demand, use renewable energy resources and use fossil fuels efficiently [23]. Applying this approach during the development of a product not only reduces the use of energy, but also ensures the use of renewable sources and increases the efficiency. The environmental impact of pollution produced during the operational lifecycle phase of a shipyard refers to the environmental performance of the production processes and systems, which can be measured by the amount of waste generated, as waste does not add any value to the manufactured product [24]. In order to minimize the impact of waste, the input of renewable materials for the production processes and systems is required [23].

The output of an operational shipyard involves different types of waste, divided into incomplete conversion of materials and resources, and inefficient use of resources [25]. The incomplete conversion of materials is in essence losses that arise from the primary production processes all the way to the finishing of the product, which can be measured in units of mass. In order to improve the environmental impact by reducing the produced pollution, a three step waste hierarchy of "reduce, reuse and recycle" can be applied [26]. The inefficient use of resources that are not directly used in the product, but are required to perform a certain production process, cannot be reduced to null. Therefore the following strategy to "avoid, use of renewable and improve efficiency" [23] is applicable, whereby the focus on environmental friendly materials as input does contribute to reduction of the environmental impact. Creating a positive environmental impact for the use of material is not possible in the operational lifecycle phase, the main objective is to eliminate the negative environmental impact for both categories of waste and compensate the impact created [11]. As the ships are not produced form completely environmental friendly materials, the resulting non-environmental friendly waste should be recycled or reused in order to reduce the impact. This results in the three waste categories shown in Figure 3.

Summarizing, the environmental impact of a shipyard is divided into energy use and pollution, where pollution refers to incomplete conversion and inefficient use of materials. A shipyard is recognized as absolutely green when achieving an environmental impact for both energy use and pollution of null.

This results in the following definition of a Green Shipyard:

> *A shipyard is considered green when the development, repair or conversion of a ship, using different processes and systems, has an environmental impact for both energy use and pollution of null.*

It is important to acknowledge that a Green Shipyard only considers sustainable production of vessels and the repairs performed, as the scope only includes the operational lifecycle phase. The materials themselves are not necessarily sustainable, since elements such as transport and recovery of resources are not taken into account in the determination of the degree of sustainability. Achieving null impact is only possible by minimizing the impact of energy use and pollution produced, and by compensating the resulting impact by positively contributing to the environment [11].

2.3. Environmental performance assessments

Measuring the environmental performance is important for acquiring insight in aspects that have a high impact on the environment. The environmental performance can be assessed by applying different methods, models, measures and sets of indices [7]. The term environmental assessment is mostly known for assessing the environmental consequence (both positive or negative) for a plan, policy, program or project. Strategic environment assessment (SEA) is known as a systematic decision support process to ensure environmental aspects are considered effectively in policies, plans and programmes, whereby an environmental impact assessment (EIA) is generally applied to more specific projects [27].

Assessing the environmental impact of an industrial product from cradle-to-grave can be done by performing a LCA [9]. LCA is a general accepted analytical tool that provides a holistic environmental perspective on a product by assessing the impact and resources used throughout its life cycle [28]. Examples of methods developed for the production (manufacturing) industry often involve an LCA approach. Zamagni [29] developed a lifecycle sustainability assessment model which combines LCA, Life Cycle Costing (LCC) and Social LCA. Chong, et al. [30] applied a metric of sustainability to a proposed sustainability indicator framework to assess waste-to-energy systems. Egilmez, et al. [31] realises an economic input-output LCA and data envelopment analysis (DEA) model for sustainability assessment of production units in the United States of America. These models focus on assessing the performance from a quantitative perspective, applying a calculation-based, measurement-based or hybrid-based approach. This requires input data from a database or actual usage to assess the performance [32].

Part of the growing environmental awareness, more specific environmental performance methods have been developed. These methods assess the environmental performance of a specific topic, for instance the production process or building performance [8]. Environmental building performance assessments have emerged as one of the major issues in sustainable construction [28]. The environmental performance assessment is a measure for the extent to which buildings might influence their environment, so that their design or operation can be altered to minimise harm and improve amenity [32]. Different environmental assessment systems and tools that are applied in the building industry are BREEAM in UK and LEED in U.S.A. [33]. Methods as BREEAM, Green Star and LEED involve a more qualitative approach to assess the performance, where underlying data is used to develop a specific performance rating. The level of objectivity may differ across categories and methods, which has led to occasional debate [32].

Finally, methods assessing the performance on a single instance, for example the focus on single production technology, single building entity or singular processing efficiency [8], are not directly transferable to the shipyard industry. As mentioned in Section 2.1, newbuilding yards differ in several aspects from repair & conversion yards [13]. Combining the different activities, ranging from simple repair work to building vessels from raw materials, into one assessment is challenging [9]. The differences in activities performed, especially on a repair & conversion yard, influences the impact on the environment. A shipyard with a reduced production might appear to be more environmental friendly, however in reality did not implement measures to improve the environmental performance [14]. Different geographic locations is an issue that needs to be taken into consideration, regarding the different laws and regulations, environmental characteristics and labour conditions [9]. The currently available assessment frameworks are not sufficient enough to cover the similarities and interdependencies of both newbuilding and repair & conversion yards. In order to cover this problem and being able to assess the environmental performance of an operational shipyard, a specifically developed framework is required.

3. Research methodology

Within this section the research design, research scope, data collection and approach for the development of the assessment framework are provided, laying down the foundation for this empirical part.

3.1. Research design

The theoretical understanding for assessing the environmental performance and the aspects of a Green Shipyard is used for the development of an environmental assessment framework to fit the assessment of shipyards, being the Green Performance Framework (GPF). The GPF is to propose a framework of environmental indicators and a metric of environmental performance to assess the performance of shipyards [34]. The framework includes a set of both qualitative and quantitative indicators with the objective to capture a view at the environmental performance. The qualitative indicators produce data that can be aggregated and analysed to describe and predict relationships, which is important to gain insight in the effectiveness of measures taken to improve the environmental performance. The qualitative indicators are formulated in accordance with ISO-standard 9004 [35]. The quantitative indicators can help explain the established relations by normalizing the shipyards performance and interpret the contextual differences in quality [36]. Combining both the qualitative and quantitative indicators, the environmental performance of a shipyard can be assessed.

The GPF is developed by applying a specific approach based on similar frameworks used for other areas of expertise. The five phase approach is explained in Section 3.4. The gap in the literature ensures that the required input to establish appropriate measurement scales is missing, and therefore a baseline performance level is required. By applying a purposive sampling method, meaning an intentionally non-random selection, fourteen appropriate shipyards are selected, in order to establish the baseline performance level. The sample involves a diversity of newbuilding and repair & conversion yards. The initial fourteen shipyards are formally approached, explaining the aim of the research and requesting their interest in participating. Finally, eight shipyards were prepared to cooperate for the establishment of the baseline performance level.

The GPF is tested and evaluated in a case study, assessing the environmental performance of three shipyards into more detail. Each of the three shipyards has a different organisational focus in order to include all relevant activities within a shipyard. Individual semi-structured interviews that are used in this research are considered as a convenient way to collect data from for the qualitative EPI. The interviews are performed on site, if the yard is easily accessible, and otherwise held by means of a conference call. The accessible locations are visited to place the collected data into perspective and understand the processes and systems performed on a yard.

3.2. Research scope

The function of the system investigated in this study is the operational phase of a shipyard, whereby sources are used as input and sinks as output [5, 6]. Dismantling shipyards are not included in this study, as they are relatively new and still under development, and therefore focusing upon newbuilding, and repair & conversion yards. The focus on the environmental impact of energy use and pollution results in specific inputs and outputs of energy, solid waste and liquid waste. The direct pollution (emissions) of production processes (i.e. during welding or painting) are not included, as the relative contribution to the total environmental impact is relatively low. This also applies to emissions produced by noise, vibrations, etc. The research focuses on the environmental dimension of sustainability. The scope of the research is visualised in Figure 4.

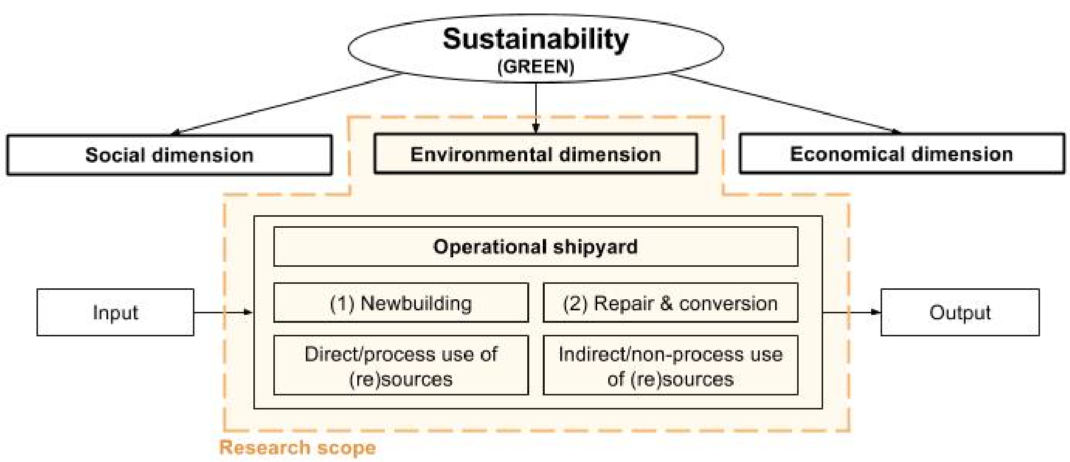

Figure 4: Visualisation of the scope of this research study.

3.3. Data collection

Data to establish the baseline performance level is gathered though sending a questionnaire to the production or Health Safety and Environment (HSEQ) department, depending on the yard. The contracting department of the main office was willing to initiate the first contact with the yards, in order to establish a direct link with the shipyards management and guarantee access to relevant information. The questionnaire asked for specific user data, regarding the energy used and pollution produced on the yard, and further data is extracted from previously reported yard consumption documents (i.e. CO_2 footprint). Through direct e-mail or telephone contact, more specific questions are asked when data on one of the two topics was missing.

Data for each shipyard in the case-study is gathered through two interviews held with each shipyard. The semi-structured interviews followed a specifically designed interview protocol in order to gain a broad understanding of the performance of each qualitative EPI. The semi-structured interviews lasted for approximately 30 minutes, and were coded and fragmented according to the measurement scales of the qualitative EPI, ensuring a consistent approach for assessing the environmental performance. The quantitative data are gathered through examining different monitoring systems available at a shipyard (i.e. an energy management systems, CO_2 footprints, etc.), which are analysed within-case and cross-case analyses.

Five additional interviews were held with both internal and external experts in specific fields of expertise (i.e. energy, waste and production experts) to evaluate the internal validity and reliability of the GPF. The expert interviews are important to determine the reliability of the collected data and the applicability of the developed GPF.

3.4. Approach developing assessment framework

This research develops the environmental assessment framework specifically to fit the assessment of different shipyards. The GPF proposes a framework of EPIs, involving specific quantitative and qualitative performance data [28, 31], to assess the environmental performance. Each EPI requires an operational metric, measurement scale and weighting factor to come to an overall performance score for a shipyard. In order to select appropriate EPIs and include the previously mentioned aspects, a five phase approach adapted from similar frameworks developed for other areas of expertise is applied (see figure 5).

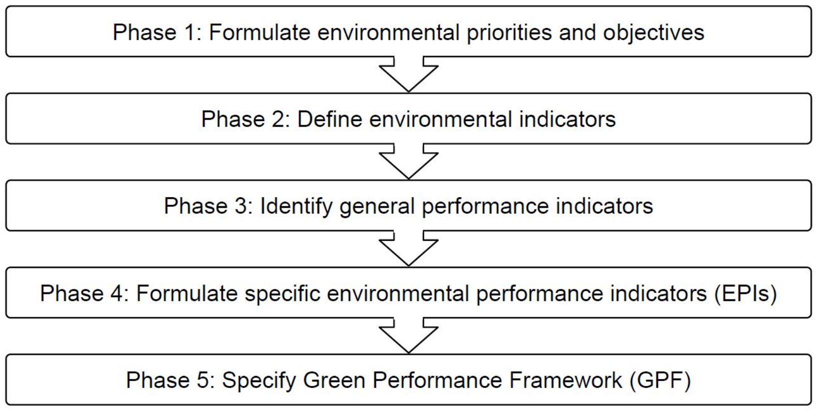

Figure 5: The five phases used for the development of the Green Performance Framework (GPF) applicable to operational shipyards.

- **Phase 1:** In the first phase, the environmental priorities and objectives for assessing the environmental performance of a shipyard are identified [31]. To ensure truly sustainable improvements for shipyards, it is essential that EPIs are consistent with the meaning and principles of green.
- **Phase 2:** In the second phase, the environmental indicators related to the priorities and objectives are specified in the previous phase defined [31]. This phase examines the input and output of an operational shipyards, adapted from the automotive industry [12], to select appropriate environmental indicators.
- **Phase 3:** In the third phase, the general performance indicators that are required to assess the environmental performance of shipyards are identified [37, 34], that measure the environmental standings on a short term basis, but do not specify the actual performance. The defined environmental objective and environmental indicators are used as guideline for the selection of appropriate performance indicators, and the selection is done based on the following criteria, namely relevance, comparability, verifiability, clarity and comprehensive [37].
- **Phase 4:** In the fourth phase, the general performance indicators are integrated into specific EPIs to measure and record environmental efforts [37]. These general indicators are not self-explanatory in terms of environmental performance of a shipyard, and therefore combining

these indicators into EPIs is necessary. A manageable number of indicators is recommended, ranging between ten and twenty, assuring that the company has relevant, few and simple performance indicators linked to its environmental objectives [34].

- **Phase 5:** In the final phase, all aspects are brought together into the GPF. Each EPI is translated into a measurable underlying indicator with appropriate measurement scale and weighting factor, thereby being able to make a comparison between the different yards [36].

4. The development of the Green Performance Framework (GPF)

Based on literature reviewed on assessing the environmental performance in Section 2.3 and the five phases explained in Section 3.4, the GPF is developed.

4.1. Environmental Performance Indicators (EPIs)

Based on analysing the main characteristics of operational shipyards, whereby the environmental focus on energy use and pollution is kept in mind, three qualitative and six quantitative EPIs are specified. The EPIs are divided into underlying indicators, varying in accordance with the EPI itself and matching with the local context. The underlying indicators are made up of different general performance indicators requiring input of operational metrics. Operational metrics refer to topics as amount of electricity used (kWh) or quantity of steel waste produced (kg), whereby the translation to an EPI normalizes the data and making it comparable between shipyards differing in size, FTE, production quantity and/or type of yard [12, 37]. Table 1 shows the list of EPIs, with underlying indicator to measure the performance.

4.2. Baseline performance level

The missing literature about the environmental performance of shipyards, required the formulation of a baseline performance level, in order to established appropriate measurement scales for each EPI. Through the use of operational metrics, it is possible to define a baseline performance level and normalize the user data of a shipyard, whereby insight in the environmental performance is acquired. Input of eight shipyards is used to establish the baseline performance level, including the average, minimum and maximum score of each underlying indicator (see Table 2). The table shows the average performance of all yards involved, with corresponding minimum and

Table 1: The quantitative and qualitative performance indicators adapted from different sources (i.a. [12, 35, 37]) to come to the GPF.

Qualitative EPIs		
Compliant with regulations	Monitoring energy/pollution laws, regulations and permits	These performance indicators examine the degree the yard incorporates changes regarding laws, regulations and permits into the yard. The measurement is performed for both the energy and pollution [35].
	Implementing energy/pollution laws, regulations and permits	
Green improvement strategy and policies	Energy/pollution reducing strategy and policy formulation process	These performance indicators examine the degree the shipyard organises everything regarding energy/pollution reducing policies and strategies. Especially looking at the formulation strategy, deployment approach and communication plans [35].
	Energy/pollution reducing strategy and policy formulation level	
	Energy/pollution reducing strategy and policy deployment	
	Energy/pollution reducing strategy, policy and plans communication	
Green performance transparency	Energy/pollution monitoring system	This performance indicator involves three (or four in case of pollution) indicators, whereby is looked at the degree a shipyard is organising the monitoring and measurement of their own performance regarding these topics [35].
	Energy/pollution performance audit	
	Energy/pollution performance data	
	External waste contractor audit	
Quantitative EPIs		
Energy use	Energy use offices (kWh/m^2)	These performance indicators examine the energy use per square meters for four different areas, involving office, warehouse, docks and production [12][37].
	Energy use warehouse (kWh/m^2)	
	Energy use production hall (kWh/m^2)	
	Energy use docks (kWh/m^2)	
Energy efficiency	Percentage energy efficiency (%)	This performance indicator compares the energy use in production with the total energy use [12][37].
Source of energy fraction	Percentage renewable energy (%)	These performance indicators measure the impact of the quantity of different resources used on the yard and the amount of renewable energy produced [12][37].
	Source of energy impact (%)	
Environmental load factor	Total scrap steel (%)	The environmental load factor divides the total waste (ton) of steel or aluminium by the quantity of material (ton) used over a year [12][37].
	Total scrap aluminium (%)	
Source of waste fraction	Source of waste impact production (kg CO_2e/ship)	The source of waste fraction determines the environmental impact of the different sources of waste produced. The indicator makes a distinction between the type of shipyards. The impact of water is determined separately [12][37].
	Source of waste impact repair & conversion (kg CO_2e/repair)	
	Water impact production (kg CO_2e/ship)	
	Water impact repair & conversion (kg CO_2e/repair)	
Waste processing factor	Waste reuse (%)	The waste treatment factor examines the waste processing performance based on the percentage of waste reused, recycled or incinerated (some form of energy recovery) [12][37].
	Waste recycling (%)	
	Energy recovery (%)	

maximum value, and specifies the amount of yards involved in formulating the scores. The objective was to use input of a single reference year for the formulation of a baseline performance level, however due to the limitations of the available data, input of previous years is required.

Table 2: The baseline performance level, specifying the average performance for each EPI, used in the formulation of the measurement scales for each EPI.

EPI	Sub-indicators	Average performance	Extreme performance	N years (number of yards)
Energy use	Energy use offices	164 kWh/m2	High: 964 Low: 40	10 (4)
	Energy use warehouse	140 kWh/m2	High: 445 Low: 38.9	5 (2)
	Energy use production hall	211 kWh/m2	High: 331 Low: 67	10 (4)
	Energy use docks	61 kWh/m2	High: 69 Low: 54	2 (1)
Energy efficiency	Percentage energy efficiency	58%	High: 86 Low: 18	10 (4)
Energy fraction	Percentage renewable energy	0%	High: 0 Low: 0	14 (6)
	Source of energy impact	61%	High: 35 Low: 81	12 (6)
Environmental load factor	Percentage total scrap steel	11%	High: 27 Low: 2	9 (3)
	Percentage total scrap aluminium	26%	High: 62 Low: 4	8 (2)
Source of waste fraction	Source of waste impact production	24,367 kg CO_2e/ship	High: 31,707 Low: 3,164	11 (5)
	Source of waste impact repair & conversion	27,798 kg CO_2e/repair	High: 11,666 Low: 402	3 (4)
	Water impact production	11,563 kg CO_2e/ship	High: 31,110 Low: 764	11 (5)
	Water impact repair & conversion	297 kg CO_2e/repair	High: 478 Low: 95	3 (4)
Waste processing factor	Waste reuse	Not Available		
	Waste recycling	Not Available		
	Energy recovery	Not Available		

4.3. Measurement and weighting

The measurement scale for each EPI is based on a point award system, where a specific performance level is awarded with a certain score. Developing a consistent measurement scale with normalizing outputs facilitates more comparable assessment results across different regions [28]. National Research Council (US) [12] compared valid methods for measuring the performance in other industries and provided clear recommendations in order to develop an useful framework. Acquiring insight in the scores for the EPIs is achieved by comparing results of other industries and the gathered data for the baseline performance level. The qualitative measurable indicators involve different maturity levels, which are based on ISO 9004:2009(E). The ISO-standard provides guidance in the formulation of a self-assessment method and thereby indicating the use of the different maturity levels [35]. The maturity levels range from one till five, namely from base level (level 1) till best practice (level 5). The quantitative measurable indicators involve a ten point measurement scale. The measurement scales are established by using the average, minimal and maximum value determined for the baseline performance level. The measurement scales correspond with an exponential decay, whereby the multiplication factor depends on the established baseline performance level, indicating a higher performance difference between score nine and ten than score one and two. The measurement scales are ranked from low performance (1) to high performance (10).

The overall performance of a shipyard is determined by specifying the relation between the underlying indicators. Even if all the scores in the rating system are similar, application of different weights of importance for each point may change the overall score [28, 32]. To calculate the weighted sum, individual weighting coefficients have to be assigned to indicate the relative significance of the different indicators under consideration. The National Research Council (US) [12] explains different methods for determining specific weights to each EPIs. As the objective is to make no distinction between different aspects and the shipyards differ in operations, the indicators are weighted equally to come to an overall score. Adding the score for each underlying EPI results in a total score for both the categories; energy and pollution. The weighted EPI score is calculated by the following Equation 1 [12]:

$$Weighted\,EPI\;score = \frac{EPI\;score\,(\%)\,*\,Weighting\,factor\,(\%)}{100} \tag{1}$$

5. Testing the Green Performance Framework (GPF)

This section tests the GPF in three specific cases, and thereby providing insight in aspects with a high environmental impact. Each case is briefly introduced, including an introduction of the organisation. The case results are compared and the testing of the framework is evaluated.

5.1. Case introduction

This research is performed in collaboration with the Damen Shipyard Group, one of the leading shipbuilding organisations worldwide. The organisation developed their own product standard, and thereby substantially reducing the delivery time [38]. They are active in areas as shipbuilding, shiprepair & conversion, maritime products production and related services. The change in regulations [4, 3] and the growing interests in sustainability by their stakeholders [20], initiated the interests in this research topic.

The case study involves three shipyards, which are selected involving the purposive selecting method [39]. The selected shipyards are an outfitting yard (Yard A), a repair & conversion yard (Yard B) and a newbuilding yard (Yard C). The three shipyards have a different organisational perspective and thereby differ in activities carrying out, which involves different parts of the overall production process. Yard A is located in the Netherlands, and consists of a large office area and is responsible for finalizing hulls which are produced at other yards. Yard B is a repair & conversion yard located in the Netherlands and follows the general production processes less clearly, since the work differs based on the clients demands. Yard C is a newbuilding yard located in Romania, responsible for the production of vessels, which are directly finalised or transported to other yards for final outfitting and painting. Table 3 summarizes the general yard information, which is also used as input to normalize the environmental performance of each shipyard.

Table 3: The input of general yard information required to perform the assessment.

General Yard Parameters		Yard A	Yard B	Yard C
Type of shipyard		Outfitting (& stock & repair)	Repair & conversion	New build
Shipyard location		Netherlands	Netherlands	Romania
Ships produced/repaired	amount	30 (16 repair/stock)	88 (70 in dock)	27
FTE offices	hours	2,069,666	104,000	1,042,080
FTE production	hours	536,311	416,000	3,733,600
Total FTE	hours	2,605,977	520,000	4,775,680
Total offices	m^2	23,226	4,966	14,784
Total warehousing	m^2	9,908	4,050	9,600
Total production	m^2	16,195	22,850	87,250
Parking garage	m^2	22,220	-	-
Docks	m^2	-	47,958	20,000
Other	m^2	123,423	6,555	421,632
Total surface/acreage yard	m^2	194,972	86,379	553,266

The EPIs require input of the general parameters and operational metrics to perform the assessment and determine the environmental performance of the shipyards. Table 4 shows the input of these metrics in order to determine the performance of each EPI.

Table 4: The input of the operational metrics required to perform the assessment.

Operational metric		Yard A	Yard B	Yard C
Electricity use office	kWh/year	1,876,668	200,000	1,827,648
Electricity use warehouse	kWh/year	437,099	820,000	-
Electricity use production	kWh/year	2,889,463	2,620,000	28,880,041
Electricity use docks	kWh/year	-	3,290,000	-
Total electricity production	kWh/year	2,523,865	2,124,907	28,098,014
Total electricity building facilities	kWh/year	3,092,088	1,291,482	4,609,675
Total electricity use green	kWh/year	5,000,000	304,058	-
Total electricity use grey	kWh/year	615,953	3,112,330	32,707,689
Renewable electricity production	kWh/year	1,246	-	-
Gas use	Nm³/year	323,818	618,678	965,273
Water use	litre/year	10,546	15,500	518,052
Bilge/Waste water ship	litre/year	-	-	137
Steel use	kg/year	-	-	2,908,540
Aluminium use	kg/year	-	-	-
Wood use	kg/year	-	-	-
Steel scrap	kg/year	81,500	-	7,704,000
Aluminium scrap	kg/year	17,650	-	19,888
Wood waste	kg/year	268,830	-	558,820
Paper and cardboard waste	kg/year	107,340	13,100	63,746
Plastic waste	kg/year	14,010	-	22,723
Commercial waste	kg/year	267,450	-	-
Oil waste	kg/year	4,340	-	2,101
Paint waste	kg/year	9,480	26,120	147,405
Batteries and accumulators waste	kg/year	-	-	-
Other waste	kg/year	70,420	1,971,000	742

5.2. Case results

Yard A

The outcome of the qualitative performance measurements shows that the overall energy performance is better than the waste processing performance. A policy statement and strategy regarding energy use is arranged, improvement plans are formulated and measurements are taken. A highly advanced monitoring system is in installed, and the facility department is pro-actively reducing the energy use of the yard. Short-term improvements are currently implemented, involving the recommendations made during an external audit. However, the Facility Manager (Interviewee 2, personal communication, Sept. 15, 2016) explains that long-term investments are not feasible due to the low energy price of approximately 0,005 €/kWh. The link between the policy statement and actual measures implemented is missing. The HSEQ

Manager (Interviewee 1, personal communication, Sept. 14, 2016) explains that the main objective is to comply with regulations and other departments may implement environmental improvements based on their own motives. The pollution reduction performance is of a significant lower level and the environmental statement misses this topic. The facility department mainly focuses on reducing costs for waste processing, and thereby improving the transparency of the whole process, however reducing the environmental impact of waste is not addressed.

The quantitative performance indicators shows that the yard has a good overall energy performance per square meter. However, the efficiency of the energy used is low, indicating that a significant part of the energy is used for the building facilities, which can be explained by the fact that the shipyard consist partly of office area. The environmental impact of the energy use is relative low, as most of the energy consists of green electricity. The environmental load for steel and aluminium could not be measured, as this data was unavailable. The impact of the waste produced per ship is relatively high, which may be caused by the fact that a significant part of the waste produced is related to office work. The waste processing factor shows a high score indicating most of the waste is reused and recycled, and thereby having a positive effect on the environment.

Yard B

The qualitative performance measurements indicate that the overall energy performance is almost similar as the waste processing performance. The HSE Manager (Interviewee 3, personal communication, Oct. 7, 2016) clearly indicated that the main focus is to comply with regulations. An energy audit is recently performed and a waste management system is in installed, both being certified according to ISO-14001 and OHSAS-18001. Energy reducing objectives are formulated in specific plans, whereby short-term improvements are implemented. The Team Leader Maintenance (Interviewee 4, personal communication, Oct. 6, 2016) states that buying green electricity is a waste of money, as it does not influence the energy use of the yard but costs more money. He has a clear preference for investing the money required to change grey electricity into green in improving the equipment and tools used on the yard. The HSE Manager (Interviewee 3, personal communication, Oct. 7, 2016) clarifies that environmental solutions are currently examined but not yet in place, for instance an inventory is taking place about the feasibility for the use of a Photovoltaic (PV) system. Waste reduction is achieved and segregation is applied where possible. The yard puts effort into persuading the client to choose alternative processes (i.e. alternative for hydro blasting) in order to reduce the impact of pollution created.

The quantitative measurements show a better performance for the use of energy than the production of waste. Both the energy used per square meter for the office, as well as the production area, score above average. The energy efficiency is average, indicating a high portion of the energy is used for building utilities. Furthermore, the impact of the different energy (re)sources scores average, indicating that a combination of high and low impact (re)sources are used on the yard. The environmental load factor could not be established as specific data is missing, however the EPI is less relevant for a repair & conversion yard, due to a significant lower amount of steel processed. The waste produced per repair scores low, indicating that the environmental impact of the produced waste per repair is high. The waste processing factors score around average, meaning that a high portion of the waste is reused and recycled.

Yard C

The outcome of the qualitative environmental indicators shows that both energy use and waste processing scores below average. The maintenance and repair department is responsible for yearly monitoring the changes in energy laws and regulations, and thereby updating the changes found. The Engineer HSEQ (Interviewee 5, personal communication, Oct. 14, 2016) mentioned that the yard recently hired an external party to perform an energy audit, which is done to comply with regulations as an audit needs to be performed once in the four years. The Head of Facility (Interviewee 6, personal communication, Oct. 14, 2016) explains that a digital monitoring system is installed, and both short-term and long-term energy performance improvements are implemented. The environmental performance of waste scores less than the energy performance. A policy statement about reducing the waste produced is missing, only water targets are specified. The performance of water is monitored quarterly by quality indicators. Only the quantity of waste produced and sent for recycling or processing is monitored. The Head of Facility (Interviewee 6, personal communication, Oct. 14, 2016) explains that employees are trained in properly handling waste, however improvement in the use of more environmental friendly materials is technically complicated and especially economically not possible due to the current financial situation.

The qualitative indicators show that the energy used per square meter scores low, whereby only data for the office area and production area is available. Most of the energy used on the yard relates to the production processes, resulting in a high score for energy efficiency. As no green energy is used or produced, the energy fraction scores low. The environmental load factor scores average, whereby 22.5% steel waste indicates a lower score compared with the 17.4% aluminium waste. The impact of the waste produced per ship scores low, as a high amount of waste is produced compared to the amount of ships produced (but does not incorporate size or weight of the vessels). Finally, waste processing scores average, where a high portion of the waste is recycled, especially steel and aluminium.

5.3. Cross-case analysis

By comparing the individual cases in a cross-case analysis, it is possible to acquire insight in which aspects have a significant impact on the environmental performance of a shipyard. The case results are shown in Figure 6 to summarise and visualise the relevant information collected through interviews, documents and different monitoring systems, and give the necessary background information for understanding the cross-case analysis. The figure shows the shipyards performance for each EPI, divided into the qualitative performance and quantitative performance. The energy and pollution are individually measured by the three qualitative EPIs, and therefore showing six results.

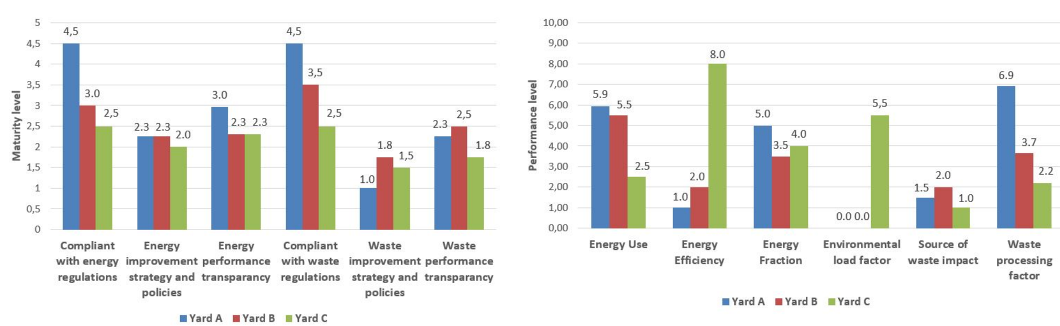

Figure 6: Outcome of the GPF resulting in a performance for each EPI related to the three shipyards, showing the qualitative indicators (left) and quantitative indicators (right).

Comparing the case results, the overall performance of Yard A, for both energy use and pollution produced, is slightly better than the other two yards. Yard A clearly structured the monitoring of changes in laws and regulations in order to keep track of change applicable to their shipyard. By buying green electricity and testing the use of a PV system, the yard is further developed compared with the other two yards. This corresponds with the ambition of yard A, being an example for other shipyards within the Damen Shipyard Group, specified by the HSEQ Manager (Interviewee 1, personal communication, Sept. 14, 2016).

The results show that the performance of the individual indicators for the three shipyards correspond with each other. No excessive differences are found and being compliant with regulations scores the highest by each yard. This is supported by answers given during the interviews, for instance by the HSEQ Manager (Interviewee 1, personal communication, Sept. 14, 2016) who mentioned that being compliant with national and EU regulations is the most important objective of yard A. The qualitative indicators score higher compared with the quantitative indicators, indicating that the slightly higher performing policy and strategic aspects not directly results in a reduction of the impact created by the resources used. By implementing clear strategies and investing in monitoring systems, the transparency of the performance can be increased and thereby possible improvements should be revealed.

The yards focus mostly on improving the energy use than reducing the emission produced by the different categories of waste, which is reflected in the environmental statement of each yard. The yards all have an energy reduction objective, whereby the Manager Contracting and Yard Support (Interviewee 9, personal communication, Oct. 19, 2016) showed that Yard C currently focuses on a reduction of 3% each year in comparison to the 2015 use. Similar objectives for the pollution produced on the yards are missing. This corresponds with the interest in solutions to produce renewable energy on their yards, as they are performing feasibility studies to determine the possibility of investing in PV system and other solutions. However, the current electricity price of 0,005 €/kWh does not provide a favourable return on investment opportunity and results in minimal investments in environmental friendly solutions. This proactive approach is not acknowledged for the reduction of pollution produced by the sources of waste.

Finally, the interviews show similar influences of costs while implementing environmental improvements. The yards all focus on the "low-hanging fruits" and low cost improvements, but measures with a return on investment longer than five years are not implemented. The costs for investing are more important than actually improving the environmental performance. An aspect that Yard B distinguishes itself by is trying to convince clients to use more environmental friendly processes for the repair work performed. The HSE Manager (Interviewee 3, personal communication, Oct. 7, 2016) explained that they try to convince clients to use a more environmental friendly grit for the blasting process, however the client is mostly not willing to pay more.

5.4. Framework evaluation

The framework is evaluated through examining the performed assessment and interviewing experts in specific fields of expertise which correspond with the GPF. The expert interviews are important to validate the case results and determine the reliability of the assessment framework.

The GPF is a valid method for self-assessing the environmental performance of a shipyard and compare individual environmental aspects between the different shipyards. First of all, the internal use of the GPF provides the opportunity to compare the policy, strategies and plans developed to improve the environmental performance with the actual energy use and waste pollution produced. Through continuously applying the GPF to assess the performance over each year, the yard is able to determine if the implemented strategies and policies on management level actually resulted in a reduction of the energy use or pollution produced. Secondly, the framework provides the opportunity to measure if the implemented improvements based on theory as Trias Energetica results in a performance improvement. For instance, the first step of Trias Energetica requires a reduction of energy use, which is directly measurable by the EPI energy use, resulting in reduction of the energy used per square meter. Similar relations are presented between the other EPIs and useful for monitoring the improvements derived from theoretical models. Thirdly, the underlying indicators of an EPI assess the environmental performance on an specific environmental aspect, and thereby provide the opportunity to compare the performance with other yards. The comparison is useful to determine whether a particular yard performs better on an specific aspect. Fourthly, mutually comparing the results is not only useful to compare the performance, but also acquire insight in the reasons why some yards outperform other yards. Through applying the GPF as method to compare the performance of yards, knowledge sharing and some form of transparency can be facilitated.

Despite the applicability for self-assessment and individually comparing the performance of specific indicators, the evaluation indicates that comparing the overall environmental performance of shipyards is complex. First of all, the yards are not always cooperating when asked for specific user data.

Employees recognize this problem and clarify that the yards may see each other as competitors, as clients are able to select their own repair yard. When a negative performance is reported, yards are afraid of losing assignments or regular clients. Secondly, the expert interviews questioned the reliability of the gathered data. The data misses important aspects, were based on assumption and not on the actual performance, or differed extremely between the different yards. A shipyard reported a steel waste of 4%, which is extremely low according to two experts, and according to their experience a steel waste of approximately 17% is more common. Thirdly, the different organisational focus and geographic location was complex to cover in the GPF. The production processes are rather different then repair and maintenance works and the geographic locations involves different natural circumstances [14], and therefore complex to compare. Individually comparing the indicators is possible, but merging the different indicators into one total score for the environmental performance of a shipyard seemed rather difficult.

Finally, due to the complexity and diversity of shipyards, the geographic location and incomplete data set available during this research, it is not possible to concluded that one yard performs better than another, however the assessment provides decent insight in aspects having a high impact on the environment and can be used as input for the formulation of an implementation strategy for a Green Shipyard concept.

6. Implementation strategy for a Green Shipyard concept

Empirical evidence emerging from the case study combined with the theoretical background results in the formulation of a specific strategy for the development of a Green Shipyard concept. The implementation strategy is divided in steps specific phases, in order to cover the different levels of detail, the complexity and diversity of shipyards, and approach the concept from different perspectives. The three steps covered by the strategy are management dedication, shipyard layout & process optimisation, and environmental friendly civil works, whereby specific requirements are formulated for the development of a Green Shipyard.

6.1. Step one: Management dedication

Green industrial production processes requires the translation of the organisational environmental management strategy into the actual production line [40]. The organisational strategy for a Green Shipyard is being able to produce a ship, using different processes and systems, without having an impact on the environment. Achieving null impact is possible by minimizing the impact of energy use and pollution produced, and positively contributing to the environment [11].

Evidence from the case studies show that environmental improvements are only implemented to comply with laws and regulations, however further development for a green shipyard are not implemented. With the objective to develop a Green Shipyard, a change on strategy and policy level is required. The first step involves dedication of the management to come from a traditional shipyard to a Green Shipyard. Without the explicit focus on achieving a high environmental performance and clear dedication, the future Green Shipyard is not achievable. The case study results confirm that focusing only on low-hanging fruits is not far-reaching enough to fundamentally change the shipyard industry [41], and therefore applying a different strategy is required. With clear dedication towards a greener shipyard, ensuring a relation between the formulated environmental policy, strategy and monitoring system is required. It is important to implement an evaluation process, with appropriate monitoring systems, in order to indicate whether the improvements have led to the desired results. This requires a more detailed reporting mechanism in order to acquire full transparency of your environmental performance, for instance implementing the GPF as self-assessment method, to monitor and evaluate the environmental performance of a shipyard. This should be the basis for implementing a successful Green Shipyard concept and results in the following requirements:

- Dedication towards null environmental impact;
- Implement clear monitoring and evaluation process;
- Achieve full transparency.

6.2. Step two: Shipyard layout & process optimisation

The second step requires a change in production processes and shipyard layout. The current core business involves stock production, and thereby reduce the delivery time of vessels, however this organisational strategy requires a significant amount of shipyard area dedicated to product inventory and warehousing. By changing the production processes towards methods as Lean Manufacturing and Design for Production, a reduction in waste pollution and energy use is achieved [42]. Changing the production processes requires a minimization of the shipyards' portfolio and stop producing unique vessels, which reduce the risk on defects and mistakes. Furthermore, implementing reduction and efficiency measures requires the optimisation of the shipyard layout. By optimising the shipyard layout, the impact of resources not directly related to the production process (i.e. minimize the distance to cover on the premises with equipment) can be reduced.

- Implementation Lean Manufacturing and Design for Production;
- Limit portfolio and do not produce unique vessels;
- Optimisation of shipyard layout.

6.3. Step three: Green civil works

The strategic changes implemented by step one and two requires environmental improvements in the civil works. The improvements can be explained by visualising the environmental impact of an existing shipyard and the Green Shipyard concept. Figure 7 shows the impact and contribution to the environment of an existing shipyard and a Green Shipyard, by converting each aspect in the operational phase into carbon dioxide equivalents (CO_2e) [43, 44, 45, 46].

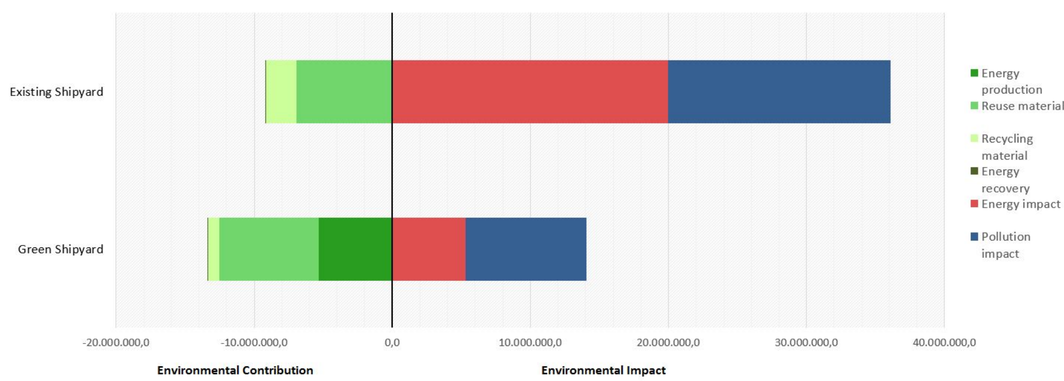

Figure 7: Visualisation of the environmental impact and contribution of an existing (traditional) and green shipyard.

The difference between a traditional shipyard and Green Shipyard concept requires the implementation of measures to improve the performance through the use of Trias Energetica (reduce energy demand, use renewable energy resources and use fossil fuels efficiently) [23] and pollution reduction measures depended on the type of pollution (reduce/avoid, reuse/use renewable and recycle/improve efficiency) [26, 23], which can be combined in the following three specific requirements.

Table 5: Detailed improvements translated from the cases and related to the three requirements to implement green civil works.

	Impact by energy use	Impact by pollution produced
(1) Reduce use	* Sun orientated building * Insulation (high Rc value of building shell, U-value doors & windows) * Include thermic requirements in spatial layout * Daylight related lighting (office) * LED lighting (no TL lighting) * Sensors (toilets, offices, meeting room DSGo) * Ventilation (mechanical ventilation with CO2 control) * Reduce office area (flex-working) * Automatic blinding of windows (reduce temp increase) * Build specific painting area/hall * Eliminate rework * Paperless office	* Different types of cutting * High pressure cleaning of vessel before painting (water, water + grit, grit blasting) * Energy saving equipment * Reduce welding splatter (welding equipment) * Eliminate rework
(2) Use renewable	* Change fossil to electric (forklifts, lifting, workboats) * Solar & wind electricity * Buy green electricity * Electric heating air & water (no gas use) * Install heat-pump	* Rainwater use for toilets, washing-machines, gardening and ship cleaning * Apply biomimetic antifouling coatings (non-chemical)
(3) Increase efficiency	* Heat transfer through water system * Electricity storage (water pump, batteries) * Heat recovery from machines (compressors) and office equipment (data servers, washing-machines) * Implement high efficient boilers for heating air & water * Different types of welding (cold metal transfer (CMT), Laser Hybrid, and Delta Spot) improve efficiency * Equipment with low energy cost in standby * Reduced leaks in pipes and equipment of compressed air systems	* Water saving toilets and showers * Reuse water of showers for gardening * Treat wastewater on yard for use of ship cleaning, gardening and toilets (repair yards) * Paper reuse for packaging material

- Reduce the use of energy and production of waste;
- Use renewable (re)sources;
- Increase the efficiency of (re)sources used.

By combining the knowledge of aspects having a high impact on the environment with the three specific formulated requirements, the following table with possible measures to reduce the environmental impact is established (see Table 5). These measures are classified as reducing the impact or improving the contribution to the environment.

7. Discussion

This section covers the scientific and practical contribution, and formulation of limitations and future research opportunities.

7.1. Scientific contribution

Although literature on sustainability in the shipping industry is flourishing, little attention has been paid to the sustainability of shipyards, and the production, repair and conversion of vessels. This research has proposed an empirical investigation of the problem by developing the GPF and analysing three cases in the light of environmental performance of operation shipyards, focusing on the use of energy and pollution produced. Specific gaps of the literature have been addressed, including:

- Throughout the literature, different interpretations of the definition of green in relation with sustainability were found, however a specific definition for a Green Shipyard is missing. Through examining an operational shipyard, gathering of a solid basis of theory and determining the boundaries of a sustainable shipyard, a definition for a Green Shipyard was established. The formulation of an appropriate definition of a Green Shipyard contributes to the fulfilment of this gap in literature.
- Prior studies addressed the environmental impact of ships, and thereby especially focusing on an operational ship [5]. Limited research focused on the environmental friendly aspects of an operational shipyard. Building on preliminary research findings in other areas of expertise, made it possible to develop a framework to assess the environmental performance of operational shipyards. Where many methods, models, measures and set of indices are able to assess the environmental performance of a specific aspects, the GPF combined different EPIs into one single model.

7.2. Practical implications

The findings of this research provide valuable insights for the industry and especially for the shipyards involved in the case study. The cases highlighted aspects having a high impact on the environment, and provide possible solutions to improve the performance. With appropriate dedication of the shipyards management, a range of improvement measures can be implemented to enhance the environmental performance of these shipyards.

Furthermore, the developed GPF is available for self-assessment, providing the opportunity for shipyards to monitor their performance over time. The combination of qualitative and quantitative indicators makes it possible to measure if the formulated policy and strategies results in a direct reduction of the environmental impact. The GPF can be used as part of the evaluation mechanism required to achieve an environmental friendlier shipyard.

Moreover, empirical evidence emerging from the cases combined with the formulated implementation strategy provides a challenging objective to be achieved in the future. The developed strategy shows that a Green Shipyard is not easily achievable by implementing environmental friendly building facilities or production process, but requires dedication of the management and a change in the design process, in order to make the Green Shipyard concept work. Although this study offers a solid foundation, further research is required in order to arrive at an actual developed Green Shipyard. Areas for further research and limitations of this study are discussed next.

7.3. Limitations and future research opportunities

As within any research project, there are some limitations acknowledged and opportunities for future research seen. A first limitation is the baseline performance level established. The baseline performance level is established by data over several years. This was necessary as available data is minimal and misses essential input. In addition, there are signals that indicate that the supplied data is not a fair representation of the use of (re)sources. In order to reduce this limitation and thereby increase the reliability of the GPF, future studies are encouraged to gather data of a larger set of shipyards and implement methods to increase the reliability of the supplied data, and thereby establishing a more trustworthy baseline performance level.

Secondly, the GPF weights each EPI equally, as the objective is acquire insight in the environmental performance, and thereby make no distinction between the various aspects. However, weighting the EPIs according to the preference of the shipyards' clients, the geographical location, or on the aspects with the highest impact on the environment, dominates the overall performance of the assessment [28]. Downton [32] clearly indicates that indicators need to be weighted according to their environmental focus, in order to provide an indication of the importance of each. By weighting each EPI equally, the dependability to compare the performance is limited. To improve the applicability, it is recommended to implement specific weights to each EPI to increase the validity of the GPF.

Thirdly, making a comparison between two different type of shipyards seemed complex. The aim was to compare the performance of the shipyards, without making a distinction between the type of shipyard. However, while testing the GPF, it is acknowledged that the measurements scales for a single EPI related to the two types of shipyards differ, and make it complex to compare. The EPI is useful for self-assessment, but not trustworthy to make an objective comparison between the general performance of the different shipyards. There is experienced that different, more detailed, aspects influence the outcome of the framework and require a more detailed assessment. By dividing the GPF into two single approaches applicable to a specific type of shipyard, the limitation can be reduced and thereby increase the validity of the framework.

8. Conclusions

The global shipping industry causes considerable impact on the environment, and its environmental upgrading lags behind on other industries. Shipyard that are intrinsically motivated to reduce their impact on the environment are missing, however the need to implement environmental friendly improvements is increasing, in order to comply with laws and regulations.

Through examining an operational shipyard and determining the boundaries of a sustainable shipyard, specific EPIs are formulated and brought together an appropriate framework to assess the environmental performance of shipyards, specified as the GPF. The developed GPF is applicable as method to compare the environmental performance of specific categories of an operational shipyard or can be applied as self-assessment method to determine the environmental performance of a shipyard. The GPF is therefore useful as method to gain insight in the shipyards own environmental performance, specify aspects that have significant impact on the environment and define possible environmental improvements.

Through testing the developed GPF, and thereby measuring the performance of the EPIs in three cases, the importance of aspects as transparency, management dedication, monitoring mechanisms and evaluation systems is acknowledged. The results of the assessment is used as input to derive a three steps implementation strategy for the development of a Green Shipyard concept. The three steps covered by the strategy are management dedication, shipyard layout & process optimisation, and green civil works, whereby specific requirements are formulated for the development of a Green Shipyard concept. The three step approach is crucial to achieve a Green Shipyard.

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[1] J. S. L. Lam, K.-h. Lai, Developing environmental sustainability by anp-qfd approach: the case of shipping operations, Journal of Cleaner Production 105 (2015) 275–284.

[2] Ecorys, IDEA Consult, CE Delft, Green growth opportunities in the eu shipbuilding sector 152 (2012).

[3] I. Third, Ghg study, 2014, IMO, London, UK (2014).

[4] Energy Efficiency Directive, Directive 2012/27/eu of the european parliament and of the council of 25 october 2012 on energy efficiency, amending directives 2009/125/ec and 2010/30/eu and repealing directives 2004/8/ec and 2006/32, Official Journal, L 315 (2012) 1–56.

[5] N. Ko, J. Gantner, Local added value and environmental impacts of ship scrapping in the context of a ship's life cycle, Ocean Engineering (2016).

[6] P. Gilbert, P. Wilson, C. Walsh, P. Hodgson, The role of material efficiency to reduce co 2 emissions during ship manufacture: A life cycle approach, Marine Policy (2016).

[7] S. Singh, E. U. Olugu, S. N. Musa, Development of sustainable manufacturing performance evaluation expert system for small and medium enterprises, Procedia CIRP 40 (2016) 609–614.

[8] B. A. Schlüter, M. B. Rosano, A holistic approach to energy efficiency assessment in plastic processing, Journal of Cleaner Production 118 (2016) 19–28.

[9] J. Pulli, L. Jonna, Heikkila Kosomaa, Designing an environmental performance indicator for shipbuilding and ship dismantling 55 (2013).

[10] B. Hopwood, M. Mellor, G. O'Brien, Sustainable development: mapping different approaches, Sustainable development 13 (2005) 38–52.

[11] R. M. Dangelico, P. Pontrandolfo, From green product definitions and classifications to the green option matrix, Journal of Cleaner Production 18 (2010) 1608–1628.

[12] N. R. C. U. C. on Industrial Environmental Performance Metrics, Industrial Environmental Performance Metrics: Challenges and Opportunities, National Academy Press, 1999.

[13] S. Misra, Sustainable development and ship life cycle, International Journal of Innovative Research and Development 1 (2012) 112–120.

[14] H. Chabane, Design of a small shipyard facility layout optimised for production and repair, in: Proceedings of Symposium International: Qualite et Maintenance au Service de lEntreprise.

[15] C. R. Harish, S. K. Sunil, Energy consumption and conservation in shipbuilding, International Journal of Innovative Research and Development 4 (2015).

[16] Y. J. Song, J. H. Woo, New shipyard layout design for the preliminary phase & case study for the green field project, International Journal of Naval Architecture and Ocean Engineering 5 (2013) 132–146.

[17] I. Sousa, D. Wallace, Product classification to support approximate life-cycle assessment of design concepts, Technological Forecasting and Social Change 73 (2006) 228–249.

[18] R. M. Dangelico, D. Pujari, Mainstreaming green product innovation: Why and how companies integrate environmental sustainability, Journal of Business Ethics 95 (2010) 471–486.

[19] C. Ngô, J. Natowitz, Our energy future: resources, alternatives and the environment, volume 16, John Wiley & Sons, 2012.

[20] Damen Shipyards Group, Sustainability report 2014 46 (2014).

[21] A. Midilli, I. Dincer, M. Ay, Green energy strategies for sustainable development, Energy Policy 34 (2006) 3623–3633.

[22] I. Dincer, M. A. Rosen, A worldwide perspective on energy, environment and sustainable development, International Journal of Energy Research 22 (1998) 1305–1321.

[23] A. G. Entrop, H. J. H. Brouwers, Assessing the sustainability of buildings using a framework of triad approaches, Journal of Building Appraisal 5 (2010) 293–310.

[24] I. Paul, G. Bhole, J. Chaudhari, A review on green manufacturing: It's important, methodology and its application, Procedia Materials Science 6 (2014) 1644–1649.

[25] P. Horton, L. Koh, V. S. Guang, An integrated theoretical framework to enhance resource efficiency, sustainability and human health in agri-food systems, Journal of Cleaner Production 120 (2016) 164–169.

[26] J. M. Allwood, M. F. Ashby, T. G. Gutowski, E. Worrell, Material efficiency: A white paper, Resources, Conservation and Recycling 55 (2011) 362–381.

[27] T. Fischer, Environmental Assessment, Critical Concepts in Built Environment Series, Taylor & Francis Group, 2015.

[28] G. K. Ding, Sustainable construction - the role of environmental assessment tools, Journal of environmental management 86 (2008) 451–464.

[29] A. Zamagni, Life cycle sustainability assessment, The International Journal of Life Cycle Assessment 17 (2012) 373–376.

[30] Y. T. Chong, K. M. Teo, L. C. Tang, A lifecycle-based sustainability indicator framework for waste-to-energy systems and a proposed metric of sustainability, Renewable and Sustainable Energy Reviews 56 (2016) 797–809.

[31] A. Mwasha, R. G. Williams, J. Iwaro, Modeling the performance of residential building envelope: The role of sustainable energy performance indicators, Energy and buildings 43 (2011) 2108–2117.

[32] P. Downton, et al., Building environmental performance assessment: Methods and tools, Environment Design Guide (2011) 8.

[33] A. Forsberg, F. Von Malmborg, Tools for environmental assessment of the built environment, Building and environment 39 (2004) 223–228.

[34] I. I. Issa, D. C. Pigosso, T. C. McAloone, H. Rozenfeld, Leading product-related environmental performance indicators: A selection guide and database, Journal of Cleaner Production 108 (2015) 321–330.

[35] International Organization for Standardization, ISO 9004: 2009: Managing for the Sustained Success of an Organisation: A Quality Management Approach, International Organization for Standardization, 2009.

[36] A. Ziout, A. Azab, S. Altarazi, W. ElMaraghy, Multi-criteria decision support for sustainability assessment of manufacturing system reuse, CIRP Journal of Manufacturing Science and Technology 6 (2013) 59–69.

[37] Ministry of Environment, Japan Government, Environmental performance indicators guideline for organizations 65 (2003).

[38] Damen Shipyards Group, Damen Corporate Brochure English 50 (2015).

[39] P. Leedy, J. E. Ormrod, Practical research, publisher not identified, 2005.

[40] T. W. Thurner, V. Roud, Greening strategies in russia's manufacturing–from compliance to opportunity, Journal of Cleaner Production 112 (2016) 2851–2860.

[41] A. Latino, D. Dreyer, Energy master planning toward net zero energy installation-portsmouth naval shipyard, ASHRAE Transactions 121 (2015) 160.

[42] M. Formentini, P. Taticchi, Corporate sustainability approaches and governance mechanisms in sustainable supply chain management, Journal of Cleaner Production 112 (2016) 1920–1933.

[43] M. Centraal, Co2 emissiefactoren, `http://co2emissiefactoren.nl/`, 2015. Accessed: 2016-10-4.

[44] C. Chai, D. Zhang, Y. Yu, Y. Feng, M. S. Wong, Carbon footprint analyses of mainstream wastewater treatment technologies under different sludge treatment scenarios in china, Water 7 (2015) 918–938.

[45] B. C. S. Association, Steel construction recycling and reuse (2015). Accessed: 2016-09-24.

[46] J. R. Freed, W. Driscoll, E. Lee, C. Lindsay, Greenhouse gas emission factors for management of selected materials in municipal solid waste (1997) 6.

Appendix A

Research Design

This section explains the research design, in order to perform the research for Damen Civil. First, an introduction to the subject is given, followed by an explanation of the research motivation, and the objective, questions and scope of the research. The research methodology explains the approach to perform the research and answer the formulated research questions. Finally, the scientific and practical relevance, the reliability, and the validity of the research is explained.

A.1 Research introduction

The research introduction covers a description of the company at which the research is performed, as well as background information on the subject of this research and the theoretical understanding.

A.1.1 Research background

Damen, established in 1927, is an international, family-owned Group of companies headquartered in the Netherlands, which is active in shipbuilding, ship-repair & conversion, production of maritime products and related services. They design, develop and produceinnovative ships of high quality, in particular according to modular design and building principles, supported by a worldwide network of sales and services. An excellent reputation in foreign countries is gained through the development of workboats and auxiliary equipment, which created great export opportunities. The growth continued steady overtime as Damen took over numerous yards specialising in niche markets, which led to the establishment of partnerships and business cooperations with yards all over the world [11]. Since the introduction of the modular shipbuilding concept, Damen has delivered more than 6,000 vessels. Today, with more than 9,000 employees, Damen Shipyards Group operates in many shipbuilding sectors, and has gained a prominent and trusted standing throughout the world. Currently, Damen builds a wide variety of standard hulls for stock at dedicated shipyards on strategic locations, with a production capacity of approximately 180 vessels per year. Damen Shipyard Group operates 32 shipyards worldwide [11].

Over the past few years, Damen saw a growing demand for advise in the development, design and construction of maritime construction. With many years of experience, an outstanding shipyard know-how is developed. Their projects are based on a combination of their own knowledge and local content, ranging from purely an advisory role to the delivery of a turnkey project, which is performed by Damen Civil [12]. The department operates all over the world, including in remote areas. Damen Civil is a part of the product group Damen Civil & Modular Construction (C&MC), which is a relatively new product group involving numerous innovative projects [12].

Part of Damens vision is to exceed its clients expectations in terms of quality, innovation and reliability. Innovation is a key of their success, serving their customers and staying ahead of their competition [3]. This is achieved by performing extensive market research determining the needs of their stakeholders. Their stakeholders, involving clients, local governments, business partners, financial institutions and their employees [13], drive their R&D department. They demand more insight in the impact of building, operating, maintaining and decommissioning Damens equipment, where sustainability is an important topic on their agenda. This forces Damen to make sustainability a more visible part of their strategy [3].

In order to cope with the growing demand for more sustainability, Damen formulated an organisational wide strategy on sustainability in the *Sustainable Report 2014* [3]. Damen realises that further improvements are necessary, especially in quantifying their performance as well as the method for collecting data throughout the organisation. The *Sustainable Report 2014* [3] explains Damens approach to the most relevant issues identified by their stakeholders, and how to add value and mitigate negative effects. As the report indicates that 77% of their annual turnover is achieved by building new vessels, which has the biggest social, economic and environmental impact, and is therefore their main sustainable focus [3].

Although the impact of their production process is small compared with the operational phase of a ship [14], a lot of effort is put into managing environmental risks as well as improving the efficiency of their shipyards. The implementation of sustainable improvements is necessary to comply with regulations and stakeholder demands. Damen has started measuring the carbon footprint of several of their yards, to gain more insight in the environmental impact of their production processes. The outcome of the measurement of three important shipyards is shown on figure A.1, and shows a significant growth in CO^2 emissions.

CO_2 EMISSION (t) DAMEN 2011-2013

YARD	2011	2012	2013
GALATI	13,763	16,765	19,407
GORINCHEM	6,389	7,262	9,261
SINGAPORE	–	–	1,053

Figure A.1: Carbon dioxide emission Damen 2011-2013 [3]

The *Sustainable Report 2014* evaluated the energy usage of several shipyards on global level [6]. The analysis of the carbon footprints and the evaluation of the energy usage of specific shipyards are used for the development of energy saving plans. With this information, shipyards are trying to improve their efficiency by implementing energy improvements, for instance with the installation of smart meters and LED lighting [3]. These implementations do improve the energy performance of this particular shipyard, however the improvements are basically quick-wins, short term oriented and locally developed. A real strategy to improve the sustainability for all shipyards is missing.

As part of their vision is to exceed their clients expectations in terms of quality, innovation and reliability, Damen wants to use this opportunity to develop a Green Shipyard concept. To comply with the future demands and be able to deliver future proof shipyards, insight in the possibilities for high sustainable solutions is desired. With the development of a Green Shipyard concept, they are able to anticipate to the needs of their stakeholders.

A.1.2 Market trends

The change in stakeholder demands can be explained by viewing the trends seen in the market. Arguments from both pull and push orientation motivates the need for more sustainability. The trend ”increased environmental awareness and growing interest in Corporate Social Responsibility (CSR)” [15] pulls the market to changes, which is also known as a market driven trend. The regulatory-driven trends, referring to the obligation to reduce the production of Greenhouse Gases (GHG), are pushing the market to change [15].

On the one hand, customer demands pull the market to change to more innovative and sustainable solutions. More environmental awareness and Corporate Social Responsibility (CSR) is required. As Damens stakeholders, and particular their customers, have significant influence on their development, the need for more transparency and having a higher value for sustainability does create opportunities. An increase in willingness to invest in green technologies to raise the environmental performance is seen [15]. Improving the sustainability of a shipyard will contribute to the reduction of the CO_2 emissions of a ship. For instance, a portion of the energy used during the built and operation of a shipyard has to be billed to the account of a ship built in that yard [16]. Reducing the energy usage or increasing the energy efficiency of a shipyard has a positive influence on the ships account, and thereby, positively influencing the ships CO_2 emission. Finally, creating a green image can also positively affects their market position.

On the other hand, regulations and agreements push the market to change. In recognition of the magnitude of the climate change challenge and the importance of global action to address the significance of the GHG emissions, regulations and agreements have been established. In order to mitigate the experienced climate changes and reduce CO_2 emission in a cost effective manner, the Energy Efficiency Directive (EED) addressed energy efficiency measures. The EU objective for energy efficiency is a reduction of 20% by 2020 [17]. Based on these European regulations, the Netherlands formulated more specific regulations. This results in the obligation for organisations with an energy usage of more than 200.000 kWh or 75.000 Nm^3, to perform an energy savings inspection, and for organisations with an energy use of more than 50.000 kWh or 25.000 Nm^3, to invest in energy saving measures with a return on investment within five years [18, Art. 2.15 Wet Milieubeheer]. Similar regulations are developed by other countries in the EU, which are based on the EU objective of 20% energy efficiency target by 2020. Research performed by the International Maritime Organization (IMO) shows that the shipping industry contributes with 938 million tonnes to the global carbon dioxide (CO_2) emission in 2012, which corresponds with approximately 2.6% of the total CO_2 emission [19]. This is an improvement compared with an emission of 1,046 million tonnes of CO_2 in 2007, which corresponds to approximately 3.3% of the global emission [20]. However, research determined that an increase between 50% and 250% can be expected by 2050 [19], despite significant regulatory and market-driven improvements in efficiency. In order to reduce the GHG emissions, the EU strives, in collaboration with IMO and other international organisations, for the universal application and enforcement of high standards of environmental protection. The shipping environment should be improved by technology, better fuels and operations, arising from the request of the EU to reduce the CO^2 emissions from the shipping industry with 40% by 2050 [21].

A.1.3 Sustainability

Before focussing on the development of sustainable shipyards, a note on the general understanding of sustainability is required. Sustainable development is a widely used term and idea, has many meanings and therefore provokes different responses. This results in different views towards the definition of "sustainability", and thereby leads to confusion about the actual meaning of sustainability [4]. In order to understand what is meant with sustainability in this research, an overview of the basic principles of sustainability will be provided.

Hopwood, Mellor and OBrien [4] examined different approaches for the term sustainable development. In general, the concept of sustainable development is an attempt to combine the growing concerns about a range of environmental issues with socio-economic issues. The first actual use of the term was introduced in 1980 and the most widely known definition of combining the socio-economic issues with the range of environmental issues is done by the World Commission on Environment and Development (WCED) in 1987. The definition is known as [22, p. 41]:

> *"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs"*

The report *Our Common Future* (1987) specifies the dependency of humans on the environment to meet the needs and well-being in a much wider sense than merely exploiting resources [19]. Hopwood, et al. [4] appoint that the sustainable development is generally seen as three separate but connected rings of environment, economy and society. Figure A.2 shows the three dimensions, where can be seen that the overlap between the dimensions has to find a balance [4]. The three dimensions have a close connection, but can individually be defined as [22]:

- Social dimension; means meeting the basic needs and providing the opportunity to achieve a better life.

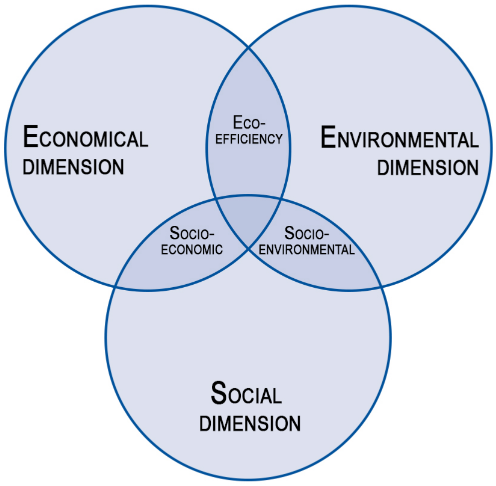


Figure A.2: The three sustainable dimensions [4]

- Economical dimension; refers to the development that is required for economic growth. However, assurance is required for the poor to get their fair share of the resources required to sustain economic growth.
- Environmental dimension; focuses on preserving the ecological environment. Economic growth has an impact on the environment which needs to be preserved for future use.

This can be summarized in a more applicable formulation, where sustainable development is the organising principle for sustaining finite resources necessary to provide for the needs of future generations of life on the planet. Sustainability is the practice of maintaining processes of productivity indefinitely, natural or human made, by replacing resources used with resources of equal or greater value without degrading or endangering natural biotic systems [23].

A.1.4 Sustainable shipyards

The literature often quickly jumps from sustainability towards the use of renewable energy resources or improving energy efficiency, however a more basic understanding of sustainability is required to understand the actual objective of this research. The above explained definition of sustainability is still comprehensive and a more deepened explanation of each dimension is required. The understanding of each dimension gives structure to the development of a more sustainable shipyard, later defined as a Green Shipyard.

In general, a shipyard can be seen as an industrial production facility, where certain input are used to design, develop, produce, repair, converse and dismantle a ship [14]. When addressing sustainability in a production process, the following definition of sustainable production is applicable: "the creation of goods and services using processes and systems that are: non-polluting; conserving of energy and natural resources; economically viable;

safe and healthful for workers, communities, and consumers; and, socially and creatively rewarding for all working people." [24, p2]. The definition of sustainable production involves all sustainability dimensions, however the social dimension is not included in this study as its involvement poses set of other challenges and questions, such as the quantification of damages to human health [16]. Furthermore, the responsibility regarding the social dimension lies with the Health, Safety, Environment and Quality (HSEQ) department, which are current assessing and monitoring elements as the safety and well-being of workers. Damen Civil is primarily responsible for the development and upgrading of shipyards, ranging for purely an advisory role to the delivery of a full turnkey project, where the social dimension is of less importance. This results in the focus on the environmental dimension for the development of a Green Shipyard concept. However, from business perspective, improving the environmental performance of a shipyard also involves the economical dimension. The improvements do require a certain investment which need to be economically feasible, as high costs may be associated with improving the environmental performance. The financial situation of the organisation must allow this.

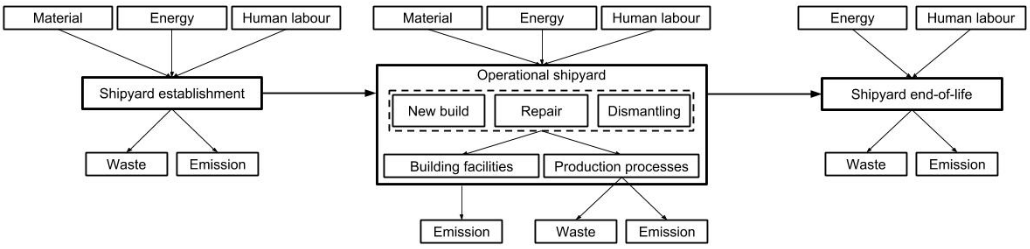


Figure A.3: Visualisation of the three life cycles of a shipyard

Environmentally sustainable development implies sustainable levels of both production (sources) and consumption (sinks). The need arose from the recognition that deterioration of global life-support systems, referring to the environment, reaches a certain limit. Environmental sustainability seeks to sustain global life-support systems indefinitely. The use of sources and sinks are large but finite, where sustainability requires that they be maintained rather than run down [24]. Now making the transition to a shipyard, the use of sources and sinks can be related to the different life cycle phases of a shipyard with the involving production processes (see Figure A.3). The capacity of sources refers to the use of raw materials as water, air, energy, etc. which are used as input for each life cycle phase, and sink capacities assimilate outputs, for example waste [14], [25]. The challenge seen in environmental sustainability is the development of an method to limit, or even bring to zero, the use of finite sources and environmental harming sinks [24].

The first lifecycle phase involves the establishment of the shipyard, which involves the input of energy, materials and human labour, and has the output of waste and emissions. The second lifecycle phase involves the operational phase of a shipyard. The shipyards operations can be divided into the three types of shipyards, namely newbuilding yards, repair & conversion yards, and dismantling yards [16]. The input requires materials, energy and human labour. The difference between these yards is important to acknowledge, because the shipyards involve different processes with a different effect on the GHG emissions. Newbuilding shipyards involves processes with an higher environmental impact, than repair & conversion yards. Repair & conversion yards are more labour oriented, where repair or retrofitting is performed. Dismantling yards are relatively new and focus on dismantling ships for the reuse of materials. Each of these yards can be divided into components directly related to the production of a ship (i.e. welding, cutting, etc.) or components indirectly related to the production of a ship (i.e. financial department, lunch room, etc.) [16], [26]. The difference between direct and indirect is hereafter also referred to process and non-process components. The production processes (process) produce certain waste and emissions, where the building facilities (non-process) only produce emissions. The final phase is known as end-of-life, where energy and human labour is required for the dismantling of the yard and results in certain emissions and waste (see Figure A.3). The output of waste, in all three life cycle phases, does not immediately mean that it cannot be reused or recycled, there is only referred to the fact that this waste product does not added value to the product produced [6]. In itself, the waste can be recycled or may be reused.

The economic dimension is interwoven with sustainability, where environmental improvements or degradation have direct influence on the economic growth. Furthermore, there is discussed that poverty is directly related with environmental degradation, which means that removal of poverty is necessary for environmental sustainability [27]. The perspective of economic sustainability is slightly different when associated with an industrial production organisation, compared with the whole society. An organisation is not only interested in improving the sustainability but also in the economic feasibility of the possible improvements. In example, production processes can be more sustainable from environmental perspective, however the change in processes are not always economic feasible. The economic feasibility has a huge influence on the decision making for an organisation to implement sustainable solution or change to a more sustainable production process [28]. The development of a more sustainable shipyard means not only implementing environmental sustainable improvements, but also ensure the economic feasibility. The direct consequence of implementing expensive improvements is seen in the costprice of ships, as part of the shipyards establishment and operational costs are billed to the ships account [16]. Therefore, the economic feasibility of sustainable improvements is important.

An important point to be noted is that development defines a process of directed change, which means that both the objective of the process and the means of achievement of the objective are defined. Misinterpretation of the definition is frequently made where sustainable development is seen as on ongoing process for more sustainability. Based on the characterization of the process, specific goal or aim should be defined to be able to speak of sustainable development [24], [27], [29].

Finally, defining the meaning of a ”Green Shipyard” is important, otherwise an improvement strategy cannot be formulated. The defined dimension will give structure to the development of the process for sustainable improvements and the clearly formulating the definition of a Green Shipyard will contribute to the formulation of the sustainable development objective. In order to acquire insight in possible performance improvements, assessing the current environmental performance of existing shipyards is required.

A.2 Research motivation

With the growing importance of sustainability, especially by their stakeholders, Damen feels the need to make sustainability a more important part of their corporate strategy. This is especially substantiated by their clients request for more insight in the environmental impact of building, operating, maintaining and decommissioning Damens equipment, where sustainability is an important topic on their agenda.

The current strategy mainly focuses on the development of more sustainable ships, and less upon their shipyards. With shipbuilding as their main activity, accounting for 77% of their annual turnover [3], it seems logical to focus on improving the sustainability of their ship, and thereby comply with their customer demands. On the other hand, with the implemented EU regulations for an energy saving of 20% by 2020 [17], country specific regulations on energy use of an organisation and the formulated objective of IMO, Damen is forced to make their shipyards more sustainable. Where specific shipyards are aware of these regulations, changes and improvements are implemented on local level. For instance, Yard A already implemented several technologies (i.e. smart meters, LED lighting, etc.) to reduce their energy use and make the shipyard more efficient. However, these improvement implementations are result oriented, focus on short-term improvements and are quick-wins. In order to exceed their clients expectations in terms of performance and innovations, a more specific strategy with a long-term vision is required.

Damen Civil sees the formulation of a specific strategy for improving the environmental performance as opportunity for the development of a Green Shipyard concept. Their own shipyards are used for marketing purposes and as reference framework, and therefore acquiring insight in their own performance is required. Being able to improve their own shipyards, with knowledge of environmental friendly measures, a strategic marketing proposition can be created.

A.3 Research objective

Elaborating on the research motivation, insight in the concept of a Green Shipyard, the current performance and highly sustainable improvements is required. Although ”green” and ”sustainability” are often used interchangeably, the definitions can be interpreted differently. Theoretical understanding of the definition ”green” and the relation with a shipyard is important for the development of a Green Shipyard concept. The environmental dimension of sustainability is applied for determining the performance of existing shipyards. The environmental performance of existing shipyards is assessed and used for the development of an improvement strategy to achieve the desired performance level. Aspects of the economical dimension of sustainability are used for evaluating the feasibility of sustainability performance improvements. This is combined in the following research objective:

> *The objective of the research is to develop an implementation strategy for a Green Shipyard concept by gaining insight in the environmental performance regarding sustainability of existing shipyards and formulating feasible improvements.*

A.4 Research questions

The following main and sub-questions are formulated to achieve the objective. The main research questions is:

> *How to develop a Green Shipyard?*

The main research question is answered by applying the following three research questions. Each of the three research questions are underpinned with three sub-questions in order to make the research questions manageable.

Research question 1: How to define a "Green Shipyard"?
A: What is the relation between "Green" and "Sustainability"?
B: Which types of Shipyards can be distinguished and what are the similarities and differences?
C: When is a shipyard recognized as "Green"?

The first research question focuses on determining the meaning of a Green Shipyard. Theory about sustainability, environmental performance and shipyards is brought together to determine when shipyards can be recognized as green.

Research question 2: How to assess the "Green" performance of shipyards?
A: What are applicable methods for assessing the environmental performance?
B: What are relevant environmental performance indicators and how to measure them?
C: What is an applicable framework to conduct a green performance assessment?

The second research question focuses on the development of a framework to assess the environmental performance of an existing shipyard. In order to do so, theory about a shipyard, the involving processes and suitable performance indicators is required. Both the first and second sub-question provides input for answering the third sub-question. The answers to these questions provide a more practical understanding of the research objective.

Research question 3: How to achieve a "Green Shipyard"?
A: What are the determining push & pull factors for "Green" improvements?
B: What are the socio-economic constraints for "Green" improvements?
C: How to prioritize feasible "Green" improvements?

The third research question combines the developed assessment framework to determine the performance of three existing shipyards with social-economic feasible environmental performance improvements to achieve an economic feasible Green Shipyard concept. The performance level of the three existing shipyards is based on gathered data from the other shipyards, which is used to formulate a baseline performance level. As Damen is interested in implementing environmental improvements in their own shipyards, the social-economic feasibility is important to verify.

The relations between the three research questions is visualised in Figure A.4. Combining the three research questions will eventually lead to the outcome of the main research question, however the questions can be answered individually. Finally, combining the derived definition of a Green Shipyard, with the current environmental performance and knowledge of performance improvements, a implementation strategy for a Green Shipyard can be formulated.

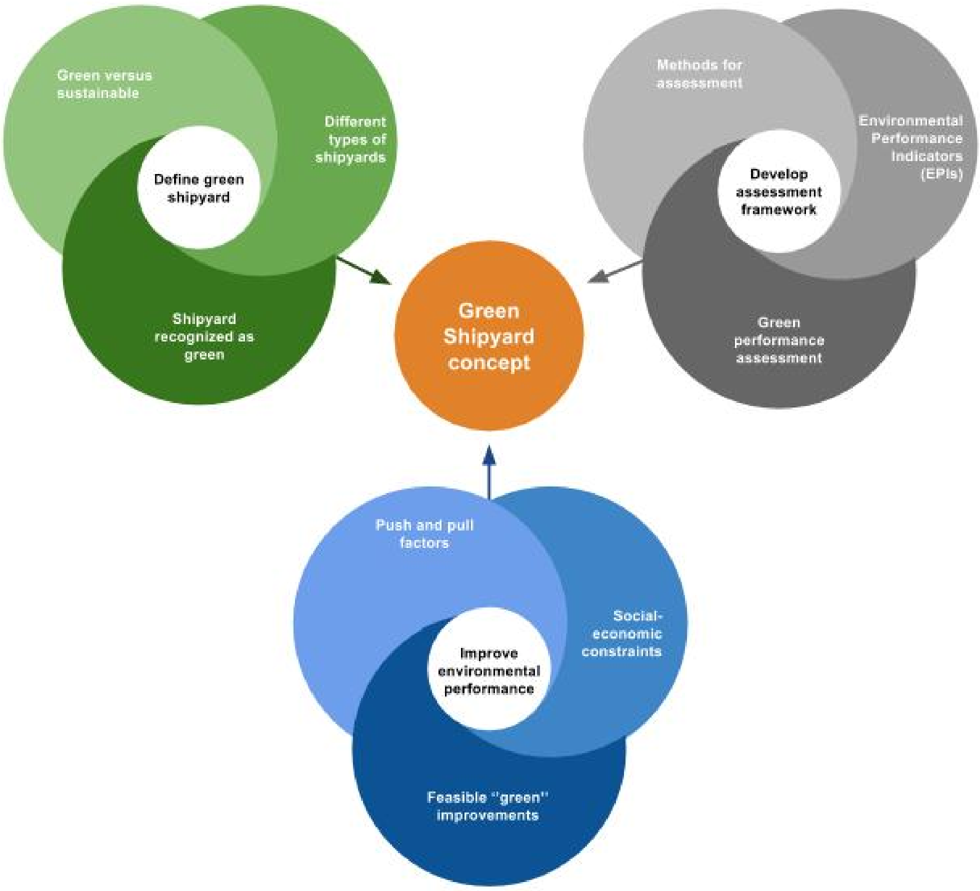


Figure A.4: Visualisation of the research questions in relation to the main research question

A.5 Research scope

The scope pinpoints the boundaries of the research. It is essential that important information, relevant to answer the research question, falls within the scope of the research and thereby ignoring irrelevant information [30]. The boundaries are also important to increase the internal validity of the research [31]. With this purpose, the scope is further defined by a number of basic principles, following from research background discussed in the introduction and supported by literature.

As briefly explained in the introduction, sustainability is divided into three dimensions where the social dimension is not included in the scope of this research. The social dimension poses other challenges and questions, such as the quantification of damages to human health [16], and is left open for further research. The main focus of the literature study is on the environmental dimension of sustainability, involving the sources as input and sinks as output, however there is limited literature available about this topic in relation with a shipyard. Therefore, other areas of expertise are used as reference material. For instance, the building industry, shipping industry and production industry are areas which involve more excessive literature about environmental development and assessment frameworks. A detailed substantiation for the selection of other areas of expertise are given in the literature review. In general, the input and output can be divided into process and non-process use of (re)sources and leftovers of sinks, where process relates to the production processes and non-process cannot directly be related to particular ships account [25], [26]. Finally, the feasibility of environmental performance improvements are addressed in relation with the economic dimension. An organisation requires insight in the economic feasibility of possible improvements to be able to make informed decisions. The stakeholders, and especially their customers, demand insight in the impact of building, operating, maintaining and decommissioning of Damens equipment. This means that they are interested in the sustainability performance of a shipyard in the operational life cycle phase. Therefore, the other two phases (the establishment of a shipyard and the shipyard end-of-life) are not addressed during this research. The introduction also defined three different types of shipyards, namely newbuilding yards, repair & conversion yards, and dismantling yards. The dismantling shipyards are relatively new and still under development, and therefore the focus is upon the sustainability performance of newbuilding, and repair & conversion yards. This all can be combined in a visualisation, shown in Figure A.5.

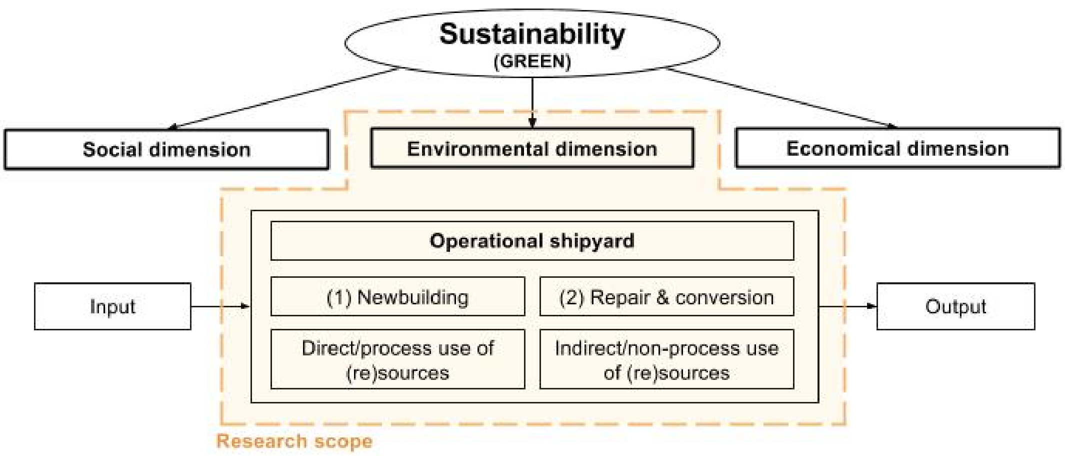


Figure A.5: Visualisation of the research scope.

Finally, the focus of the research is mainly on the European market, because of the implemented European regulations involving an energy efficiency target by 2020. Therefore, the three shipyards that are used during the case study are located anywhere in Europe.

A.6 Research methodology

This section explains the research methodology that is applied for this research. First, the research framework is shown, followed by an explanation of the methods that are used to perform the research.

A.6.1 Research framework

In order to answer the proposed research questions, the following research framework is applicable. The research is divided into four phases which are closely connected with each other. Figure A.6 shows the four phases which are explained in the next section.

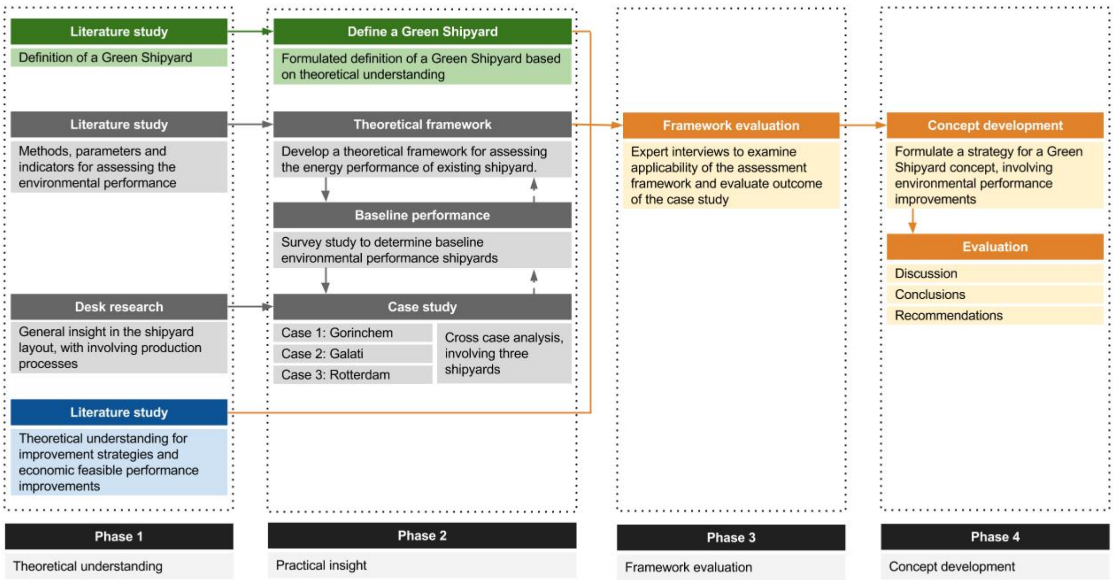


Figure A.6: The research framework applicable during this research

A.6.2 Research method

The research methods are explained by briefly discussing each phase of the research, which are shown in Figure A.6. The colors used in the research framework are related with the three research questions, corresponding with the visualisation of the research questions (see Figure A.4).

Phase 1

The first phase consists of different studies, involving a literature study and desk research. Each of the three research questions requires a certain theoretical basis. The first research question searches for theoretical understanding of the definition green related to an operational shipyard. The second research question requires information about assessment methods applicable for assessing a shipyard. The third research question searches for insight in possible improvement strategies and highly environmental sustainable solutions.

The literature study describes theoretical perspective and previous research findings related to the problem at hand, by reviewing scientific journals and articles. There is looked at what others have done in similar but not directly identical areas [30]. The literature review is written from a comprehensive perspective, which means that the beginning of the literature review is broad oriented and proceeds into more detail, in order to focus on the research problem. The introduction briefly looked at terms relevant for this research, the literature review is having a more extensive view to the existing literature and identifies the gap this research can contribute. The literature relevant for formulating a definition of a Green Shipyard, the theoretical framework that is developed in the next phase and theory about implementing environmental performance improvements is reviewed.

However, not all knowledge can be covered by the literature review, as company relevant information also plays an important role. The desk research will focus on mapping important facets of the shipyards used in the case study, which will involve the evaluation of documents written by the company providing relevant information. The study will focus on acquiring knowledge about the environmental performance, involving the input of sources (i.e. energy) and the output of leftovers (i.e. waste), also known as sinks. The layout of the shipyards with involving processes are used for quantifying the use of the input sources and acquiring knowledge about the output sinks. This will contribute to perform the case study, during the next phase of the research.

Phase 2

The second phase focuses on making a transition from theoretical insight to more practical verification. The gathered theory about green in relation with sustainability is used to formulate a definition for a Green Shipyard. As is mentioned earlier, sustainable development requires a specific goal to work towards, which makes it necessary to define green and understand the relation with a shipyard.

The theoretical understanding for assessing the environmental performance of a shipyard is applied in a survey study and case study. The survey study captures a data of a specific moment in time, such as a photograph, which can be used to draw conclusions form one transitory collection of data [30]. Gathering data about the performance of shipyards during specific moment in time can be used for the formulation of a specific baseline performance level. The baseline performance level is relevant while performing the case study, which can be used to benchmark each case against the baseline performance [1].

The case study assesses the environmental performance of three shipyards into more detail. The case study is often applied with the objective to compare, build theory, or propose generalization of cases that either differ or are similar in certain keyways. This method is particular suitable in situations where little is known or poorly understood about a specific topic [30]. The objective is to compare different shipyards and acquire insight in their environmental performance. Each of the three shipyards that are used for the case study will have a different organisational focus in order to include all relevant activities within a shipyard. First, the performance of each shipyard is examined individually, and afterwards, the outcome of the three cases is compared [31]. The case study will visualize the results of a shipyard in a specific performance profile.

Phase 3
The third phase brings together the outcome of the three research questions for evaluating the developed assessment framework. Expert interviews will provide insight in the applicability of the assessment framework and substantiates the results of the case study. The interviews with experts in this particular area of expertise is used for the validation of the developed framework. As the outcome of the case study is visualized in a performance profile, the expert interviews are important to determine if the performance profiles can be compared. Furthermore, the interviews with experts is important to perform, as limited theory about environmental performance assessment for shipyards is available. The knowledge of the experts is used to determine the appropriateness of the measurement scales and weighting systematics of the assessment framework.

The outcome will not only validate the assessment framework, but will also provide insight in measures to improve the performance applicable for the development of a Green Shipyard concept. As limited theory about environmental performance improvements for shipyards is available, the interviews may provide insight in the applicability of performance improvements translated from other industries (i.e. the automotive industry).

Phase 4
The final phase involves the formulation of an implementation strategy for a Green Shipyard concept, finalizing the research findings and formulating the conclusions, discussion and recommendations. Through insight in the current performance, the definition of a Green Shipyard and the measures to improve the environmental performance, a Green Shipyard concept can be developed. Finally, a proposition for further research and other general remarks are made during this final phase.

A.7 Data collection and analysis

Literature study
An extensive literature study is performed for the formulation of a Green Shipyard. Not only searching for applicable information about sustainability, environmental performance and green, also insight in the activities performed by a shipyard is required. The found literature about a Green Shipyard is aligned with the formulated research scope, in order to ensure the relevance research assignment.

An assessment framework is developed using the literature that is gathered and examined during the literature study for the assessment of existing shipyards. In order to assess the environmental performance, an combination of both quantitative and qualitative approach is most suitable for the assessment. The complexity of a shipyard, involving the geographical location, differences between shipyard types and the amount of processes performed on a shipyard, requires an combination of both qualitative and quantitative research. The literature study specifies the data that is required as input for the theoretical framework, which is based on determining environmental performance indicators [32]. The assessment framework is developed using a five step approach, which is based on other assessment methods and explained in the literature study.

Relevant literature is gathered using specific keywords (see Table A.1), which are based on the research questions. Most of the relevant literature is covered by searching for different combinations of the keywords. This approach is known as quantitative content analysis [31]. Searching for specific phrases can be achieved by applying quotes, for instance for ”energy performance assessment”. The resulting papers involve these specific combinations of keywords. In example the paper ”Energy efficient shipping between research and implementation” shows references to other papers, which involve interesting topics applicable to one of the research questions.

Table A.1: The keywords used during the literature study.

Research question	Keywords
How to define a “Green Shipyard”?	“green production” + “green manufacturing” + “green innovation” + “environmental impact” + “trias energetica” + “waste management” + ”waste processing” + “shipyard lifecycle” + “shipyard layout”
How to assess the “Green” performance of shipyards?	“lifecycle assessment” + “environmental performance assessment” + “environmental impact assessment” + “environmental performance indicators”
How to achieve a “Green Shipyard”?	“push factors” + “pull factors” + “social-economic constraints”

Limited available literature about shipyards requires reviewing similar approaches and techniques in other areas of expertise. As knowledge about these areas is missing, an iterative process for selecting relevant literature is used. An similar approach is known as the snowball approach, where the supported literature of relevant papers is reviewed. This process provides sufficient theoretical understanding of the research topic, in a short amount of time [31]. The gathered literature is reviewed searching for useful elements that can be applied in an assessment framework.

Survey Study

The survey study involves an questionnaire that is sent to the different shipyards, with the purpose to gather yard specific data to determine a baseline environmental performance. Through applying a purposive sampling method, meaning an intentionally non-random selection [30], fourteen appropriate shipyards are selected, in order to establish the baseline performance level. The fourteen shipyards are selected because the yards generate around 50% of Damens revenue. These yards are their primary focus as most progress can be achieved when these yards are improved [3]. The sample involves a diversity of newbuilding and repair & conversion yards. The initial fourteen shipyards are formally approached, explaining the goal of the research and requesting their interest in participating. Finally, eight shipyards were prepared to cooperate for the establishment of the baseline performance level. The questionnaire applies an mixed-method format, including both open and closed questions, to cover all aspects to determine the baseline performance level. The closed questions are used to establish the baseline performance level and the open questions are used to ask for supporting information to get a better understanding of the performance. The participants selected for this survey are employees working at the HSEQ, facility and production department, which are most frequently involved in topics as the environmental performance of the yard.

Case study

Due to the scope of the research, the case study is limited to three different shipyards. The three shipyards selected for the case study also involves purposive selecting method. As the main process of Damen involve the production, and the repair & conversion of ships, shipayrds related to these activities are selected. Yard A is selected as both main office and outfitting yard, Yard B is selected as repair & conversion yard and Yard C is selected as newbuilding yard.

The case study applies the developed assessment framework and therefore gathers both quantitative and qualitative data. In short, quantitative methods produce data that can be aggregated and analysed to describe and predict relationships, and qualitative methods can help to probe and explain those relations and to explain contextual differences in the quality [33]. The qualitative data is gathered through two semi-structured interviews with each yard, following a specifically designed interview protocol in order to gain a broad understanding of the performance. The interviews are performed on site, if the yard is easily accessible, and otherwise held by means of a conference call. The semi-structured interviews lasted for approximately 30 minutes, and were coded and fragmented according to the measurement scales of the qualitative EPI, ensuring a consistent approach for assessing the environmental performance. The quantitative data is gathered through examining different monitoring systems available at a shipyard (i.e. an energy management systems) and is used for determining the environmental performance. The input for the framework involves detailed user data (i.e. energy usage (kWh), gas use (m^3), etc.) for each involving building facility and production process. Statistically analysing the data is not of itself research, and therefore interpretation of the data is required [30]. The outcome of the different indicators is evaluated, identifying aspects which have a huge influence on the environmental and might be relevant for the development of an improvement strategy.

Besides the quantitative and qualitative data required for the assessment framework, general insight in the shipyard is required. Preliminary information about the involving shipyards was acquired through the desk research, giving insight in the layout of the shipyards and the involving processes. The shipyards involved in the case study, which are easily accessible, are visited to place the collected data into perspective and understand the processes and systems performed on a yard.

Expert interview

Face-to-face interviews are used for the expert interviews, which are applied in a semi-structured manner. This gives the opportunity to change the course of the interview and thereby focus on gathering relevant information. The interviews will apply a standard set of questions with several individually tailored questions to get more clarification. The use of face-to-face interviews has the preference, as this approach yields the highest response rates and potential to gain cooperation [30]. Experts regarding energy use, waste processing and production processes of a shipyard are interviewed (i.e. facility manager, production employee, yard personnel, HSEQ manager, etc.). However the research is performed for internal purpose, both internal and external experts are approached.

A.8 Research planning

In order to perform the research within the planned timeframe, the following schedule is formulated. Each of the phases explained in the research framework are shown in the schedule below. Figure A.7 shows the Gantt chart.

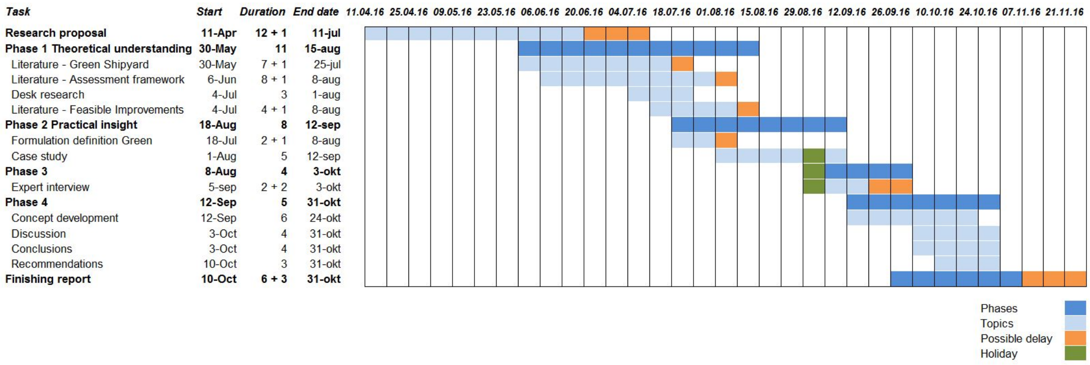


Figure A.7: Gantt Chart research planning

A.9 Scientific relevance

As is previously explained, literature about the environmental performance of shipyards is limited. When examining the existing literature, there is seen that the current focus is mostly on sustainable ship development, involving a whole lifecycle analysis. However, specific research about sustainable improvements of a shipyard is missing.

The development of a Green Shipyard concept requires a definition of a Green Shipyard. As a specific definition is missing, literature of other areas of expertise is examined and used for the formulation of an appropriate definition of a Green Shipyard. Furthermore, the development of an assessment framework for measuring the environmental performance of existing shipyards is required. The complexity of assessing the environmental performance of a shipyard is the difference between components seen on a shipyard, for instance buildings, equipment, production processes, etc. As a standardised approach is not available, the development of a framework to assess the environmental performance of existing shipyards combines methods seen in other industries, whereby both quantitative and qualitative measurable indicators are used. Finally, the theoretical framework examines the complex production system of a shipyard, which however can be generalized to other industries. For instance, the production of airplanes and trains do require a complex but similar production system, where the framework can be applied on.

A.10 Practical relevance

The practical relevance of this research is acquiring knowledge about the environmental performance of Damens shipyards, and developing a concept for a Green Shipyard. Currently, specific performance improvements are independently implemented on their shipyards, however an organisational broad strategy to improve the sustainability of shipyards is missing.

The information gathered while assessing the environmental performance of existing shipyards gives insight in systems specific performance and can be used to determine components that require attention to improve the environmental performance. The concept that is developed for improving the environmental performance gives Damen the possibility to launch a new product on the market.

A.11 Validity and reliability

In order to ensure a reasonable degree of validity and reliability, the several actions are undertaken.

The validity of the environmental assessment framework is increased by discussing the developed framework with the HSEQ department. This should ensure that both the survey study and case study measure what is required to be measured. The expert interviews contribute to the internal validity of the research, as their expertise provides insight in the results acquired. The use of triangulation increases the internal validity, and is seen as a precaution to eliminate other possible explanations for the results observed [30]. On the one hand, three methods are used in order to answer the main research question (literature study, survey study and case study). On the other hand, three types of data are gathered during the research (articles and documentation, questionnaire and expert interviews). Furthermore, a relation is sought between the use of quantitative and qualitative data during the assessment framework, which also positively influences the validity. The use of both types of data will support each other while determining the performance of a shipyard. The external validity is creased by examining literature of different areas of expertise (i.e. automotive industry) and performing the assessment rather general (limiting details), which makes it able to generalize the research results. Addressing both repair & conversion yards, as newbuilding yards, increase the external validity of the research.

The reliability is improved by performing a survey study and expert interviews. As theory directly related to shipyards is limited, the definition of a Green Shipyard and approach to measure the environmental performance are both derived from other areas of expertise. The survey study gathers data to determine a baseline performance level, which makes it able to compare different shipyards. Involving experts with specific knowledge about sustainability and/or shipyards improves the reliability of the research. Possible improvements can be suggested and implemented with the use of their knowledge.

Appendix B

Definition of a Green Shipyard

This section gives theoretical understanding for the formulation of a ”Green Shipyard”. The first research question gives substance to this section.

Research question 1: How to define a ”Green Shipyard”?
A: What is the relation between ”Green” and ”Sustainability”?
B: Which types of Shipyards can be distinguished and what are the similarities and differences?
C: When is a shipyard recognized as ”Green”?

The literature discusses a variety of definitions for the term ”Green”, for instance dimensions as ecological, political, corporate social responsiveness, fair trade, conservation, sustainability and equality are identified. Each of these dimensions are broad oriented and incorporate different aspects, which generates confusion for organisations to become green [34]. Therefore, defining an organisational focus for the use of sustainability is required, which will be considered as green.

B.1 Relation between ”Green” and ”Sustainability”

In order to define a ”Green Shipyard”, insight in the relation between ”Sustainability” and ”Green” is required. The use of different definitions makes it complex to explicitly determine what defines green. For instance, certain products focus on less environmental problems than conventional products, however, these products still have a negative environmental impact and are not per definition sustainable [5], [34], [35]. Even though recent trends show that implementing green innovation is becoming mainstream among organisations, there is still much confusion what constitutes a green product or process. Some use green interchangeable with sustainable, others say that green falls under the overarching umbrella of sustainability [36] or classifies green products into seven categories [37]. Therefore specifying a definition for green applicable to all instances is impossible, however, by decomposition of the environmental performance regarding sustainability, characteristics relevant for this research objective can be identified. Although some definitions and characteristics of green mention the social performance regarding sustainability, in this research the definition of "Green" only refers to the basis of its environmental performance.

In general, the environmental focus can be classified into three categories, namely materials (inc. water), energy, and pollution (emissions and toxic waste) [5], [34]. A product is distinguished based on their main environmental focus, respectively materials, energy or pollution. For example, a furniture companys environmental focus may be primarily on the forest (material) whereas washing machine manufacturers main environmental focus is on the product usage (energy use, water use, and detergent use) [5]. In order to determine if a product is green, three different types of environmental impact can be considered, namely less negative, null, or positive. A product can be seen as green, in relation of one of these three environmental impact categories, if it has an environmental impact lower than conventional products, or if it has null impact, or if it positively contributes to environment, reducing the impact of other products [34]. The environmental impact is evaluated in the different lifecycle phase of the product, therefore important to understand that a product may have a different impact on the environment relative to the different lifecycle phases [5], [34]. The lifecycle phases of a product in general are, production process, product use and disposal. Dangelico and Pujari [5] visualised the interconnection of the three environmental focuses in a conceptual framework for green product innovation (see Figure B.1).

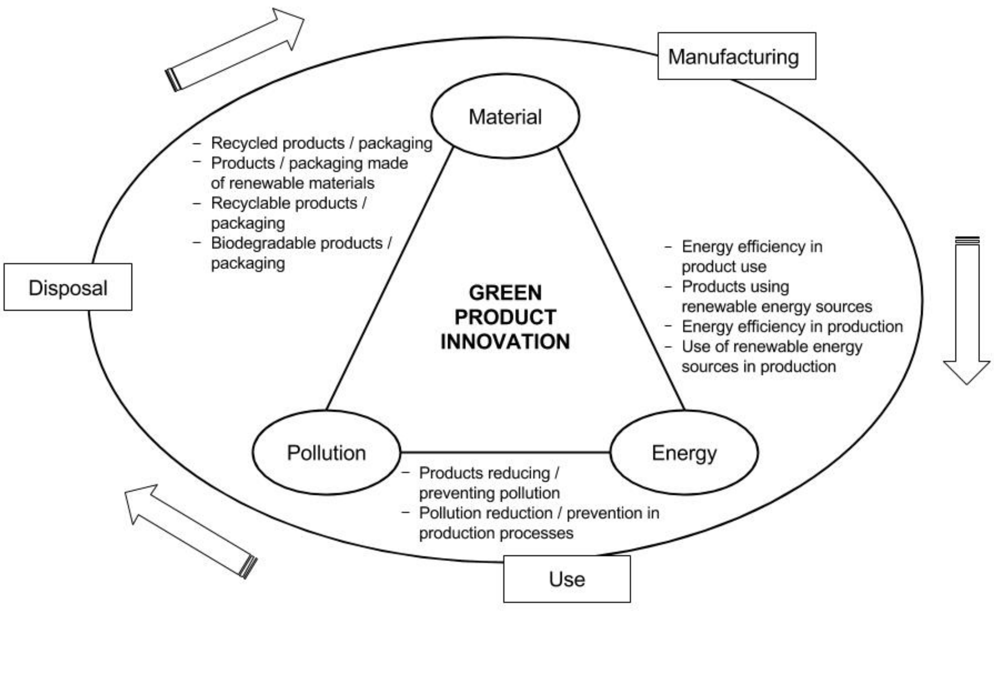


Figure B.1: The conceptual framework for the definition of green [5].

Finally, there can be said that a product is green when it has an environmental impact lower than conventional products, or if it has null impact, or if it positively contributes to environment, however, this is still rather broad interpretable. Dangelico and Pontrandolfo [34] saw the complexity of the variety of definition used for green, and therefore translates the relation between the environmental impact, the environmental focus and the lifecycle phases of a product to specific sectors. The relation of each of these topics with the industry sector can be used to determine the specific characteristics of a green product within this sector, including companies whose businesses are mainly related to the production and distribution of capital good. However, before looking into detail to the shipyard industry, the difference between absolute green and relative green is important. Absolute green contributes to the improvement of the environment, where as relative green reduces the harm the cause to the environment [34]. For this research, a Green Shipyard requires the focus on absolute green, but the relative green will play a role in the development of the assessment framework.

B.2 Shipyard lifecycle phase and environmental focus

The literature shows that clarifying a general relation between green and sustainability is complicated. Identifying the environmental focus, environmental impact and specific lifecycle phase, it is possible to define a more specific definition for green relevant for this research. Considering that every product (even a green product) impacts the environment, it is important to clarify when, why and how much a product is green. It is then necessary to point out: what is the specific lifecycle phase focusing on (when), what is the main environmental impact to be able to say that the product is green (why), and what is the degree of the environmental impact (how much)?

In order to answer the when, why and how much, understanding in the facilities with corresponding processes of a shipyard is required. Chabane [38] explains that production processes are rather different than repair & maintenance works, which involves different building complexes for the work performed by the shipyard. A shipyard layout may consist of a repair layout, production layout or a mixed layout combining both production and repair activities. A shipyard building new ships involves nine processes, namely cutting, forming, sub-assembly, unit assembly, grand assembly, outfitting, painting, pre-erection and erection [2]. A ship repair & conversion yard involves five main processes, namely ship docking, dry-docking, sandblasting, scaffolding and repair work (i.e. steel, pipe and cable repair). The process which is shared between both shipbuilding and shiprepair is painting [39]. Each of the previously mentioned processes require a certain building facility to be performed. Chabane 2004 [38] explains the building facilities that are required for both repair and production. Figure B.1 visualizes the different types of shipyards (repair & conversion, newbuilding or both) and the thereby involving building facilities with corresponding production processes.

The specific lifecycle phase focusing on is defined in Section A.1, namely the operational lifecycle of a shipyard. This means that the environmental dimension of sustainability only involves the impact of the operations performed on the shipyard. Separating both the building facilities and production processes, provides the basic understanding that one envi-

Table B.1: Building facilities and involving production processes on shipyards.

Facilities		Processes
Shipbuilding	Steel stockyard Steelwork hall Pipe shop	Cutting & Forming
	Outfitting centre	Outfitting centre
	Units and blocks storage area	Sub. Assembly Unit. Assembly Grand assembly
	Erection area	Pre-erection Erection
Ship repair	Berth	Docking
	Docking area	Dry-docking Scaffolding Sandblasting
	Machine shop Electrical shop Carpenter shop Steel shop Afloat repair shop	Repair work
	Treatment plant	
Equally shared	Paint shop	Painting
	Warehouse	
	Lifting installations	
	Administrative office	
	Technical service	
	Health and medical services	
	Training centre	
	Transportation station and parking	
	Catering services	
	Indirect	Direct

ronmental focus is not covering all important elements of environmental sustainability. The energy usage of a shipyard is the main environmental focus, which includes process and non-process energy use. However, looking into more detail to the production process, the pollution during the operational phase of a shipyard is the main environmental focus. Dangelico, et al. [34] also explains that the environmental focuses are not mutually exclusive, and therefore selecting multiple environmental focuses may be required to cover all environmental sustainability components. Due to the diversity of shipyards and the involvement of both production processes and building facilities, applying both the energy and pollution as environmental focus is necessary to cover the most important elements coherent to the environmental performance. The environmental focus of materials would be important to incorporate when involving the environmental impact of a ship, but is off less importance when examining the operational phase of a shipyard. This means that the environmental impact of both energy and pollutions need to be associated with the operational lifecycle phase. Including these two categories can be supported by the fact that not only the environmental impact is reduced, but also cost savings benefit customers [34]. In example, the energy used for administration, design, etc. are indirectly billed to the ships account [16]. Furthermore, focusing on energy and pollution will have an indirect positive influence on the environmental emission, however European (and local) regulation applicable to a shipyard do mainly focus on the environmental impact of energy and pollution. Concluding, the environmental sustainability coherent with a shipyards focus on the impact of energy use and pollution during the operational lifecycle phase of a shipyard.

B.3 Recognising a shipyard as "Green"

Both the energy use and pollution during in the operational lifecycle phase of a shipyard, aims at a certain degree of environmental impact, considering less negative, null or positive. Even through the environmental focus and lifecycle phases is determined, a variety of greening levels are available. Specifying the degree of environmental impact is subjective, and depends on the perspective of the organisational. The research aims at developing a concept for a product that achieves a more advanced level then the current implemented performance improvements. Latino and Dreyer [40] explains that environmental improvements to achieve less negative effects that address only "low-hanging fruit" fail to maintain current rate of energy reduction, and will thereby become less economically attractive. In other words, a more strategic approach is required to achieve more sustainable solutions.

B.3.1 Energy

The use of energy can be distinguished between primary and secondary energy sources. Primary energy resources are resources which exist prior to the modification by humans and secondary resources are obtained by the transformation of primary resources [41]. When speaking of energy usage of a shipyard, there is referred to secondary energy resources, for instance electricity, gasonline and gasses [3]. The energy usage of a shipyard can be divided into direct (process) and indirect (non-process) use of energy, which can be described as [16], [26]:

- Direct energy consumed in production of a ship involves processes as welding, framing, use of cranes, transportation of block, etc.
- Indirect energy consumed (or overhead) in a shipyard refers to energy or fuel consumed in areas like drawing office, warehouse, canteen, transportation of personnel, administration, etc.

The use of renewable energy resources reduces the negative effects of fossil energy resources and the overall emissions form electricity generation, degreases the GHG and provides the opportunity to activity improve the environment [35], however addressing the environmental performance of energy from a wider perspective, a more positive contribution to the environment can be delivered. Not only applying sustainable energy resources, but also increase energy efficiency of processes, contributes to attain sustainable development [42]. Lysen (1996) [43] introduced an energy policy that integrates three parts to establish fully sustainable energy systems. The three parts involved are: continuous efforts to increase energy efficiency and promote energy conservation, maximum use of available renewable energy sources and cleaner use of fossil fuels. This energy policy was translated into a strategy by Duijvestein (2001), commonly used in the building industry and known as

Trias Energetica [44]. The Trias Energetica approach is a method to ensure that the use of conventional and renewable energy is optimised as much as possible. This strategy can also be used for the development of a Green Shipyard concept, involving the following three topics:

1. Reduce energy demand
2. Use renewable energy resources
3. Use fossil fuels efficiently

Each of the principles are taken consecutively, so that the improvements made by the first principle are first implemented. This approach is useful to develop a proper strategy for implementing energy-saving measures, otherwise unintentionally more expensive and less efficient measures are implemented. Each of the principles are explained below [44].

The first principle of Trias Energetica involves the reduction of the energy demand. This can be achieved by reducing the overall energy use or improve the energy efficiency of involving buildings and corresponding processes. This step is the most sustainable, as it has direct influence on the energy use in the user phase. It concerns passive measurements, referring to measures that do not require additional energy. The second principle of the Trias Energetica approach focuses on switching to sustainable energy sources. When no more energy demand reduction is achieved, then measures related to the second step need to be implemented. In order to cope with this principle, current resources should switch to other techniques or tools to comply with the objective to use sustainable resources. Renewable energy sources are sustainable available and therefore energy sources which can be applied for sustainable energy improvements. Current building facilities or processes may use resources which are not sustainable, but switching to more sustainable resources could be possible [45]. Therefore, insight in the use of the different resources is required. At some point, changing to sustainable energy resources might not be possible. The third principle focuses on the use of fossil energy as economically and efficiently as possible.

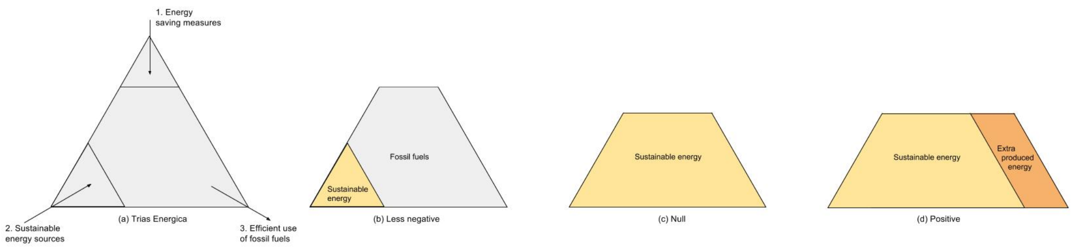


Figure B.2: Visualisation of different degrees for energy environmental performance.

The environmental impact of energy, considering less negative, null or positive, combining with the Trias Energetica method, can be visualized in the following manner (see Figure B.2). As mentioned before, the aim is to achieve a more advanced level of environmental improvement. The focus on less negative impact is already applicable, with solving "low-hanging fruit". The development of a Green Shipyard concept should incorporate an environmental impact of null for the use of energy, which will be considered as green.

B.3.2 Pollution

The use of resources and materials, applicable in the operational lifecycle phase of a shipyard, involves the production of waste during the production of a ship. The sustainability of the materials used for the production of a ship, for instance the use of recycled materials, is related to the sustainability of a ship, and less relevant for the sustainability of the shipyards. The environmental impact of pollution produced during the operational lifecycle phase of a shipyard refers to the environmental performance of the production processes and systems. The environmental performance of the production processes and systems can be determined by the amount of waste generated, as waste does not add any value to the manufactured product. The role of production industry in a sustainable system is visualised in Figure B.3 [6].

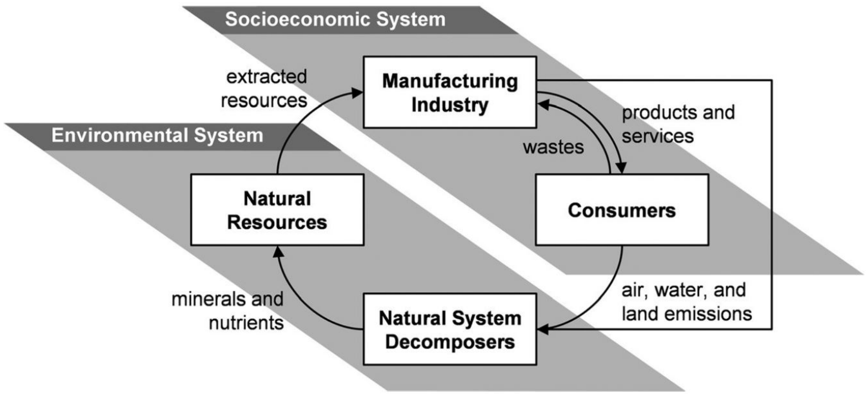


Figure B.3: The role of production (manufacturing) industry in sustainable systems [6].

The materials and resources are used as an input for the production process, and the waste is an output of the process. The output of waste can be divided into two categories, namely incomplete conversion of materials and resources, and inefficient use of resources [46]. The incomplete conversion of materials is in essence losses that arise from the primary production processes all the way to the finishing of the product, which can be measured in units of mass. In order to improve the environmental impact by reducing the produced waste, a three step waste hierarchy of ”reduce, re-use and recycle” can be applied [47]. The first step is to reduce the amount of waste generated by the production processes. The second step involves the reuse of waste, in example the material leftovers by cutting steel can be reused in other processes and thereby reduce the percentage waste. The third step focuses on recycling the produced waste, and thereby eliminate the waste produced during the production.

The second category involves inefficient use of resources that are not directly used in the product, but are required to perform a certain production process. In example, the ships need to be cleaned before delivers to the client, which requires a certain amount of water. As achieving zero waste in this category is impossible, the focus is on changing to renewable resources. This involves the strategy to ”avoid, use of renewable and improve efficient” [44]. The first step focuses on the unnecessary use of materials and resources. Implementing

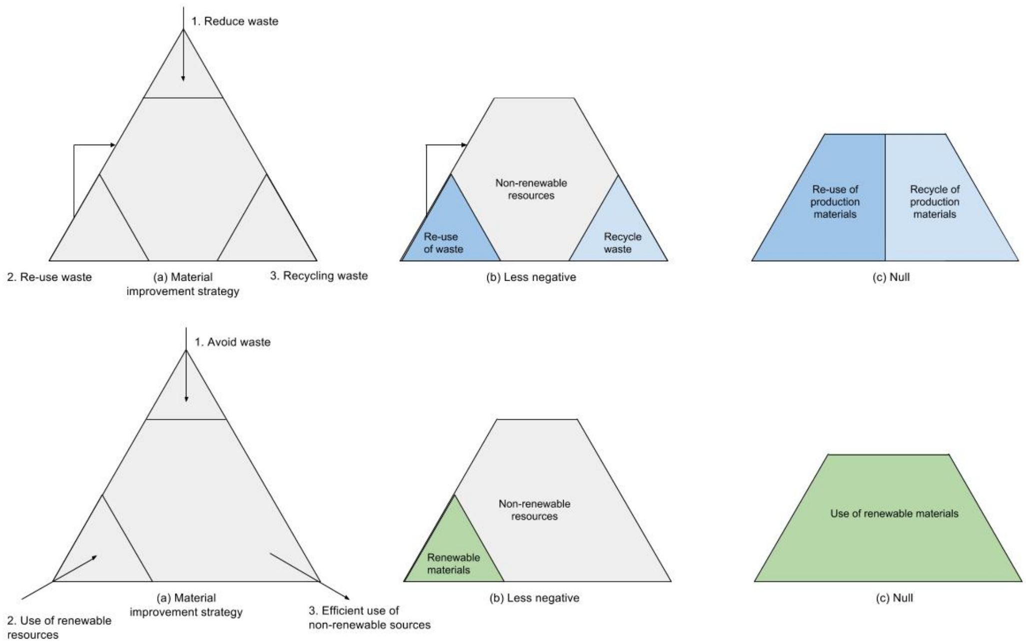


Figure B.4: Visualisation of different degrees of environmental performance for material usage.

more efficient techniques has a positive effect on the environmental impact. The second step focuses on preventing the use of resources which have a more negative impact on the environment. The use of rainwater for certain processes is more environmental friendly than the use of tap water. Finally, the third step focuses on more efficient use of resources which are not renewable and cannot be replaced by alternative resources. In example, water-saving products can be implemented to improve the efficiency of the water resources used [44].

In order to determine the environmental impact of waste as less negative, null, the difference between incomplete conversion of materials and inefficient use of resources is visualised in Figure B.4. Creating a positive environmental impact for the use of material is not possible in the operational lifecycle phase [34], the main objective is to eliminate the negative environmental impact for both the categories of waste created.

B.4 Conclusion Green Shipyard

Concluding, the environmental impact of a shipyard is divided into energy use and pollution, where pollution refers to incomplete conversion and inefficient use of materials. A shipyard is recognized as absolutely green when achieving an environmental impact for both energy usage and pollution of null. This can be summarized in the following definition for a Green Shipyard:

A shipyard is considered green when the development, repair or conversion of a ship, using different processes and systems, has an environmental impact for both energy use and pollution of null.

It is important to acknowledge that a Green Shipyard only considers sustainable production of ships, as the focus is upon the operational lifecycle phase. The materials themselves are not sustainable, since elements such as transport and recovery of resources are not taken into account within the degree of sustainability. Achieving an environmental impact for both energy use and pollution of null, makes it able to clarify that the shipyards production is green. The relation between the input and output of the operational shipyard is visualised in figure B.5.

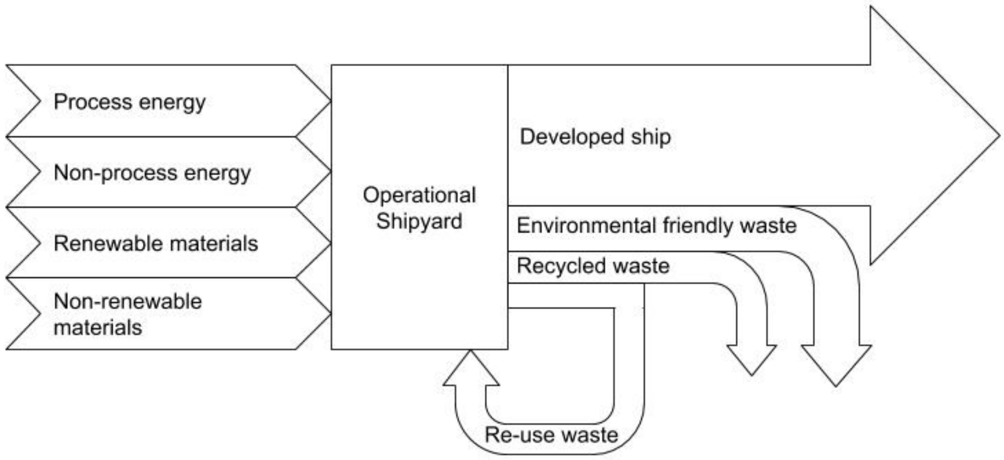


Figure B.5: Input and output of an operational Green Shipyard.

Appendix C

Green performance assessment

This section explains the development of the assessment framework, where the second research question gives substance to this section.

Research question 2: How to assess the "Green" performance of shipyards?
A: What are applicable methods for assessing the environmental performance?
B: What are relevant environmental performance indicators and how to measure them?
C: What is an applicable framework to conduct a green performance assessment?

C.1 Environmental performance assessment

Many methods, models, measures and sets of indices have been developed to assess the environmental performance [48]. The term environmental assessment is the term used for assessment of the environmental consequence (both positive or negative) for a plan, policy, program or project. "Environmental impact assessment" are generally applied to more specific projects and "strategic environmental assessment" for plans, policies and programmes [49]. Assessing the environmental impact of a product from cradle-to-grave can be done by performing a Life Cycle Assessment (LCA) [50]. Part of the growing environmental awareness, more specific environmental performance methods are developed. Figure C.1 shows a three-dimensional framework which locates different forms of assessment on three scales, namely the themes covered, the techniques used and perspective applied [7]. Based on the objective of an assessment a more specific approach can be used.

General method for assessing the environmental performance focus on specific topics, for instance assessing the production processes or building performances. Environmental building performance assessments have emerged as one of the major issues in sustainable construction [23]. Assessing the environmental performance provides a measure to the extent to which buildings might influence their environment, so that their design or operation can be altered to minimise harm and improve amenity [51]. Different environmental assessment systems and tools seen in the building industry are BREEAM in UK and LEED in U.S.A. [52]. Measuring and identifying the environmental impact of industrial products

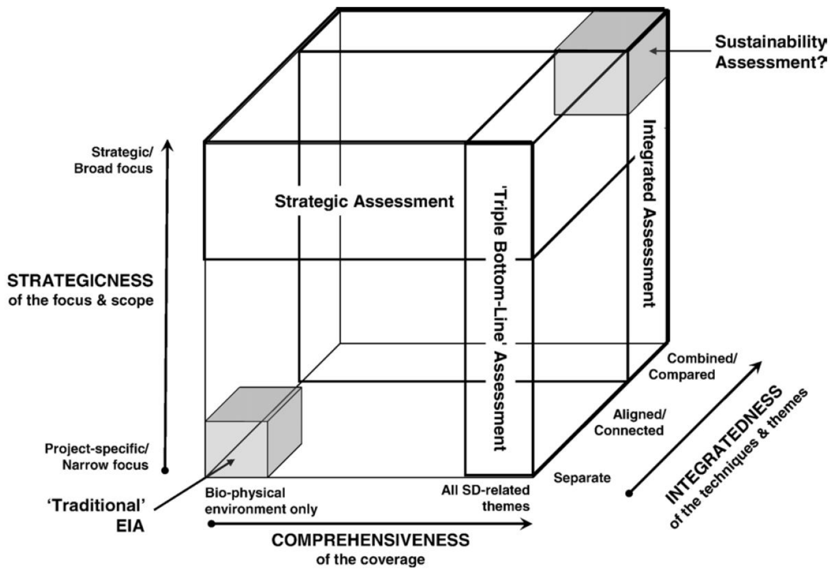


Figure C.1: Spectrum of SD-directed features within the assessment process [7].

can be done by environmental life cycle analysis. A life cycle assessment is general accepted analytical tool that provides a holistic environmental perspective on a product by assessing the impact and resources used throughout its life cycle [23]. Examples of methods developed for the production (manufacturing) industry mostly involve a LCA approach. Zamagni [53] presented a life cycle sustainability assessment model which combines LCA, Life Cycle Costing and Social LCA. Chong, et al. [54] presents a lifecycle-based sustainability indicator framework. Egilmez, et al. [32] presents an economic input-output LCA and data envelopment analysis (DEA) model for sustainability assessment of production units in the United States of America. These models focus on assessing the performance from an quantitative perspective, applying a calculation-based, measurement-based or hybrid-based approach. This may involve input data from a database to assess the performance [51]. However, methods as BREEAM, Green Star and LEED apply a more qualitative approach to assess the performance, where underlying data is used to develop a specific performance rating. The level of objectivity may differ across categories and methods, which has led to occasional debate [51].

The methods shown above assess the performance on a single instance, in example the focus on single production technology, single building entity or singular processing efficiency [55]. The aim is to assess, in a simplified way, the environmental performance of a shipyard. However, a shipyard involves the following complexities and diversities while assessing the performance:

1. There are a variety of different shipyards around the world, for instance, newbuilding yards, repair yards and dismantling yards. The processes and environmental effects cannot be pinned down to one standardized example. The complexity of comparing the performance of shipyard A with almost no production process with shipyard B with full production processes is seen. Shipyard A will have less influence on the environment

compared with B in general, however in reality the processes performance are less negative than the processes of Shipyard B [50].

2. As shipyards are positioned all around the world, the various geographical locations involve different environmental consequences. Different geographical locations may involve different weather conditions, and thereby result in different environmental performance on for instance energy use [50].

3. The focus is upon the environmental performance during the operational phase of a shipyard involves the performance of both production processes and building facilities [16].

The available methods are not directly transferable to the shipyard industry, due to the complexity of a shipyard and involving factors. Elements as environmental conditions, geographical location and shipyards complexity need to be covered by a specific assessment approach, which requires the development of a newly tailored framework.

C.2 Assessment framework

The environmental assessment framework will be specifically designed to fit the assessment of different shipyards. The assessment method is to propose a framework of environmental indicators and a metric of environmental performance that can serve as references for assessing the performance of shipyards. As the framework should cover a range of performance indicators, relevant environmental indicators need to be determined. Each of the formulated EPI requires operational metrics, measurements and weightings to determine the overall performance of a shipyard. The measurement of an EPI involves specific quantitative and/or qualitative performance data [23], [32]. Through examining the interlinking factors, specific weighting factors for each EPI is established, whereby the indicators are validated. The EPIs can be evaluated by performing a comparative evaluation with baseline performance [8]. The survey study is performed to define a baseline performance level, which makes it able to compare the outcome of the case study and formulate conclusions about the ”green” performance of a shipyards.

These elements are covered in a five phase approach, based on similar frameworks developed for other areas of expertise (see figure C.2). In the first phase are the environmental priorities and objectives for assessing the environmental performance formulated [32]. In the second phase are the environmental indicators related the priorities and objectives defined [32]. In the third phase are the general performance indicators that can be used to assess the environmental performance of shipyards identified [8], [56], which measure the environmental standings on a short term basis. In the fourth phase are specific EPIs formulated [8] and in the fifth phase the Green Performance Framework (GPF) is developed, and thereby being able to make a comparison between the different yards [33].

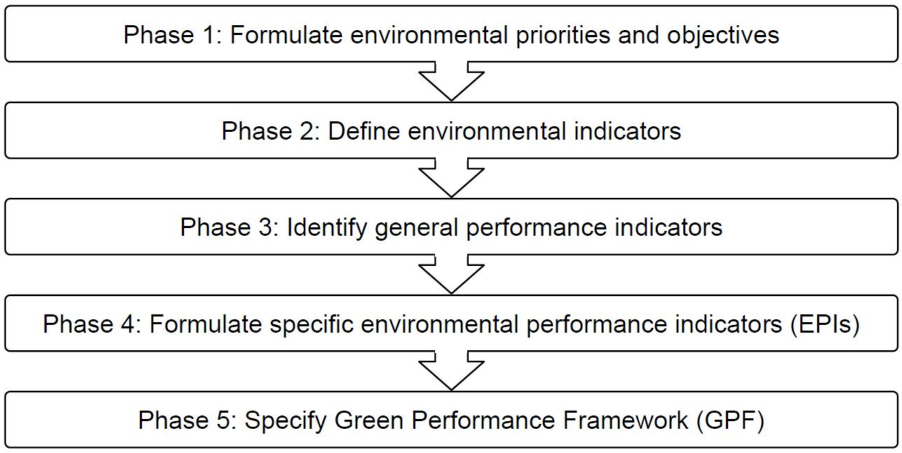


Figure C.2: The five phases used for the formulation of a Shipyard Performance Assessment method.

C.2.1 Phase 1: Formulate environmental priorities and objectives

In the first are the definition and principles of sustainability applicable to this research objective. To ensure truly sustainable improvements for shipyards, it is essential for shipyard EPIs to be consistent with the meaning and principle of a Green Shipyard. As previously defined, a shipyard is absolute green when the environmental impact of both energy use and pollution is null during the shipyards operational lifecycle phase. Therefore, the framework aims at identifying the performance of a shipyard related to both energy use and pollution during the operational phase.

C.2.2 Phase 2: Define environmental indicators

Environmental indicators refer to the choice of variables to be used to assess the environmental impact of the investigated shipyard system (said variable being hereafter also referred to as the ”environmental indicator”). The shipyards greenness is determined by the environmental impact of both energy use and pollution.

The gross inputs and outputs of a shipyards processes are visualized in Figure C.3, which is adapted from on the automotive industry [1]. The focus on the environmental impact of energy use and pollution results in specific inputs and outputs relevant for measuring the environmental performance. Selecting the elements appropriate to the operational phase of a shipyard, involves the use of energy, solid waste and liquid waste (see Figure C.3), and pollution through gas, noise, vibration, etc. are not included as the relative contribution to the total environmental impact is relatively low. This results in three environmental indicators, namely energy use, material waste and liquid waste. The inputs and outputs shown in the figure are useful for selecting general parameters related to the three environmental indicators.

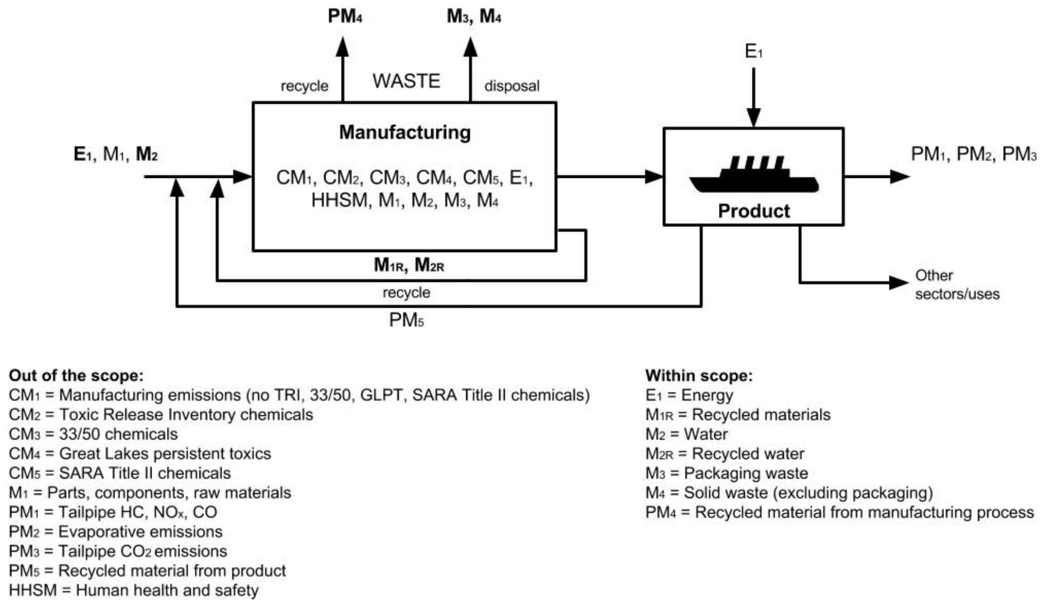


Figure C.3: The gross input and output of a shipyards processes (adapted from [1].

C.2.3 Phase 3: Identify general performance indicators

The third phase involves the selection of general performance indicators. The literature reveals a wide variety of indicators that have been used to measure environmental performance in different sectors, for instance the production (manufacturing) industry and building industry. This section aims at combining indicators of different industries, to come to a suitable framework for assessing shipyard environmental performance. The defined environmental objective and environmental indicators figure as guideline for the selection of appropriate performance indicators. The selection is done based on the following criteria, namely relevance, comparability, verifiability, clarity and comprehensive [8]. The general performance indicators are divided into core indicators and sub-indicators, which are also categorized in operational indicators, environmental management indicators and management related indicators.

The use of different categories and priorities makes it possible to combine quantitative and qualitative measurements. Where the core indicators are defined as more quantitative indicators, are sub-indicators more supporting and use more qualitative data. Indicators applying a quantitative measurement do not show any corrective measures already taken, which is only shown when a second measurement is performed. Types of data included are tons of waste generated, number of work days, or pounds of packaging produced [57]. The use of these indicators easily quantifies the performance on a specific topic, however using more qualitative measures is important to have insight in the action performed to improve environmental performance. Examples of measure are the amount of performance audits performance during a year. If such an audit is implemented, the performance of the quantitative indicators should improve over time [57]. The use of these indicators are important to cover the complexity, diversity and interlinking factors of a shipyard. However, these indicators are complex to quantify and therefore measurable in a more qualitative manner. The operational indicators measure the environmental burden caused by the shipyards activities, these EPIs are designed based on the principle of resource balance, e.g. considering input and output of energy and resources into/from an entire shipyard activity and designed to understand the whole shipyards activities. Environmental management indicators measuring methods that manage and operate resources for the shipyard activities and their environmental activities. Management relative indicators do not measure environmental burdens directory, however, they are considered as indicator because they are necessary to calculate energy or resource efficiency, and to reduce environmental burden per unit regarding the economic influence in order to realize a sustainable society. The combination of these types of indicators is necessary to understand environmental activities, as the core activities only measure the environmental efforts quantitatively.

Selecting appropriate indicates requires insight in the shipyards activities as mentioned above. A hierarchical perspective is commonly used to classify specific tasks in modern production systems, where organising activities are performed at multiple levels. The hierarchical perspective is not only useful for the selection of appropriate performance indicators, but also to be able to distinguish between baseline performance and the case study. For the purpose of this research, there is concentrated on the following three levels: whole factory, process chains and individual production processes [58].

A shipyard is mostly specialised in one of the following three purposes, namely newbuilding, repair & conversion or dismantling. This research focuses on newbuilding, and repair & conversion yards, whereby each process chain consist of a number of production activities. Production activity is the individual production operation of a process chain or production line where operational activities occur. Each production process involves other non-process related building facilities. Figure C.4 shows the relation between the input, throughput and output of the production process. With the knowledge of the process-chains of a shipyard, there can be determined if a specific production process or building facility has a relation with the determined indicators, which is required to make the assessment framework operational.

Besides referring to the shipyard activities, knowledge about the different environmental indicators is required and therefore, a reference is made to the topics discussed in the previous Section B.3. Improving the environmental impact of energy is done by reducing the use, changing to renewable sources and improving efficiency of fossil fuels. The impact of material waste and liquid waste is reduced by reducing the use, improving the reuse and recycling or minimizing the use, change to renewable sources and improve efficiency of the resources used. These elements are important to consider while selecting appropriate EPIs.

In total, there are nine core indicators, of which there are four corresponding with the defined environmental indicators. Each of these core indicators involves specific sub-indicators related to one of the three categories explained above. Some sub-indicators supplement the core indicators to quantify the performance and others give more insight in other factors related to a shipyards processes and performance. The indicators applicable for this research objective, corresponding with the environmental indicators and five criteria are shown in

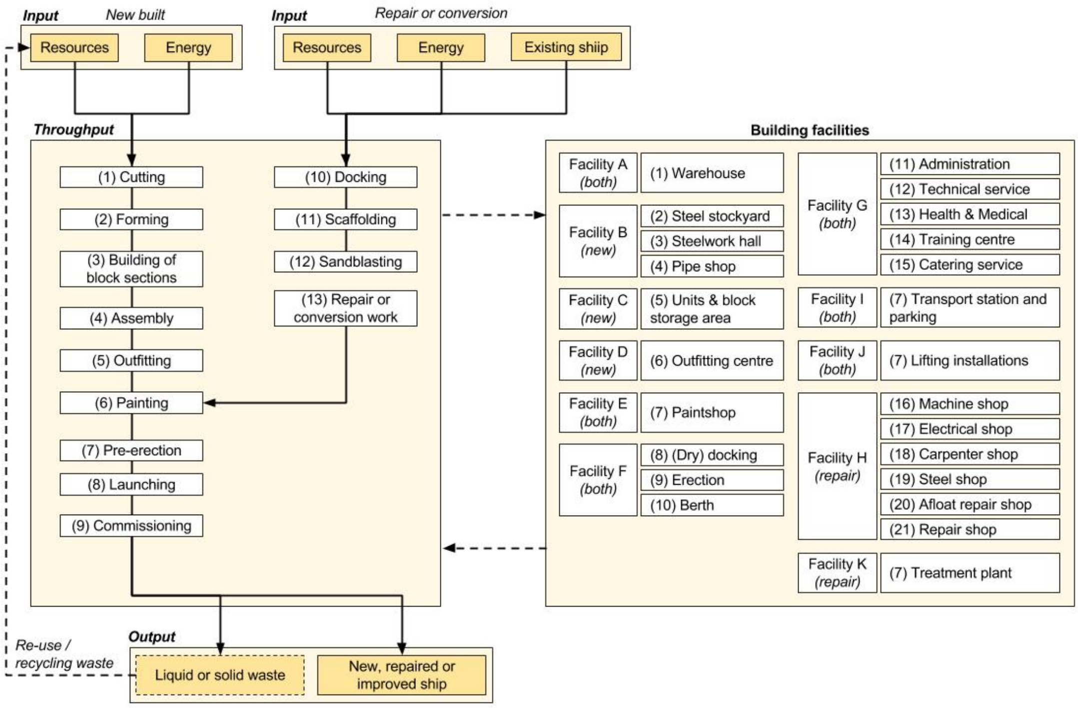


Figure C.4: The input, throughput and output of the production processes (new built, repair or conversion)

Figure C.5.

C.2.4 Phase 4: Formulate specific environmental Performance Indicators (EPIs)

Integrating the general performance indicators into specific EPIs is important to measure and record environmental efforts [8]. These general indicators are not self-explaining in terms of the performance of a shipyard, and therefore combining these indicators into EPIs is necessary. The customization is necessary for the development of a framework applicable for assessing the performance of a shipyard. It is recommendable to use a manageable number of indicators, normally between ten and twenty, assuring that the company has relevant, few and simple performance indicators linked to its environmental objectives [56]. The EPIs aim to compare shipyards in terms of their performance regarding energy use, material waste and liquid waste. Table C.1 shows a list of EPIs, whereby the translation to EPIs is a way to normalize the data [1], for instance per product produced or persons worked.

C.2.5 Phase 5: Design Green Performance Framework (GPF).

The final phase brings together all aspects into the GPF. Each EPI is translated into a measureable unit with appropriate measurement scale and weighting factor. This section will briefly discus the elements required to develop the GPF, however more detailed formulation

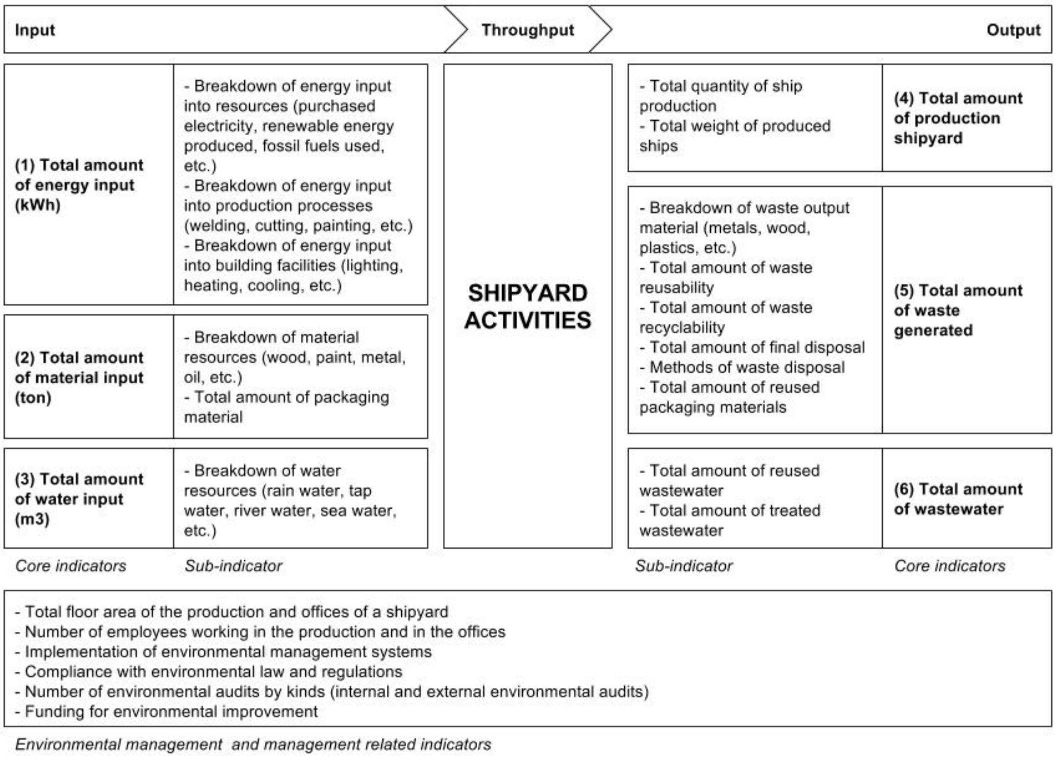


Figure C.5: The performance indicators (adapted from [8]).

of the framework will be done in the next section. This is done due to the complexity and size of the framework.

Measurement scale

The measurement scale for each EPI is generally based on a point award system, where a specific performance level is awarded with a certain score. Developing an consistent measurement scale with normalizing outputs facilitates more comparable assessment results across different regions [23]. Acquiring insight in the performance of the EPIs is achieved by comparing results of other industries, and the use of theory explained by the National Research Council (US) [1]. The difference between qualitative and quantitative EPIs requires different measurement scales to measure the performance.

The qualitative measurable indicators involve different maturity levels, which are based

Table C.1: The quantitative and qualitative EPIs.

Quantitative EPIs	Qualitative EPIs
Energy use	Compliant with regulations
Energy efficiency	Green improvement policies and plans
Source of energy fraction	Green improvement goals and targets
Environmental load factor	Green performance tracking and monitoring
Source of waste fraction	Green performance audit
Waste reuse factor	Wastewater treatment prior to off-site discharge
Waste recycle factor	External waste contractor audit

on ISO 9004:2009(E). The ISO-standard provides guidance in the formulation of a self-assessment method and thereby indicating the use of the different maturity levels [9]. As the ISO-standard is formulated for quality aspect and not environmental aspect, the ISO-standard organization in the Netherlands is contacted. Their response however was ”currently no similar maturity rating model is available for the ISO-14000 serie”, and therefore the ISO 9004:2009(E) is applied. The maturity levels range from level 1: base level till level 5: best practice. The criteria given for the higher maturity levels can assist the organisation to understand the issues it needs to consider and to determine the improvements required to reach a higher level of maturity. ISO 9004:2009(E) explains a step-by-step method to define each maturity level [9].

The quantitative measurable indicators involve a ten point measurement scale, which is based on the established baseline performance level and input from other industries. Through the use of operational metrics, it is possible to define a baseline performance level and normalize the user data of a shipyard, and thereby acquire insight in the environmental performance. The measurement scales are ranked from low performance to high performance, where the lowest performance level (1) indicates that the shipyards performance is low regarding that specific indicator and the highest score (10) indicates that the shipyards performance is high regarding that specific indicator. The measurement scales are established by using the average, minimal and maximum value determined for the baseline performance level. The measurement scales correspond with an exponential decay, whereby the multiplication factor depends on the established baseline performance level, indicating a higher performance difference between score nine and ten than score one and two. Due to the complexity of measuring certain indicators, specific employees or partner organisations are contacted for supporting information. In example, RCN is an waste consultant with more specific information about the processing and distribution of waste. Their input is important for the formulation of measurement scales where little to no information or data is available.

Weighting and scoring

The above explained measurement is not sufficient enough to compare the performance of shipyards, as the performance of a single indicator needs to be added with the other indicators in order to determine a final performance level for a shipyard. Even if all the scores in the rating system are similar, application of different weights of importance for each point may change the overall score [23], [51]. To calculate the weighted sum, individual weighting coefficients can to be assigned to indicate the relative significance of the different indicators under consideration. The National Research Council (US) [1] explains different methods for determining specific weights to EPIs. The complexity is to determine if it is required to make a specific indicator or category more important than the others (i.e. the hazardous waste produces more emissions then non-hazardous, the EPI may have a higher weighing factor). However, the assessment focuses on an objective assessment of the performance and thereby make no distinction between the various aspects. Furthermore, the difference between the type of shipyards influence the applicability of EPIs measureable (i.e. a repair & conversion yard has a whole other material use pattern then newbuilding yards), and therefore, the indicators are equally weighted to come to an overall score. The general equation used for scoring the EPI is shown below (Equation C.1 [1]). Adding the score for each underlying EPI results in a total score for both the categories energy and pollution.

$$Weighted\,EPI\,score\;=\frac{EPI\,score\,(\%)\,*\,Weighting\,factor\,(\%)}{100} \tag{C.1}$$

Visualisation

The outcome of the assessment is visualized in three separate figures. Both the performance of each qualitative EPI and quantitative EPI are shown in two clustered column figures. The height of the column indicates the maturity level of the qualitative EPI and the performance level of the quantitative EPI. The third figure visualizes the qualitative performance against the quantitative performance, in order to search for patterns and relations between the indicators. Examples of the three figures are shown in Figure C.6.

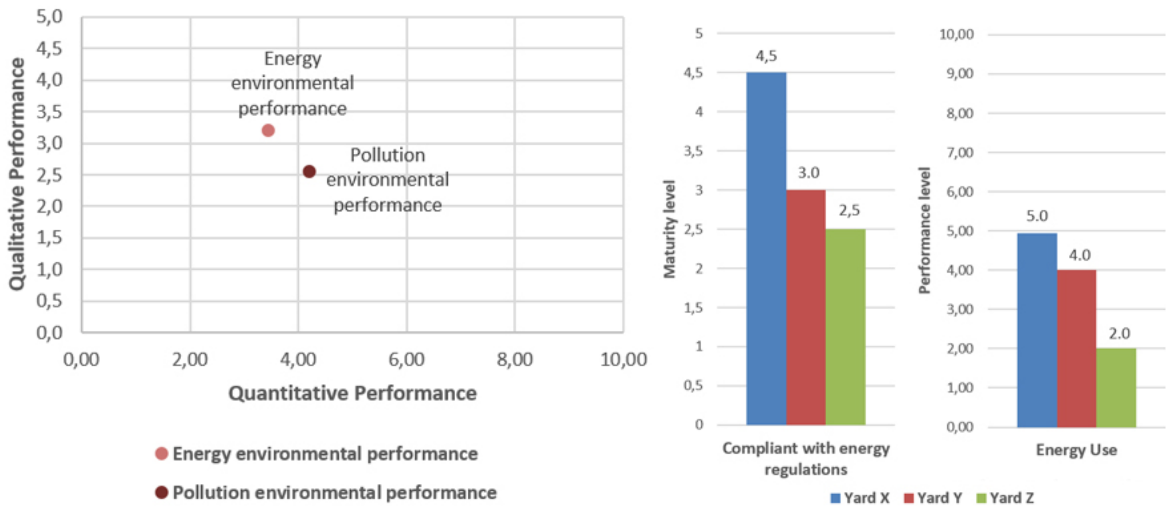


Figure C.6: Visualising the performance with left the qualitative EPIs against the quantitative EPIs, middle the qualitative EPIs and right the quantitative EPIs.

C.3 Design the Green Performance Framework (GPF)

This section explains the development of the assessment framework into more detail. This involves a brief explanation of each EPI, followed by the formulation of a baseline performance level. The baseline performance level is essential for the formulation of specific measurements scales.

C.3.1 Qualitative measurement

Through the process of formulating the measurement scales for the qualitative indicators, there is decided to change to three specific EPIs, involving multiple underlying indicators. This is done to capture all relevant aspects related to a specific topic. In example, the performance of energy regulations is a combination of the performance of monitoring laws, regulations and permits, and the performance of implementing changes seen in laws, regulations and permits within an operating shipyard. Furthermore, each EPI is divided into indicators specifically focusing on the energy performance and other indicators focusing on the waste management performance. This change is based on the self-assessment method explained in the ISO 9004:2009 [9] standard. Table C.2 briefly explains each EPI and defines the amount of underlying indicators involved.

Table C.2: Brief explanation of each qualitative measurable EPI.

Qualitative EPIs	
Compliant with regulations	This performance indicator examines the degree to which the yard incorporates changes regarding laws, regulations and permits into the yard. The measurement is performed for both the energy and pollution [9].
Green improvement strategy and policies	This performance indicator examines the degree the shipyard organises everything regarding energy/pollution reducing policies and strategies. Especially looking at the formulation strategy, interpretation of the strategy, deployment approach and communication plans [9].
Green performance transparency	This performance indicator examines the degree a shipyard is organising the monitoring and measurement of their own performance regarding energy and pollution. An additional indicator is included regarding the auditing of the external waste contractor [9].

C.3.2 Quantitative measurement

As previously explained, there is limited information about the environmental performance of shipyards, and therefore input of user data of shipyards is required to determine the baseline performance level. The input of operational metric is required for evaluating the environmental performance and determine the baseline performance level. First, the involving operational metrics are explained and afterwards, the baseline performance level is established.

Operational metric

The operational metrics do not quantify the performance of a shipyard by themselves, however are used to determine the baseline performance level. The operational metrics are also used for the normalization of EPIs in an appropriate way [1]. The normalization is different for each type of industry or factory. Commonly seen in the automotive industry, is the normalization per car produced and in the steel industry per ton of steel produced [1]. The diversity of processes performed on a shipyard, the difference between each ship produced and the difference between the type of shipyard involved, influence the normalisation appropriate for measuring the environmental performance. Table C.3 shows a list of operational metrics and general yard information with corresponding unit, translated from several sources as the EPIs established [21], [43], [45] and European Waste Catalogue and Hazardous Waste List
.

Baseline performance

Finally, eight shipyards provide data to establish the baseline performance level. Due to the

Table C.3: The input required for measuring the quantitative EPIs and determine the baseline performance level.

Yard information	Unit
FTE Office	Hours
FTE Production	Hours
Total FTE shipyard	Hours
Area office	m^2
Area production	m^2
Area warehouse	m^2
Area docks	m^2
Total area shipyard	m^2
Type of shipyard	New build or repair & conversion
Total quantity of ships new build over specific period of time	Amount
Total quantity of ships repaired or converted over specific period of time	Amount
Yard consumption	**Unit**
Electricity use office	kWh/year
Electricity use warehouse	kWh/year
Electricity use production	kWh/year
Electricity use docks	kWh/year
Total electricity production	kWh/year
Total electricity building facilities (lighting, heating, cooling, etc.)	kWh/year
Total electricity use	kWh/year
Renewable electricity production	kWh/year
Gas use office	Nm^3/year
Gas use warehouse	Nm^3/year
Gas use production	Nm^3/year
Total gas use	Nm^3/year
Water use	litre/year
Bilge/Waste water ship	litre/year
Steel use	kg/year
Aluminium use	kg/year
Wood use	kg/year
Steel scrap	kg/year
Aluminium scrap	kg/year
Wood waste	kg/year
Plastic waste	kg/year
Paper and cardboard waste	kg/year
Commercial waste	kg/year
Oil waste	kg/year
Paint waste	kg/year
Batteries and accumulators waste	kg/year
Chemical waste	kg/year
Other waste	kg/year
Total waste	kg/year

missing data and minimal shipyards involved in the survey study, data over several years of the same shipyard is also used, even though the objective was to determine the baseline performance level over 2015. The baseline performance indicates the average performance of a shipyard regarding each EPI and is used to determine the one to ten performance scales. Table C.4 shows the results of the gathered data for each EPI with underlying sub-indicator. The table shows the amount of yards that delivered input, the average performance

Table C.4: The baseline performance level, specifying the average performance for each EPI, used in the formulation of the measurement scales for each EPI.

EPI	Sub-indicators	Average performance	Extreme performance	N years (number of yards)
Energy use	Energy use offices	164 kWh/m2	High: 964 Low: 40	10 (4)
	Energy use warehouse	140 kWh/m2	High: 445 Low: 38.9	5 (2)
	Energy use production hall	211 kWh/m2	High: 331 Low: 67	10 (4)
	Energy use docks	61 kWh/m2	High: 69 Low: 54	2 (1)
Energy efficiency	Percentage energy efficiency	58%	High: 86 Low: 18	10 (4)
Energy fraction	Percentage renewable energy	0%	High: 0 Low: 0	14 (6)
	Source of energy impact	61%	High: 35 Low: 81	12 (6)
Environmental load factor	Percentage total scrap steel	11%	High: 27 Low: 2	9 (3)
	Percentage total scrap aluminium	26%	High: 62 Low: 4	8 (2)
Source of waste fraction	Source of waste impact production	24,367 kg CO_2e/ship	High: 31,707 Low: 3,164	11 (5)
	Source of waste impact repair & conversion	27,798 kg CO_2e/repair	High: 11,666 Low: 402	3 (4)
	Water impact production	11,563 kg CO_2e/ship	High: 31,110 Low: 764	11 (5)
	Water impact repair & conversion	297 kg CO_2e/repair	High: 478 Low: 95	3 (4)
Waste processing factor	Waste reuse	Not Available		
	Waste recycling	Not Available		
	Energy recovery	Not Available		

level determined and the extreme values seen regarding each EPI.

Table C.5: Brief explanation of each quantitative measurable EPI.

Quantitative EPIs	
Energy use	This performance indicator examines the energy use per square meters for four different areas, involving office, warehouse, docks and production [1][8].
Energy efficiency	This performance indicator compares the energy use in production with the total energy use [1][8].
Source of energy fraction	This performance indicator measures the impact of the quantity of different resources used on the yard and the amount of renewable energy produced [1][8].
Environmental load factor	The environmental load factor examines the relation between the waste produced and materials used over a year [1][8].
Source of waste fraction	The source of waste fraction determines the environmental impact of the different sources of waste produced [1][8].
Waste processing factor	The waste treatment factor examines the waste performance based on the percentage of waste reused, recycled or incinerated (some form of energy recovery) [1][8].

Both the literature and gathered data misses essential input to establish appropriate measurement scales for each EPI formulated in the beginning of the research. Therefore, the final EPIschanged slightly from the previously established EPIs, explained in Section C.2.4. Table C.5 briefly explains each EPI with underlying indicators.

C.4 Green Performance Framework

Bringing together each phase results in the formulation of the GPF. This section provides detailed interpretation of the framework, whereby the theory explained in the previous section is translated into an operational model.

C.4.1 Qualitative indicators

The measurable qualitative indicators, underlying the qualitative EPIs, are shown in table C.6 with first the energy performance indicators and followed by the pollution performance indicators of a shipyard.

Table C.6: The maturity levels for the qualitative measurable indicators (see below).

EPI Energy	Maturity level Level 1 (initial)	Level 2 (defined)	Level 3 (managed)	Level 4 (integrated)	Level 5 (optimised)
1A. Monitoring energy laws, regulations and permits	While information about applicable laws, regulations and permits regarding energy performance is collected, the process is performed in an ad-hoc manner.	Changes in laws, regulations and permits regarding energy performance are tracked systematically through a formally designed mechanisms.	The process of tracking changes in laws, regulations and permits regarding energy performance are effective and efficient, through a formally designed mechanisms.	The process of tracking changes in laws, regulations and permits regarding energy performance are effective and efficient, and includes cross-checks with external data resources.	The monitoring process delivers reliable data and trends about laws, regulations and permits regarding energy performance, and is managed in a planned way. Expected changes are considered, and if necessary, implemented.
1B. Implementing energy laws, regulations and permits	Changes and improvements in the requirements are only determined in an ad-hoc manner, in order to comply with regulations and permits.	Structured implementation of improvements in the statutory and regulatory requirements regarding energy performance are applied.	Structured implementation of improvements in the statutory and regulatory requirements regarding energy performance are defined, beneficial outcomes can be linked to recent improvements. Possible changes are not anticipated.	Integrated approach to implement improvements in the statutory and regulatory requirements is applied, and the approach is periodically reviewed. Possible changes regarding energy performance regulations are anticipated.	The implementation and improvement of statutory and regulatory requirements regarding energy performance are continuously aligned and refined. Future regulatory and statutory changes are anticipated.
2A. Energy reducing strategy and policy formulation process	The formulation process for energy reducing strategy and policies is organised in an ad-hoc manner.	A structured process for the formulation of energy reducing strategy and policies is in place.	A structured process for the formulation of energy reducing strategy and policies is in place. Beneficial outcomes can be linked to past strategy approaches, in consideration of changing external trends and the needs of interested parties, making necessary re-alignments when needed.	The outcome of the organisation's processes for strategy and policies formulation are consistent with the needs of interested parties. The strategy and polices are formulated in a structured manner, and the formulation process is periodically reviewed.	The outcome of the organisation's processes for strategy and policies formulation are consistent with the needs of interested parties. The formulation process for an energy reducing strategy and policies are aligned with pervious results, effectively monitored and reporting mechanisms are in place.
2B. Energy reducing strategy and policy formulation level	Energy reducing strategy and policies are only partly defined. Inputs are ad-hoc, and only product and financially related aspects are formulated.	Energy reducing strategy and policies are formulated, including analysis of the needs and expectations of customers, along with analysis of statutory and regulatory requirements.	Formulated energy reducing strategy and policies are evolved, including an analysis of the needs and expectations of a broader range of interested parties. Beneficial outcomes can be linked to past strategy approaches.	Energy reducing strategy and policies cover aspects related to the preferences of interested parties. Threats, opportunities and availability of resources are evaluated and considered before plans are confirmed.	It can be demonstrated that the energy reducing strategy has resulted in the achievement of the shipyard's objectives and optimisation of the needs of interested parties. Interested parties are engaged in and contributing to the shipyard's success, there is confidence that the level of their contribution will be maintained.
2C. Energy reducing strategy and policy deployment	Short-term energy reducing objectives are used and deployed in daily operations.	Energy reducing strategy and policies are translated into objectives for different organisational levels. Plans are developed in accordance with the balance of the needs and expectations of customers, deployed into clearly defined processes and objectives. They are the basis for performance reviews and audits.	Measurement of progress towards achievement of the shipyard's energy reducing strategic objectives is undertaken. Positive and negative variances against plans are analysed and acted upon.	Measurable objectives are defined, for each process and organisational level, and are consistent with the strategy. The management system is reviewed and updated, following changes in the strategy. Measurement of progress towards the achievement of objectives demonstrates that many positive trends exist.	Strategy, planning and policy deployment are regularly reviewed and updated using data from the monitoring and analysis of the shipyard's environment. Analysis of past energy reducing performance can demonstrate that the shipyard has succeeded in overcoming emerging or unforeseen challenges.
2D. Energy reducing strategy, policy and plans communication	Communication takes place in a reactive way regarding energy performance.	A process for external and internal communication is defined and implemented regarding the energy performance.	Effective systems are in place to communicate changes in strategy and plans regarding the energy performance to relevant people within the shipyard.	Energy performance changes in policies and plans are communicated to relevant interested parties, and to all organisational levels.	Energy performance changes in policies and plans are effectively communicated and periodically reviewed. There is evidence that communication processes meet the needs of interested parties.

3A. Energy monitoring system	Monitoring the energy performance is done on a sporadic basis, with no system or process in place.	Periodically monitoring the energy performance, with required monitoring system, is available and performed.	Periodically monitoring the energy performance is performed. The monitoring process is evaluated regularly to improve effectiveness. Feedback from key players is gathered in planned manner.	The monitoring process is performed in a systematic and planned way, and includes cross-checks with external data sources. Feedback from key players is gathered through professionally conducted surveys and other mechanisms, such as focus groups.	The monitoring process is systematically performed, including cross-checks with external data sources, delivering reliable data and trends. Feedback from key players is gathered through professionally conducted surveys and other mechanisms, which is used to optimize performance and implement expected changes. Performance improvements are monitored in systematic manner.
3B. Energy performance audit	Energy audits are reactively performed in response to problems, customer complaints, etc. Collected data is mostly used to resolve problems.	Energy audits are performed on regular basis for key processes. Data and results are starting to be used in a preventive way.	The energy audit is embedded in a structured process. When necessary, qualifying studies are conducted to verify data, particularly when data is derived from judgements and opinions. Audits ensure accuracy of data and the effectiveness of management system.	Energy audits are continually evaluated and their effectiveness and efficiency improved. The outcome is integrated into the strategic planning process. The identified gaps regarding the energy performance are compared with the strategy, and actions are taken to solve them in a planned way.	The shipyard involves energy professionals to perform periodic and comprehensive energy audits, in order to identify additional opportunities for improvement. The audits are performed on all organisational levels, continuously evaluated and improved over time.
3C. Energy performance data	A very limited set of data from measurements and assessments is available to support management decisions or tracking of the progress of actions. Data is not always reliable.	There is a formal set of definitions for key indicators related to the organisation's strategy and main processes. Data is used systematically to review the management system.	Data is available to show how the shipyard performs compared with others. The main conditions for success are identified. Management decisions are supported by adequate data from the measurement systems.	Data is available to show how the shipyard performs. Systematic analysis of data allows future performance to be predicted. The main conditions for success are identified and used for decisions regarding trends and long-term planning.	Systematic analysis of comprehensive data allows future performance to be predicted with confidence. KPIs are selected and acted upon in a way that provides reliable information for predicting trends and for taking strategic decisions. Risk analysis is performed as a tool for prioritizing improvement.
			Maturity level		
EPI Waste	**Level 1 (initial)**	**Level 2 (defined)**	**Level 3 (managed)**	**Level 4 (integrated)**	**Level 5 (optimised)**
1A. Monitoring waste laws, regulations and permits	While information about applicable laws, regulations and permits regarding waste performance is collected, the process is performed in an ad-hoc manner.	Changes in laws, regulations and permits regarding waste performance are tracked systematically.	The process of tracking changes in laws, regulations and permits regarding waste performance are effective and efficient, through a formally designed mechanisms.	The process of tracking changes in laws, regulations and permits regarding waste performance are effective and efficient, and includes cross-checks with external data resources.	The monitoring process delivers reliable data and trends about laws, regulations and permits regarding waste performance, and is managed in a planned way. Expected changes are considered, and if necessary, implemented.
1B. Implementing waste laws, regulations and permits	Changes and improvements in the requirements are only determined in an ad-hoc manner, in order to comply with regulations and permits.	Structured implementation of improvements in the statutory and regulatory requirements regarding waste performance are applied.	Structured implementation of improvements in the statutory and regulatory requirements regarding waste performance are defined, beneficial outcomes can be linked to recent improvements. Possible changes are not anticipated	Integrated approach to implement improvements in the statutory and regulatory requirements is applied, and the approach is periodically reviewed. Possible changes regarding the waste performance regulations are anticipated.	The implementation and improvement of statutory and regulatory requirements regarding waste performance are continuously aligned and refined. Future regulatory and statutory changes are anticipated.
2A. Waste reducing strategy and policy formulation process	The formulation process for waste reducing strategy and policies is organised in an ad-hoc manner.	A structured process for the formulation of waste reducing strategy and policies is in place.	A structured process for the formulation of waste reducing strategy and policies is in place. Beneficial outcomes can be linked to past strategy approaches, in consideration of changing external trends and the needs of interested parties, making necessary re-alignments when needed.	The outcomes of the shipyard's processes for strategy and policies formulation are consistent with the needs of interested parties. The strategy and polices are formulated in a structured manner, and the formulation process is periodically reviewed.	The outcome of the organisation's processes for strategy and policies formulation are consistent with the needs of interested parties. The formulation process for an waste reducing strategy and policies are aligned with pervious results, effectively monitored and reporting mechanisms are in place.
2B. Waste reducing strategy and policy formulation level	Waste reducing strategy and policies are only partly defined. Inputs are ad-hoc, and only product and financially related aspects are formulated.	Waste reducing strategy and policies are formulated, including analysis of the needs and expectations of customers, along with	Formulated waste reducing strategy and policies are evolved, including an analysis of the needs and expectations of a broader range of interested parties.	Waste reducing strategy and policies cover aspects related to the preferences of interested parties. Threats, opportunities and availability of	It can be demonstrated that the waste reducing strategy has resulted in the achievement of the organisation's objectives and optimisation of the

		analysis of statutory and regulatory requirements.	Beneficial outcomes can be linked to past strategy approaches.	resources are evaluated and considered before plans are confirmed.	needs of interested parties. Interested parties are engaged in and contributing to the shipyard's success, there is confidence that the level of their contribution will be maintained.
2C. Waste reducing strategy and policy deployment	Short-term waste reducing objectives are used and deployed in daily operations.	Waste reducing strategy and policies are translated into objectives for different organisational levels. Plans are developed in accordance with the balance of the needs and expectations of customers, deployed into clearly defined processes and objectives. They are the basis for performance reviews and audits.	Measurement of progress towards achievement of the shipyard's waste reducing strategic objectives is undertaken. Positive and negative variances against plans are analysed and acted upon.	Measurable objectives are defined, for each process and organisational level, and are consistent with the strategy. The management system is reviewed and updated, following changes in the strategy. Measurement of progress towards the achievement of objectives demonstrates that many positive trends exist.	Strategy, planning and policy deployment are regularly reviewed and updated using data from the monitoring and analysis of the shipyard's environment. Analysis of past waste reducing performance can demonstrate that the shipyard has succeeded in overcoming emerging or unforeseen challenges.
2D. Waste reducing strategy, policy and plans communication	Waste communication takes place in a reactive way.	A process for external and internal communication is defined and implemented regarding the waste performance.	Effective communication systems are in place to communicate changes in strategy and plans regarding the waste performance to relevant people within the shipyard.	Waste performance changes in policies and plans are communicated to relevant interested parties, and to all organisational levels.	Waste performance changes in policies and plans are effectively communicated and periodically reviewed. There is evidence that communication processes meet the needs of interested parties.
3A. Waste monitoring system	Monitoring the waste performance is done on a sporadic basis, with no system or process in place.	Periodically monitoring the waste performance, with required system, is performed.	Periodically monitoring the waste performance is performed. The monitoring process is evaluated regularly to improve effectiveness. Feedback from key players is gathered in planned manner.	The monitoring process is performed in a systematic and planned way, and includes cross-checks with external data sources. Feedback from key players is gathered through professionally conducted surveys and other mechanisms, such as focus groups.	The monitoring process is systematically performed, including cross-checks with external data sources, delivering reliable data and trends. Feedback from key players is gathered through professionally conducted surveys and other mechanisms, which is used to optimize performance and implement expected changes. Performance improvements are monitored in systematic manner.
3B. Waste performance audit	Waste audits are not or reactively performed in response to problems, customer complaints, etc. Collected data is mostly used to resolve problems.	Waste audits are performed on regular basis for key processes. Data and results are starting to be used in a preventive way.	The waste audit is embedded in a structured process. When necessary, qualifying studies are conducted to verify data, particularly when data is derived from judgements and opinions. Audits ensure accuracy of data and the effectiveness of management system.	Waste audits are continually evaluated and their effectiveness and efficiency improved. The outcome is integrated into the strategic planning process. The identified gaps regarding the waste performance are compared with the strategy, and the shipyard takes action to solve them in a planned way.	The shipyard involves waste professionals to perform periodic and comprehensive waste audits, in order to identify additional opportunities for improvement. The audits are performed on all organisational levels, continuously evaluated and improved over time.
3C. Waste performance data	No data or a very limited set of data from measurements and assessments is available to support management decisions or tracking of the progress of actions. Data is not always reliable.	There is a formal set of definitions for key indicators related to the organisation's strategy and main processes. Data is used systematically to review the management system.	Data is available to show how the shipyard performs compared with others. The main conditions for success are identified. Management decisions are supported by adequate data from the measurement systems.	Data is available to show how the shipyard performs. Systematic analysis of data allows future performance to be predicted. The main conditions for success are identified and used for decisions regarding trends and long-term planning.	Systematic analysis of comprehensive data allows future performance to be predicted with confidence. KPIs are selected and acted upon in a way that provides reliable information for predicting trends and for taking strategic decisions. Risk analysis is performed as a tool for prioritizing improvement.
3D. External waste contractor audit	The external waste contractor's environmental performance is not or limited communicated.	Processes are in place to audit the environmental performance of the external waste contractor.	Processes are in place to audit the environmental performance of the external waste contractor. The audit is performed periodically.	Processes are in place to audit the environmental performance of the external waste contractor. The audits are performed periodically, and evaluated and improved were needed.	Systematic analysing waste recycling and reuse of the external contractor is done. The analysis process is evaluated and improved. The waste handling performance of the external waste contractor is monitored.

C.4.2 Quantitative indicators

Based on data of different industries and specific user-data of shipyards shown in Section C.3.2, measurement scales for the quantitative sub-indicators are defined. Each EPI with sub-indicator are explained below.

Energy use
A shipyard can be divided into specific areas. As is already shown Figure C.4, a shipyard consists of different building facilities with corresponding processes. In order to quantify the performance and being able to compare different types of shipyards, the yard will be divided into four areas, namely office, warehouse, production hall and dock area. Depended on the type of shipyard and the availability of data, performance of specific areas can be determined. The energy use will be quantified by dividing the energy use (kWh) by the area used (m^2). The performance level of the areas is translated into one single performance level for the energy use. The performance levels of the offices (m^2) are based on reference figures used for official energy audits [59], and results in a specific measurement scale. However, performance data of the other areas, namely warehouse, production hall and dock, is limited in the literature and therefore use data of other shipyards to formulate the measurement scale. Through the use of the baseline performance level a relation between the office performance and the other three areas can be established. This results in the performance measurement scales for the quantitative EPI energy use shown in Table C.7. Through the use of the average, minimum and maximum value, and applying a reverse exponential reduction, the measurement scales are established.

Table C.7: Measurement scale for the EPI energy use.

Performance level	1	2	3	4	5	6	7	8	9	10
Energy use offices (kWh/m2)	≥ 205	204-164	163-131	130-105	104-84	83-67	66-54	53-43	42-34	34 ≥
Energy use warehouse (kWh/m2)	≥ 445	444-318	317-227	226-162	161-116	115-83	82-59	58-42	41-30	30 ≥
Energy use production hall (kWh/m2)	≥ 331	330-265	264-212	211-169	168-136	135-108	107-87	86-69	68-56	56 ≥
Energy use docks (kWh/m2)	≥ 69	68-53	52-41	40-31	30-24	23-18	17-14	13-11	10-8	8 ≥

Energy efficiency
The energy efficiency EPI examines the efficiency of the energy used. As the objective is to use energy during production, whereby other energy not directly used in the production is non-process related and therefore not efficient. The indicator measures the difference between the energy used for the production processes of a shipyard divided by the total energy used, which includes the production and the utilities (as HVAC, light, ICT). The performance scale is determined using data from the automotive industry [60], and results in the following measurements scale shown in Table C.8.

Table C.8: Measurement scale for the EPI energy efficiency.

Performance level	1	2	3	4	5	6	7	8	9	10
Energy efficiency (%)	≥ 54%	55%-59%	60%-64%	65%-69%	70%-74%	75%-79%	80%-84%	85%-89%	90%-94%	95% ≥

Energy fraction
The energy fraction involves two measurements, where one determines the percentage re-

newable energy produced by the shipyard and the other measures the impact of the quantity of different resources used. The renewable energy factor indicates the difference between the amount of renewable energy produced and the actual amount of energy used. As starting point, zero energy production is assumed, as the production of energy by production facilities is not that common. High performance is achieved when a shipyard is able to produce the full 100% of energy by their own renewable energy production.

Furthermore, each source of energy has a different impact on the environment, and therefore examining the ratio between the different resources can be used to determine a specific performance. For instance, the use of 100% renewable energy resources has an impact of almost zero, however using diesel, gasoline or LPG has an high impact on the environment. The objective of this indicator is to stimulate the use of more environmental friendly types of energy sources. Through translating each energy resource into Megajoules (MJ), the total MJ of each yard is calculated, whereafter the percentage of each type of energy resource part of the 100% is multiplied with the CO_2equivalent impact. Adding all the outcomes together results in an specific value, ranging from 1,2 till 292. The 1,2 refers to the use of renewable energy resources and 292 to the use of marine diesel or other high impact sources [61], [62]. The measurement scale ranges from 0% (which refers to the 292 value corresponding with the high impact resources) and 100% (which refers to the 1,2 value corresponding with the low impact resources). This results in the following measurement scales for both the underlying indicators of the EPI energy fraction shown in Table C.9.

Table C.9: Measurement scale for the EPI energy fraction.

Performance level	1	2	3	4	5	6	7	8	9	10
Percentage renewable energy	≤ 10%	11%-20%	21%-30%	31%-40%	41%-50%	51%-60%	61%-70%	71%-80%	81%-90%	91% ≤
Source of energy impact	≤ 10%	11%-20%	21%-30%	31%-40%	41%-50%	51%-60%	61%-70%	71%-80%	81%-90%	91% ≤

Environmental load factor

The environmental load factor divides a type of waste (ton) by the total material (ton) used over a year. This EPI however is only applicable to newbuilding yards, because the use of materials for repair & conversion is not that significant and the monitoring is not properly organised, which is seen while gathering data for the baseline performance level. The gathered data shows that the use of steel, wood and aluminium are the high consumer materials (based on the type of shipyard). However, the wood is mostly used in supporting constructions during the production of a ship, and therefore, completely ends as waste product. This means the performance regarding steel and aluminium will be included in this EPI. Furthermore, the measurement scales cannot be established without the baseline performance, as limited literature is available about these measurements. The input from the newbuilding shipyards made it able to determine the following performance measurement scale for each of these materials (see Table C.10).

Source of waste fraction

Each source of waste has a specific environmental impact, as the production of that specific (re)source involved the production of a certain amount of GHG emission [63]. The objective

Table C.10: The measurement scale for the EPI environmental load factor.

Performance level	1	2	3	4	5	6	7	8	9	10
Total scrap steel (%)	≥ 32,5%	32,4%-29,0%	28,9%-25,4%	25,3%-21,8%	21,7%-18,2%	18,1%-14,6%	14,5%-11,0%	10,9%-7,4%	7,3%-3,8%	3,7% ≥
Total scrap aluminium (%)	≥ 34,8%	34,7%-31,4%	31,3%-28,1%	28,0%-24,8%	24,7%-21,5%	21,4%-18,1%	18,0%-14,7%	14,6%-11,5%	11,4%-8,1%	8,0% ≥

of this EPI is to determine the environmental impact of the shipyards waste, whereby the overall impact is divided by the amount of ships produced or repaired. The different types of waste are divided into specific categories, according to the European Waste Catalogue and Hazardous Waste List [64]. The waste is multiplied with specific CO_2 emission factors and divided by the amount of ships produced or repaired (or conversed) by a yard [63]. The measurements scale is established through input from the established baseline performance level.

The treatment of water also produces a certain amount of emissions, and thereby creating an environmental impact [65]. The performance of water use is measured by comparing the impact of water divided by the amount of ships produced or repaired. This results in four measurement scales, as there is a huge difference between the production and repair work performed on a ship. Based on the baseline performance level, the following measurement scales could be formulated (see figure C.11).

Table C.11: The measurement scale for the EPI source of waste fraction.

Performance level	1	2	3	4	5	6	7	8	9	10
Impact waste production	≥ 45,773	45,772-33,906	33,905-25,116	25,115-18,605	18,604-13,182	13,781-10,209	10,208-7,562	7.561-5,602	5,601-4,150	4,149 ≥
Impact waste repair/conversion	≥ 29,503	29,502-27,445	27,444-25,530	25,529-23,749	23,748-22,092	22,091-20,551	20,550-19,117	19,116-17,783	17,782-16,543	16,542 ≥
Impact water production	≥ 22,222	22,221-15,873	15,872-11,338	11,337-8,099	8,098-5,785	5,784-4,133	4,132-2,952	2,951-2,109	2,108-1,507	1,506 ≥
Impact water repair/conversion	≥ 399	398-333	332-278	277-232	231-193	192-161	160-134	133-112	111-94	93 ≥

Waste processing factor

The waste treatment factor examines the waste performance based on the percentage of waste reused, recycled and different types of incineration by a shipyard. The type of waste processing influence the degree of environmental impact, as for instance, between 70% - 90% of the steel can recycled and thereby saves the use of other resources to produce steel [66]. But also paper and cardboard that can be reused or recycled, leaving trees that otherwise would be harvested standing [67]. The preferred options for waste handling is reuse or recycling, whereby reuse has no environmental impact and recycling a significant lower impact, then other non-sustainable recovery methods as incineration with energy recovery (heat-oven) or incineration without energy recovery (landfill). Green performance is achieved when the amount of waste that is not reused, is recycled. This results in zero non-sustainable recovery methods [66]. The initial objective was to include amount of waste reused by the shipyard internally, however, it seems that these figures are not available.

The EPI is divided into three sub indicators with a specific relation between the indicators. The percentage reused, recycled and incinerated through some form of energy recovery are determined. The reuse of material has the most positive effect as it has no environmental impact, and therefore counts for 100%. Recycling has an positive effect, whereby the impact can reduced with 46% (compared to the average impact of waste of a shipyard) and therefore is multiplied with 0.46. The third form of waste processing is incineration whereby the waste is used as fuel to recover energy. The recovered energy can be compared with an environmental impact reduction of 27% (compared with the average impact of waste of a shipyard) and therefore is multiplied with 0.27. This creates the following measurement scale seen in Table C.12.

Table C.12: The measurement scales for the EPI waste processing factor.

Performance level	1	2	3	4	5	6	7	8	9	10
Waste reuse (%)	≤ 10%	11%-20%	21%-30%	31%-40%	41%-50%	51%-60%	61%-70%	71%-80%	81%-90%	91% ≤
Waste recycling (%)	≤ 10%	11%-20%	21%-30%	31%-40%	41%-50%	51%-60%	61%-70%	71%-80%	81%-90%	91% ≤
Energy recovery (%)	≤ 10%	11%-20%	21%-30%	31%-40%	41%-50%	51%-60%	61%-70%	71%-80%	81%-90%	91% ≤

Appendix D

Case study

This section tests the developed GPF, by applying the framework in a case study. Three cases are discussed and compared, and the assessment framework is briefly evaluated by performing three expert interviews.

D.1 Case study introduction

In case study research, the researcher tries to gain deep and overall understanding of a constrained object or process. Characteristics of this type of research are the small number of research objects (cases), a combination of both qualitative and quantitative research approach, and the in-depth (labour intensive) data analysis. This type of research has the advantage of investigating the context of the case, being able to adjust to research specific circumstances and results are easier accepted by people in the field [31]. The case study involves the hierarchical method, which investigates the cases independently form each other and thereby simplifies the comparison afterwards.

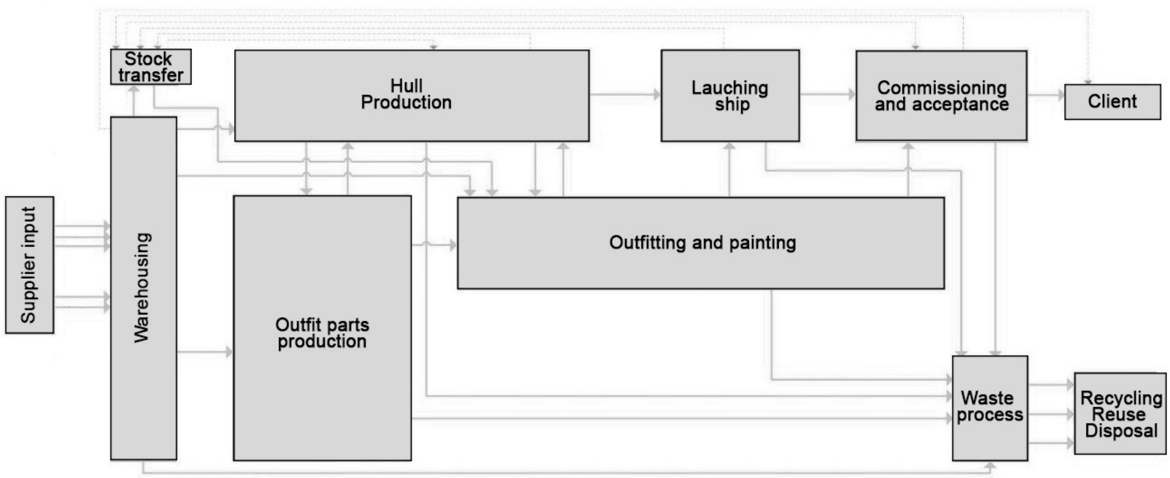


Figure D.1: The production blueprint used by a traditional shipyard.

The case study involves three shipyards, which are selected involving the purposive selecting method [68]. The three selected shipyards have a different organisational perspective and thereby differ in activities they carry out, which involves different parts of the overall production process. Figure D.1 shows a visualization of the total production process in general seen at the shipyards of Damen. Yard C is a new build yard, responsible for the construction of vessels, however also able to produce the hull of a vessel and transport that to another yard for outfitting and painting. Yard A is formally seen as the main office with partly shipbuilding activities, which is basically outfitting hulls that are produced at other yards (i.e. Yard C). Yard B is a repair & conversion yard, and therefore less clearly following the general production processes. The activities are depended on the clients demand, involving different repair & conversion works, which may be caused through a collision, fire or malfunctioning of equipment. The portfolio of Damen yards worldwide, ranges from all types of vessels (tugs, ferries, offshore vessels, etc.) to supporting equipment (shown in Table D.1 [10].

Table D.1: The portfolio of Damen yards worldwide (reference website [10].

Tugs & workboats	Offshore vessels	High speed craft	Shipping
Escort tug	Accommodation unit	Crew supply vessel	Combi coaster
Harbour tug	Anchor handling tug	Firefighting vessel	Container vessel
Push boat	Buoy / lighthouse vessel	Pilot vessel	Dry cargo vessel
Sea tug	Cable laying vessel	Search and rescue vessel	Heavy lift / load vessel
Ice class tug	Construction vessel	**Naval vessels**	Liquefied gas carrier
Utility / support vessel	Emergency towage vessel	Amphibious support vessel	Multi-purpose vessel
Dredging & equipment	Heavy lift / load vessel	Auxiliary	Oil tanker
Booster station	Inspection, repair and maintenance vessel	Combatant	**Fishing vessel**
Cutter suction dredger		Crossover	Beam trawler
DOP dredger / pump	Jack-up unit	Training vessel	King crab fisher
Dredging instrumentation	Multi-purpose vessel	**Patrol vessels**	Live fish carrier
Dredger	Offshore support vessel	Offshore patrol vessel	Shellfish dredger
Floating dry-docks	Platform supply vessel	Stan Patrol	Factory trawler
Floating dry-dock	Research vessel	Training vessel	Sea fisher
Modular floating dry-dock	**Pontoons & barges**	**Interceptors & rhibs**	**Yachting**
Modular constructions	Stan pontoon	Interceptor	Superyachts
Modular vessel	Bunker barge	Rigid hull inflatable boat	Yacht support
Modular pontoon	Hopper barge	**Ferries**	SeaXplorer
Modular jetty	Crane barge	Passenger car ferry	**Ballast water treatment**
Modular tidal turbine	Custom built	Passenger ferry	InvaSave

Yard A

Yard A is located in the Netherlands and is divided into two areas. The head office and production facilities are located at one of the areas, and the distribution centre with warehouse is located at the other. While it still functions as yard, the main activity of Yard A involves the daily management of Damen Shipyards Group. The main production process performed on the yard is outfitting of the majority of ship types in the Damen portfolio, except the larger cargo (CV), offshore and transport (O&T) vessels. There are three indoor outfitting halls, with a size of 84 m x 26 m x 12 m and 94 m x 28 m x 19 m. These halls cover five indoor slipways up to 1100 tons of ship weight. The outside area has a 200 m jetty for ship commissioning and used as temporary mooring place.

Yard B

Yard B is a shiprepair & conversion yard in the Netherlands and one of the largest yards in Western Europe. The yard consists of three dry docks (one covered dry dock) and two floating docks at their disposal. The yard is fully equipped with all the necessary workshops, cranes, transport facilities, tools and resources to execute the most challenging repairs and conversions. The yard is ideally situated in the middle of a port and has unrestricted access to open waters.

Yard C

Yard C is one of the largest of Damen Shipyards Groups 32 shipyards, repair yards and related companies worldwide. While Damens international sales organisation takes care of product development, self-managed Yard C focuses on a highly efficient production processes. Yard C recently joined the group, and their expertise and closely-managed supply chain is able to deliver the full groups product portfolio. The yard is located in Romania and occupies a 45-hectare site. Yard C employs 2,400 people directly and every day up to 1,500 subcontractors work at the yard. The yard is responsible for around a third of the Groups turnover, with a production of approximately 24 vessels a year.

D.2 Data gathering and interpretation

In order to gather sufficient data for both quantitative and qualitative performance indicators, several semi-structured interviews are conducted, documents are analysed and specific user data is gathered. This section explains the types of data gathered and discusses the method for analysing the data. Table D.2 shows the amount of semi-structured interviews performed, document analysed and spreadsheets used.

Table D.2: Specifications of the input used during the case study.

Shipyard	Yard A	Yard B	Yard C
Semi-structured interviews	2 HSEQ Manager & Facility Manager	2 HSEQ Manager & Team Leader Maintenance Department	2 Engineer HSEQ & Head of Facility
Open discussions	15	2	3
Written documents	20	38	4
Data spreadsheets	9	10	2

Qualitative data

The qualitative indicators, translated into five maturity levels, are measured applying a semi-structured interview format to determine the actual maturity level. The interview is formulated using the five maturity levels for each indicator. Multiple questions are used to determine the performance level of an EPI. The interview format is shown in Figure D.4 In order to capture the problem, which is not always directly answered by the questions asked, a clearly formulated approach for coding and fragmenting the answers given to the interview questions is used. Figure D.3 shows an example of labelled and fragmented data, extracted from the two interviews about the performance of DSGo. Each fragment has a corresponding code and the colours correspond with a particular maturity level. The colours used to determine the specific maturity level are also shown in Figure D.3. The closed questions give specific answers about the performance of an EPI, and the open questions makes it able to ask for supporting information. While discussing the outcome of the qualitative indicators, the interviews can be used to clarify specific results. The interviewees are referred to in the following format, namely (Interviewee X, personal communication, day and month, year). The interviewees are not named because of the confidentiality of the research.

Table D.3: Visualisation of labelling and fragmenting the interview data.

W.11	*To what degree is the waste performance monitoring processes performed?*	D – NCR is hired for as our waste manager and they monitor the waste. The outcome is discussed once a year. They also report on the progress.	D – Nick communicates with NCR on the progress. They provide use with an waste report.
W.12	*To what extend are waste reducing measures implemented? What kind of reusing measures were taken?*	There are only measures to reduce costs, not from environmental aspect. For example, focussing on dividing the waste in different categories and sell certain quantities to others.	As previously mentioned, the objective is to reduce costs and not the impact of waste. However, there is focussed on reducing the impact of transport, for example not transporting waste to Belgium or Germany. We focus on reducing the CO2 impact of transport.

Maturity levels
1
2
3
4
5

Table D.4: The assessment survey for the qualitative measurable indicators (see below).

ENVIRONMENTAL PERFORMANCE EXPERT SURVEY

Issue date: 14 September 2016
Document number: ……….
Revision number: Rev. 1
Pages: 6

I. Introduction

Consumer awareness towards environment and sustainability is on the rise, which is forcing the shipping industry to increase their transparence. Although the impact of manufacturing process of a ship is small compared with the operational phase of a ship, implementing environmental improvements is necessary to comply with both consumer demands and implemented regulations, which require the market to change. In order to comply with these changes, insight in the actual performance of Damen's shipyards is required.

II. Purpose of survey

The purpose of this survey is to acquire insight in the current environmental performance of all Damen Shipyards. Questions will refer to both the general performance and more specific environmental policies. The results of the survey are used for the formulation of an internal benchmark value, and used for the development of a Green Shipyard concept.

III. Scope of survey

Address environmental performance on shipyards operational phase, not focusing on product or health and safety issues.

IV. General requirements

It is expected that the interviewee has insight in the shipyards performance and has knowledge of the topics focusing on during the questionnaire. The given answers should be substantiated with additional information if asked for.

V. Usage guidelines

First, several questions are formulated to acquire general information about the shipyard. Afterwards, questions related to energy use and pollution are asked. These questions focusses on acquiring insight in the environmental performance of the shipyard.

---

1. General information

G.1 *Name of the shipyard:* ……….

G.2 *Contact Name:* ……….
Title: …….........

G.3 *Date of completion:* ………………………………………………………………………………………………..............

G.4 *Type of shipyard, new build or repair & conversion?* ………………………………………………………..........

G.5 *Has the shipyard a certified Environmental Management System (ISO 14001)? If "no", please explain why?*
……

2. Energy environmental performance

E.1 *What laws and regulations are important for the shipyard's energy use, and is the shipyard compliant with the applicable environmental laws and regulations?*
……

E.2 *Are the changes regarding energy laws, regulations and permits monitored and implemented?*
A. Ad-hoc monitoring and implementation

B. Systematically tracked and structured implemented
C. Systematically tracked through formal mechanisms, structured implementation process and beneficial outcomes can be linked to recent improvements.
D. Systematically tracking and cross-checking with external data, integrated approach for strategic implementation with periodically review
E. Advanced monitoring with reliable data and trends, expected changes are considered and continuously alignment of implementation process

E.3 *Does the shipyard have a written environmental policy statement and strategy? If "yes", please mention below. What does it say about the energy performance?*

………

E.4 *Does the shipyard have a written energy performance objective, goal or plan (i.e. efficiency improvement, minimization target, etc.)?*

………

E.5 *Is there an effective monitoring and reporting mechanism in place to measure performance of implemented policy statement and strategy (and show positive results)?*

A. Ad-hoc formulated and partly defined, no monitoring in place
B. Structured process of formulation and clearly defined with expectations
C. Structure process of formulation, beneficial outcomes can be linked to previous strategies, and stakeholder interests are anticipated
D. Structured formulation with periodic evaluation, stakeholder interests are anticipated, and threats, opportunities and availability are considered during formulation
E. Effective monitoring and reporting mechanisms are in place, feedback of interesting parties is included and achievements of energy reducing strategies can be demonstrated

E.6 *Are the strategy, planning and policy deployment regularly reviewed and updated using data from monitoring and analysis of the shipyard's energy performance?*

………

E.7 *To what extent are changes regarding the energy performance in the strategy, policy and plans communicated?*

A. Reactive communication
B. External and internal communication is defined and implemented
C. Effective systems to communicate to interesting parties are in place
D. Effective systems to communicate to interesting parties within all levels of the organization
E. Effective systems to communicate, with periodic evaluation and evidence that the needs of the interesting parties are met

E.8 *Are there energy performance audits performed by the shipyard and are the audits internally or external performed?*

………

E.9 *To what degree is the energy performance monitoring processes performed?*

A. Sporadic
B. Periodic monitoring
C. Periodic monitoring with evaluation
D. Systematic monitoring with evaluation
E. Systematic monitoring with cross-check evaluation and key players feedback

E.10 *Does the shipyard have an energy monitoring system? If "yes", what kind of system (analog, digital, etc.)?*

………

E.11 *Is the shipyard able to divide the energy use in production energy (crane, welding, etc.) and building utilities energy (lighting, heating, cooling, etc.)?*

………

E.12 *Does the shipyard buy green energy from the energy provider? If "yes", how much (%) is approximately green?*
………

E.13 *Does the shipyard produce green energy (use renewable energy sources)? If "yes", what technology/system is used? If "not", please explain why?*
………

E.14 *To what extend are energy reducing measures on short-term notice implemented and monitored? If "yes", what were those measures? If "not", what are possible measures to implement?*
………

E.15 *To what extend are energy reducing measures on long-term perspective implemented and monitored? If "yes", what were those measures? If "not", what are possible measures to implement?*
………

3. Waste environmental performance

W.1 *What laws and regulations are important for the shipyard's waste handling, and is the shipyard compliant with the applicable environmental laws and regulations?*
………

W.2 *Is the shipyard required to have specific waste environmental permits, license or registrations (select all that are applicable)?*
- A. Industrial waste water discharge
- B. Hazardous waste/material storage
- C. Hazardous waste treatment
- D. Radioactive material
- E. Water treatment
- F. Others?

W.3 *Has the facility received any fines, prosecution, or warnings by regulators in relation to (select all that are applicable)?*
- A. Storage or use of hazardous substances
- B. Preventing soil and groundwater contamination
- C. Wastewater management
- D. Waste issues
- E. Water pollution
- F. Others?

W.4 *Are the changes regarding waste laws, regulations and permits monitored and implemented?*
- A. Ad-hoc monitoring and implementation
- B. Systematically tracked and structured implemented
- C. Systematically tracked through formal mechanisms, structured implementation process and beneficial outcomes can be linked to recent improvements.
- D. Systematically tracking and cross-checking with external data, integrated approach for strategic implementation with periodically review
- E. Advanced monitoring with reliable data and trends, expected changes are considered and continuously alignment of implementation process

W.5 *Does the shipyard mention something about waste reduction in the environmental statement and strategy?*
………

W.6 *Does the shipyard have a written waste (including water) performance objective, goal or plan (i.e. efficiency improvement, minimization target, recycling program, etc.)?*
………

W.7 *Is there an effective monitoring and reporting mechanism in place to measure performance of implemented policy statement and strategy (and show positive results)?*
- A. Ad-hoc formulated and partly defined, no monitoring in place
- B. Structured process of formulation and clearly defined with expectations
- C. Structure process of formulation, beneficial outcomes can be linked to previous strategies, and stakeholder interests are anticipated

D. Structured formulation with periodic evaluation, stakeholder interests are anticipated, and threats, opportunities and availability are considered during formulation
E. Effective monitoring and reporting mechanisms are in place, feedback of interesting parties is included and achievements of energy reducing strategies can be demonstrated

W.8 *Are the strategy, planning and policy deployment regularly reviewed and updated using data from monitoring and analysis of the shipyard's waste performance?*
……

W.9 *To what extent are changes regarding the waste performance in the strategy, policy and plans communicated?*
A. Reactive communication
B. External and internal communication is defined and implemented
C. Effective systems to communicate to interesting parties are in place
D. Effective systems to communicate to interesting parties within all levels of the organization
E. Effective systems to communicate, with periodic evaluation and evidence that the needs of the interesting parties are met

W.10 *Does the shipyard have an waste management system (including water)? If "yes", what kind of system (including collection, transport, treatment, disposal, monitoring and regulations)?*
……

W.11 *To what degree is the waste performance monitoring processes performed?*
A. Sporadic
B. Periodic monitoring
C. Periodic monitoring with evaluation
D. Systematic monitoring with evaluation
E. Systematic monitoring with cross-check evaluation and key players feedback

W.12 *To what extend are waste reducing measures implemented? What kind of reusing measures were taken?*
……

W.13 *To what extend are waste recycling measures implemented? What kind of recycling measures are taken?*
……

W.14 *To what extend are measures taken to use renewable resources (i.e. change plastic cups for paper, use rain water, etc.)?*
……

W.15 *To what extend does the shipyard maintain records of off-site transfer and disposal of waste, and does it monitor performance of external contractor (i.e. certifications)?*
……

W.16 *Does the shipyard have a system in place to manage and monitor water withdrawals and consumption?*
……

W.17 *What sources of water are used (rainwater, tap water, etc.) and is the external supply assessed on quality?*
……

W.18 *Does the shipyard have a program or procedure to reduce water use or reuse/treat used water?*
……

W.19 *Does the shipyard treat wastewater prior to off-site discharge?*
……

W.20 *Is there wastewater treatment system? If "yes", what does the treatment system filter?*
……

Quantitative data

The quantitative indicators, which are translated into performance scales of 1 to 10, measured by specific user-data of a shipyard. Through communication with the facility department, production department and HSEQ department, user-data is gathered.

Table D.5: General yard information over 2015.

General Yard Parameters		Yard A	Yard B	Yard C
Type of shipyard		Outfitting (& stock & repair)	Repair & conversion	New build
Shipyard location		Netherlands	Netherlands	Romania
Ships produced/repaired	amount	30 (16 repair/stock)	88 (70 in dock)	27
FTE offices	hours	2,069,666	104,000	1,042,080
FTE production	hours	536,311	416,000	3,733,600
Total FTE	hours	2,605,977	520,000	4,775,680
Total offices	m^2	23,226	4,966	14,784
Total warehousing	m^2	9,908	4,050	9,600
Total production	m^2	16,195	22,850	87,250
Parking garage	m^2	22,220	-	-
Docks	m^2	-	47,958	20,000
Other	m^2	123,423	6,555	421,632
Total surface/acreage yard	m^2	194,972	86,379	553,266

During the last couple of years, the HSEQ department was working on the development of a reporting format on CO_2 emissions for each shipyard word wide. The underlying data used for the formulation of the CO_2 footprint is useful, involving specification about the energy use and pollution produced through waste. Missing information was supplemented by more specific documentation, for instance an energy audit or production data. In order to understand the outcome of the GPF, input of the parameters referring to general yard information over 2015 is shown in Table D.5. The information is used for the quantitative performance indicators, to determine the performance on specific areas and being able to normalize the performance.

D.3 Case study results

This section briefly discusses the results of the case study, explaining both the results of both the qualitative and quantitative indicators for each shipyard.

Yard A

The outcome of the qualitative performance measurements shows that the overall energy performance is better than the performance of pollution reduction. A policy statement and strategy regarding energy use is formulated, improvement plans are defined and measurements are taken. A highly advanced monitoring system is in place, and the facility department is pro-actively reducing the energy use on the yard. Short-term improvements are currently implemented, involving the recommendation made during the external audit performed by Optivolt. However, the Facility Manager (Interviewee 2, personal communication, Sept. 15, 2016) explains that long-term investments are not feasible due to the low energy price of approximately 0,005 €/kWh. Furthermore, the link between the policy statement and actual measures implemented are missing. The HSEQ Manager (Interviewee 1, personal communication, Sept. 14, 2016) explains that the main objective is to comply with regulations and other departments may implement environmental improvements based on their personal motives/interests. The pollution performance has a lower priority, as the environmental statement misses the whole topic of pollution reduction. The facility department focuses mainly on costs reduction of waste processing, and thereby improving the transparency of the whole process. Reducing the environmental impact of the pollution produced is not part of the objective.

The quantitative performance indicators show that the yard has a good overall energy performance per square meter (kWh/M^2). The efficiency of the energy used is low, indicating that a huge part of the energy is used for the building facilities, however, this can be explained by the fact that Yard A dedicated a large area of the yard to office space. The environmental impact of the energy resources used is relative low, as most of the energy consists of green electricity. The environmental load for steel and aluminium could unfortunately not be measured, as this data was not available. The impact of the waste produced per ship is relatively high, which may be caused by the fact a significant part of the waste produced is related to office work. The waste processing factor shows a high score indicating most of the waste is reused and recycled, and thereby having a positive effect on the environment.

Yard C)

The qualitative performance measurements indicate that the overall energy performance is almost similar as the pollution performance. The HSE Manager (Interviewee 3, personal communication, Oct. 7, 2016) clearly indicated that the main focus is to comply with regulations. An energy audit is recently performed and a waste management system is in place, both being certified according to ISO-14001 and OHSAS-18001. Energy reducing objectives are formulated in specific plans, whereby short term improvements are implemented. The Team Leader Maintenance (Interviewee 4, personal communication, Oct. 6, 2016) stated that buying green energy is a waste of money, whereby a clear preference for using that money to invest in improving the equipment and tools is present. The HSE Manager (Interviewee 3, personal communication, Oct. 7, 2016) clarifies that environmental solutions are currently examined but not yet in place, for instance an inventory is taking place about the feasibility for the use of Photovoltaic (PV) systems. Waste reduction is achieved and segregation is applied where possible. The yard puts effort into persuading the client to choose alternative processes (i.e. alternative for hydro blasting) in order to reduce the impact of materials used.

The quantitative measurements show a better performance for the use of energy than the pollution produced. Both the energy used per square meter for the office and production area scores above average. The energy efficiency is average, indicating a relative huge part of the energy is used for building utilities. The impact of the energy sources also scores average, indicating that a combination of high and low impact sources are used on the yard. The environmental load factor could not be established as specific data is missing, thereby important to acknowledge that this EPI is less relevant for a repair & conversion yard. The waste produced per repair score positive, indicating that the environmental impact of the produced waste per repair is limited. The waste processing factors score around average, meaning that a high portion of the waste is reused and recycled.

Yard C
The outcome of the qualitative environmental indicators show that both energy use and the production of pollution scores below average. The maintenance and repair department is responsible for the monitoring of changes in energy laws and regulations, and thereby update the changes made. The Engineer HSEQ (Interviewee 5, personal communication, Oct. 14, 2016) mentioned that they recently hired an external party to perform an energy audit, which is done to comply with regulations as an audit needs to be performed once in the four years. The Head of Facility (Interviewee 6, personal communication, Oct. 14, 2016) explains that a digital monitoring system is in place, and both short-term and long-term energy performance improvements are implemented. The environmental performance of waste is significantly lower than the energy performance. A policy statement about the produced waste is missing, only water targets are specified. The performance of water is monitored quarterly by quality indicators. Only the quantity of waste produced and sent for recycling or processing is monitored. The Head of Facility (Interviewee 6, personal communication, Oct. 14, 2016) explains that employees are trained in properly handling waste, however improvement in the use of more environmental friendly materials is technically complicated and especially economically not possible due to the current financial situation.

The qualitative indicators show that the energy used per square meter scores low, whereby only data for the office area and production area was available. Most of the energy used on the yard relates to the production processes, resulting in a high score for energy efficiency. As no green energy is used or produced, the energy fraction scores low. The environmental load factor scores average, whereby 22.5% steel waste indicates a lower score compared with the 17.4% aluminium waste. The impact of the waste produced per ship scores low, as a huge amount of waste is produced compared with the amount of ships produced. As this indicator does not incorporate the size or weight of the ships, score can be low when the largest vessel of the Damen portfolio are produced in that period. Finally, waste processing scores average, where a high portion of the waste is recycled, especially for steel.

D.4 Cross-case comparison

By comparing the individual cases in a cross-case analysis, it is possible to acquire insight in which aspects have a significant impact on the environmental performance of a shipyard. The case results are shown in Figure D.2 to summarise and visualise the relevant information collected through interviews, documents and different monitoring systems, and give the necessary background information for understanding the cross-case analysis. The figure shows the shipyards performance for each EPI, divided into the qualitative performance and quantitative performance. Furthermore, the qualitative and quantitative indicators are also plotted against each other in Figure D.3, to search for specific patterns and relations.

Comparing the case results, there is seen that the overall performance of Yard A, for

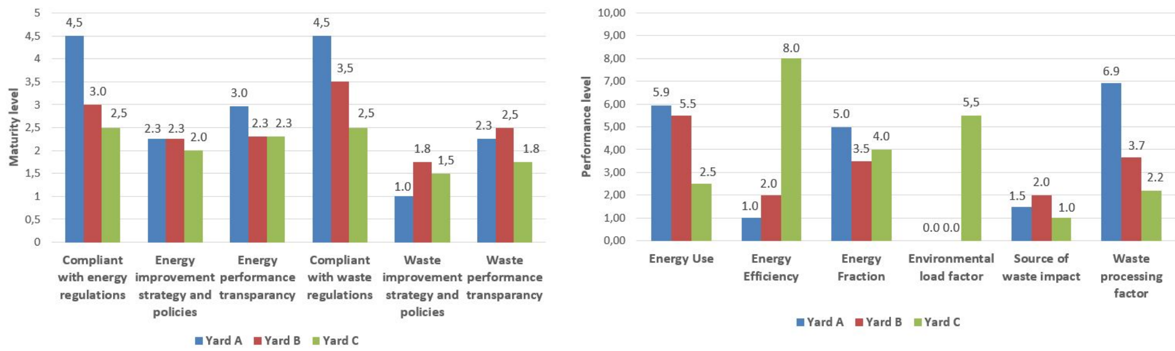


Figure D.2: Outcome of the GPF visualised in one figure.

both energy use and pollution produced, is slightly better than the other two yards. They clearly structured the monitoring of changes in laws and regulations in order to keep track of change applicable to their shipyard. By buying green electricity and testing the use of a PV system, they are a step ahead of the other yards. This corresponds with the ambition of being an example for the other shipyards within the Damen Shipyard Group, specified by the HSEQ Manager (Interviewee 1, personal communication, Sept. 14, 2016).

Figure D.2 shows that the performance of the individual indicators for the three shipyards corresponds with each other. No excessive differences are seen and being compliant with regulations has the highest score. This is supported by answers given during the interviews, for instance the HSEQ Manager (Interviewee 1, personal communication, Sept. 14, 2016) mentioned that being compliant is the most important objective of the shipyard. The qualitative indicators also score higher compared with the quantitative indicators, indicating that the slightly higher performing policy and strategic aspects not directly results in an reduction of the impact created by the resources used. By implementing a clear strategy and investing in monitoring systems, the transparency of the performance should increase and thereby possible improvements should be revealed.

The yards focus mostly on improving the energy use than reducing the emission produced by the different categories of waste, which is reflected in the environmental statement of each yard. The yards all have an energy reduction objective, whereby the Manager Contracting and Yard Support (Interviewee 9, personal communication, Oct. 19, 2016) showed that Yard C currently focuses on a reduction of 3% each year in comparison to the 2015 use. Similar objectives for the pollution produced on the yards are missing. This corresponds with the interest in solutions to produce renewable energy on their yards, as they are performing feasibility studies to determine the possibility of investing in PV system and other solutions. However, the current electricity price of 0,005 €/kWh does not provide a favourable return on investment opportunity and results in minimal investments in environmental friendly solutions. This proactive approach is not seen for the reduction of pollution produced by the sources of waste.

Finally, the interviews showed similar influences of costs while implementing environmental improvements. The yards all focus on the ”low-hanging fruits” and low cost improvements, but measures with a return on investment longer than five years are not implemented.

The costs for investing are more important than actually improving the environmental performance. An aspect that Yard B distinguishes itself by is trying to convince clients to use more environmental friendly processes for the repair work performed. The HSE Manager (Interviewee 3, personal communication, Oct. 7, 2016) explained that they try to convince clients to use a more environmental friendly grit for the blasting process, however the client is mostly not willing to pay more.

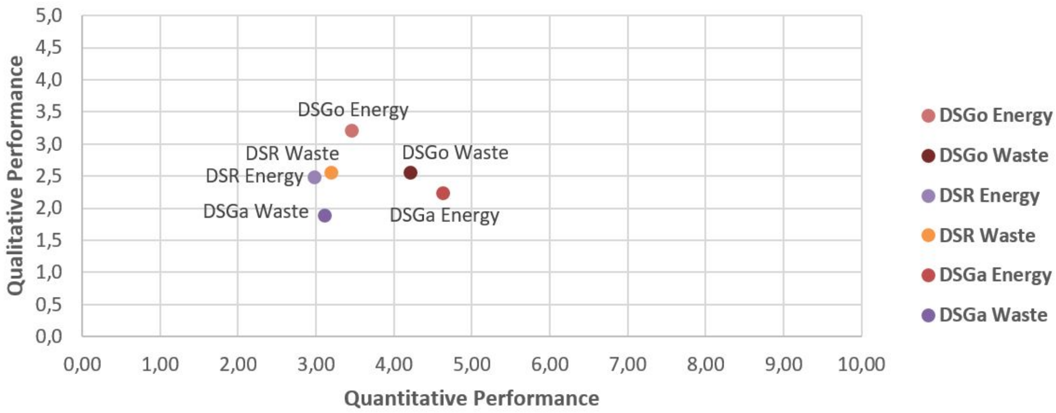


Figure D.3: Visualisation of the EPIs for each of the three yards in one figure.

Finally, the quantitative and qualitative indicators are plotted against each other in Figure D.3, in search for patterns between the different indicators and topics. However, based on the figure, there can be concluded that the results are grouping together and therefore not useful to see clear patterns or relations. Where each yard shows clear difference between the performance of energy use and pollution produced, an overall difference between the yards is hard to establish.

D.5 GPF evaluation

While going through the process of establishing a baseline performance and developing the GPF, the complexity of collecting data is experienced throughout the process. While performing the literature study, there was assumed that specific user data would be available and could be used for the measurement of the EPIs. However, while gathering data for the baseline performance level, there is seen that the data is unstructured and reported in different formats. Part of the data is gathered through the use of CO_2 footprint calculations, whereby more than eight different layouts were seen. Another complication was gathering data of sub-contractors, which are working on the yard but are not officially employed by the shipyard. For instance, the painting on Yard A is done by a subcontractor who is also responsible for the processing of their own waste.

In order to validate the case results, expert interviews are held. Specific parts of the assessment framework were discussed with these experts, whereby the reliability of the gathered data seems questionable. Besides the different formats of the CO_2 footprints, the calculations missed important data or were based on assumption. For instance, the energy use over specific areas is divided by applying standards seen in the literature, and not based on the actual performance. Furthermore, the specific user data differed between yards, whereby certain outcomes are questionable. Damen Shipyard Kozle reported a steel waste of 4%, which is not possible according to both the Project Manager Yard Support (Interviewee 8, personal communication, Oct. 18, 2016) and Manager Contracting & Yard Support (Interviewee 9, personal communication, Oct. 19, 2016), as an average of 17% steel waste is more common. Through different channels, a more complete data set is established, however the complete reliability is not guaranteed.

The third part of this evaluation reflects on the difficulty of assessing the environmental performance of the different type of shipyards, positioned at different geographic locations. Section A.6.2 specified that the shipyards examined during the case study are selected through the purposive selecting method, keeping in mind the geographic locations and type of shipyard. In order to cover all aspects of a shipyard, both a newbuilding and repair & conversion yard is selected. Also the geographic location is limited to Europe, in order to make sure the yards are covered by similar regulations. However, during the development of the GPF, there is seen that the differences between the type of yards and the geographic locations are complex and not easily simplified in specific performance indicators. The production processes are rather different then repair and maintenance works [38], and therefore complex to compare the outcome of the assessment. The assessment framework is currently used for the development of an implementation strategy and is useful for self-assessment of the internal performance, however more research is required in order to make a reliable comparison.

In line with the above explained topic, it is questioned whether this assessment approach is missing essential details influencing the environmental performance of a shipyard. The research objective required an approach which does not address too much details, in order to acquire general insight in elements that have impact on the environmental performance, however evidence from the cases suggests that this approach misses details that have huge influence on the outcome of the assessment. It appears for instance that a significant part of the pollution of one of the cases is created by the vessels that come to the yard for repair work or that the responsibilities for pollution are sheared to the subcontractors. This make it questionable whether a more detailed assessment approach would be beneficial to the GPF.

Finally, another interesting fact seen during the case study, is that yards are not always cooperating when asked for specific user data. Employees recognize this problem and clarify that the yards may see each other as competitors. For instance, an organisation is able to repair their vessels at different repair & conversion yards of Damen in the Netherlands, which are basically different organisations within the Damen Group. When a negative performance is reported, they are afraid of losing assignments or regular clients. These shipyards try to avoid reporting performance regarding the environment. This is more pronounced by repair & conversion yards, then the newbuilding yards. The HSEQ manager (Interviewee 1, personal communication, Sept. 14, 2016) explained that the collaboration and the ties with newbuilding yards are better than with repair & conversion yards.

D.6 Conclusions

Based on the case results, there can be concluded that formulated policies and strategies do not directly result in an actual impact reduction for the use of energy and production of pollution. The relation between the formulated policies and strategies with underlying monitoring and evaluation mechanism is missing. The need to define a environmental statement and strategy is seen, techniques and tools are implemented to monitor the use and performance, however a clear relation between both is missing. By monitoring the energy use and waste production, possible improvements should be revealed and improved, however the results show that this is done to a lesser extent. The monitoring and evaluation should figure as a verification and validation strategy, to see if the environmental statement and strategy are achieving the expected, and even more important, the required performance improvements.

The case results show that the main driver for implementing and improving the environmental performance, for both the energy use and pollution created, is to comply with laws and regulations. The only objective is to prove that the shipyards comply with regulatory requirements, whereby differentiating in terms of sustainability and looking into the future is not an objective. The case interviews showed similar influence of costs while implementing environmental improvements, as the ”low-hanging fruits” and low-cost improvements are always implemented, but more expensive improvements are not implemented. This approach can be associated with the reactive stage of environmental management [69] and fails to maintain current rate of environment improvement resulting in a less economic feasible strategy [40].

Thirdly, the energy performance of all the three yards is higher than the performance of pollution (including water). The focus on improving the energy use is more present than the pollution created by waste, which is reflected in the environmental statements of each yard. The yards formulated an energy reduction objective, whereby the Manager Contracting and Yard Support (Interviewee 9, personal communication, Oct. 19, 2016) showed that Yard C focusses on a reduction of 3% per year. Similar objectives are missing for the pollution created by the waste produced on the yards. Yard B distinguishes themselves by trying to convince clients to use more environmental friendly solutions for the repair work performed. The HSE Manager (Interviewee 3, personal communication, Oct. 7, 2016) explained that Yard B is trying to convince clients to use a more environmental friendly grit for the blasting process, however the preference of the client is leading, and therefore resulting in a less environmental friendly material since they are not willing to pay more.

Appendix E

Green Performance Improvements

This section answers the main research question, by answering the third research questions with underlying sub-questions and looking onto the future for the development of a Green Shipyard. The third research questions with underlying questions is:

Research question 3: How to achieve ”Green Shipyard”?
A: What are the determining push & pull factors for ”Green” improvements?
B: What are the socio-economic constraints for ”Green” improvements?
C: How to prioritize feasible ”Green” improvements?

The case results provide insight in the current environmental performance of shipyards, and thereby shows aspects that play an important role in the greenness of a shipyard. As specified in Section B.4, a shipyard is considered green when the development, repair or conversion of a ship, using different processes and systems, has an environmental impact for both energy use and pollution of null. Achieving null impact is only possible by minimizing the impact of energy use and pollution produced, and compensate the resulting impact by positively contributing to the environment [34]. Section D presented the case results and formulated conclusions, which can be used to determine the push and pull factors, and look at the social-economic constraints important for the develop of a Green Shipyard concept. Through converting both energy and pollution to carbon dioxide equivalents (CO_2e), the impact can be visualised and thereby useful to provide understanding of the top priority aspects. By applying the underlying principle of the Pareto analysis, it is possible to select the aspects with top priority [70]. Finally, the outcome of the three research questions is combined to answer the main research question:

How to develop a Green Shipyard?

Finally, theoretical models as Trias Enegetica and Waste Hierarchy (see Section B.3) are used for the formulation of an implementation strategy for a Green Shipyard concept. The implementation strategy consist of three phases in order to cover all relevant aspects.

E.1 Push & pull factors

In order to develop a "Green Shipyard", data and information gathered during the case study is used to determine both the push & pull factors. The definition of a "Green Shipyard" formulated in Section B provides sufficient insight in the theoretical perspective, however both internal and external factors may influence the route to a "Green Shipyard". Section A.1 introduces push and pull factors relevant in the industry, where to comply with laws and regulations is acknolwedged as important push factor and the environmental awareness of the clients is seen as important pull factor [15].

E.1.1 Push factors

The main pull factor experienced during the case study are the laws and regulations, which is the main factor for shipyards to invest in new tools and equipment. Each shipyard scores high on the EPI about being compliant with laws and regulations in teh case study. The HSEQ Manager (Interviewee 1, personal communication, Sept. 14, 2016) of Yard A explained that the main objective is to comply as this directly influences their business. Clients may loos there confidence and assignment can be missed, when the shipyards fail on compliancy. This motive is addressed in two different ways, as local regulations do require a shipyard to reduce the amount of energy used, improve the waste processing and other regulations. However, the Damen Group is also forcing the yards within the group to change, as they are currently asking the yards to improve their monitoring mechanisms and start reporting their emissions on regular basis through a CO_2 footprint. Both aspects are driven by changing laws and regulations regarding the environmental performance. These aspects can be substantiated with the outcome of the paper Green growth opportunities in the EU shipbuilding sector [15], showing that the market trends are mainly based on regulations as key driver.

E.1.2 Pull factors

The pull factors are less clearly present. A factors that could pull the market to change, is the clients preferences, as Damen attaches great importance to their opinion. However, the clients have more eye for the product, especially the operational phase of the vessels. Increasing the energy efficiency of the vessels does have positive influence on the environment, but more important, saves the client a lot of fuel costs. The HSE Manager of Yard B (Interviewee 3, personal communication, Oct. 7, 2016) clarified that they try to convince their clients to pay more for the use of environmental friendly production materials, however clients are often not cooperating. It seems that clients are less interested in the environmental aspects of the production processes and more in the product itself. Clients are also required to comply with specific regulations while using the ship, and therefore more interested in solutions related to the operational phase of the ship. In example, ballast water treatment is a fairly new regulation which is also accepted by IMO, forcing ships to treat their ballast water before discharge. These type of changes have a direct influence on the work performed by Damen. An other factor that could lead to changes, is the cost reduction. Investing in solutions as renewable energy sources or reducing the energy use by lighting, are aspects that could contribute to an environmental friendly change. However, the long term profit seems minimal and therefore not leading to actual investments for improving the environmental performance.

E.2 Social-economic constraints

Examining the social and economical constraints is necessary to make effective operational and capital investment decisions, that positively influence the organisational objectives, and thereby satisfies the objective of multiple stakeholders [71]. The case study showed signs of social and economic constraints, which are important for the development of a "Green Shipyard".

E.2.1 Social constraints

With the knowledge about the increasing importance of sustainability, there is expected that the social domain would have a positive influence on the improvement of environmental performance. However, the clients and organisational awareness is still minimal. Different employees throughout the organisation are trying to improve different aspects, however the collaboration with the higher management is missing, and therefore not realising actual environmental improvements. Dedication of the higher management is required to salvage sustainability to a higher level within the organisation.

E.2.2 Economic constraints

The current economic situation influences the view of the organisation towards sustainable improvements. During the period of this research, the organisation experienced financial distress due to a huge decrease in sales. Where the organisation grew tremendously in the past 10 years, with an employee growth of approximately 500%, Damen is currently forced to fire employees and excessively cut in costs. While the organisation was in a financial positive period, no attention was paid to the environmental aspects, since sales went extremely well. However, now when costs need to be reduced, the facility department is focussing on measures to reduce the use of energy and thereby save costs, as is mentioned by the Facility Manager (Interviewee 2, personal communication, Sept. 15, 2016). However, the current financial situation leaves no room for investments to improve the environmental impact. Referring to both Trias Energetic [44] and waste hierarchy [47], the steps to reduce the use of resources and environmental impact is important. Unfortunately, the financial situation leaves no room for investments, and therefore resulting in only improving the "low-hanging fruits". The Manager contracting and Yard Support (Interviewee 9, personal communication, Oct. 19, 2016) mentioned that Yard C implemented changes to lighting over a period of five years, and thereby saw the investment as general costs and not as investment costs. These clever solutions makes it able to improve the performance, but dodge the request for a big investment.

The financial aspects also play role in the waste management of the shipyards. Through collaboration with a waste management consultation (NCR), Damen is reducing the costs of waste treatment. The consultant searches for organisations that are willing to pay for specific types of waste, is trying to arrange cost price reduction through improving the efficiency and frequency of transport, and audits the performance of the sub-contracted waste processors. However, the focus is mainly on cost reduction and not to improve the environmental performance, however this is understandable due to the financial situation of Damen.

Another aspects that influences the decision to deviate from improving the environmental performance, is the currently low energy price payed by Damen. The Facility Manager of Yard A (Interviewee 2, personal communication, Sept. 15, 2016) explained that Damen arranged a low energy price of approximately €0,05 for each kWh (compared with €0,22 for each kWh as household), which is done in collaboration with several Damen yards. Regulations demand that organisation needs to invest when they can achieve a return on investment of approximately 5 years and less [17], however, the low energy price often results in a return on investment of more than 5 years for energy reducing measures.

E.3 Visualize environmental impact

The collected data of each shipyard is used to determine a specific environmental impact, which is based on the GHG emissions. The environmental impact is established by converting the amount of GHG emissions, including carbon dioxide (CO_2), CH_4 and N_2O, into carbon dioxide equivalents (CO_2e). The CO_2e can be established using the Global Warming Potentials (GWPs) over 100 years, namely, 1 for CO_2, 25 for CH_4 and 298 for N_2O. For each type of (re)source used on the shipyard, the amount of CO_2equivalent is calculated indicating the environmental impact of the (re)sources [63]. Reuse, recycling and different types of incineration (energy recovery) have a positive effect on the environment. Reuse and recycling material reduces the need for production of resources and different types of incineration produces energy by burning the waste [34]. Based on the case study and baseline performance data, a list of resources that are used and sources of pollution that are produced is established. Values acquired from the literature are used to formulate the following table with the emission factors for each type of (re)source (see Table E.1 [61], [63], [67], [73]).

Through the use of these emission factors, it is possible to visualise the environmental impact for the three cases (see Figure E.1), which is used to understand the impact created by the use of resources and the pollution produced. Based on the figure, with underlying knowledge of each case, the following conclusions can be drawn for each case.

- *Yard A:* This yard has almost 3 million CO_2e impact on the environment, whereby the impact is divided into several aspects. Where the other two yards clearly impact the environment by their use of electricity and specific type of waste, is the impact of Yard

Table E.1: Environmental impact emission factors to visualise the shipyards performance.

Resource	Emission Factor (EF)	Unit	Reference	Reduction	
				Recycling	Incineration
Gas usage	1,880	kg CO^2e / Nm^3	[67] [72]		
Building electricity	0,526	kg CO^2e / kWh	[67] [72]		
Process electricity	0,526	kg CO^2e / kWh	[67] [72]		
Total electricity	0,526	kg CO^2e / kWh	[67] [72]		
LPG	1,900	kg CO^2e / liter	[67] [72]		
Gasoline	2,880	kg CO^2e / liter	[67] [72]		
Diesel	3,240	kg CO^2e / liter	[67] [72]		
Ethanol	2,186	kg CO^2e / liter	[67] [72]		
Gas oil	3,490	kg CO^2e / liter	[67] [72]		
Steel	1,770	kg CO^2e / kg	[63] [65]	-0,862	-0,530
Aluminium	5,940	kg CO^2e / kg	[63] [65]	-4,270	0,030
Wood	2,250	kg CO^2e / kg	[63] [64]	-1,528	-0,720
Paper and cardboard	2,242	kg CO^2e / kg	[63] [64]	-1,220	-0,780
Plastic	1,739	kg CO^2e / kg	[63] [64]	-1,024	-0,540
Commercial waste	1,840	kg CO^2e / kg	[67]	-1,249	-0,140
Waste (other than above)	1,130	kg CO^2e / kg	[67]	-0,768	-0,140
Oil	3,190	kg CO^2e / kg	[63] [64]	-2,759	-0,205
Packaging (Paint, chemicals etc.)	0,364	kg CO^2e / kg	[63] [64]	-0,205	-0,205
Paint	1,739	kg CO^2e / kg	[63] [64]	-0,205	-0,205
Batteries and accumulators	1,334	kg CO^2e / kg	[63] [64]	-0,205	-0,205
Chemical waste (other than above)	3,190	kg CO^2e / kg	[64]		-2,200
Water use yard	1,360	kg CO^2e / m3	[65]		
Bilge water	3,190	kg CO^2e / m3	[65]		-2,759

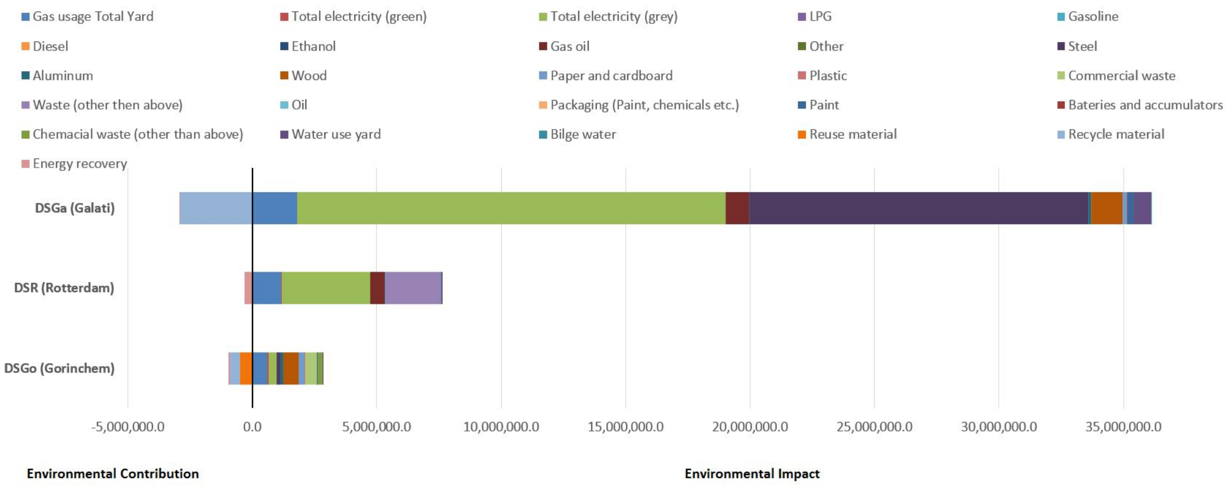


Figure E.1: Visualising the environmental impact through the use of emission factors.

C divided over different categories. By buying green electricity, the impact of electricity use is reduced and results in a relatively higher impact of the other categories. For instance, the use of gas has a higher impact than the green electricity used. The main impact of pollution is created by wood, paint, commercial waste, and paper and cardboard. This yard has the highest contribution to the environment relatively to the impact created by the yard.

- *Yard B:* This yard has an impact of approximately 7,5 million CO_2e, whereby the main impact is created by the use of electricity and the other waste produced. The data did not specify the types of waste, and therefore categorised as other. The use of gas oil and gas has a reasonable impact, compared with the other sources of impact. The positive contribution to the environment is minimal compared with the other two yards.
- *Yard C:* This yard has a significant higher impact on the environment, compared with the other two yards, with over 36 million CO_2e. The visual shows the impact in general and does not make a distinction between the amount of people or what so ever. The main impact is created by the use of electricity and the amount of steel pollution created during the production of a vessel. The yard does contribute to the environment by recycling the steel waste.

E.4 Prioritizing environmental impact

Through the use of emission factors, it is possible to look into more detail at the aspects having an high impact on the environment. The qualitative aspects are extensively discussed in the case study, but more specific view on the quantitative aspects is done through calculating the impact based on emission factors. Through underlying thought of the Pareto analysis, assuming that the vital few energy resources and pollution categories occupy a substantial amount of the cumulative impact occurred [70], aspects having a high impact on the environment can be defined. There is only focused at the impact side and not at aspects that have a positive contribution to the environment (i.e. the reuse and recycling of materials).

E.4.1 Energy impact

Table E.2 shows the emission factors of each resource, and by multiply the amount of resource used with the emission factor, the impact is calculated. The percentage range mentioned in the table shows the contribution of the resources to the total impact of the energy used by the shipyards. The data used for the baseline performance is included in this calculation. Figure E.2 shows the average impact for each category.

Figure E.2 shows that of all sources of energy used by the shipyards, electricity covers almost 90% of the environment impact. The electricity is divided into the production process and building facilities, whereby most of the electricity is used for the production processes. Processes that require a significant amount of electricity are the lifting of materials, metal working in the production (welding, cutting, surface treatment, etc.) and the compressor for painting. The impact of the building facilities is mostly related to the lighting and cooling of

Table E.2: The emission factors and impact of the different source for energy used.

Energy impact	EF	Range (%)		
Gas usage	1,880	2%	-	61%
Building electricity	0,526	0%	-	64%
Process electricity	0,526	0%	-	84%
LPG	1,900	0%	-	0%
Gasoline	2,880	0%	-	0%
Diesel	3,240	0%	-	0%
Ethanol	2,186	0%	-	0%
Gas oil	3,490	0%	-	15%

a shipyard. The 5% of gas oil used on a yard relates to the use of equipment and tools, as forklifts, cranes, etc. The 12% of gas uses relates to the heating of water or indoor air. A more detailed separation of energy resources is not possible, due to the incompleteness of the available data.

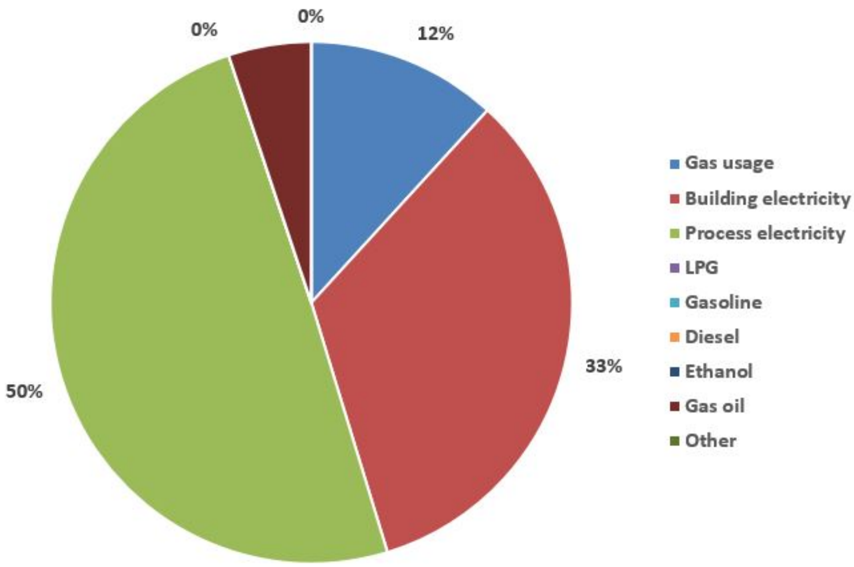


Figure E.2: Visualisation of impact created by the different source of energy used on a yard.

The case study showed that changing from grey electricity to green electricity reduces the impact by 97%, based on the difference in emission factors between both types of electricity (green: 0.012 and grey: 0.526) [73]. Also by changing from gas to electricity for heating of water and air on a yard, results in a reduction of the impact, especially when the used electricity is green. Similar effect is seen when the equipment on the yard is changed form fossil fuels to electric driven. Based on the available data, there can be estimated that a reduction of approximately 95% can be obtained, by implementing the three improvements explained above. Important to acknowledge is that the reduction only refers to the operational phase, whereby energy used on the yard that does not fall within the scope the research, is not included in the calculation.

The measures suggested only change the resources used to more environmental friendly resources. Measures as increasing the efficiency of production, reducing the amount of energy required for the building facilities, reduce the space used for the warehouse and reducing the office m^2 also positively influences the impact, but cannot not be quantified into a specific reduction.

E.4.2 Pollution impact

Table E.3 shows the emission factors of the types of waste that lead to the total pollution of a shipyard. The range shows the contribution of each type of waste to total impact of the pollution produced by a shipyard. These values also involve the data used for the baseline performance level. Figure E.2 shows the average impact for each category.

Table E.3: The emission factors and impact of the different source for the pollution produced.

Pollution impact	EF	Range (%)		
Steel	1,770	0%	-	88%
Aluminium	5,940	0%	-	26%
Wood	2,250	0%	-	32%
Paper and cardboard	2,242	1%	-	33%
Plastic	1,739	0%	-	4%
Commercial waste	1,840	0%	-	46%
Waste (other than above)	1,130	0%	-	96%
Oil	3,190	1%	-	12%
Packaging (Paint, chemicals etc.)	0,364	0%	-	0%
Paint	1,739	2%	-	44%
Batteries and accumulators	1,334	0%	-	0%
Chemical waste (other than above)	3,190	0%	-	12%
Water use yard	1,360	1%	-	7%
Bilge water	3,190	0%	-	8%

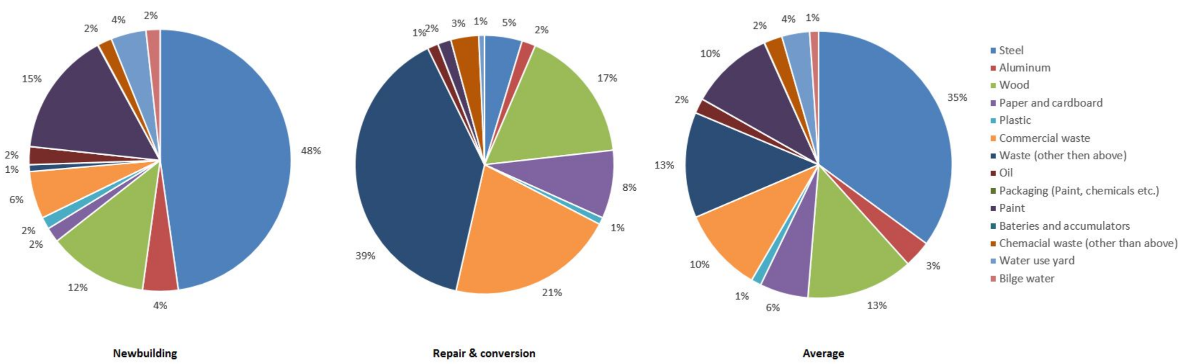


Figure E.3: Visualisation of impact created by the different source of pollution produced on a yard.

Figure E.2 shows the difference between the newbuilding and repair & conversion yards, due to the different impact on the environment. The production of vessels results in a huge amount of steel and aluminium waste (depended on the type of vessel build), and thereby having a high contribution to the impact created by the yard. Almost 50% of the impact by pollution is created by the waste of steel during the production process. In addition, painting leftovers (15%) and wood (12%) have both a significant impact on the environment. The other categories variate between the 6% and 1% impact. The other waste category has a large contribution to the impact of the repair & conversion yards, which is due to the format of reporting applied by the repair & conversion yard. Furthermore, the source that have a significant impact are commercial waste (21%), wood (17%), and paper and cardboard (8%).

Changing to methods as Lean Manufacturing and Design for Production results in a reduction of waste produced during production, whereby the quantity of steel (or aluminium) is most important. Due to the stock production technique, materials get lost or need to be altered when the design changes. Most of the waste sources can be processed on a more environmental friendly way, and therefore contacting the sub-contracted waste processor is recommended. The complexity is seen of chemical waste and bilge water, as these types of waste can not yet be processed in a environmental friendly way. Also the shipyard layout influences the impact on the environment, due to complexity of the different production processes performed within similar areas. In example, painting requires a specific temperature range where other processes, as welding, require ventilation. Dividing the processes over specific yard areas in order to control the environment and reduce the impact is required. Specific percentage of impact reduction is hard to establish, however by focussing on the method of production and the processing of waste is useful to achieve a significant reduction.

E.4.3 Specific improvements

Finally, by combining the knowledge of aspects having a high impact on the environment with the theory of a Green Shipyard, the following table with possible measures to reduce the environmental impact is established (see Table E.4). These measures are classified as reducing the impact or improving the contribution to the environment.

E.5 Prioritize feasible improvements

Besides seeing opportunities to improve the environmental performance, the feasibilities plays an important role the possibility to implement actual improvement measures.

From technological perspective, sufficient research shows possibilities to reduce the impact created by the production (or repair & conversion) of a ship. However, both the push and pull factors, and the social-economic constrains, show that a Green Shipyard, with null impact on the environmental, is still far from feasible. The current economic situation combined with aspects as a low energy price, limit the possibility of investing in green solutions. The clients request for more environmental friendly production processes could pull the market to change, however this change is limited throughout the industry. Despite these limitations,

Table E.4: Detailed improvements translated from the cases and related to the three requirements to implement green civil works.

	Impact by energy use	Impact by pollution produced
(1) Reduce use	* Sun orientated building * Insulation (high Rc value of building shell, U-value doors & windows) * Include thermic requirements in spatial layout * Daylight related lighting (office) * LED lighting (no TL lighting) * Sensors (toilets, offices, meeting room DSGo) * Ventilation (mechanical ventilation with CO2 control) * Reduce office area (flex-working) * Automatic blinding of windows (reduce temp increase) * Build specific painting area/hall * Eliminate rework * Paperless office	* Different types of cutting * High pressure cleaning of vessel before painting (water, water + grit, grit blasting) * Energy saving equipment * Reduce welding splatter (welding equipment) * Eliminate rework
(2) Use renewable	* Change fossil to electric (forklifts, lifting, workboats) * Solar & wind electricity * Buy green electricity * Electric heating air & water (no gas use) * Install heat-pump	* Rainwater use for toilets, washing-machines, gardening and ship cleaning * Apply biomimetic antifouling coatings (non-chemical)
(3) Increase efficiency	* Heat transfer through water system * Electricity storage (water pump, batteries) * Heat recovery from machines (compressors) and office equipment (data servers, washing-machines) * Implement high efficient boilers for heating air & water * Different types of welding (cold metal transfer (CMT), Laser Hybrid, and Delta Spot) improve efficiency * Equipment with low energy cost in standby * Reduced leaks in pipes and equipment of compressed air systems	* Water saving toilets and showers * Reuse water of showers for gardening * Treat wastewater on yard for use of ship cleaning, gardening and toilets (repair yards) * Paper reuse for packaging material

the following recommendations can be made to improve the environmental performance within a feasible context.

Environmental aspects can be improved by starting to improving the transparency within a shipyards and the Damen Shipyard Group. Gathering specific user data of shipyards was complicated during the research. When comparing the shipping industry with the automotive industry, the shipping industry lacks transparency and insight in the environmental performance. Galitsky and Worrel [60, p. 13] show the energy distribution of vehicle assembly plant, divided into the topics HVAC, Painting, Lighting, Compressed air, Material tools, Metal forming, Welding and Miscellaneous. This data dates back to 2001, however similar data is not available in the shipping industry. While gathering data for the case study, shipyards were only able to share a single energy bill or share an energy audit performed by another organisation. The yards had minimal insight in their own environmental performance and did not implement the outcome in their own system.

Part of the improvement of transparency, is the step towards more standardisation. While gathering specific performance data of different shipyards, the data was delivered in different formats, missed essential elements and was incomplete. By strategically defining the required information and data, a standardised format could be developed. By gathering similar data over several years, the yard will be able measure the increase or decrease in performance and is able to support the measure taken. The importance of this topic is acknowledge with the organisation, as both the Project Manager Yard Support (Interviewee 8, personal communication, Oct. 18, 2016) and Manager Contracting and Yard Support (Interviewee 9, personal communication, Oct. 19, 2016) referred to strategies to improve the overall process by changing to methods as Lean Manufacturing, Design for Production and the Building Strategy.

Furthermore, there should be focused on sharing knowledge between the yards of the Damen Shipyard Group. Different departments of a yard work by their own agenda, and do not share topics working on or possible improvements acknowledged. For instance, the facility department of Yard A implemented energy reduction improvements. Similar improvements might be useful for other shipyards, however this information is not shared between the yards. The same problem is seen while performing this research, different departments within the organisation already did some research about sustainability and searched for methods to improve the greenness of a shipyard. As organisation, it would be beneficial if not each and every yard/department reinvents the wheel again. Similar problem is acknowledged when asking yards to report on specific information, but no feedback on the delivered data is given. Direct benefits could be achieved when the outcome of an Energy Efficiency Audit is shared between the shipyards, as conclusions drawn in the audit could also be beneficial for other shipyards.

Measures that have direct influence on the impact on the environment are changing to green electricity and reducing the waste produced on the yard. The impact of green electricity is significantly lower than the impact of grey energy (green: 0,012 CO_2 emission factor, grey: 0,526 CO_2 emission factor). Also pro-actively reducing the use of material, for instance changing to a paperless office, results in an reduction of the impact. By investing a little time and effort, current shipyards are able to reduce the impact on the environment.

E.6 Shipyard comparison complexity

While developing the GPF and assessing the performance of each case, making a trustworthy comparison between the shipyards seemed complicated. This problem is related to the diversity and complexity of the shipyards. I.e. a newbuilding yard uses an extensive amount of steel (or aluminium), whereby monitoring the percentage scrap is important. However, repair & conversion yards are less related to the amount of steel (or aluminium) used and are more focused on FTE hours. Furthermore, the availability of data limited the possibility of comparing the performance of shipyards. Different levels of data monitoring and reporting are seen, where yards not always reporting each category or only shared absolute values without looking into more details. This is supported by the Table E.2 about the energy use and Table E.3 about the pollution produced, which show that the reliability of the provided data is minimal. The impact of the different sources involve a broad range, and therefore only usable to acquire insight in aspects having a high influence on the environment but not useful for comparing each individual aspects between the different shipyards.

By translating the use of energy and production of pollution into one figure, and divide that by operational metrics as FTE, production quantity or tons of steel used, the complexity of comparing shipyards can be shown. Figure E.4 shows the total environmental impact, and compares the total environmental impact (based on the emission factors) with the amount of FTE, the amount steel/aluminium used and total ships produced/repaired. Damen uses the amount of FTE as calculation factor in their CO_2 footprint to report on the CO_2 emissions process (related to scope one emissions (direct), and scope two and three (indirect)), in order to make the outcome comparable between their shipyards.

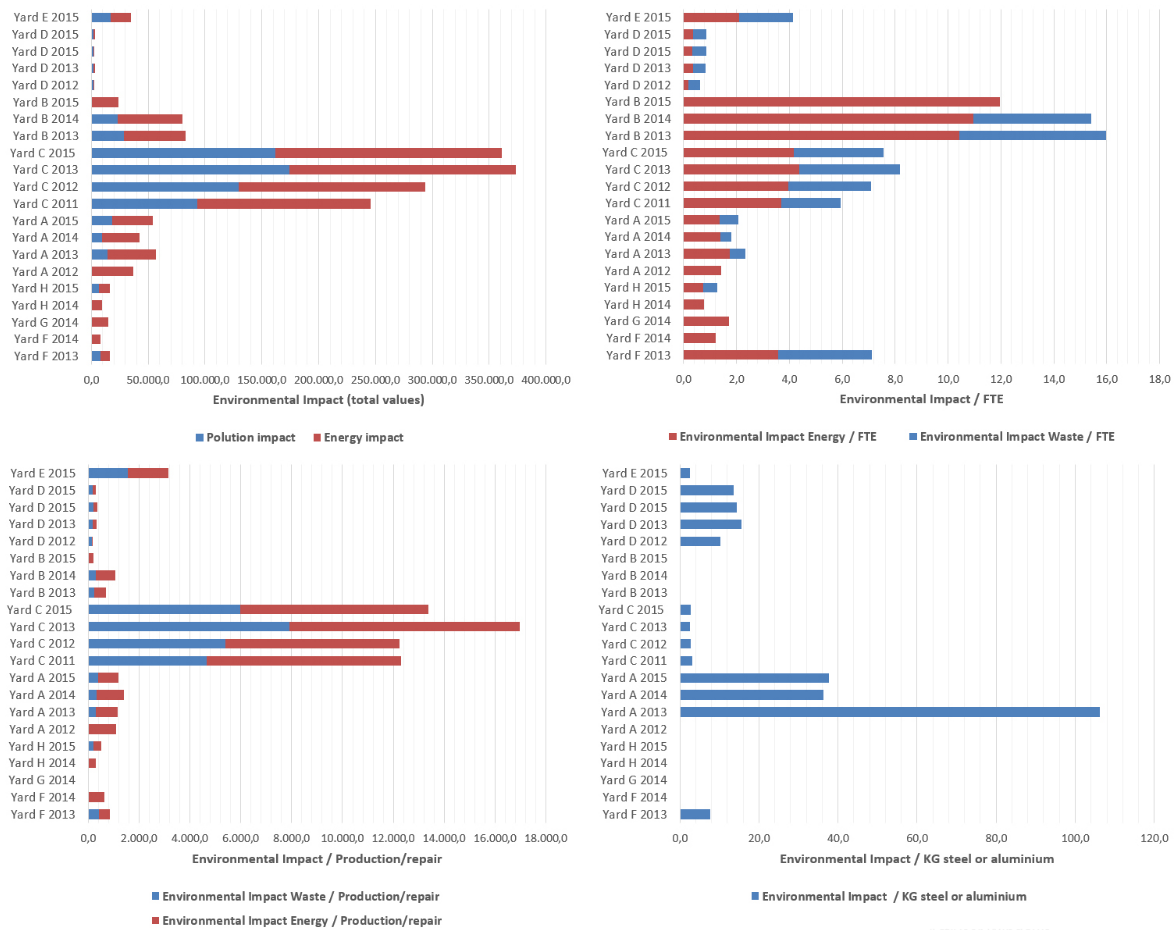


Figure E.4: Visualising the environmental impact through the use of emission factors.

The results shown in Figure E.4 confirms that it is not possible to simplify the environmental performance of a shipyard into one figure, and thereby make them comparable. The values shown differ in every perspective and are thereby not useful for comparing the environmental performance in a single measurement. The following substantiations confirm why the measurements do not deliver the desired results.

- The total impact of a shipyard differs tremendously with the size of the yard. A shipyard with ten time the production, amount of personal and production quantity has a higher environmental impact and therefore not comparable with each other.

- Dividing the impact by the amount of FTE is not reliable due to the difference in wage for each FTE. Some countries have a higher electricity and material price, and a lower hourly wage for each employee, meaning that shipyards do not invest in automation or better equipment, but hire more people to do the work.
- The impact per repair or production does not give a fair distribution of the impact, as repair and production differ extensively. Also the production of vessels is not easily comparable without looking into more detail to the product produced. The production of a Tug is very different then the production of a Multi-Purpose Vessel, and therefore complicated to compare.
- The amount of resources used per type of yard differ tremendously, and therefore not easily comparable. For instance, the amount (kg) steel used by a newbuilding yards is much higher than at a repair yard, even if the amount of employees is similar. Therefore dividing by the amount of steel/aluminium used is also not applicable for a comparison.

Finally, there can be concluded that more research is required to be able to compare the performance of existing shipyards. It is advised to examine the specific type of shipyards (newbuilding, repair & conversion or dismantling) into more detail, and thereby develop a method to compare a single type of yard with each other. Furthermore, it is advised to leave Yard A out of the scope of the comparison, as more than halve of the yard is focused on office related work and thereby not a representative shipyard.

E.7 Formulation of implementation strategy

Empirical evidence emerging from the case study combined with the theoretical background results in specific strategy for the development of a Green Shipyard concept and thereby answers the main research question. The implementation strategy is described into three specific steps, in order to cover the different levels of detail, the complexity and diversity of shipyards, and approach the concept from different perspectives. The three steps covered by the strategy are management dedication, shipyard layout & process optimisation, and green civil works, whereby specific requirements are formulated for the development of a Green Shipyard.

Step one: Management dedication
Green industrial production processes requires the translation of the organisational environmental management strategy into the actual production line [74]. The organisational strategy for a Green Shipyard is being able to produce a ship, using different processes and systems, without having an impact on the environment. Achieving null impact is possible by minimizing the impact of energy use and pollution produced, and positively contributing to the environment [34].

Evidence from the case study shows that environmental improvements are only implemented to comply with laws and regulations. With the objective to develop a Green Shipyard, a change on strategy and policy level is required. The first step involves dedication of the management to come from a traditional shipyard to a Green Shipyard (see Figure E.5). Currently, environmental aspects have little to no attention during board meetings and the management meetings of a shipyard. Without the explicit focus on achieving a high environmental performance and clear dedication, the future Green Shipyard is clearly absent. The case study results confirm that focussing only on low-hanging fruits is not far-reaching enough to fundamentally change the shipyard industry [40], and therefore altering the strategy is required.

With clear dedication towards a greener shipyard, ensuring a relation between the formulated environmental policy, strategy and monitoring system is required. It is important to implement an evaluation process in order to indicate whether the improvements have led to the desired results, and be transparent regarding your environmental performance. In order to accomplish a certain level of transparency, specific monitoring instruments should be implemented into a shipyard. For example, measuring the energy use of all the production equipment or installing a weighting system to measure weight of production waste, would improve the transparency of a shipyard and thereby make it able to examine their own performance. This should be the basis for implementing a successful Green Shipyard concept and results in the following requirements:

- Dedication towards null environmental impact;
- Implement clear monitoring and evaluation process;
- Achieve full transparency.

Step two: Shipyard layout & process optimisation

The second step requires a change in production processes and shipyard layout. The current core business involves stock production, and thereby reduce the delivery time of vessels, however this organisational strategy requires a significant amount of shipyard area dedicated to product inventory and warehousing. By changing the production processes towards methods as lean manufacturing and design for production, a reduction in waste pollution and energy use is achieved [73]. Changing the production processes requires a minimization of the shipyards' portfolio and stop producing unique vessels, which will reduce the risk on defects and mistakes. Currently, too much changes to the design during the production process influences the amount of pollution produced.

Furthermore, implementing reduction and efficiency measures requires the optimisation of the shipyard layout. Dividing the processes into specific areas of the yard, for example the use of a specific painting shop inside the production hall, makes it able to control the process performed and have minimal influence on the other production processes. By optimising the shipyard layout, the impact of resources both directly related to the production process and not directly related to the production process can be reduced. This should be the second step for implementing a successful Green Shipyard concept and results in the following requirements:

- Implementation lean manufacturing and design for production
- Limit portfolio and do not produce unique vessels

- Optimisation of shipyard layout

Step three: Green civil works

Besides the strategic changes implemented by step one and two, improvements in the civil works is required. The improvements can be explained by visualising the environmental impact of an existing shipyard and a Green Shipyard with null impact on the environment. Figure E.5 shows the impact and contribution to the environment of both shipyards (existing (traditional) shipyard and a Green Shipyard), by converting each aspect in the operational phase into carbon dioxide equivalents (CO_2e) [61], [65]–[67].

The difference between a traditional shipyard and Green Shipyard concept requires the implementation of measures to improve the performance through the use of Trias Energetica (reduce energy demand, use renewable energy resources and use fossil fuels efficiently) [44] and pollution reduction measures depended on the type of pollution (reduce/avoid, reuse/use renewable and recycle/improve efficiency) [44], [47], which can be combined in three specific requirements.

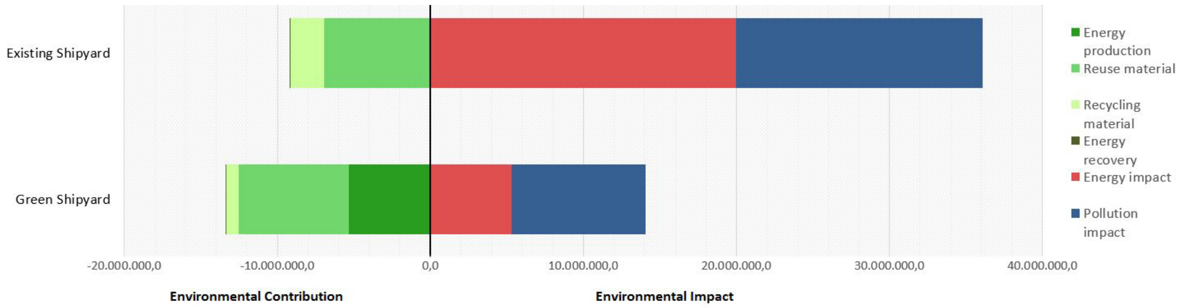


Figure E.5: Visualisation of the environmental impact and contribution of an existing (traditional) and green shipyard.

- Reduce the use of energy and production of waste;
- Use renewable (re)sources;
- Increase the efficiency of (re)sources used.

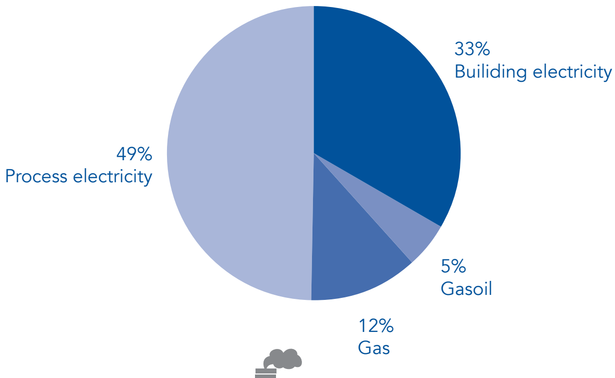
Finally, applying the three steps with corresponding requirements is useful for the development of a Green Shipyard concept. The requirements are important during the different phases of the shipyard development, especially to validate if the developed concept incorporates enough measures to become a Green Shipyard. In order to make these steps understandable and marketable for Damen Civil, the impact of an existing (traditional) shipyard, the implementation strategy and conceptualisation of a Green Shipyard is visualised on two infographics (see Figure E.5).

Table E.5: Two infographics visualizing the impact of a traditional shipyard, the implementation strategy for a Green Shipyard and conceptualise a Green Shipyard.

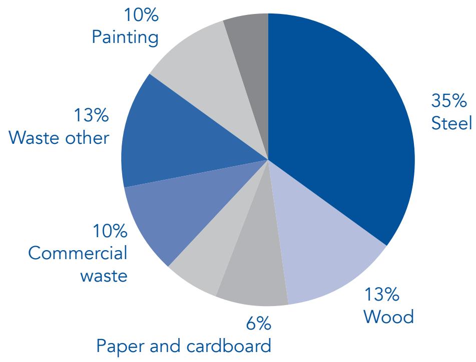
GREEN SHIPYARD CONCEPT

'ASPECTS OF A GREEN OPERATIONAL SHIPYARD'

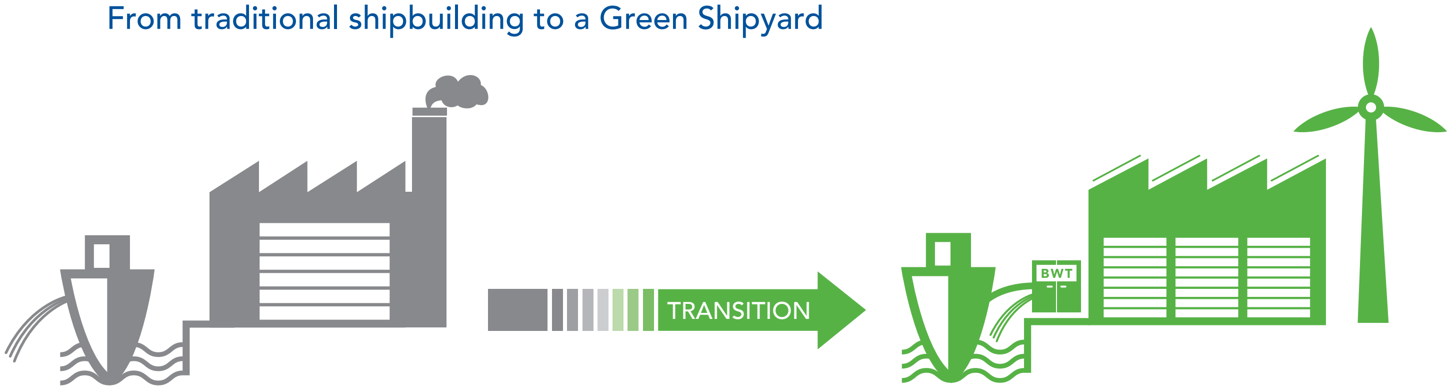
ENERGY IMPACT 58%



POLLUTION IMPACT 42%



From traditional shipbuilding to a Green Shipyard

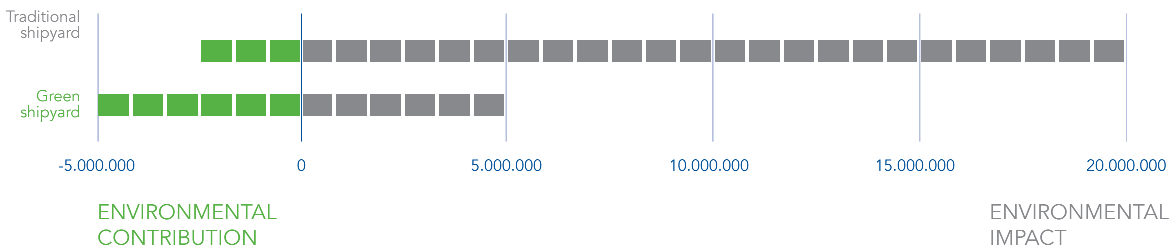


1 Management dedication
- Transparancy
- Monitoring and evaluation

2 Shipyard layout and process optimalisation
- Lean Manufacturing / Design for Production
- No one-off production

3 Green civil works
- Reduce the energy use and waste produced
- Use renewable (re)sources
- Increase efficiency

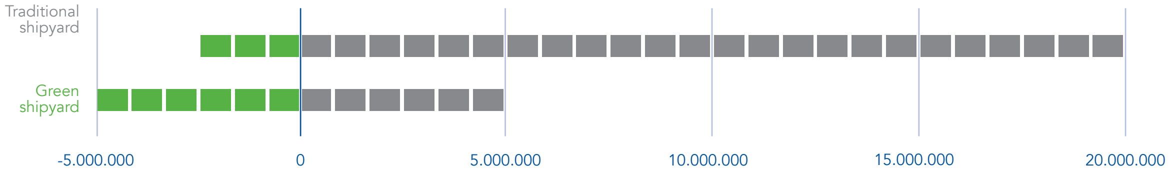
CO_2 equivalent impact of an operational shipyard



GREEN SHIPYARD CONCEPT

'ASPECTS OF A GREEN OPERATIONAL SHIPYARD'

CO_2 equivalent impact of an operational shipyard



1 Management dedication
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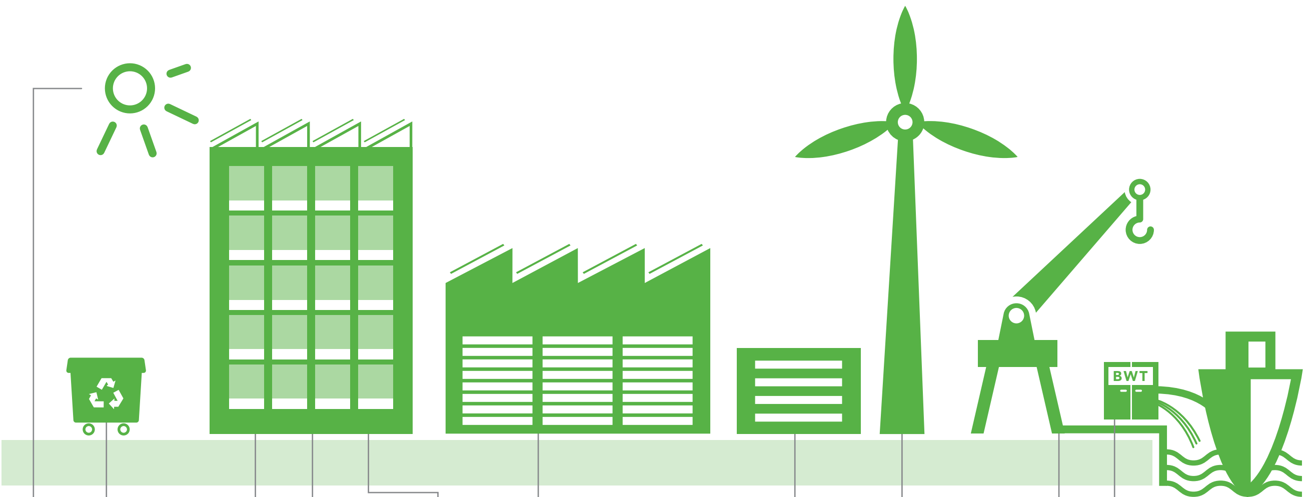

Waste
- Divide waste according to regulations
- Recycle all non-chemical waste
- Minimize chemical waste produced

Production
- Divide production into different areas
- Implement energy efficient equipment
- Indoor blasting and painting

Renewable energy
- produce all electricity on the yard

Ballast Water Treatment
- Treat ballast water through BWT system

Water
- Implement rainwater reservoir
- Reuse rainwater (i.e. toilets)
- Grey water treatment (recycling)

Insulation
- Apply low Rc-value
- Apply high U-value
- Use mechanical ventilation

Paper
- Apply paperless office
- Reuse paper in packaging materials

Tools and equipment
- No fossil fuels
- Minimal energy use in standby mode

Lighting
- Use LED lighting use
- Implement sensors
- Significant use of daylight
- Apply smart meters

Sun
- Use automatic window covers
- Sun orientated building
- Heat recovery/exchange design

Bibliography

[1] N. R. C. U. C. on Industrial Environmental Performance Metrics, *Industrial Environmental Performance Metrics: Challenges and Opportunities*. National Academy Press, 1999.

[2] Y. J. Song and J. H. Woo, “New shipyard layout design for the preliminary phase & case study for the green field project,” *International Journal of Naval Architecture and Ocean Engineering*, vol. 5, no. 1, pp. 132–146, 2013.

[3] Damen Shipyards Group, “Sustainability report 2014,” vol. 46, 2014.

[4] B. Hopwood, M. Mellor, and G. O’Brien, “Sustainable development: mapping different approaches,” *Sustainable development*, vol. 13, no. 1, pp. 38–52, 2005.

[5] R. M. Dangelico and D. Pujari, “Mainstreaming green product innovation: Why and how companies integrate environmental sustainability,” *Journal of Business Ethics*, vol. 95, no. 3, pp. 471–486, 2010.

[6] I. Paul, G. Bhole, and J. Chaudhari, “A review on green manufacturing: It’s important, methodology and its application,” *Procedia Materials Science*, vol. 6, pp. 1644–1649, 2014.

[7] T. Hacking and P. Guthrie, “A framework for clarifying the meaning of triple bottom-line, integrated, and sustainability assessment,” *Environmental Impact Assessment Review*, vol. 28, no. 2, pp. 73–89, 2008.

[8] Ministry of Environment, Japan Government, “Environmental performance indicators guideline for organizations,” vol. 65, 2003.

[9] International Organization for Standardization, *ISO 9004: 2009: Managing for the Sustained Success of an Organisation: A Quality Management Approach*. International Organization for Standardization, 2009.

[10] Damen Shipyard Group, “Damen corporate website,” http://www.damen.com/, 2015, accessed: 2016-10-10.

[11] Damen Shipyards Group, “Damen Corporate Brochure English,” vol. 50, 2015.

[12] Damen Shipyards Group Civil, “Damen Civil Brochure Civil Works,” vol. 4, 2015.

[13] Damen Communications department, “Damen magazine 3,” vol. 137, 2015.

[14] N. Ko and J. Gantner, “Local added value and environmental impacts of ship scrapping in the context of a ship’s life cycle,” *Ocean Engineering*, 2016.

[15] Ecorys, IDEA Consult, CE Delft, “Green growth opportunities in the eu shipbuilding sector,” vol. 152, 2012.

[16] S. Misra, “Sustainable development and ship life cycle,” *International Journal of Innovative Research and Development*, vol. 1, no. 10, pp. 112–120, 2012.

[17] Energy Efficiency Directive, “Directive 2012/27/eu of the european parliament and of the council of 25 october 2012 on energy efficiency, amending directives 2009/125/ec and 2010/30/eu and repealing directives 2004/8/ec and 2006/32,” *Official Journal, L*, vol. 315, pp. 1–56, 2012.

[18] Rijksdienst voor Ondernemend Nederland, “The energiemanagementsysteem,” 2016. [Online]. Available: http://www.rvo.nl/subsidies-regelingen/meerjarenafspraken-energie-effici%C3%ABntie/verplichtingen-mja3/mee/energiemanagement/softwaresystemen/het-energiemanagementsysteem

[19] I. Third, “Ghg study, 2014,” *IMO, London, UK*, 2014.

[20] Ø. Buhaug, J. Corbett, Ø. Endresen, V. Eyring, J. Faber, S. Hanayama, D. Lee, D. Lee, H. Lindstad, A. Markowska *et al.*, “Second imo ghg study 2009,” *International Maritime Organization (IMO) London, UK*, vol. 20, 2009.

[21] E. C. D.-G. for Mobility and Transport, *White Paper on Transport: Roadmap to a Single European Transport Area: Towards a Competitive and Resource-efficient Transport System*. Publications Office of the European Union, 2011.

[22] G. Brundtland, M. Khalid, S. Agnelli, S. Al-Athel, B. Chidzero, L. Fadika, V. Hauff, I. Lang, M. Shijun, M. M. de Botero *et al.*, “Our common future (’brundtland report’),” 1987.

[23] G. K. Ding, “Sustainable construction - the role of environmental assessment tools,” *Journal of environmental management*, vol. 86, no. 3, pp. 451–464, 2008.

[24] R. Goodland, “The concept of environmental sustainability,” *Annual review of ecology and systematics*, pp. 1–24, 1995.

[25] P. Gilbert, P. Wilson, C. Walsh, and P. Hodgson, “The role of material efficiency to reduce co 2 emissions during ship manufacture: A life cycle approach,” *Marine Policy*, 2016.

[26] C. R. Harish and S. K. Sunil, “Energy consumption and conservation in shipbuilding,” *International Journal of Innovative Research and Development*, vol. 4, no. 7, 2015.

[27] S. M. Lele, “Sustainable development: a critical review,” *World development*, vol. 19, no. 6, pp. 607–621, 1991.

[28] C. Tisdell, “Economic indicators to assess the sustainability of conservation farming projects: an evaluation,” *Agriculture, ecosystems & environment*, vol. 57, no. 2, pp. 117–131, 1996.

[29] V. Veleva, M. Hart, T. Greiner, and C. Crumbley, “Indicators of sustainable production,” *Journal of Cleaner Production*, vol. 9, no. 5, pp. 447–452, 2001.

[30] P. Leedy and J. E. Ormrod, *Practical research*. publisher not identified, 2005.

[31] P. J. M. Verschuren and H. Doorewaard, *Het ontwerpen van een onderzoek*. Lemma, 2007.

[32] A. Mwasha, R. G. Williams, and J. Iwaro, “Modeling the performance of residential building envelope: The role of sustainable energy performance indicators,” *Energy and buildings*, vol. 43, no. 9, pp. 2108–2117, 2011.

[33] A. Ziout, A. Azab, S. Altarazi, and W. ElMaraghy, “Multi-criteria decision support for sustainability assessment of manufacturing system reuse,” *CIRP Journal of Manufacturing Science and Technology*, vol. 6, no. 1, pp. 59–69, 2013.

[34] R. M. Dangelico and P. Pontrandolfo, “From green product definitions and classifications to the green option matrix,” *Journal of Cleaner Production*, vol. 18, no. 16, pp. 1608–1628, 2010.

[35] A. Midilli, I. Dincer, and M. Ay, “Green energy strategies for sustainable development,” *Energy Policy*, vol. 34, no. 18, pp. 3623–3633, 2006.

[36] A. Singh, D. Philip, and J. Ramkumar, “Quantifying green manufacturability of a unit production process using simulation,” *Procedia CIRP*, vol. 29, pp. 257–262, 2015.

[37] C.-C. Tsai, “A research on selecting criteria for new green product development project: taking taiwan consumer electronics products as an example,” *Journal of Cleaner Production*, vol. 25, pp. 106–115, 2012.

[38] H. Chabane, “Design of a small shipyard facility layout optimised for production and repair,” in *Proceedings of Symposium International: Qualite et Maintenance au Service de lEntreprise*, 2004.

[39] SHIPMATES project consortium, “Shiprepair to maintain transport which is environmentally sustainable,” vol. 33, 2004.

[40] A. Latino and D. Dreyer, “Energy master planning toward net zero energy installation-portsmouth naval shipyard,” *ASHRAE Transactions*, vol. 121, p. 160, 2015.

[41] C. Ngô and J. Natowitz, *Our energy future: resources, alternatives and the environment*. John Wiley & Sons, 2012, vol. 16.

[42] I. Dincer and M. A. Rosen, “A worldwide perspective on energy, environment and sustainable development,” *International Journal of Energy Research*, vol. 22, no. 15, pp. 1305–1321, 1998.

[43] E. Lysen, “Energy availability, renewables and energy use,” vol. 47, 2011.

[44] A. G. Entrop and H. J. H. Brouwers, “Assessing the sustainability of buildings using a framework of triad approaches,” *Journal of Building Appraisal*, vol. 5, no. 4, pp. 293–310, 2010.

[45] C. W. Bullard, P. S. Penner, and D. A. Pilati, “Net energy analysis: Handbook for combining process and input-output analysis,” *Resources and energy*, vol. 1, no. 3, pp. 267–313, 1978.

[46] P. Horton, L. Koh, and V. S. Guang, “An integrated theoretical framework to enhance resource efficiency, sustainability and human health in agri-food systems,” *Journal of Cleaner Production*, vol. 120, pp. 164–169, 2016.

[47] J. M. Allwood, M. F. Ashby, T. G. Gutowski, and E. Worrell, “Material efficiency: A white paper,” *Resources, Conservation and Recycling*, vol. 55, no. 3, pp. 362–381, 2011.

[48] S. Singh, E. U. Olugu, and S. N. Musa, “Development of sustainable manufacturing performance evaluation expert system for small and medium enterprises,” *Procedia CIRP*, vol. 40, pp. 609–614, 2016.

[49] T. Fischer, *Environmental Assessment*, ser. Critical Concepts in Built Environment Series. Taylor & Francis Group, 2015. [Online]. Available: https://books.google.nl/books?id=fiTCrQEACAAJ

[50] J. Pulli and L. Jonna, Heikkila Kosomaa, “Designing an environmental performance indicator for shipbuilding and ship dismantling,” vol. 55, 2013.

[51] P. Downton *et al.*, “Building environmental performance assessment: Methods and tools,” *Environment Design Guide*, no. 70, p. 8, 2011.

[52] A. Forsberg and F. Von Malmborg, “Tools for environmental assessment of the built environment,” *Building and environment*, vol. 39, no. 2, pp. 223–228, 2004.

[53] A. Zamagni, “Life cycle sustainability assessment,” *The International Journal of Life Cycle Assessment*, vol. 17, no. 4, pp. 373–376, 2012.

[54] Y. T. Chong, K. M. Teo, and L. C. Tang, “A lifecycle-based sustainability indicator framework for waste-to-energy systems and a proposed metric of sustainability,” *Renewable and Sustainable Energy Reviews*, vol. 56, pp. 797–809, 2016.

[55] B. A. Schlüter and M. B. Rosano, “A holistic approach to energy efficiency assessment in plastic processing,” *Journal of Cleaner Production*, vol. 118, pp. 19–28, 2016.

[56] I. I. Issa, D. C. Pigosso, T. C. McAloone, and H. Rozenfeld, "Leading product-related environmental performance indicators: A selection guide and database," *Journal of Cleaner Production*, vol. 108, pp. 321–330, 2015.

[57] G. E. M. Initiative *et al.*, "Measuring environmental performance: A primer and survey of metrics in use," *Washington DC: Global Environmental Performance Measurement Initiative*, pp. 1–34, 1998.

[58] S. Mousavi, S. Kara, and B. Kornfeld, "A hierarchical framework for concurrent assessment of energy and water efficiency in manufacturing systems," *Journal of Cleaner Production*, vol. 133, pp. 88–98, 2016.

[59] SenterNovem, "Cijfers en tabellen 2007," 2007.

[60] C. Galitsky, "Energy efficiency improvement and cost saving opportunities for the vehicle assembly industry: an energy star guide for energy and plant managers," *Lawrence Berkeley National Laboratory*, 2008.

[61] M. Centraal, "Co2 emissiefactoren," http://co2emissiefactoren.nl/, 2015, accessed: 2016-10-4.

[62] , "Emission factors in kg co2-equivalent per unit," -.

[63] D. A. Turner, I. D. Williams, and S. Kemp, "Greenhouse gas emission factors for recycling of source-segregated waste materials," *Resources, Conservation and Recycling*, vol. 105, pp. 186–197, 2015.

[64] Environmental Protection Agency, "European waste catalogue and hazardous waste list," vol. 49, 2002.

[65] C. Chai, D. Zhang, Y. Yu, Y. Feng, and M. S. Wong, "Carbon footprint analyses of mainstream wastewater treatment technologies under different sludge treatment scenarios in china," *Water*, vol. 7, no. 3, pp. 918–938, 2015.

[66] B. C. S. Association, "Steel construction recycling and reuse," 2015, accessed: 2016-09-24.

[67] J. R. Freed, W. Driscoll, E. Lee, and C. Lindsay, "Greenhouse gas emission factors for management of selected materials in municipal solid waste," p. 6, 1997.

[68] J. S. L. Lam and K.-h. Lai, "Developing environmental sustainability by anp-qfd approach: the case of shipping operations," *Journal of Cleaner Production*, vol. 105, pp. 275–284, 2015.

[69] A. B. L. de Sousa Jabbour, C. J. C. Jabbour, H. Latan, A. A. Teixeira, and J. H. C. de Oliveira, "Quality management, environmental management maturity, green supply chain practices and green performance of brazilian companies with iso 14001 certification: Direct and indirect effects," *Transportation Research Part E: Logistics and Transportation Review*, vol. 67, pp. 39–51, 2014.

[70] G. Karuppusami and R. Gandhinathan, “Pareto analysis of critical success factors of total quality management: A literature review and analysis,” *The TQM magazine*, vol. 18, no. 4, pp. 372–385, 2006.

[71] M. J. Epstein and A. R. Buhovac, *Making sustainability work: Best practices in managing and measuring corporate social, environmental, and economic impacts*. Berrett-Koehler Publishers, 2014.

[72] J. Potting, M. Hekkert, E. Worrell, and A. Hanemaaijer, “Circulaire economie: innovatie meten in de keten,” 2016.

[73] M. Formentini and P. Taticchi, “Corporate sustainability approaches and governance mechanisms in sustainable supply chain management,” *Journal of Cleaner Production*, vol. 112, pp. 1920–1933, 2016.

[74] T. W. Thurner and V. Roud, “Greening strategies in russia’s manufacturing–from compliance to opportunity,” *Journal of Cleaner Production*, vol. 112, pp. 2851–2860, 2016.