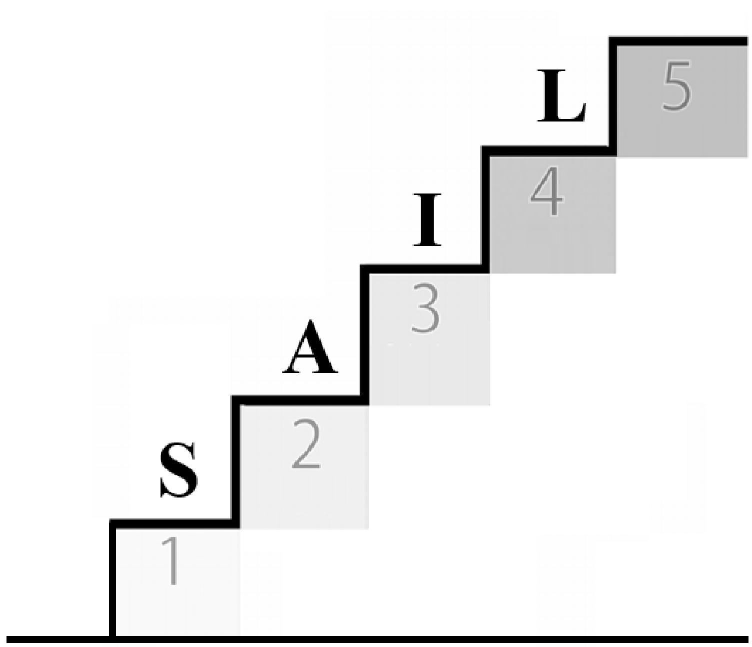
The Seafaring Applied Impact Ladder

A lifecycle approach to mitigating environmental impacts in sailing cruise lifecycle systems



Thesis project

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Tom de Ruyter van Steveninck

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2. Abstract

Environmental impacts of a sailing cruise voyage have not yet been assessed from a lifecycle perspective. Thus far, only conventional fuel-based cruise holidays are related to various environmental impacts and are known as an energy intensive form of tourism. International regulations are increasingly stringent on direct pollution and energy-use related impacts but exclude upstream and downstream externalities in sustainability targets for cruise tourism. Whether sailing cruise tourism can form a truly low-impact alternative to conventional (i.e. fuel-based) cruise tourism however, depends on a myriad of lifecycle interactions. Consequently, a manageable lifecycle approach is needed for estimating the distribution of direct and indirect impacts of a sailing cruise voyage. Furthermore, when sailing cruise operators wish to mitigate their environmental impacts, focal points of impact hotspots and alternatives need to be determined.

In this design-oriented research report the Seafaring Applied Impact Ladder (SAIL) is introduced. This framework makes use of fast track-LCA methodology for determining systemwide impact distribution and mitigation pathways for major impact contributors in sailing cruise lifecycle systems. By applying the SAIL to a case study sailing cruise voyage on board the Clipper Stad Amsterdam (CSA), insights in impact distribution and feasible impact reduction emerge.

The case study found that a passengers' fuel related carbon footprint is greater for conventional cruises than for a sailing cruise on board the CSA. In the SAILs systemwide assessment however, fuel-related impacts remain the major culprit for all three included indicators. Food consumption and crew flights generate a considerable additional share of systemwide impacts. For fuel combustion and food consumption, technological substitution can result in feasible impact reduction, which is quantified in the fourth step of the case study.

The SAIL proves itself a useful and improvement focused approach for impact assessment in sailing cruise lifecycle systems. The presented procedures form a straightforward approach from which practical inferences for impact reduction follow. Further application of the framework in case studies will contribute to sustainable development in (sailing) cruises and broadens the scientific domain of impact assessment.

3. Abbreviations

CSA	Clipper stad Amsterdam
CTU	Comparative toxic unit
DT	Design thinking
DWT	Dead weight tonnage
ECA	Emission control area
EEA	European emission agency
EEDI	Energy efficiency design index
EEOI	Energy efficiency operational indicator
EOL	End of life
GHG	Greenhouse gas
GO-SAIL	General output seafaring applied impact ladder
GT	Gross tonnage
GWP	Global warming potential
HVO	Hydrotreated vegetable oil
ISO	International organisation for standardisation
LCA	Lifecycle analysis
LCI	Lifecycle inventory
LCIA	Lifecycle inventory analysis
LWT	Light weight tonnage
MARPOL	Marine pollution
PAF	Potentially affected fraction
RCSA	Rederij clipper stad Amsterdam
SAIL	Seafaring applied impact ladder
SCR	Selective catalytic reduction
SEEMP	Ship energy efficiency management plan
SOI	Sustainability-oriented innovation
SOLAS	Safety of life at sea

4. Glossary

This glossary provides definitions of the key terms used in this thesis, most terms originate from LCA methodology. All definitions are based on the Handbook on Life Cycle Assessment by Guinée et al. (2002a), except for terms marked with an asterisk (*), which are defined by Bruinsma (2016) and definitions marked in *italic,* which were specifically defined for this particular study.

Activity*
Any activity within a service, process or location, ranging from building a ship to scrubbing the deck.

Alternative
One of a set of product or service systems studied in a particular LCA, e.g. for comparison of a revised subsystem with the original subsystem.

Background data
Secondary data sourced from databases, public references or estimations.

Complex system
A system containing a myriad of products, utilities and activities, which are all associated with their own life-cycles. One example of a complex system is a sailing cruise voyage lifecycle system.

Conventional cruise holiday
A cruise holiday provided by a non-sailing (i.e. fuel-based) cruise ship.

Conventional LCA
Also called detailed LCA, a type of LCA complying with the ISO 1404X standards. The aim of this type of LCA is to deliver a robust model and accurate quantifications.

Economic flow
A flow of goods, materials, services, energy or waste from one unit process to another; with either a positive (e.g. steel, transportation) or zero/negative (e.g. waste) economic value

Emission
A chemical or physical discharge (of a substance, heat, noise, etc.) into the environment.

Environmental impact
A consequence of any activity that leads to harmful effects in a natural environment

Feasible impact reduction
Theoretical environmental impact reduction possibility for an alternative system element.

Foreground data
A type of data for which primary, site or system-specific inputs are available (e.g. fuel consumption data).

Functional unit
The quantified function provided by the product system(s) under study, for use as a reference basis in an LCA.

Goal and scope definition
The first phase of an LCA, establishing the aim of the intended study, the functional unit, the reference flow, the product system(s) under study and the breadth and depth of the study in relation to this aim

Impact category
A class representing environmental issues of concern to which environmental interventions are assigned, e.g. climate change, eutrophication or ecotoxicity

Impact hotspot *
A concentration of impact(s) attributed to a specific activity. The relative impact contribution of this element, activity or subsystem is considerable.

Intervention
A human intervention in the environment, either physical, chemical or biological; in particular resource extraction, emissions (incl. noise and heat) and land use; the term is thus broader than ('elementary flow')

Inventory analysis
The second phase of an LCA, in which the relevant inputs and outputs of the product system(s) under study throughout the life cycle are, as far as possible, compiled and quantified

Inventory table
The result of the Inventory analysis phase: a table showing all the environmental interventions associated with a product system, supplemented by any other relevant information (adapted from ISO)

Lifecycle approach
An assessment procedure that is based on a systemic perspective and partly uses LCA methodology for impact assessment. It differs from LCA as it does not make use of standardized ISO procedures.

Life cycle assessment (LCA)
Compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system throughout its life cycle; the term may refer to either a procedural method or a specific study

Life cycle impact assessment (LCIA)
The third phase of an LCA, concerned with understanding and evaluating the magnitude and significance of the potential environmental impacts of the product system(s) under study

Life cycle inventory analysis (LCI)
Inventory analysis

Life-cycle
The consecutive, interlinked stages of a product system, from raw materials acquisition or natural resource extraction through to final waste disposal

Product-service system
A lifecycle system both including service and product related elements.

System boundary
The interface between a product system and the environment system or other product systems.

Systemwide
Extending throughout the whole of the system, i.e. considering an extensive amount of system elements within a system boundary.

Techno-ecological domain
The technological possibilities for influencing ecological aspects such as environmental impact reduction.

Technosphere
Another name for anthroposphere, that part of the environment which is made or modified by humans.

5. Introduction

Due to increasing global ecological concerns, international organisations are tightening environmental policies on tourism, including those in the cruise shipping sector (Pallis & Vaggelas, 2019). Where many businesses align their energy targets to those of the Paris Agreement and converge in business principles and reporting standards, cruise tourism still falls behind (Ferreira et al. 2019; Lloret et al. 2021). In addition to GHG-emission targets, marine environmental regulations are increasingly stringent, emphasising the need to adapt the cruise tourism sector to low-impact strategies (Čampara et al. 2018). Impact assessment methods for the shipping sector mainly focus on emissions related to energy (fuel) usage, as other material and service-related impacts are relatively small for most ships (IMO, 2020). Impact assessment efforts for cruise tourism consequently focus mainly on energy usage, pollution or single aspects such as ship production (Strazza et al. 2015). Moreover, different types of cruise holidays are likely to differ in environmental footprints, whilst the potential of low-impact alternatives such as sailing cruise holidays are yet to be studied. Due to the extent of fuel-use-related impacts in the general shipping sector, cruise tourism impact assessment has mainly focused on fuel use. Including multiple product- and service-related aspects could, however, provide a systemwide impact perspective, which may yield useful insights for a greater set of elements and impacts categories. Thus far, few studies have aimed to compose a systemwide impact perspective by relating conventional cruise holidays to their carbon footprint (Farr & Hall, 2015; Simonsen, 2014).

Albeit currently being less competitive regarding economies of scale,[1] sailing cruise tourism is potentially a low-impact alternative to conventional fuel-based cruise tourism (see Appendix A2.3). Where academic attention for wind-assisted cargo vessel propulsion is experiencing a revival, interest in impact reduction through sailing cruise tourism has not yet set off (Chou et al. 2021). Furthermore, a lifecycle approach to systemwide impact estimation of sailing cruises has not yet been documented (see Table 1, p. 11). Although sailing cruise tourism and conventional fossil fuel-based cruise tourism do not directly provide the same type of service, important insights in per capita impact contribution of sailing cruise holidays, and possible mitigation pathways for cruise tourism in general, might be overlooked. Impact assessments applied to sailing cruise ship tourism are consequently not staying current with its potential, methodologies and environmental concerns.

[1] The largest sailing cruise ship; the Club med 2, has a Gross Tonnage of 14,983GT and hosts up to 386 passengers. The largest fuel powered cruise ship is the Wonder of the Seas, with 236,857GT and a maximum of 6988 passengers, it is considerably more extensive.

Where sailing or wind-assisted propulsion is a potential low-emission alternative to fuel-based propulsion, externalities of altered material demands must be considered (Koumentakos, 2019). Furthermore, to gain complete insights into the impact of all upstream and downstream processes related to sailing cruise services, systemwide analysis is required, in which aggregated relatable elements comprise the final delivered product or service. Lifecycle assessment (LCA) is a tool for estimating the systemwide environmental footprints of products or services within a specified study scope and boundary which has been used in several cases in the shipping and cruise tourism industry (Önal et al. 2021; Paiano et al. 2020; Simons [2021]; Simonsen [2014]). Although LCA has the potential to be an inclusive systemwide approach, system boundaries, research scope and assumptions differ across studies, as modelling choices are interpretations subject to the author.

Where LCA can potentially demystify the focal points of environmental impacts, its usage is a new issue for sailing cruise tourism, and only recently gained interest for conventional cruise tourism. Table 1 displays the number of results for a given combination of search operators in Google Scholar. According to these search results, using LCA for cruise tourism is a relatively novel development and yet to be performed for sailing cruise tourism.

Search operators (in title and text)	Only in title	Title + text: 1950–2022	Title + text. Percentage within last five years
LCA AND 'sailing cruise' OR 'sail cruise' OR 'sailing tourism'	0	0	0
LCA AND 'cruise tourism'	2	226	67%
LCA AND 'shipping'	6	15,400	48%
'wind assisted propulsion'	38	330	69%

Table 1. Google Scholar results for a given set of search operators

Lifecycle analysis is generally used to determine impacts related to product- or service-related activities, from which low-impact strategies can be distilled. To streamline the complexity of analysis, preliminary LCA studies in the cruise tourism sector focused only on a reduced set of aspects within the sector, disregarding many other service related issues. However, the complex system of cruise holidays relies on a plethora of lifecycle interactions responsible for providing recreational services, rather than being 'just' a mode of transport. Similarly, for sailing cruise experiences, where propulsion is assisted by wind,[2] environmental impacts can

[2] All passenger ships are required to have an engine, including sailing cruise ships. According to SOLAS, sails are theoretically a form of auxiliary propulsion (IMO, 1974)

be related to more than just the sum of fuel usage and construction burdens. Unravelling the impact contribution of systemic interactions and activities will foster the comprehension of the sustainability of a sailing cruise experience. Moreover, to set a focused course towards (further) impact mitigation of sailing cruises, novel insights are required.

Because a systemwide impact assessment of sailing cruise services has not yet been performed, impact mitigation policies relating to sailing cruise companies are difficult to compose. Nevertheless, the International Maritime Organisation (IMO) prescribe international regulations for passenger ships in a set of protocols for pollution and waste management and list their ambitions for the reduction of harmful emissions (Joung et al. 2020). The gravitational centre of the IMO's sustainability targets mainly revolves around climate change mitigation and other impacts related to energy (i.e. fuel) demand (IMO, 2020). A lifecycle focus for systemwide impact mitigation of cruise tourism is missing, as fuel consumption is the main source of environmental harm for most types of shipping. Additionally, for sailing cruise holidays, relative impact contribution assigned to several system elements can potentially result in a different distribution of impact hotspots. Sustainability focused targets for improvement of sailing cruises are therefore expected to need a wider focus: substantial impacts may be related to more than direct energy use for transportation. In addition to energy-use-related impact categories (e.g. climate change), other sustainability issues such as damage to ecosystem resilience can be implemented within a lifecycle approach by using ecosystem-related impact indicators. To assess and improve the sustainability of sailing cruises, a systemwide perspective is needed on the effects of a sailing cruise experience on various impact categories.

The lifecycle system of a sailing cruise holiday is regarded as a complex system which is dependent on multiple material, energy and service interactions (Roth-Cohen & Lahav 2022). Increasing the usage of wind-powered propulsion for sailing cruises can reduce the usage of fuel, although it may enhance the material-demand-related impacts. Meanwhile, the share of consumption-related impacts might be relatively greater contributors to the total impact estimation of a sailing cruise holiday. Furthermore, the provided service or 'function' of cruise lifecycle systems cannot be directly related to travelled distance but is more relatable to leisure or experience values. Developing strategies to reduce the environmental impacts of sailing cruise holidays will not be straightforward, as using LCA for impact estimations of complex systems can be challenging and thus complicate the formation of a sustainable approach. Low-impact policies for the sailing cruise sector consequently require a manageable lifecycle approach which focuses on practicability rather than robustness.

The assessment of environmental impacts of complex product service systems with LCA has proven to be challenging (Bruinsma, 2016; Scheepens et al. 2016; Wang & Shen, 2013). Research teams studying complex systems with LCA state that with larger product and service systems, not every element can be included in a systems boundary or scope. Accurate results which respect 'real' complexity would require infinite amount of human resource and data availability (Kjaer et al. 2016). Furthermore, LCA practitioners have conflicting views on what approaches are allowed in standardised procedures for reducing complexity. Some state that a 'one-size-fits-all' approach to complex systems cannot be formalised due to the variability of decision contexts (Finnveden et al. 2009).

Nevertheless, LCA methodology can accurately estimate impacts along the supply chain of uncluttered product and service systems by thoroughly charting the product or service lifecycle from cradle to grave. With increased system scale, however, modelling accuracy decreases as available data become progressively scarce and interactions are demanding to map. The International Organisation for Standardisation (ISO) prescribe generalised LCA guidelines and frameworks for data management of a systemic approach, ensuring the reliability of quantified outcomes and interpretation (Finkbeiner et al. 2006). This makes LCA of small scale product-service systems a useful research method and a reliable and policy instrument. On the contrary, for larger product-service systems, the amount of variables and interactions are increasingly numerous and make outcomes less accurate, reducing the LCA model's reliability for policymaking (McAvoy et al. 2021). This can consequently cripple the initial potency of LCA as a steering method for sustainable innovation. As a result, assembling matching data for understudied cases is either time consuming or the dependency on assumptions and proxy data increases (Heijungs et al. 2019). When a substantial quantity of variables must be translated to available datasets, proper data management is key to functional outcomes. For the assessment of the environmental impacts of sailing cruise holidays, a revised lifecycle approach can improve its practicability. A procedure for untangling the complexity of sailing cruise holiday impacts within a manageable timeframe, whilst maintaining a lifecycle perspective, will benefit constructive sustainable policymaking. This emphasises the need for a lifecycle approach to sailing cruise systems which is based on functionality for sustainable policy rather than computational accuracy.

This resonates with a famous quotation by statistician George EP Box – 'All models are wrong, but some are useful' – emphasising that model estimations cannot be exact, but can, in some cases, be used effectively for interpretation (Churchoe, 2020). The challenge of a systemwide lifecycle approach is therefore the compilation of a useful model which respects the complexity of interactions, whilst properly managing time and data constraints. Nonetheless, this view on a usefulness focus for LCA is not revolutionary. Where some LCA practitioners commit their lifework to perfectionating a detail-focused ISO approach (i.e. accuracy), other scholars have argued that reducing complexity and crossing with other disciplines is the way forward for functionality focused sustainability analysis (Guinée & Lindeijer, 2002; Weidema et al. 2002).

However, this report does not aim to revive a methodological debate on LCA procedures; instead, the focus is on evaluating whether a usefulness-focused lifecycle approach is a foundation for sustainable policy. In this report, usefulness relates to *informing sailing cruise holiday stakeholders with insights on impact contributing elements and feasible impact reducing alternatives.* For the realisation of this use, data integrity and constraints should be anticipated in a study design from which this functional interpretation can be distilled. This report therefore aims to combine procedural elements of LCA in a comprehensible improvement-oriented framework design. Certain elements from standardised LCA are included in the study design, but the research structure is focused on a broader lifecycle approach by relating elements to existing datasets. The study design follows a pathway from a systemwide, aggregate and comparative impact level, to a detailed and solution focused subsystem level. By targeting system elements on their contributions to a collection of environmental impacts, detail and scope will increase for a filtered set of activities. The aim of this design-oriented research is to assess the effectivity of this approach as a policy tool for case study stakeholders. The case study is performed on sailing cruise holidays provided by the *Rederij Clipper Stad Amsterdam* (RCSA). The research design, inputs for case study computations and systemic perspectives of impact assessment are partly based on semi-structured interviews with various stakeholders and experts.

This report ultimately aims to answer the following main research question by studying five chronological sub questions. First, however, a theoretical framework for design-oriented research is presented and linked to predominant design thinking (DT) and sustainability concepts. A framework design for the lifecycle approach to sailing cruises is subsequently presented, after which it is applied to a case study. Lastly, the effectivity of the approach is discussed, followed by a conclusion on its wider inferred implications for the study domain.

Main research question:

How can a lifecycle approach be applied to sailing cruise ship services and contribute to a better understanding of the distribution of environmental impacts related to a sailing cruise voyage and provide feasible impact reduction alternatives for major impact contributing elements in a case study?

Sub questions:

1. What aspects of LCA can be applied to a design for a systemwide functionality-focused lifecycle approach?
2. What background and foreground data sources serve as an input for the lifecycle inventory of a sailing cruise lifecycle system?
3. What are the focal points of impact hotspots and impact recurrence when implementing fast-track LCA on a clipper ship case study?

4. Which low-impact system elements can substitute for main impact contributors and lead to a quantifiable impact reduction?
5. How can insights into the complex lifecycle system of sailing cruises contribute to the design of a generalised method for the sector?

5.1 Thesis overview

This report consists of ten chapters that build upon each other. After the introduction chapter, the approach of the study is presented. As the report follows a design-oriented research structure, the choice for this type of research is clarified (see chapter 6.1.). The approach chapter focuses on the theoretical background of the usage of design thinking within sustainability disciplines. The chapter introduces the benefits of visualising and evaluating novel conceptual designs: innovation is dependent on new perspectives, therefore sustainability solutions require design thinking.

The following chapter introduces the central framework design for this report (see chapter 7). The chronological procedures are explained and visualised in a sequential design that reflects the main goal of the thesis: determining the distribution of environmental impacts related to a sailing cruise voyage and formulate feasible mitigation pathways. Furthermore, the chapter couples the framework design to the methodological context of DT, sustainability science and LCA. The chapter concludes with a template pathway for the assessment of a hypothetical sailing cruise lifecycle system.

In the subsequent case study chapter (see chapter 8.), all framework steps are applied to a sailing cruise voyage with the RCSA. This results in an overview of how the design should be followed and how insights emerge from following the framework's lifecycle approach. A quantification is made for the systemwide impacts, and consequently for the two main contributing subsystems' feasible reduction. The final step concludes in presenting the general output of the approach.

After completing the case study, the frameworks' inferences are discussed and its capability of answering the main research question is reflected upon (see chapter 9.). The strengths and weaknesses of the approach are discussed in relation to a wider application in the sailing cruise sector. Finally, the main conclusions of this reports design oriented lifecycle approach in relation to the research questions are presented in the last chapter. In the reference section and appendices, additional information can be consulted. Confidentiality of certain information resulted however in the exclusion of certain company specific information in this document.

6. Approach

This chapter is dedicated to the theoretical substantiation of the usage of a design-oriented research approach. To design a framework which has the capability of answering the aforementioned research questions, an introduction into this type of research approach is indispensable. As the report orientates on designing and testing a framework for the fulfilment of the research objective, the research design is part of the outcome, along with the lessons drawn from testing it. First, however, the concept of a design-oriented research approach is explained and linked to the use of a lifecycle approach.

6.1. Design-oriented research

One can see design-oriented research, where research is the area and design the means, as a conduct which seeks to produce new knowledge by involving design activities in the research process. Here, design drives and propels research (Fallman, 2007). In the 1960s, design-oriented research began to draw the attention of scientific researchers and methodologists, not only in technical engineering but also in the social sciences (Verschuren & Hartog, 2005). Later, Frayling (1993) propelled a debate after publishing *Research in art and design*, in which he parsed the prevailing concepts and discussed how art can be research and research can benefit from DT. More recently, Carlgren et al. (2014) formulates DT's part in research as 'a prescriptive process where multidisciplinary teams take a user-oriented approach to come up with relevant solutions to complex or "wicked" problems'.

Over the years, DT and design-oriented research have received increasing interest in sustainability science (Buhl et al. 2019). As most sustainability issues require an interdisciplinary approach to various complex systems, the development of research designs or frameworks help to make systemic interactions comprehensible. In the field of industrial ecology, DT took a part in the development of sustainability frameworks and assessment methodology such as LCA (Ehrenfield, 2004; Melles et al. 2011; Baldassarre et al. 2019). Moreover, industrial ecology is as a designed system approach, which has been continuously tested and improved since its conception. According to Jelinski (1992), 'Industrial ecology is a new approach to the industrial design of products and processes and the implementation of sustainable manufacturing strategies'. Design-oriented research has thus been a widely used theory for approaching various abstraction levels of system science. Furthermore, design-oriented research has played a significant role in the development of sustainability-oriented innovations (SOI; Buhl et al. 2019). Hansen and Grosse-Dunker (2012, p1.) define an SOI as follows:

> Sustainability-oriented innovation (SOI): the commercial introduction of a new (or improved) product (service), product-service system, or pure service which – based on a traceable (qualitative or quantitative) comparative analysis – leads to environmental and/or social benefits over the prior version's physical lifecycle (from cradle to grave).

This definition therefore relates to the aim of this report: mitigating environmental impacts by examining and filtering technically feasible low-impact alternatives in the product-service system of sailing cruise holidays. The conceptual background of DT and SOI should thus be followed to compose a functionality-focused lifecycle approach to sailing cruise holidays.

Conceptual design for SOI

Although Frayling (1993) initially noted that DT in research should follow from a creative and free process, Buhl et al. (2019) conceptualised the process of research design for SOI (see Figure 1). As their definition of an SOI relates to the research objective of this report, it incorporates their approach benefits in the framework design of this study (see chapter 7.2.). They state that there is a continuous need for adequate methods, frameworks and tools which enable companies to successfully develop an SOI, for which proper design is key. Buhl et al. (2019) state that in a proper research design for SOI, the five DT key principles should be related to the four main SOI challenges. Figure 1 depicts connections which illustrate the favourable conceptual approach to SOI development according to their study. The DI-SOI relations depicted in Figure 1 (P1 to P4 and visualisation) are connected to a proposed design.

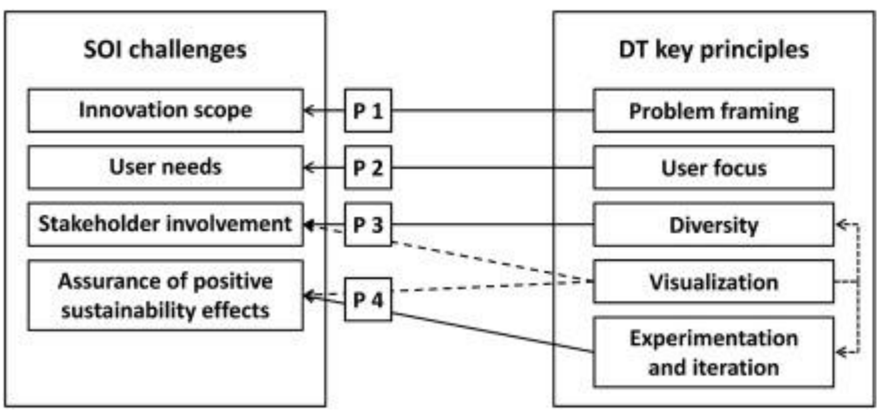

Figure 1. Overview of the four central SOI challenges and the five DT key principles. Source: Buhl et al. (2019).

7. The SAIL framework

This chapter introduces the Seafaring Applied Impact Ladder (SAIL), the framework design which forms the basis of this report. The following sections describe the SAIL procedures and link it to design-oriented research concepts, such as DT-SOI relations and (fast-track) LCA methodology.

The SAIL serves as a tool to quantitively substantiate transition pathways for sailing cruise lifecycle systems. The framework consists of five consecutive steps, starting at an aggregate system level and concluding with a description of subsystems for which a decrease in environmental impacts is technically feasible. The tool design is focused on gaining useful information from systemwide impact assessment in situations where data and time are limited. The SAIL therefore integrates parts of classical 'robust' LCA, such as terminology and procedures from the LCA framework (see Figure 4, Section 7.3.); however, it mainly focuses on 'fast-track' LCA (explained in the SAIL and LCA section) in specified phases of the framework's 'ladder steps'. Insights gained from the ladder steps cultivate focal points for impact reduction governance, as quantified outputs of the model present feasible impact reduction pathways. The SAIL reduces complexity by coupling system elements with existing datasets where possible and only extending subsystem-specific complexity where it is argued to be necessary. Consequently, the SAIL includes LCA elements but differs from other types of LCA procedures in dynamically interpreting the level of (sub)system detail. The SAIL's procedures are tailored to the research questions and inspired by a design-oriented research approach. In the figure below (see Figure 2), the conceptual design of the SAIL is presented. The letters within the SAIL acronym are corresponding with themes in the adjacent steps: Seafaring (step 1 and 2) Applied (step 2 and 3), Impact (step 3 and 4) and Ladder (step 4 and 5).

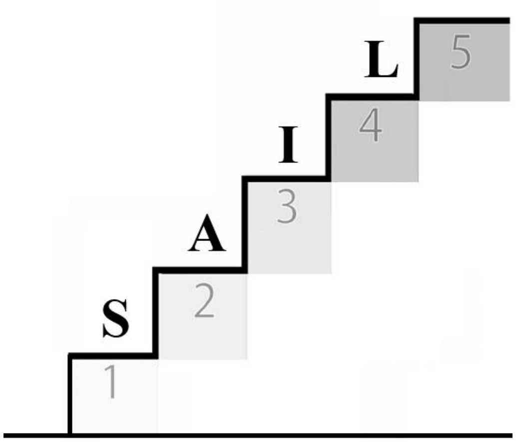

Figure 2. Conceptual design of the SAIL.

7.1. The SAIL procedure

1. Rules of the game: Explore conditions of the sailing cruise tourism sector in which the system is embedded and set the overarching system boundaries and scope. A set of three indicative impact categories are selected which form the basis of comparison. To set the initial system boundaries and scope, ISO 14040 procedures are followed (see SAIL and LCA section). System properties are condensed in a set of rough-cut subsystems (i.e. a maximum of 10) and their accessory flows, which are collectively required by the functional unit (i.e. a single guest one-week voyage).

2. Relative contribution: The formulated subsystems are related to quantified inputs derived from (case-specific) foreground data inputs and coupled to background datasets for the performance of a comparative fast-track LCA analysis. The relative impact contribution of subsystems form the conditional basis for progressive analysis. Subsystems with a relative impact contribution below 5% are excluded from impact reduction analysis in step 4.

3. Results and discussion: Reflect on the interpretation of foreground data, use of background datasets, assumptions and computation of relative impact contribution. Perform a sensitivity analysis to subsystem detail and modelling choices. Determine subsystems to consider for further analysis based on recurrence and justified relative contribution.

4. Impact reduction feasibility: Explore low-impact substitution of elements in high-impact subsystems. Perform another fast-track LCA analysis for comparison of ex-ante and ex-post implementation of the low-impact intervention.

5. General output (GO-SAIL): In this phase, the interpretation of the computations in previous steps are presented. Recommendations for the substitution of high-impact contributing elements are set out. Policy suggestions are based on the technically feasible impact reduction potential of substituting elements and discussed with the involved stakeholders.

The aforementioned procedures are summarized in a visualisation presented in Figure 3 below.

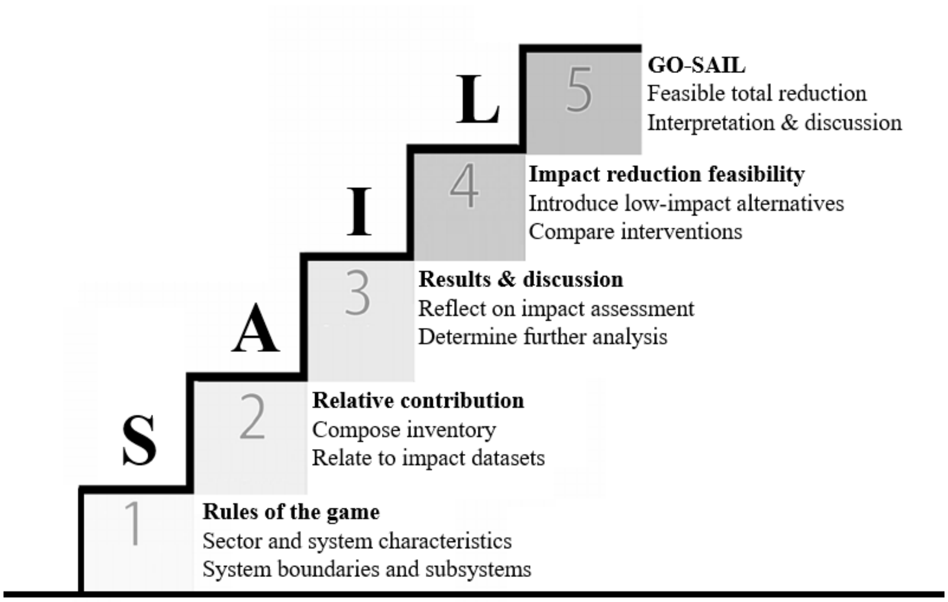

Figure 3. Chronological SAIL progress.

7.2. SAIL and DT-SOI relations

This section discusses the design of the SAIL framework in relation to the prerequisites which Buhl et al. (2019) prescribe for an SOI design. The paragraphs below refer to DT-SOI relations (P1 to P4 and visualisation) presented in Figure 1 (see Section 6.1) and justify the design of SAIL as a conceptual trajectory for SOI.

P1: Innovation scope and problem framing

When attempting a transition towards a more sustainable sailing cruise holiday product-service system, it is time-consuming to map exact environmental burdens of every element. More effective is a research design which focuses on major culprits and increase data resolution only for high-impact elements. An impact focus follows from relating the provided service (functional unit) to a comprehensible set of impact categories. An impact reduction focus follows from exploring feasible impact reduction by substituting high-impact elements.

P2: User needs and user focus

Companies who offer sailing cruise holidays need a strategy to minimise the environmental burdens of their practices. Although sailing cruise holidays are potentially a low-impact alternative to conventional fuel-based cruise holidays, the distribution of impact contributions of sailing cruise holidays are underexamined. To comply with increasingly stringent international targets, shifting consumer demands and cruise tourism regulations, sailing cruise operators must transition towards more sustainable practice of their services. Sailing cruise operators need a comprehensive approach to estimating impacts and setting targets for feasible impact reduction.

P3: Stakeholder involvement and diversity

Diversity in DT refers to the collaboration between multidisciplinary innovation perspectives. Input from stakeholders of sailing cruise operators is needed to properly understand and approach the sailing cruise lifecycle system with the SAIL. Practical policy advice resulting from a quantified impact reduction opportunities will help stakeholders to make substantiated considerations for the implementation of low-impact innovations.

P4: Assurance of positive sustainability effects, experimentation and iteration

The integration of LCA methodology into the SAIL seeks to assure a decrease in environmental impacts. By testing, reflecting and iterating within the SAIL steps, insights are gained for improving initial assumptions whilst estimating the impacts of subsystems, substituting elements and the functional unit. The design aims to be self-improving and critical of its dimensional limitations.

Visualisation

The visualisation of the SAIL framework facilitates the communication of the research design to various stakeholders and shows a simplified progressive trajectory in which computational considerations are set out. Ascending the ladder is an analogy for improving the level of sustainable practice, whereas its limited dimensions provide room for interpretive discussion.

7.3. SAIL and LCA

This section presents the LCA elements which are incorporated into the SAIL framework. The SAIL does not aim to scrutinise classical views of LCA, but rather seeks to form a symbiosis with more progressive views on functional implementation of a lifecycle approach such as fast-track LCA methodology. Nevertheless, general LCA guidelines form a practical lifecycle approach to impact assessment methodology and terminology. For definition of LCA nomenclature and concepts, please consult the glossary (see page 6). The following paragraphs are dedicated to clarifying the methodological elements of LCA which are incorporated in the SAIL.

As mentioned in the introduction, LCA comprises standardised sets of regulations and computational methods for safeguarding the generalisability of results. ISO 14040 and ISO 14044 are the leading current international standards on LCA (Heijungs et al. 2021). The focus of these standards is on how an LCA assessment should be performed when following a service or product's impact from cradle to grave. ISO 14040 describes the 'principles and framework for LCA', while ISO 14044 'specifies requirements and provides guidelines' for LCA (ISO, 2020). The aim of these guidelines is to articulate a standardised pathway for the practice and reporting of LCA studies. In the guidelines, a framework of four interrelated steps is presented (see Figure 4). The guidelines state that the intended application of LCA interpretation and lifecycle impact assessment (LCIA) results should be considered during the goal and scope definition. A lifecycle inventory (LCI) is subsequently composed with the considered data elements. During the impact assessment phase, the LCI is related to the adequate impacts with the use of computational software. Interpretation is interlinked with all previous steps and forms the basis for its intended application.

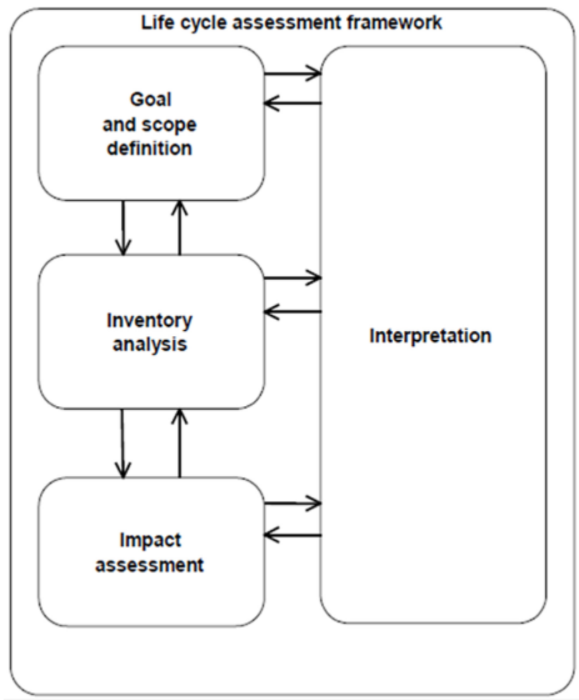

Figure 4. Framework for LCA (ISO 14040; from: Guinée & Lindeijer, 2002).

The classic LCA design as described in the ISO standards is formalised to safeguard reliability and accuracy for numerous modelling situations. However, one of the aforementioned major drawbacks, which the SAIL aims to reduce, is the time-consuming nature of data acquisition required for performing this classical type of robust LCA. Preserving the integrity of the outcomes thus forms a trade-off with the usability of the method. For this reason, several attempts have been made to perform fast-track LCA in diverse fields of study (Bakker et al. 2012; Cozijnsen, 2019; Ng, 2016). Although the accuracy of this type of LCA analysis is reduced, the generic usability for comparative assessment is still viable. Consequently, the SAIL includes fast-track methodology in its lifecycle approach.

Flexible use of reducing a systems complexity has thus shown to benefit the usefulness of the LCA approach (Hong et al. 2017). The SAIL is an example of a framework which aims to increase analytical complexity for phases where robustness is needed for comparative assessment. A systemwide analysis can thus be performed over a large and complex system: sailing cruise holidays. The SAIL forms a visualised design of the goal and scope definition step from LCA analysis, whilst interpretations of interrelated phases are continuously performed. The SAIL relates to the LCA steps presented in the figure above (see Figure 4) as follows:

Goal and scope definition – SAIL

The systemwide scope, related to providing the functional unit (i.e. a single guest, one-week sailing voyage), is divided across a set of subsystems which are required to provide a sailing cruise holiday. With this reduced scope complexity, only aggregate subsystems are analysed, and the goal is to find the greatest contributing subsystem. The scope of this subsystem will remain rough-cut or increase in detail according to the interpretation of the SAIL 'result and discussion' step (step 3). A second goal is to explore technical impact reduction feasibility of major subsystems, resulting in a feasible reduction of the systemwide impacts. The single direction of assessment, moving up the ladder, translates to the goal of the SAIL assessment.

Inventory analysis – SAIL

The inventory is based on provided foreground data (from a case study) and background datasets (from several LCA databases) with the use of (initially) rough-cut assumptions. The inventory lists are divided over a manageable amount of aggregate subsystems, depending on the study case. The reflection on inventory and assumptions makes the inclusivity of the inventory a dynamic feature: inventories may increase in detail based on the justification of the subsystem scope in SAIL step 3.

Impact assessment – SAIL

The aggregate comparative impact assessment of the subsystems is performed to shape an idea of the distribution of impacts between subsystems. However, consecutive impact assessments between subsystem elements and substitutes allow more detail when progressing along the ladder. Impact assessment is focused on comparative assessment, as the rough-cut approach to certain elements will result in deviated impact outcomes.

Interpretation – SAIL

During the SAIL procedures (see section 7.1.), interpretations are made in multiple steps. During the results and discussion step, the numerical results are interpreted and used for justification of modelling assumptions. The GO-SAIL step is another typical interpretation step, in which inferences are composed from the numerical modelling outputs. Apart from these two steps, the interpretation step is dynamically integrated in the SAILs procedures as the interpretation influences the practice.

Computational methodology

For the arrangement of the LCI, various compatible datasets which are available in the SimaPro 9.2.0.2 software tool are used: Ecoinvent 3.8, ELCD, IDEMAT 2.1, LCA Food DK, and World Food LCA Database. For the LCIA, the Ecocosts 2022 V1.1 calculation method is used, which generates outputs in the form of absolute and relative impact quantifications and provides a function for the costs to remove environmental burdens (see Figure 5). The methodological focus is suitable for fast-track LCA and comparison of alternatives (Bakker et al. 2012). In addition, the calculations, figures and LCI are supported by using Microsoft Excel. The impact assessment is related to the functional unit: *a single guest, one-week sailing cruise voyage*.

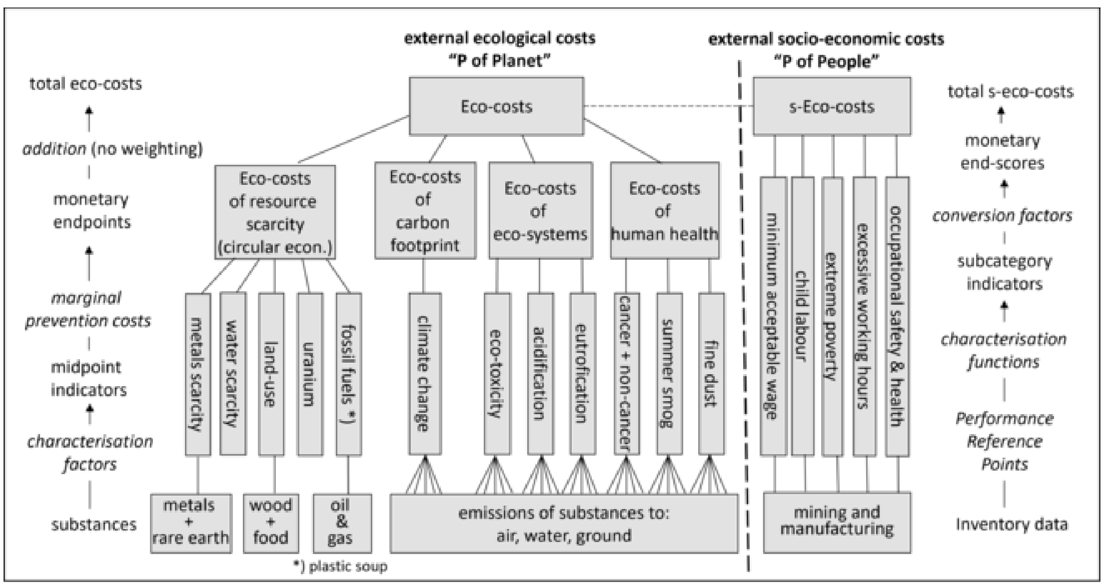

Figure 5. Ecocost conceptual framework. Source: Vogtländer et al. 2019.

7.4. Template for SAIL analysis

The previous chapters illustrated the research gap in impact assessment applied to sailing cruises. The SAIL framework has been introduced and coupled to the principles of DT, SOI and LCA. Before performing a case study with the SAIL, it is important to elaborate on the dynamic properties of the SAIL. This section is therefore dedicated to a fictional pathway of analysis with the SAIL (see Figure 6). The visualisation of this template pathway is dedicated to ensuring the understanding and generalisability of the SAIL approach to wider application, before coupling the design to a case study in subsequent chapters.

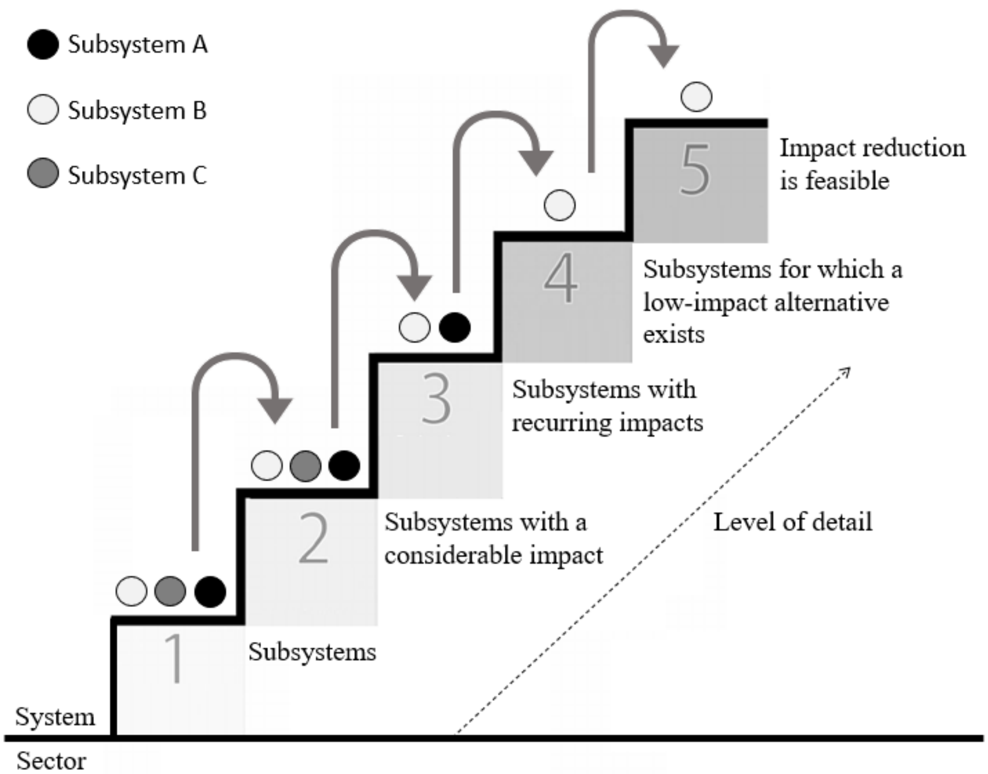

Figure 6. Template pathway for analysis of a fictional sailing cruise lifecycle system with SAIL.

Base level: The characteristics of the analysed sailing cruise lifecycle system are described, forming a distinction of the system relations which can be ascribed to the system and the interrelations with sector aspects. Impact indicators are of interest for analysis. Furthermore, the functional unit for sailing cruise holidays is: providing a single guest with a one-week voyage.

Step 1: Using the means available in fast-track LCA and the various available datasets, the complete lifecycle of a sailing cruise holiday is simplified for computational analysis with the SAIL. Foreground datasets are assembled and coupled to three subsystems. The choice for an amount of subsystems is based on the complexity of the system (i.e. case-specific) and on the amount of separable systems to be analysed (i.e. subjective). Consequently, a comparative analysis is based on rough-cut assumptions.

Step 2: The inventory of foreground processes is coupled to background datasets, from which comparative subsystem assessment is computed. In the fictional example case above (see Figure 6), all three subsystems contribute to more than 5% of the total impacts and are thus regarded to have a considerable impact contribution to the provided service. Therefore, subsystems A, B and C are visualised in step 2 of the SAIL.

Step 3: The results from the previous steps are discussed and assumptions are reflected upon. As previous analysis is based on rough-cut assumptions, justifications should be properly listed. Subsystems which are related to non-recurring impacts can be omitted from detailed analysis. Additionally, impact alterations due to increased inventory completeness or detail of analysis may influence the 5% rule justification. In this case, subsystem C is not included in further steps of the SAIL, as its impact was either non-recurring or improved detail resulted in an ‘inconsiderable’ impact contribution.[3]

Step 4: For the two subsystems with considerable recurring impact contributions (i.e. A and B), low-impact alternatives are sought. Substituting elements in the subsystems form an intervention which is tested in another comparative fast-track LCA analysis. The impacts relatable to the revised subsystem are compared to the original subsystem. Comparative analysis excluded subsystem A from the next step, as no feasible reduction can be observed.

Step 5: The low-impact alternatives are combined in a revised systemwide impact computation. Based on the feasible impact reduction in subsystem B, inferences are made for a quantitatively justified impact mitigation strategy. The suggestions for impact mitigation, combined with the model’s general output, contribute to insights for sustainability policies.

[3] A non-recurring impact relates to an event from the past that is not likely to repeat itself. An example: antifouling paints have recently been replaced with a durable coating that will outlive the ships lifetime, an antifouling paint subsystem would in this case show nonrecurring impacts (reasoning from a single ship).

8. Case study

In this chapter, the SAIL framework is applied to a case study on a sailing cruise company. As described in the chronological frameworks steps, the base level step of the SAIL focuses on an orientation of the sailing cruise holiday sector and their relation to the case study. The case study for this report is performed in collaboration with the RCSA. The company organise business events, luxurious cruises and adventure sailing trips. The focus of impact assessment with the SAIL is on adventure sailing trips (i.e. sailing cruises) provided by the RCSA. The following sections outline the SAIL steps from the base level to the final step (i.e. general output). Before determining the scope of analysis and impact indicators of interest, the SAIL's base level orientates on sailing cruise tourism sector characteristics.

8.1. Rules of the game

Rules of the game refers to the conditions and interactions set out by the sailing cruise tourism sector and the general shipping industry. By setting a theoretical basis for the SAIL ladder, substantiation of modelling choices in later phases relate to sector-wide conditions. Sector characteristics are therefore linked to the case study company. The system boundary and scope for the SAIL are based on this theoretical background.

8.1.1. The sector

In the shipping industry, concerns about environmental impacts have led to regulations on energy efficiency, marine pollution and other harmful externalities (IMO, 2020). The IMO, shipping's main regulatory body, have made efforts to develop technical and operational measures aimed at enhancing onboard environmental efficiency (Blanco-Davis et al. 2016). The Energy Efficiency Design Index (EEDI) promotes the use of more energy-efficient (i.e. less polluting) equipment and engines and defines the energy efficiency of a ship by its design. The EEDI requires a minimum energy efficiency level per capacity mile (e.g. tonne mile) for different ship types and size segments. The EEDI was made mandatory for new ships in 2011 (Joung et al. 2020) as the first legally binding climate change treaty to be adopted since the Kyoto Protocol. The Ship Energy Efficiency Management Plan (SEEMP), implemented simultaneously with the EEDI, is a ship-specific plan with energy-efficiency measures which must be implemented. It is an operational measure which establishes a mechanism to improve the energy efficiency of a ship in a cost-effective manner. The Energy Efficiency Operational Indicator (EEOI) is the indicator which expresses the efficiency in CO_2 emissions per unit transported cargo over a certain distance. The difference between the EEDI and EEOI is that the EEDI is and indicator for ships design, and the EEOI is an operational indicator.

The EEOI is calculated by the following equation:

$$EEOI = \frac{CO_2\ emissions}{\text{Transport}\cdot\text{Work}}. \tag{1}$$

The IMO aim to lower the CO_2 emissions of the shipping industry by 40% in 2030, by 70% in 2050 and to reduce emissions of all other greenhouse gases by 50% in 2050 (IMO, 2020). Recently, the IMO included passenger ships in GHG reduction factor regulations, which are implemented in phases. These regulations apply to passenger ships above 25,000 gross tonnage (GT). For smaller vessels, such as the Clipper Stad Amsterdam (CSA; 723 GT), GHG reduction targets remain voluntary (Lee et al. 2021). In addition to regulating GHG emissions, the IMO regulate marine pollution through the International Convention for the Prevention of Pollution from Ships (MARPOL), which focuses on direct pollution as well as pollution by air (Peet, 1992) and includes annexes on wastewater treatment and emissions of sulphur oxides (SOx), nitrogen oxides (NOx) and particulate matter (PM; Čampara et al 2018).

Another important regulatory body which has been established by the IMO is the convention for Safety Of Life At Sea (SOLAS). Especially for passenger ships such as the CSA, these standards form a recurring theme. The main objective of the SOLAS Convention is to specify minimum standards for the construction, equipment and operation of ships, compatible with their safety. Flag States are responsible for the surveying of ships sailing under their flag, after which passenger vessels can request their certificates (Brodie, 2014).

The current regulatory bodies mainly focus on safety, pollution and direct emissions from shipping. Indirect (lifecycle-related) environmental impacts of cruise tourism receive less attention. However, cruise tourism comprises a set of social and economic activities which use large amounts of natural capital and generate various significant environmental impacts (Paiano et al. 2020). Direct environmental impacts may be related to physical impacts, air emissions and discharges to water (see Figure 7). Indirect impacts can be attributed to all other lifecycle interactions related to production, maintenance and consumption patterns.

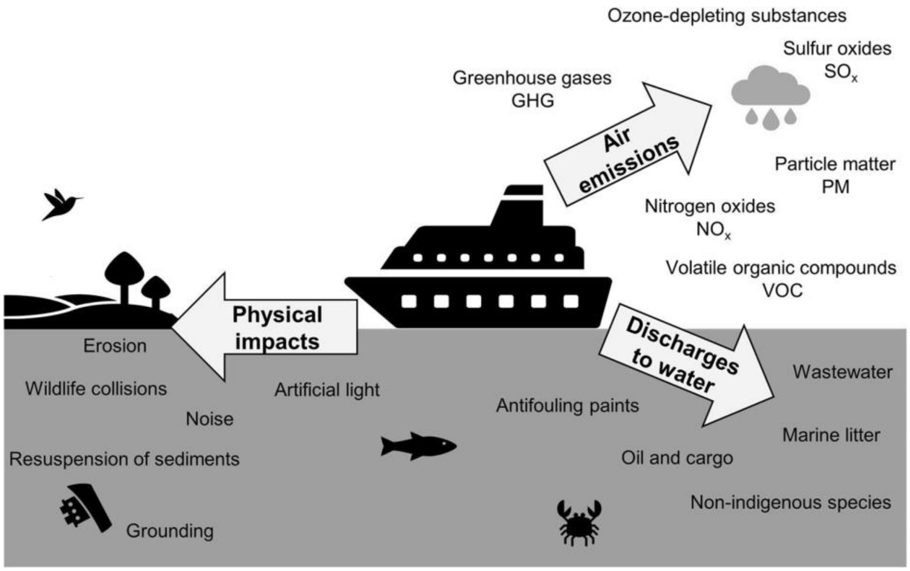

Figure 7. Direct environmental impacts of shipping. Source: Jagerbrand et al. 2019.

Thus far, LCA analysis has been of increasing interest mainly in the shipbuilding sector (Cozijnsen, 2019; Favi et al. 2018; Simons, 2021; Tincelin et al. 2010). As noted in the introduction, no LCA studies on operational sailing cruise tourism have yet been published. For the two systemwide LCA studies on conventional cruise tourism mentioned in the introduction (see Table 1, Chapter 5 p. 11), a conventional (fuel-based) cruise holiday lifecycle system was related to a reduced number of elements and subsystems. In Simonsen (2014), an LCA analysis was composed for a cruise holiday based on fuel use and shipbuilding estimations. Farr and Hall (2015) also included food consumption and excursions within their scope of analysis for a one-week, single-passenger voyage. Both studies included one impact indicator, the global warming potential (GWP), expressed in CO_2 equivalents (carbon footprint). Simonsen (2014) assumed five materials for production and accounted for production and combustion emissions of fuel usage. It concludes with the estimation of CO_2 emissions per passenger km. The passenger km measurement is thus their functional unit of choice for analysis. Similarly, the previously introduced operational efficiency indicator, the EEOI, is also based on fuel consumption during operation and thus assumes that most impacts of ship operation are a linear function of fuel consumption. Whether this also accounts for sailing cruise holidays is reflected upon later in the last step of the SAIL, the general output (GO).

8.1.2. Functional unit and indicators

Choosing a functional unit and impact categories should be considered with care in a lifecycle approach (Heijungs et al. 2019). To determine the function of a product-service system such as cruise tourism, one should ask about the main product or service fulfilled by this system. A voyage on a cruise ship is not solely undertaken to cover a certain distance. Guests join a cruise ship voyage for recreational purposes. A commonly used statement by seafaring tourists is: 'It is not about the destination; it is about the journey itself'. The functional unit of cruise tourism should thus comprise more than distance travelled. Choosing a single guest, one-week voyage as a functional unit, as Farr and Hall (2015) suggest and the SAIL framework advised, is a more inclusive approach to impact assessment. Moreover, including multiple impact indicators provides a better representation of the complexity of systemic environmental impacts (Pieragostini, 2012). In addition to analysing the carbon footprint (GWP), as approached by the EEOI, in Simonsen (2014) and Farr and Hall (2015), impact assessment of the environmental impacts of (sailing) cruises would benefit from including additional relevant impact categories. Additional impact categories which relate to ecosystem functioning will provide valuable insights, as the 'experience values' of cruise tourism relate to cultural ecosystem services (Lillebø et al. 2017). Furthermore, the SAIL prescribes a set of three impact indicators relevant to a case study. The SAIL consequently assesses the following impact indicators:

1. *Carbon footprint (GWP):* a measure of the impact our activities have on the environment in terms of the amount of greenhouse gases we produce. It is measured in units of carbon dioxide equivalents (kg CO_2-eq).

Although the GHG-emission regulations set out by the IMO do not account for small passenger vessels such as the CSA, including the carbon footprint as an impact indicator is a viable modelling choice (IMO, 2020). As previously noted, sector-wide attention revolves around GHG emissions, whilst preliminary studies and carbon footprint indicators exist, which paves the way for future comparative analysis.

2. *Eutrophication*: a measure of the impact of activities on nutrient enrichment of water bodies, for which the damage is measured in units of phosphate equivalents (kg PO_4-eq).

Nutrient enrichment can occur with the spreading of various types of chemicals needed for primary production (plant growth). Eutrophication is the process in which an ecosystem receives an excess of nutrients, which can strongly harm ecosystem resilience and composition.[4] The effects of eutrophication can thus harm cultural ecosystem services required for a sailing cruise experience, making it a relevant indicator for analysis.

[4] Examples of eutrophication are the nitrogen crisis in The Netherlands and the ocean dead zone of the Chesapeake bay (USA) (Diaz & Rosenburg, 2008; Erisman, 2021)

3. *Ecotoxicity:* The comparative toxic unit for aquatic ecotoxicity impacts (CTUe) expresses the estimated potentially affected fraction of species (PAF) integrated over time and the volume of a water compartment, per unit of mass of the chemical emitted.

Ecotoxicity is, just as eutrophication, an ecosystem-focused environmental impact indicator. The (sailing) cruise lifecycle systems interacts with the marine environment by releasing various degrees of toxic elements into the biosphere. Including this indicator offers another viewpoint for the harmful effects of sailing cruises on an ecosystem (services) level.

8.1.3. The company

The RCSA's organisational structure is unique as a collaboration between the Municipality of Amsterdam and Randstad, a global leader in the human resources (HR) industry. The company headquarters are in Amsterdam, whereas the ship itself operates globally. The company prioritise sustainability progress and hope to reduce their environmental impacts, which makes it a suitable study case.

Data were gathered from online resources and through personal communication with the staff. Furthermore, interviews were held with varying stakeholders related to the company, and external experts in the fields of (cruise) shipping and sustainability assessment. The company provided reports and data sheets for analysis upon request. These reports and data sheets formed the basis for quantification of stocks and flows. A series of semi-structured interviews were conducted to compose realistic assumptions for modelling choices and add first-hand insights to the system. Certain data are confidential and will not be publicly disclosed.

The base year of all the retrieved data is 2018, unless stated otherwise. This was chosen as 2018 was the last 'normal' year for the travel sector. During the recent and ongoing global pandemic, activities have been paused and recontinued, resulting in fluctuating data points. Pre-pandemic numbers of passengers have thus shown to be higher, as unrestricted events and journeys were more common than at the time of writing. Therefore it is assumed that data from 2018 will be most useful for determining the structure and environmental interactions of the CSA. This was the year before a large maintenance refit took place (October 2019), making it the closest full year in which business was 'normal'. The current continuation of the business strategy focuses on the revival of pre-pandemic activities, making a pre-pandemic data review the most useful alternative.

As previously specified, the RCSA divide into three core business activities: (corporate) events, luxurious (sail) cruises, and adventure (sail) cruises. The focus for analysis is on the adventure sailing cruise, for which data on activities are condensed to a weeklong voyage onboard the CSA. The data collection for each specific subsystem were used to build a general insight into the sailing cruise lifecycle system, which was then used for further interpretation.

8.1.4. System boundary

This section presents the system boundaries and scope of study. As noted in the SAIL introduction, the system boundaries and scope is a typical LCA methodological step and is incorporated into the SAIL. This section thus contains multiple figures and terminology related to LCA; however, these steps are all part of the SAIL.

First, the subsystems are set out in a flow chart, which is then related to the perspective of analysis. Secondly, the inventory table and impact assessment were based on the databases available in the software and preliminary LCA studies in the shipping sector. This is followed by a description of how the relative contribution of subsystems play a role in decision making for analysis at an increased resolution. The thoroughness of analysis of subsystems therefore varies, after testing its relative contribution and scope of influence. The relative contribution shows a ratio in which a subsystem is responsible for certain impacts determined by the functional unit and impact categories. The relative contribution consequently serves as a proxy for the sensitivity of the system to a specified subsystem.

Figure 8 below presents the system boundaries and subsystem of the sailing cruise lifecycle system. For each subsystem, the economic flows are given as an input (arrow coming in) and output. The final reference flow is a single guest one-week voyage onboard. Consequently, there is one output flowing out of the system boundaries: the reference flow to be analysed. For each subsystem, it is noted how background data for the first aggregate inventory table and impact assessment were handled.

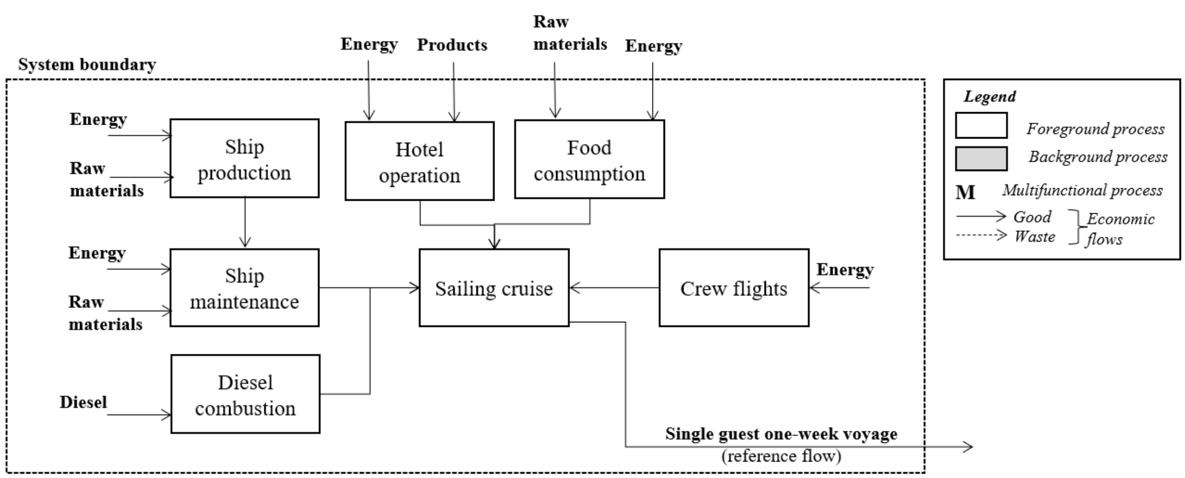

Figure 8. Flow chart LCA system of a single guest one-week voyage onboard the CSA.

As the CSA is currently operating and providing sailing voyages, the system is examined from a cradle-to-gate perspective (see Figure 9). Upstream processes are included in the scope of analysis, therefore including raw materials and historical inputs. Downstream processes however, such as an end-of-life (EOL) scenario for the ship are kept out of the scope.

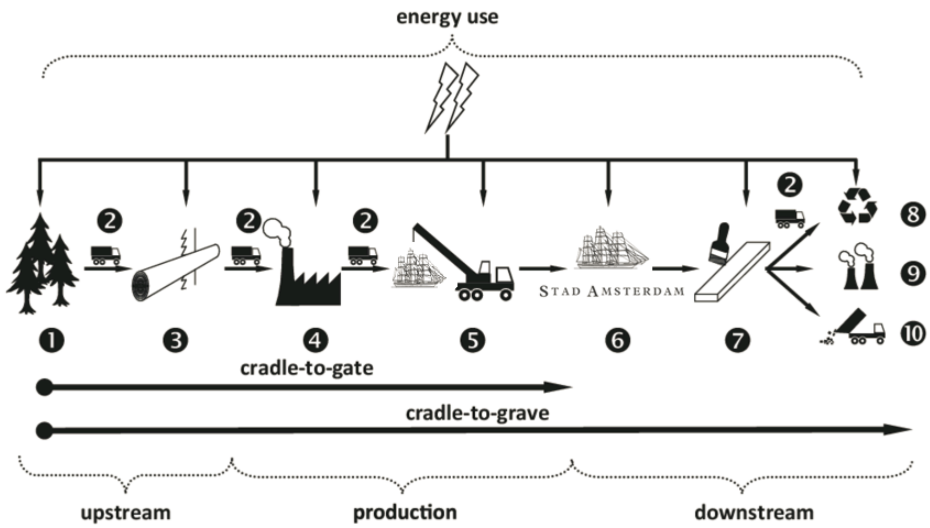

Figure 9. Cradle to gate perspective CSA.

Furthermore, on-board domestic waste scenarios are not included in the LCI model. The LCIA results are assigned to the previously introduced three impact categories. Consequently, the first step of the SAIL is completed; sector and system characteristics are described, preliminary impact assessment papers are considered, six subsystems are sketched and related to a set of impact indicators (see Figure 10). The colour coding for the subsystems presented below, will be used for the corresponding sections that follow in the report.

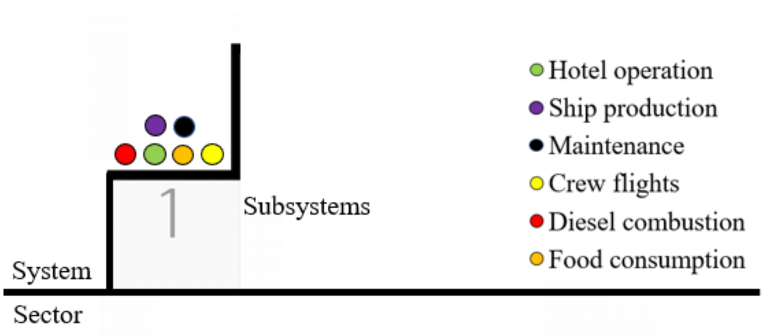

Figure 10. SAIL progress and subsystem colour coding.

8.2. Relative contribution

This section follows a course approach for the composition of each LCI subsystem in the model. The modelling choices for each subsystem is explained, as it relates to available background data in the used databases. The LCIA in this section notes which systems are considered for the next level of analysis in the SAIL. The corresponding LCI tables and figures are in Appendix A1. The subsystem analyses are addressed as listed below, followed by a comparative impacts assessment.

1. Ship production
2. Hotel operation
3. Food consumption
4. Ship maintenance
5. Crew flights
6. Diesel combustion

8.2.1. Ship production

The CSA was designed by Gerard Dijkstra and build at the Damen Shipyard in Amsterdam (see Appendix A1.1). In 2000, the ship was launched and taken into use. The starting point for the determination of the environmental footprints of the shipbuilding process is the mass balance, which was composed during the design and production phase (see Appendix A1.1). The mass balance comprises the inputs for the first (aggregate) model of the production subsystem. Estimations were made for the composition of the specific material with the use of interviews and personal communication., the lifetime of a commercially operating ship is Generally assessed to be approximately 25 years, whereas for pleasure yachts a lifetime of 40 years has been approximated (Cozijnsen 2019; Dinu & Ilie, 2015). As the CSA has another cultural and iconic function and some similar ships are antiques, the assumption for its lifetime must be approached differently. In several meetings, it was discussed that assuming a lifetime of 50 years for the CSA would serve the situation better (see Appendix A2.5).

In these interviews, material distributions were matched with the functional description in the mass balance table. Furthermore, sail specific materials and activities were matched to Simons (2021), in which an LCA on the shipbuilding process of a 500GT sail cargo ship is described. The sail-specific categories were coupled to material data present in the database (see Appendix A1.1). After relating these specific categories to the according proxy data from Ecoinvent, the residual mass was ascribed to be non-sail specific (bare ship). The non-sail specific parts include the assemblage of all parts which are related to the basic functioning of a ship. By relating the residual light weight tonnage (LWT; non-sail specific) to the LWT of a background dataset on ship production, a proxy was created for the non-sail specific burdens of ship production. Including this category resulted in an additional group of inputs, which are included in the LCI.

8.2.2. Hotel operation

Under the 'hotel operation' subsystem, all of the needed supplies for providing a comfortable stay onboard are considered, including a variety of materials which need to be in place to make the hotel service a complete system. In this system, the material demand for various products (e.g. matrasses, washing machines, lamps and cleaning detergent) are considered. In the Ecoinvent database, a dataset for hostel operation is available. In this dataset, which is based on a short stay at a hostel in Rio de Janeiro, Brazil, various datapoints are embedded and calculated accordingly. This dataset ultimately provides a useful basis for an estimation of the impact contribution of the hotel services on-board the CSA. To perform a rough estimation of an impact assessment, the background dataset will serve a useful input for the LCI. For the hotel operation category, the input unit is a guest night. The input in the table was therefore seven guest nights, which comprise the functional unit of one passenger week. In Appendix A1.2, the full description of the included categories is visible.

8.2.3. Food consumption

For the estimation of the impacts related to the food consumption during a voyage onboard the clipper, the RCSA provided a provisioning order list. The order lists specify the products for provisioning. Generally, food and drinks are bought in bulk when in ports. In Europe, and especially in the Netherlands, certain food types and products are extensively gathered. Among these are specialty goods and goods which are hard to find in other locations (e.g. *bitterballen: fried meat balls*). When stocking up for journeys or events, local suppliers are requested to deliver the goods. These local suppliers rely on imports, which vary by location. The demanded goods are generally not adapted to the visited country, but rather tailored to the guest's demand (hospitality interview, Appendix A2.11). Transport of food products to exotic destinations (e.g. the Caribbean) is not included in the LCI. The order list which is studied for this subsystem was used for the provisioning of an adventure sailing cruise from Las Palmas to Martinique in 2018. The trip lasted 18 days and was sold out (28 passengers onboard; A2.2). For the calculation, it is assumed that all the food which was ordered in Las Palmas was consumed during the crossing, and that this was the sole source of food input for the passengers. All products are categorised according to the provisioning list, resulting in 15 consumable categories which were then related to a proxy dataset from Ecoinvent, World Food database and LCA Food DK database. For example, all fish related orders were summed for the 'fish' category; the amount of consumed fish per person per week was related to the Ecoinvent background dataset on fish sticks ('Fish sticks Hake'). For the summary of all category inputs and related datasets, see Appendix A1.3. As previously specified, the transport to Las Palmas (Canary Islands) is not included in the LCI, the location to which the used dataset corresponds is listed in the LCI table.

8.2.4. Ship Maintenance

For the composition of the LCI table related to the maintenance regime of the CSA, the Ecoinvent database was consulted. In the databases, a dataset on container ship maintenance was found. A container ship clearly serves a different purpose than the CSA, but if carefully used, it can serve as a proxy for the first LCI composition. For this reason, the underlying modelling choices of this background dataset are assessed. A container ship has different characteristics in regard to durability, sailing time, wear and tear, regulations and materials. Nevertheless, the material of the hull is in both cases steel, for which protective layers have to be applied on a regular basis. For this estimation, the sail specific characteristics of the CSA are thus left out of the first scope for this subsystem. The following description is given for the container ship dataset:

> The dataset represents the maintenance of one container ship with a load capacity (DWT) of 43,000 tonnes. It is assumed that the ship undergoes two full maintenance regimes (stripping and repainting of all surfaces) and four smaller maintenance regimes (stripping and repainting of the hull) during an assumed 25-year lifetime (Demirel et al., 2013 and Hayman et al., N.d.) The dataset includes the quantity of paint used, emissions of volatiles, and emissions of paint to land and water from stripping and application. The dataset also includes the material and energy required for sandblasting, and emissions of particulates. A 10% replacement of steel over the ship’s lifetime is assumed from Johnson & Fet (1998).

For the lifetime of the CSA, a similar lifetime assumption as for the production subsystem is made: a lifetime of 50 years (i.e. 25 years for the container ship example). For intervals of maintenance regimes, assumptions are adjusted to the background dataset. The input value for the CSA is corrected for lifetime and scaled based on the dead weight tonnage (DWT). Following this assumption regime, the net input per person per week is 1.373E-06 container ship maintenance regimes (see Appendix A1.4).

8.2.5. Crew flights

The CSA and its passengers are continuously taken care of by a varying crew. Crewmembers take shifts in manning the CSA with an average of 32 members. The crew onboard the CSA works according to a schedule. In general, most of the crew will be onboard for a period of two months, after having a single month leave. As the ships operation area is mainly around the Atlantic ocean and Mediterranean, crew will often travel by flight towards their home destination (see Figure 11). The green line in the figure depicts the route which is undertaken in most years (and in 2018), meaning that the travelled distance by crew is relatively stable over the years, depending on nationalities and activities.

Figure 11. Main sailing route Clipper Stad Amsterdam. Source: Stad Amsterdam (2022).

This subsystem is consequently seen as an important element which contributes to providing the guests with an experience onboard. The journey which passengers undertook for joining the cruise onboard the CSA however, is left out of the study scope. The crew flight distance is based on a dataset provided by the RCSA, in which all the flight movements made in 2018 are presented. In 2018, 375 flights were booked, covering 1,807,500 km. For the interpretation of the amount of flights per week, the total flight distance was corrected to a weekly input per person (i.e. guest). A repeated assumption of a total of 52 operational weeks and 28 passengers onboard is used. Furthermore, it is assumed that all flights were direct, long-haul flights. This results in the LCI show in A1.5.

8.2.6. Diesel combustion

For the calculation of fuel usage per passenger week, another set of input data was gathered from the RCSA. The fuel input is used to power the main engine, the generators and a diesel hot water boiler. The main engine is used for propulsion of the ship moving in and out of harbours and when the wind is unfavourable on the open water. A set of two main generators and an emergency backup generator power all electrical systems onboard. Furthermore, the diesel boiler is used to produce hot water for domestic facilities. The main engine and generator systems were renewed during a refit which started in October 2019 to improve the efficiency of the diesel consuming systems to reduce fuel usage. A selective catalytic reduction (SCR) system was installed, which filters the exhaust fumes. The implications of this refit on the results is discussed in the reflection section.

The available data on diesel usage ranges from January 2019 till May 2022. As 2018 is considered for this analysis, the focus is on a relatable period closest to the reference year. In this stage of analysis, the period from January to September 2019 is thus consulted for input. The total amount (in litres) of these nine months is converted into consumption per week, followed by a division for the 28 passengers. This is subsequently converted from litres into megajoule (MJ), which is the preferred input for the background dataset. The conversion results are presented in Appendix A1.6.

The available background dataset is composed for the usage of diesel in fishing vessels. For the use of this background dataset, it must be assumed that diesel engines and generators in fishing vessels operate at a similar efficiency. A certain amount om MJ of diesel input is thus assumed to be relatable to a certain quantity of impacts when combusted. The description of the background dataset is as follows:

> This process describes the consumption of diesel in fishing vessels. The process includes the combustion of diesel in marine engines. Tier 1 emission factors for fishing vessels using marine diesel oil/marine gas oil were retained, following the EMEP/Corinair 2013 guidance of the European Union (Nielsen, 2013).

8.2.7. Comparative computation

In this step of the SAIL analysis, the focus is on comparative assessment between the subsystems with the use of the previously described *ecocosts 2022 V1.1 V1.01 / eco-costs 2022* calculation method. For the characterisation of the impacts in the chosen categories, the next section presents a revision of the initial input (see Section 8.3). With the use of this first analysis, the percentual relative contribution of the subsystems is distinguished in a graph (see Figure 12).

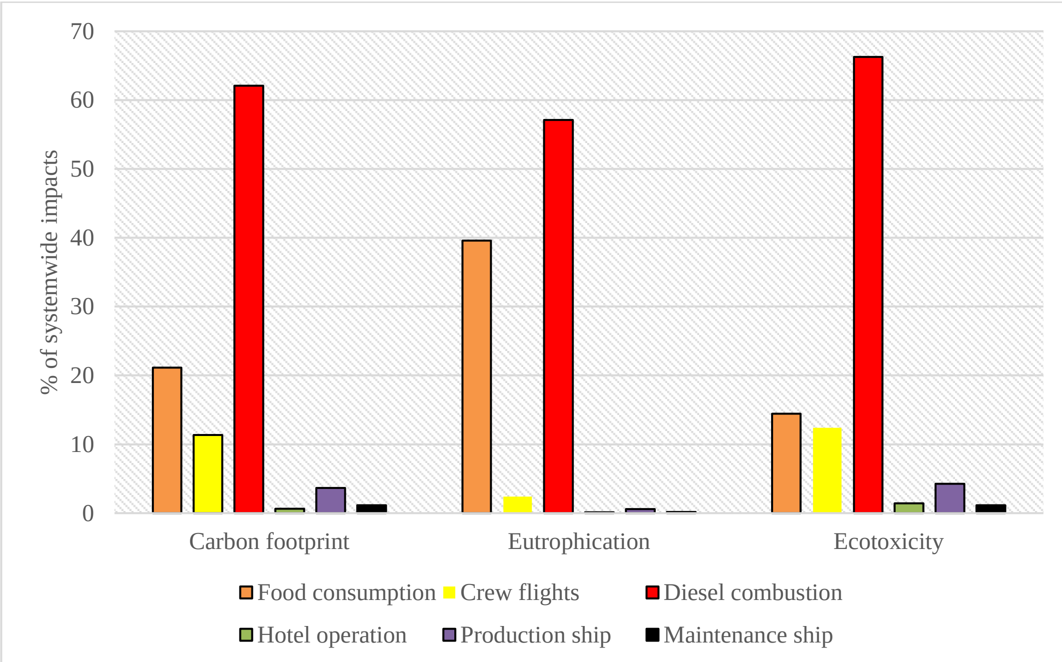

Figure 12. Relative contribution of subsystems.

In Figure 13 below, the SAIL progress is depicted. The second phase of the SAIL is completed and resulted in a set of three subsystems with a considerable impact contribution. Another set of three subsystems had an impact contribution below 5% and will therefore not be included in further steps. First however, the next section discusses the results.

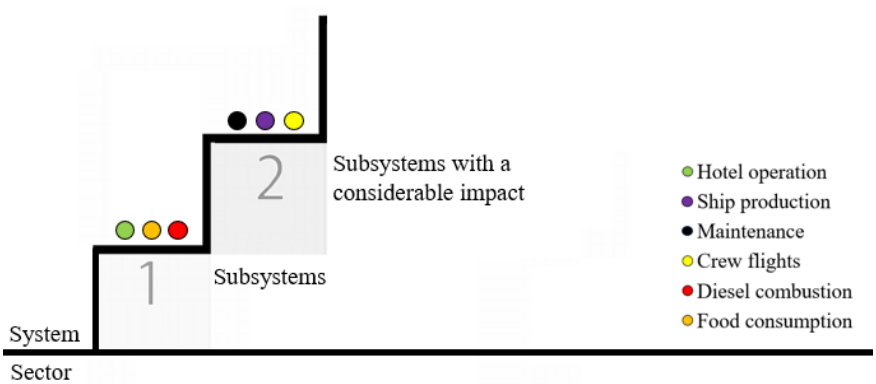

Figure 13. SAIL progress.

8.3. Results and discussion

This section discusses the results from the comparative subsystem analysis. In this step of the SAIL, it is important to reflect on modelling choices and justify whether previously computed steps are sensible. If needed, previous assumptions and proxy datasets are adjusted. Furthermore, based on the possible of recurrence of impacts, subsystems are included or omitted from the following steps.

8.3.1. Ship production

Table 2 displays the contribution of the ship production subsystem to the total of impact categories. For all three categories, the relative contribution of ship production to the total impacts are below 5%.

Impact category	Production ship (%)
Carbon footprint	3.65
Eutrophication	0.60
Ecotoxicity	4.27

Table 2. Relative contribution ship production.

In the aggregate ship production subsystem, the impacts related to the sail-specific categories can be distinguished from the non-sail specific (bare ship) impacts. In Table 3, this distinction is shown.

Impact category	Unit	Sail -specific	Non-sail specific
Carbon footprint	%	11.23	88.77
Eutrophication	%	13.88	86.12
Ecotoxicity	%	7.86	92.14

Table 3. Relative contribution of subsystem.

In the ship production subsystem, the non-sail specific activities are responsible for the most impacts. As previously described, the dataset on container ship production serves as a proxy for the non-sail specific production categories of the CSA, after correcting for LWT and lifetime. In Appendix A1.1B, the inputs from the technosphere which were used in this dataset are depicted. For most materials, it is presumed that these are likely to be present in the construction parts of the CSA. Nevertheless, some materials which are present in the dataset have not been used. The use of asbestos chrysotile, for example, has been prohibited in the Netherlands since 1994, in the EU since 2005 and since 2011 according to SOLAS (Hegger et al. 2014; Fraguela-Formoso et al. 2016).

The assumption of the CSA's lifetime of 50 years is naturally debatable. Nevertheless, the iconic value of the ship makes it more than likely that it will surpass the standard ship lifetime assumption. Furthermore, an end of life (EOL) scenario is not taken into consideration, as the LCA is set out from a cradle-to-grave perspective. When a great deal of the ship can be recycled at the EOL phase, it is likely that this would only diminish the environmental impact contribution.

Although the inventory analysis for the ship production of the CSA is a rough-cut approach, it forms an idea of its contribution in the complete system by providing the functional unit. As non-sail specific categories form most of the impact contribution, the hull and mechanical parts of the ship are the main contributors to the total impact. A more detailed and case-focused approach could improve the accuracy of outcomes but is not considered in the SAIL. The RCSA do not plan to construct another ship, so the construction-related impacts are not recurrent. Furthermore, the relative impact contribution is considerably small (< 5%).

8.3.2. Hotel operation

For the hotel operation subsystem onboard the CSA was chosen for an existing dataset constructed for the building operation of a hostel. By relating the dataset to a week (7 day) visit, a proxy was made for the one-week sailing cruise voyage functional unit. The share of impacts per category to the systemwide impacts are depicted in Table 4. For all impact categories, the shares are relatively low (< 5%). Nevertheless, this reflection is composed in order to assess whether modelling choices could have led to its limited contribution.

Impact category	Hotel operation (%)
Carbon footprint	0.64
Eutrophication	0.11
Ecotoxicity	1.44

Table 4. Relative contribution hotel operation.

In this available dataset, certain inputs differ from the actual situation onboard. Nevertheless, to gain an insight into the contribution to the total impacts, it serves its goal. Still, it should be identified that certain subsystem dataset elements can affect the total outcome. In Appendix A1.2B, the LCI of the dataset is listed. As depicted in the third column, not all processes can be regarded as relevant for the 'hotel' onboard the CSA. Furthermore, these parts allow for double counting in other subsystems. Firstly, the construction of the hostel should not be included, as this is considered in the shipbuilding section. Secondly, electricity usage is indirectly covered by fuel usage, as the diesel generators produce the electricity for the CSA. Thirdly, heat is produced by the Heating Ventilation and Air Conditioning system (HVAC), which consumes electricity and thus fuel. Lastly, cleaning detergents are on the provisioning list and assessed in the food consumption subsystem. These double-counting factors could thus have led to an overestimation of the related impacts. However, other datasets are available for three types of hotels (i.e. all in Brazil), ordered according to their level of convenience. Among the alternatives, '*building operation budget hotel'* and '*building operation luxury hotel'* were available options. All datasets contained some superfluous element. Figure 14 shows the relative impacts of the other datasets normalised to the environmental impacts of the current dataset.

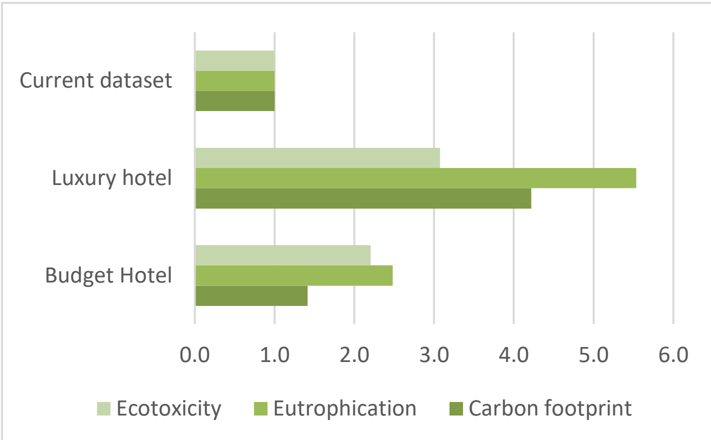

Figure 14. Proportional impact difference for other datasets.

In Table 5 below, the differences in assumed per capita room surface area for the CSA and the three background dataset alternatives are presented.

Hotel type	m^2
CSA (estimate)	5.55
Hostel	5.76
Budget hotel	7.65
Luxury hotel	58.62

Table 5. Room surface area per guest in various datasets.

All impacts are clearly greater for the alternative options than in the original dataset of choice (hostel). Nevertheless, the current dataset resembles the situation onboard the CSA the most. When comparing the three options with the use of room surface area per person, other datasets would result in an overestimation of the impacts. In sum, the contribution of the hotel subsystem to the total aggregate systemwide impacts is relatively low (< 5%). The subsystem is therefore excluded from any further steps up the SAIL.

8.3.3. Food consumption

For the estimation of the food consumption impacts, the provided order list with products were places in associated categories. This was then coupled to a representable proxy dataset as described in Appendix A1.3. The calculation of per person input is based on the number of passengers (28). As the crew also consumes food, the environmental burden of the food consumed by crew is shifted to the functional unit of a single guest one-week voyage: the food consumed by the crew is included in the calculation for the guests.

Table 6 below presents the relative contribution of food consumption to the total systemwide impacts.

Impact category	Food consumption (%)
Carbon footprint	21.12
Eutrophication	39.59
Ecotoxicity	14.45

Table 6. Relative contribution food consumption.

For all three impact categories, especially for eutrophication, the food consumption related share of the total is considerable. Appendix A1.3 presents the inventory table as programmed in the Simapro software tool. As the relative contribution of this subsystem to the total systemwide impacts are considerable, a reflection on modelling choices, assumptions and interpretation contribute to understanding the origin of its significant contribution.

Impact reduction feasibility is the final aim of the SAIL analysis, so considering the average impacts of food consumption in relation to the food consumption onboard the CSA may contribute to an improved understanding of the subsystem. Figure 15 below presents the percentage of impacts of an average Danish diet in relation to the CSA diet, where 100% is the LCIA of the CSA food consumption subsystem.

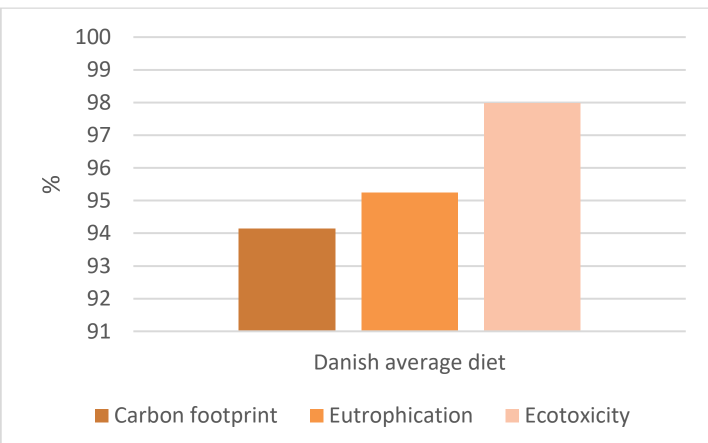

Figure 15. Impacts of an average Danish diet in relation to the CSA diet.

As the main data source for food consumption comes from a Danish database and a great share of the crew is of Danish nationality, average Danish consumption patterns were assessed. Data for the average per capita food consumption in Denmark were gathered from Saxe et al. (2013) and data for per capita use of cleaning detergents from the European Commission (2006). Per capita data were corrected to account for both crew and guests and placed in the same background data categories. For all impact categories, the average Danish diet scores slightly lower. The CSA food consumption related impacts are therefore slightly higher than for an average person in Denmark. There is consequently room for improvement, which is an important takeaway for further analysis in the following stage of the SAIL.

Furthermore, the main contributing data points in the subsystems are set out in Table 7. The meat category scores relatively high for carbon footprint and eutrophication.

Impact category	Peak contributor	% of total
Carbon footprint	Beef fillet	74.66
Eutrophication	Beef fillet	90.32
Ecotoxicity	Cleaning consumables	25.57

Table 7. Per category peak contributing element in food consumption subsystem.

8.3.4. Ship maintenance

As described in the previous stage of the SAIL, the maintenance of the CSA was related to the container ship maintenance background dataset available in the Ecoinvent database. The relative contribution of this subsystem to the aggregate impacts is in depicted in Table 8. The relative impacts to providing the functional unit is relatively low (< 5%).

Impact category	Maintenance (%)
Carbon footprint	1.15
Eutrophication	0.18
Ecotoxicity, freshwater	1.15

Table 8. Relative contribution maintenance.

To validate these findings, we need to reflect on the model formalisation of this subsystem. The interacting flows for the background dataset are in Appendix A1.4. To verify whether the inputs and assumptions align with the maintenance procedure of the CSA, expert interviews were conducted. An author of the Ecoinvent dataset was consulted, as well as the logistics manager of the CSA (see Appendices A2.3 and A.2.5).

As mentioned previously, the ship maintenance dataset in the Ecoinvent database focused on container ships, for which steel and paint are the main things to be replaced. For the CSA, the maintenance regime differs in various aspects. Steel work, for example, is of a significantly smaller extent (i.e. 1% was renewed in the previous 20 years, which is approximately 10% for container ships; see Appendix A2.5; Johnsen & Fet, 1998). On the contrary, other inputs and emissions can be estimated with more completeness. Consequently, a new LCI was tailored to foreground data inputs from the company (see Appendices A2.1, A2.5, A2.3 and A2.12).

The main periodical maintenance activities for the CSA differ in their frequency. There is a **continuous** replacement of small parts, as well as an upkeep of paint, woodwork and machinery. **Every two years,** periodic drydock maintenance takes place, where antifouling is renewed. In addition, the rigging is checked and updated as needed. **Every six years,** larger maintenance occurs. Certain parts of the ship needed replacement in 2006, 2013 and 2019, for which material demand was relatively high. **Every 20 years,** a large refit takes place to update the ship to modern standards and (sustainable) innovations. Among the replaced materials are the main engine, generators and electronic equipment.

When the revised more detailed and tailored material inputs, emissions and outputs are considered, a comparison can be made with the previous maintenance subsystem model. Figure 16 below presents the share of impacts for the revised subsystem, where 100% is the original impact calculated in the first subsystem computation.

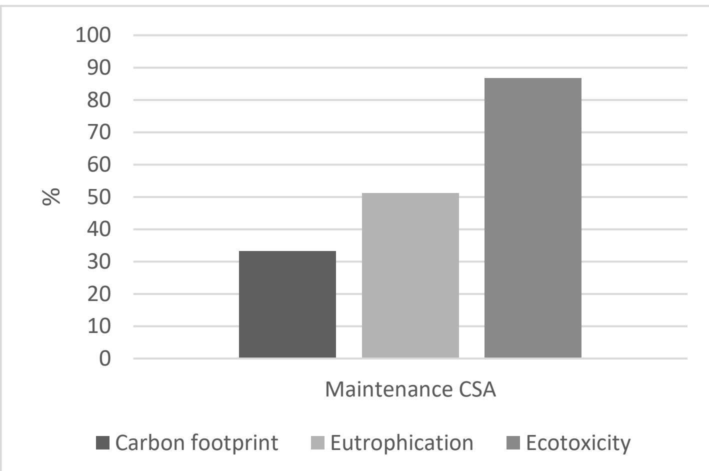

Figure 16. Relative contribution of the revised maintenance regime compared with previous assumption regime (100% is previous model).

Although the revised LCI is more complete, the impact assessment scores lower for all three categories. Only for ecotoxicity the reduction is relatively low, but still apparent. As the original subsystem approach already resulted in an inconsiderable impact contribution, the revised subsystem contribution is also below 5%. The maintenance regime is thus not a main contributing subsystem to the total environmental impacts of a sailing cruise holiday onboard the CSA and a justification is made for excluding it from further SAIL steps.

8.3.5. Crew flights

The modelling choices for crew flights are relatively straightforward. In the databases available in the Simapro software tool, existing models are available on the estimation of the impacts per passenger km. The preferred background dataset of choice is an Ecoinvent dataset for long-haul flights. Indirect flights generally relate to increased impacts, as energy is lost during landing (Baumeister, 2017). Differences between flight-distance-related impacts were beyond the scope, possibly leading to a minor underestimation of impacts. Table 9 presents the relative contribution of the crew flights to the estimated total systemwide impacts of the functional unit.

Impact category	Crew flights (%)
Carbon footprint	11.34
Eutrophication	2.41
Ecotoxicity, freshwater	12.39

Table 9. Relative impact contribution of crew flights.

In the sample year (i.e. 2018), crew flights were a considerable contributor to the estimated impact categorisation. As the CSA operate globally, finding realistic alternatives to this mode of transport is not straightforward. Nevertheless, for part of the year, the operation area is around Europe, making land transport for a part of the crew more achievable. In an expert interview with the Randstad global head of sustainability, she proposed that replacing all short distance flights (< 750 km) with train journeys could become one of Randstad's sustainability strategies (see Appendix A2.7). Thirty-one journeys made in 2018 could have been completed by train, corresponding to a total of 15,900 km for this year. When implementing this different crew journey approach into the LCA model, by correcting it to passenger week and including a train voyage dataset, the following impact reduction is feasible (see Table 10).

Impact category	% Reduced
Carbon footprint	0.86
Eutrophication	0.86
Ecotoxicity	0.87

Table 10. Feasible reduction for trips below 750km.

Although a distance travelled by train shows significant lower impacts than by airplane, the situations for which the train is a feasible alternative mode of transport for the CSA crew are limited.

8.3.6. Diesel combustion

The relative contribution of the diesel combustion subsystem is presented in Table 11 below. The contribution is given in percentage of the total systemwide impacts.

Impact category	Diesel combustion (%)
Carbon footprint	62.10
Eutrophication	57.11
Ecotoxicity	66.29

Table 11. Relative contribution of diesel combustion.

The impacts related to diesel combustion are relatively high and form the greatest contribution of all subsystems. For the environmental impacts of fuel usage, a dataset on diesel combustion in fishing vessels was used. The emissions related in this dataset were coupled to an input (MJ) of diesel, based on data from the European Emission Agency (EEA, Nielsen, 2013). As the emissions in this dataset are coupled to mass and energy units, which are inherently characteristics of marine diesel, using this dataset can give a proper estimation of the emissions related to CSA fuel use (assuming efficiency of engines are equal). Nevertheless, CSA fuel usage originates both from the main engine and generators. A comparison between a generator-related dataset and the marine-engine dataset showed little difference in impacts. A partition of the fuel consumers is therefore excluded from further analysis, at the assumption is that all fuel is burned in a marine diesel engine. Since the compilation of the datasets, certain marine diesel characteristics have changed. Since 1 January 2020 the global upper limit on the sulphur content of ships' fuel oil has been reduced to 0.50% (previously 3.50%). In the regulation presented in IMO 2020, the reduced limit is mandatory for all ships operating outside certain designated Emission Control Areas (ECA), inside the ECA the limit was already 0.10%, which it will remain (Li et al. 2020). The reduction for the CSA inventory is based on emissions outside of an ECA, thus from 3.50% to 0.50%. It is consequently concluded that the previously assumed sulphur contents in fuel emissions can be reduced by a factor of 7. Additionally, the RCSA installed an exhaust gas treatment (SCR) during the refit in 2019, which cuts nitrogen oxide and particulate matter emissions since (see Appendix A3.1). Table 12 below presents the total reduction percentages of for three emission categories that are realised in the revised fuel combustion subsystem.

Reduced	%	By
Nitrogen oxides	80	Company (SCR)
Particulate Matter (PM)	64	Company (SCR)
Sulphur	85.7	IMO (2020)

Table 12. Reduction in airborne fuel related emissions.

Figure 17 below visualises the impact reductions since the interventions by the IMO and the company's SCR (100% is original). The new, more detailed modelled impacts of fuel consumption describe the current processes more accurately and a reduction is visible for eutrophication and ecotoxicity.

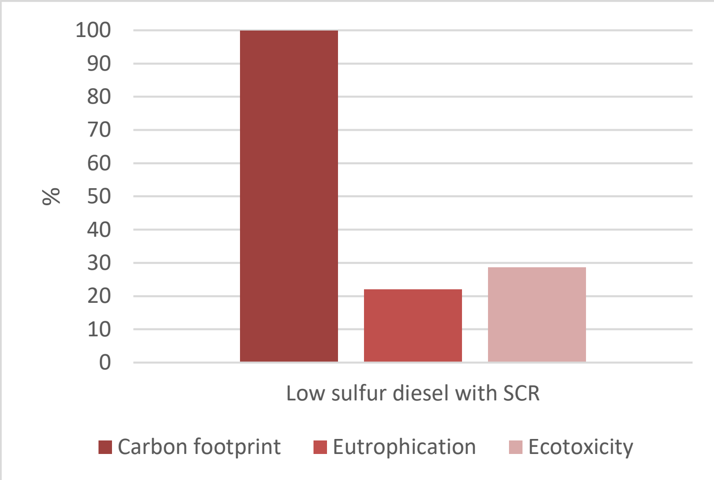

Figure 17. Impacts revised fuel system (100% is original dataset).

Moreover, until this point, the data inputs for the subsystems have been focused on 2018 (2019 for fuel). However, the fuel consumption changed as a result of the refit in 2019. The estimated reduction in fuel consumption since the refit is set between 15–20% by the RSCA (see Appendix A3.1). Relating the model pre-refit fuel consumption data was chosen, as since the outbreak of COVID-19, fluctuating corporate activities have resulted in less reliable data input for fuel consumption. In the revised systemwide model, fuel used will be corrected for post-refit efficiency. The model will include a conservative interpretation of the fuel-saving statement and include a fuel consumption reduction of 15% in the analysis.

8.3.7. Revised computation

In this section, the improvements are incorporated in a revised inventory of the subsystems, which results in a revised computation of the damage assessment and relative contribution of the subsystems. Table 13 summarises the modification in assumptions and data inputs discussed in the previous sections.

Ship production	Subsystem compilation is usable for systemwide comparison. It contains a relatively low and nonrecurring impact contribution and is excluded from further analysis.
Hotel operation	Double counting occurred in certain model elements. Low-impact contribution excludes it from further detail.
Food consumption	Comparison with an average diet showed a more than average impact. This could form opportunities for further analysis.
Ship maintenance	A new dataset with increased detail was composed for this subsystem. Total contribution was however still limited and excludes it from further analysis.

Crew flights	The subsystem contributes to a considerable share of aggregated systemwide impacts. An alternative mode of transport is limited in covering the same service.
Diesel combustion	A revised model reduces the relative contribution of the subsystem. Nevertheless, impacts are still considerable and recurring. Further analysis is needed.

Table 13. summarised reflections for further model interpretation

Figure 18 below presents the results of the revised comparative model. Only the maintenance and diesel combustion subsystems have new modelling inputs. The total impacts are, in line with the previous comparative computation, calculated for the fulfilment of a single guest, one-week sailing voyage onboard the CSA.

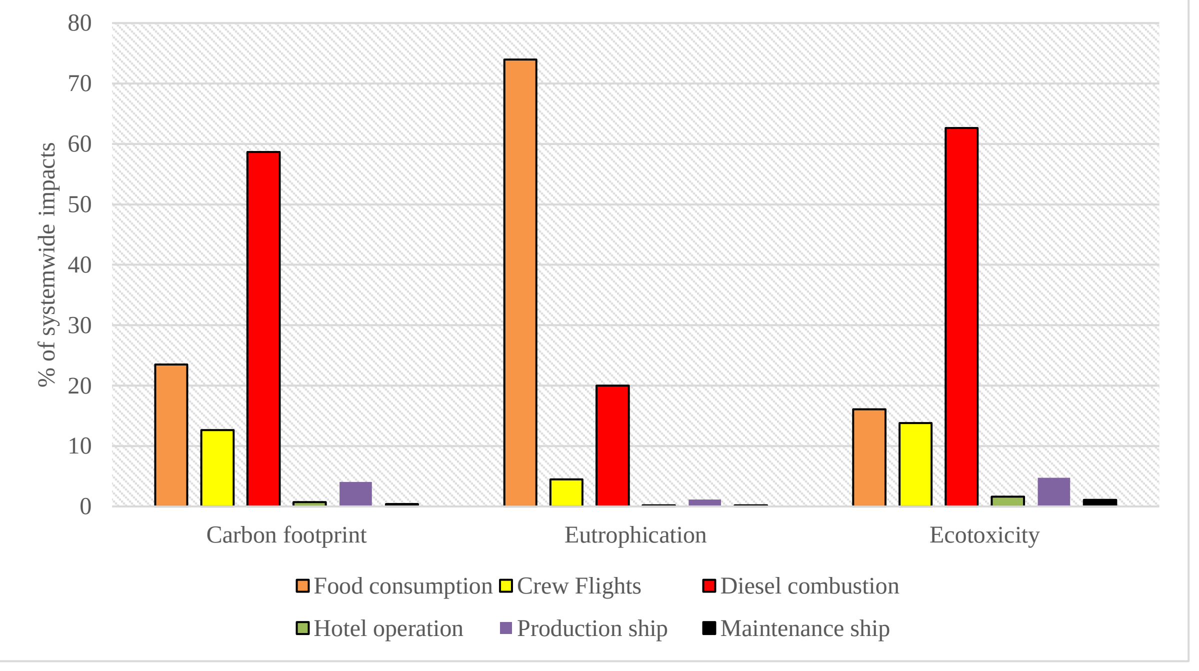

Figure 18. Environmental impacts of a single-guest, one-week sailing cruise voyage.

In Figure 19 below the SAIL progress is visualised. For three subsystems there are recurring and considerable impacts observed. Furthermore, the three remaining subsystems are, also after revision, remaining at the first stage of the SAIL, as their systemwide impact contribution to systemwide impacts is inconsiderable.

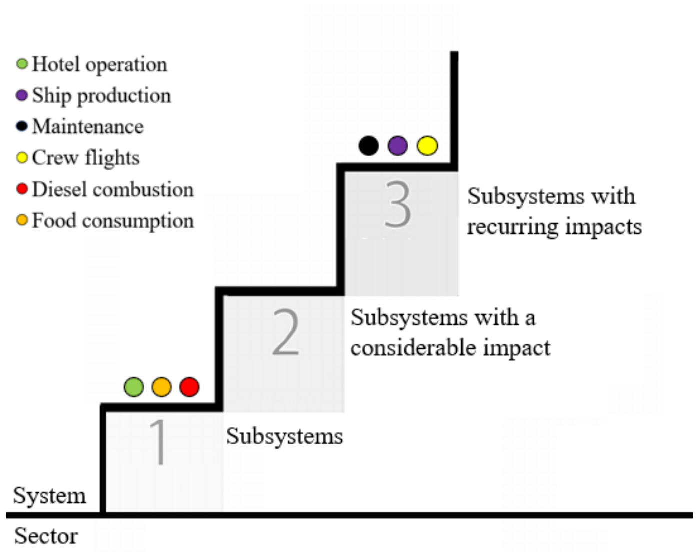

Figure 19. SAIL progress.

8.4. Impact reduction feasibility

This section aims to quantify the reduction opportunities which substituting elements of the main contributing subsystems can offer. Ship production is not an element which shows to have recurring impacts for the analysed case study. Maintenance and hotel operation will have periodically returning environmental impacts. However, for the chosen impact categories, the contribution of these subsystems to the total impacts is relatively low. For crew flights, the contribution is considerable and it entails recurrent activities: crew will take flights to reach the CSA. Nevertheless, the technically feasible alternatives (transport by land) will not show a considerable reduction to the total impact categorisation (less than 1%). For the impact reduction related to fuel and food consumptions, alternatives are assessed.

8.4.1. Food consumption

After relating the impacts of the consumed food products onboard the CSA to the average consumption in Denmark, the difference becomes visible. In addition to (carefully) concluding that the environmental impacts related to this provisioning list are greater than an average diet would induce, more useful inferences can be made. The food consumption subsystem showed considerable contributions to the all impact categories, which means that changes in provisioning are likely to have an overall impact on the system. However, reducing the provisioning is not a technically feasible option, as crew and guests naturally demand nutritious, sufficient and tasty food inputs. Nevertheless, changing the composition of the diet can affect the impacts related to this subsystem.

Many studies exist on the environmental impacts of different diets, including studies which utilised LCA methodology. Technically, reducing the environmental impacts related to food consumption is straightforward. When shifting from a meat-based (average) omnivorous diet to a healthy plant-based diet, it has been estimated that GHG emissions can be reduced by 33–82% and eutrophication by 20–45% (Chai et al. 2019; Detzel et al. 2021; Kustar & Patino-Escheverri; Lacour et al. 2018; Pairotti et al. 2015). Furthermore, Baroni et al. (2007) find that ecotoxicity impacts of a diet can be reduced by 54%–98%, depending on the extent in which pesticides are used. The quantification of the reduction is less straightforward, as it depends on geographical variables and modelling choices. When implementing these reduction factors to the food consumption subsystem, the range in reductions shown in Table 14 can be expected.

Category	Reduction (range)
Carbon footprint (kg CO_2 -eq.)	43.80–108.83
Eutrophication kg (PO_4 -eq.)	1.601–3.612
Ecotoxicity (CTUe)	8.69-15.76

Table 14. Feasible impact reduction of food consumption

8.4.2. Crew flights

In the techno-ecological scope of the SAIL framework, there are limited strategies for reducing the environmental impacts related to the crew voyages. Technically, the train is a low-impact alternative mode of transport, which is only feasible within a certain acceptable range. According the performed LCA model, the crew-flight-related impacts of the provided functional unit can be marginally reduced (see Table 15).

Impact category	Reduction (unit)
Carbon footprint (kg CO_2 -eq.)	1.05
Eutrophication (kg PO_4 -eq.)	7.22E-03
Ecotoxicity (CTUe)	4.54

Table 15. Feasible reduction crew-flight-related impacts

8.4.3. Diesel combustion

The RCSA attempted to improve their efficiency of fuel usage during their refit in 2019. However, the realised reduction quantification cannot be accurately estimated due to the pre- and post-COVID differences in continuity of use. Currently, the CSA runs on low-sulphur marine diesel and has an SCR installation in place. Nevertheless, the use of diesel is still the greatest contributor to the carbon footprint, eutrophication and ecotoxicity of a single guest, one-week voyage onboard. As is currently assumed, a major technical refit for the CSA takes place every 20 years (for maintenance assumptions, see Appendix A2.5). A major innovative technical refit which would replace the current fuel system (e.g. hydrogen or electric) is therefore highly unlikely within the next few years. Consequently, the impact reduction feasibility must be assessed in the current fuel-regime to be compatible with the currently installed engine and generators. The feasible impact reduction with renewable fuels is thus estimated. The operation and maintenance manual of the manufacturer of the engine systems states:

> Caterpillar is not in a position to test all varieties of renewable and alternative fuels that are advertised in the marketplace. If a renewable or alternative fuel fulfils the performance requirements described in Cat Fuel Specification, the latest version of 'ASTM D975', the latest version of 'EN 590', or the latest version of the paraffinic fuel specification 'CEN TS 15940' (which defines quality requirements for Gas to Liquids [GTL], Biomass to Liquids [BTL] and hydrotreated vegetable oil [HVO]), then this fuel or a blend of this fuel (blended with appropriate diesel fuel) can be used as a direct replacement of petroleum diesel in all Cat diesel engines (Caterpillar, 2020).

Consequently, a substitution of current marine fuel with biologically sourced diesel is possible for the CSA, provided that it meets the listed performance requirements. According to a study on lifecycle impacts of biodiesel the following is estimated:

> […] though, biodiesel is a renewable energy, one ton of biodiesel production contributes to the global warming potential around 287.3 kgCO_2 eq. However, the amount is smaller than other conventional fuel such as fossil fuel and coal. Other environmental impacts such as eutrophication, terrestrial eco-toxicity can be negligible. The transesterification stage is the main reason for the (69.27%) total environmental impacts. Thiruketheeswaranathan, S. (2022, p5)

The EU further specify the differences in GHG emissions of various biodiesel types (EU, 2009). The EU default values for GHG emissions from 'well to tank' for various types of biodiesel (see Figure 20).

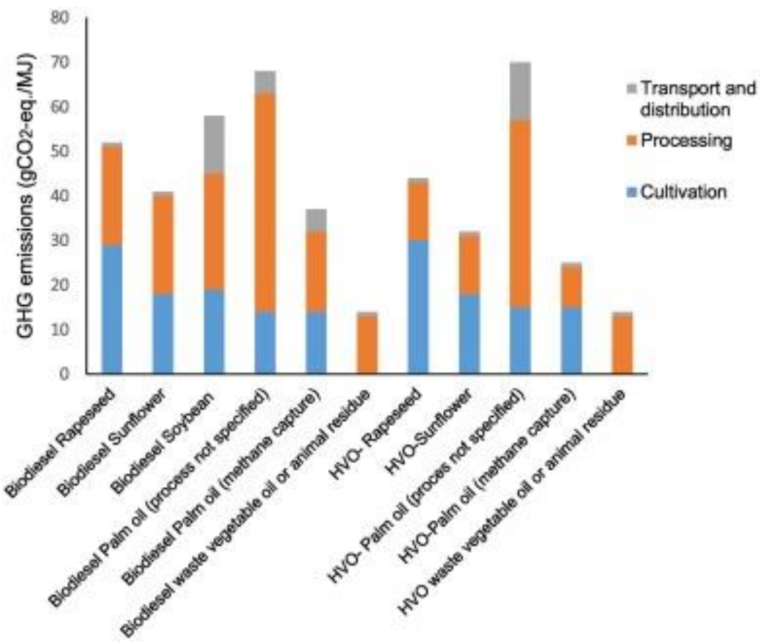

Figure 20. EU default estimations of well-to-tank impacts of biofuel types (Source: Soam & Hillman, 2019).

From an LCA perspective, a great difference exist between first-(i.e. from cultivation) and second-generation (i.e. from waste flows) biodiesels. As the graph in figure 20 focuses on GHG emissions, it does not present all (environmental) impacts. Factors not included in this graph, such as land use, further stress the preferability of using recycled material flows as an input for biodiesel, as first-generation biofuel requires cropland (Happonen et al. 2012). By including the aforementioned factors in the analysis of the diesel combustion subsystem, a feasible impact reduction for the CSA can be estimated. Substituting the current marine diesel with second-generation HVO (100%) can lead to a reduction of impacts (see Table 16). The impact reduction is corrected to the functional unit of a single guest one-week voyage. Furthermore, a commercial party who sell this type of second-generation HVO in various blends is available in the Netherlands (see Appendix A4.2).

Category	Reduction (unit)
Carbon footprint kg CO_2 eq	482.01
Eutrophication kg PO4 eq	3.53
Ecotoxicity CTUe	2245.66

Table 16. Reduction total impacts for substitution with 100% HVO

8.4.4. Feasible reduction

In this section the feasible reduction is presented as a result of the previously described low-impact measures (see Sections 8.4.1 to 8.4.3). The previous sections provided a quantified reduction for the food consumption, crew flight and the fuel combustion subsystems. Figure 21, 22 and 23 present the feasible reduction quantifications for the three subsystems. The darker blue bars represent the previously quantificatied reductions, the light blue bar for the food consumption subsystem represents the maximum reduction for optimal situations.

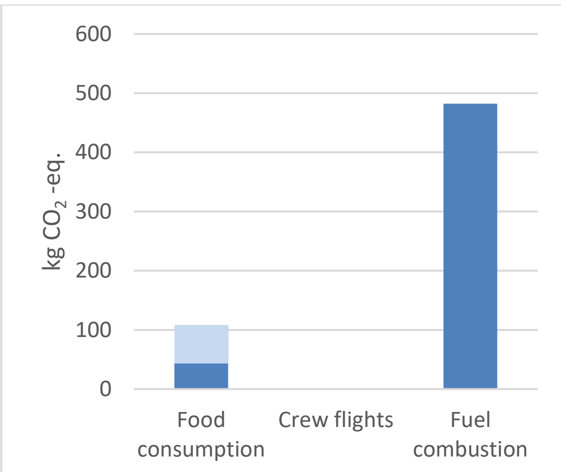

Figure 21. Feasible carbon footprint reduction.

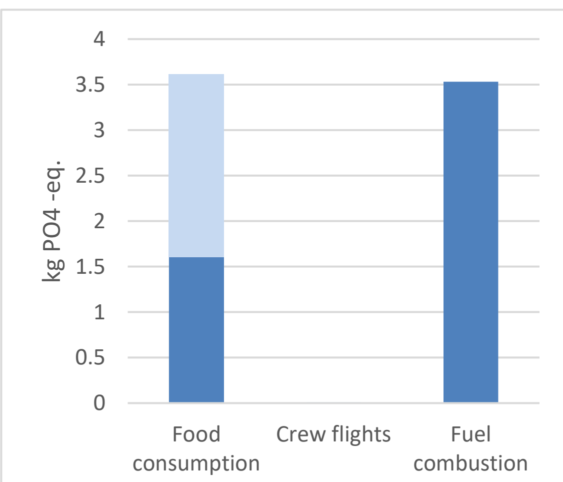

Figure 22. Feasible eutrophication reduction.

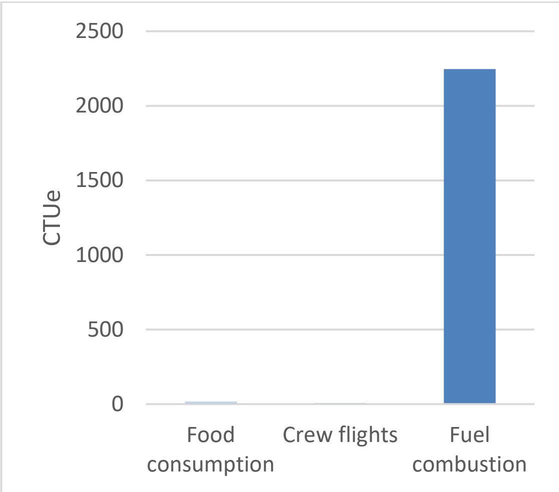

Figure 23. Feasible ecotoxicity reduction.

The intervention for the fuel combustion subsystem, substituting marine diesel fuel with HVO-100, shows to be the most promising intervention for reducing the carbon footprint and ecotoxicity impacts of a sailing cruise voyage. Altering the diet within the food consumption subsystem however, has the greatest potential of reducing eutrophication related environmental impacts. For all three reduction opportunities, the crew flight low-impact alternative, replacing short distance flights with train journeys, shows to have a limited capacity in reducing impacts. Impact reduction in the crew flights subsystem domain will consequently not be considered a feasible reduction, as an effective alternative does not exist. Figure 24 below visualises the current assessment progress.

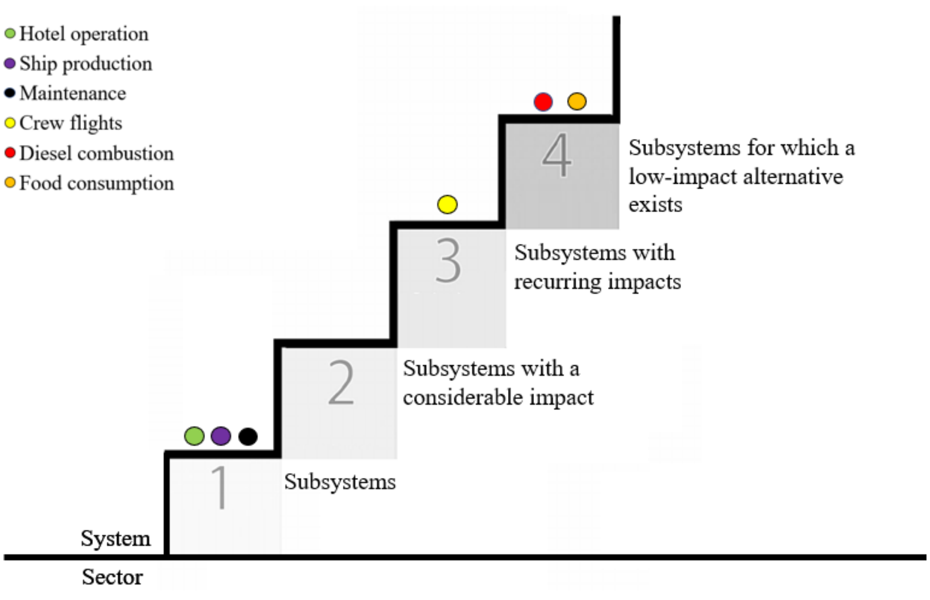

Figure 24. Sail progress.

8.5. GO-SAIL (General Output)

Analysing the environmental impacts related to a single guest, one-week voyage onboard the CSA with the use of the SAIL led to several insights into the sailing cruise lifecycle system. For a single guest one-week sailing voyage onboard the CSA, the greatest share of eutrophication, ecotoxicity and climate change impacts are attributed to diesel combustion, crew flights and food consumption. The contribution of the hotel operation, ship maintenance and ship production subsystems to systemwide impacts were each below 5% and therefore remained at the first SAIL abstraction level (see Figure 25). In addition, the ship production subsystem is regarded a nonrecurring activity, in contrast to other subsystems, as the RCSA does not plan to construct another ship in the (near) future. Although the crew-flight-related environmental impacts are regarded as both ‘considerable’ and ‘recurring’, no technical alternative is available for the greatest share of the crew journeys. Consequently, the crew flights subsystem progressed no further than the third level of the SAIL. The only two subsystems which have progressed along all five abstraction levels of the SAIL are the diesel combustion and food consumption subsystems. For these two subsystems, a low-impact alternative exists, which could lead to a feasible impact reduction in the subsystem. According to the SAIL assessment, a potent strategy for mitigating eutrophication, ecotoxicity and climate change related impacts, should include substituting elements within the fuel combustion and food consumption subsystems. The visualised completed SAIL procedures are presented in Figure 25 below.

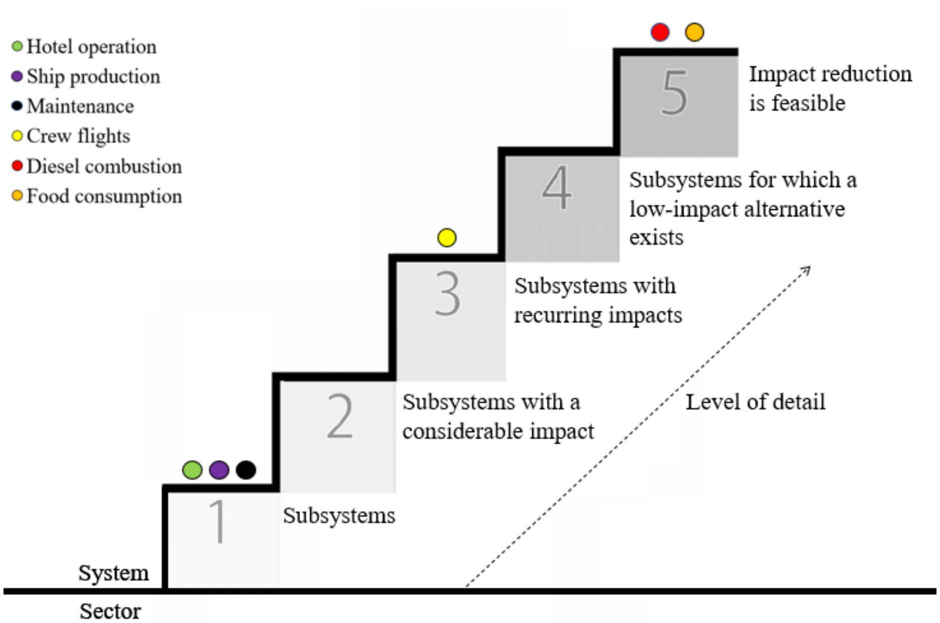

Figure 25. SAIL progress.

8.5.1. Bycatch

This section discusses insights which emerge from bridging the SAIL's lifecycle approach to a wider comparative focus. The SAIL assessment on the CSA provides insights on feasible low-impact pathways for main contributing subsystems as presented in the GO-SAIL section. In addition to the completion of the SAIL procedures, another comparative analysis is performed in this section, classified as 'bycatch'. A major area which the SAIL framework does not address is the comparison of the sailing cruise lifecycle impacts to a fuel-based cruise LCIA, which Simonsen (2014) and Farr and Hall (2015) have assessed previously. First, a comparison with Simonsen (2014) is made based on their chosen functional unit. A comparison of the SAIL computations for the CSA is subsequently related to Farr and Hall's (2015) findings.

Simonsen (2014) estimated the impacts of fuel usage and shipbuilding in conventional cruise holidays by relating them to distance covered and amount of passengers. This was a case study on the Norwegian Gem, a 93.530 GT cruise ship, carrying 2,394 passengers and 1,070 crew. Although there is no LCA coverage on the full dimension of impacts related to conventional cruise shipping, as the scope was limited to fuel consumption and ship production, it can still be compared solely on the provided fuel and production-related impacts.

Another form of data manipulation is needed for comparison; the functional unit used in SAIL, must be converted to a distance-related unit (i.e. passenger km). To make this comparison, additional foreground data from the CSA are needed, namely the distance travelled during a sailing voyage. The CSA provisioning list, which is used in the SAIL computations, is based on an adventure sailing cruise of 18 days which took place in 2018 from Las Palmas to Martinique. The shortest distance between the two destinations is approximately 4900 km (2643 nm). There were 28 passengers onboard the CSA during this adventure sailing cruise (see Figure 26). As depicted, the share of ship-production-related impacts is significantly smaller for the Norwegian Gem (i.e. approximately 1% of combined impacts). The total carbon footprint of the Norwegian Gem (per passenger km) is estimated at 38.53 CO_2 -eq. The carbon footprint per passenger km of the CSA (for fuel use and ship production) is approximately 17% lower and is estimated at 31.82 kg CO_2-eq/passenger km.

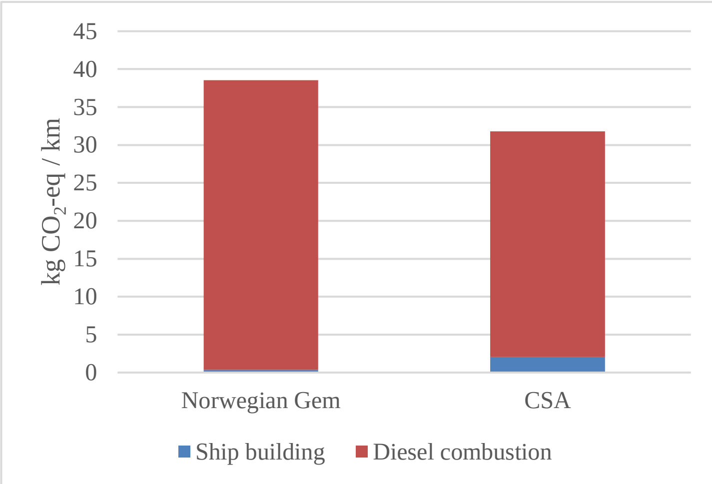

Figure 26. Carbon footprint per passenger km for a conventional cruise on the Norwegian Gem and for a sailing cruise on the CSA.

In comparison with the assessed carbon footprint in Farr and Hall (2015), the comparability is more straightforward. The outcomes of the SAIL assessment for the CSA can be related to the outcomes of Farr and Hall (2015) with the use of the same functional unit, a single guest, one-week voyage. A spatial dimension (distance) was not included, so Farr and Hall (2015) is not comparable with Simonsen (2014).

Figure 27 (see below) compares a single guest, one-week voyage onboard the CSA with an Oasis-class voyage based on carbon footprint. In Farr and Hall (2015), assumptions and data inputs were mainly based on combining assumptions with available online data; foreground data was not included in an LCI. Furthermore, certain assumptions on system boundaries were different for the subsystems. The ‘travel’ subsystem in Figure 27 below corresponds to excursion trips and transfers, whereas for the CSA it only comprises crew flights.

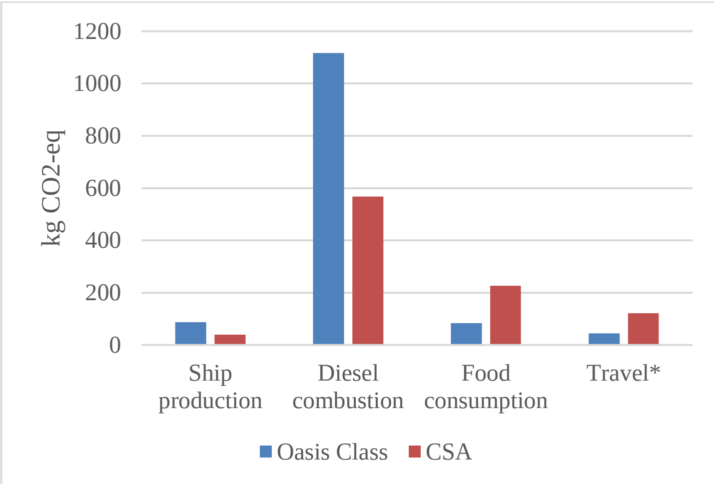

Figure 27. Carbon footprint of a single guest one-week voyage comparison CSA and Oasis-class. *Note: system scope for 'travel' subsystems do not match.

For all categories combined, the carbon footprint of a voyage onboard the CSA is 28% lower than a voyage onboard an Oasis-class cruise ship. Fuel-use-related impacts are the major contributor to the carbon footprint for both types of cruises, however, diesel-combustion-related impacts are reduced by 49% for the CSA. Although this potentially addresses the superior fuel efficiency of the CSA, the difference in scale should not be ignored (see Figure 28).

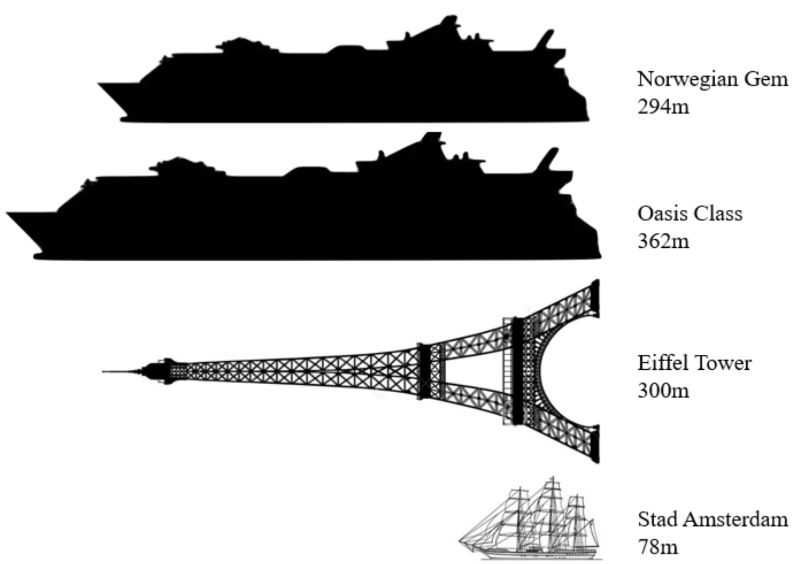

Figure 28. Comparison of scale.

9. Discussion

This section reflects on whether the SAIL research design has the capability to provide useful insights for resolving the main research question: *'How can a lifecycle approach be applied to sailing cruise ship services and contribute to a better understanding of the distribution of environmental impacts related to a sailing cruise voyage and provide feasible impact reduction alternatives for major impact contributing elements in a case study?'.* The report introduced the strengths and limitations of assessing the environmental impacts of complex service systems using LCA methodology. Following a lifecycle approach to impact assessment has the potency of including systemic relations in a charted system boundary and scope. It thus forms a more inclusive approach to the analysis of upstream and downstream processes, whereas other forms of impact assessment are more suitable for less sophisticated point source quantifications (Jeswani et al. 2010). In the cruise tourism industry, impact assessments have mainly focused on point source estimations related to fuel use and pollution. Following a lifecycle approach to the estimation of systemic environmental impacts and feasible mitigation pathways in sailing cruise holidays can consequently benefit the scientific domain of cruise tourism impact assessment. The effectiveness of LCA in striving for complexity creates limitations in its capability as a manageable methodology. Fast-track LCA has proven to be a more practical approach, which in turn is limited in charting a complete overview of interrelations which reflect the complexity of reality.

The SAIL is a useful fast-track LCA approach by targeting usefulness rather than accuracy. Nevertheless, as with any type of fast-track LCA approach, the analysis is based on a network of assumptions and previously conducted studies. By reducing the complexity of this systemwide approach, a manageable tool is created, but this reduction in complexity could be its Achilles' heel if complex feedback relations are not properly considered. The SAIL mainly follows a single-dimensional pathway for improvement (up the ladder), which disregards the complexity system science: it proposes end-of-pipe solutions rather than system innovations. Nevertheless, the SAIL proves that multiple subsystems and impact indicators can be condensed into a single improvement-focused approach, in which it differentiates itself from point source impact assessments methods, such as the extensively studied carbon footprint of fuel consumption in the shipping sector.

Evaluating a case study of a sailing cruise lifecycle system with the use of SAIL, offers new insights into sailing cruise tourism's potential to be a low-impact alternative to conventional fuel-based cruise holidays. Notwithstanding the fact that fuel consumption remains an established major impact contributor in the case study, per capita fuel consumption is lower than in previous estimations for conventional cruise holidays. Moreover, the SAIL effectively unravels the distribution of multiple impacts in the sketched subsystems and increases the understanding of feasible systemwide impact mitigation. The SAIL thus effectively forms a generalisable approach to the sailing cruise tourism sector.

Although the SAIL is effective in providing quantified ‘feasible’ impact reduction pathways, it is limited in its dimensions of assessment. From an environmental-impact dimension based on three indicators, recommendations are formed for technological interventions. While the perspective of the SAIL focuses on techno-ecological solutions for impact reductions for the CSA, it neglects social, spatial and monetary dimensions. Furthermore, potential technological and environmental downsides of introduced low-impact innovations are outside of the scope of analysis; changing characteristics in one system could have spin-off effects in another (sub)system. As the definition of an SOI is inherently systemic, the SAIL may fail to deliver truly sustainable system innovations. For instance, using HVO in an improved fuel consumption subsystem could cause budgetary and technological challenges. Although the manufacturer of the generators and main engine (i.e. Caterpillar) state that certified HVO fuels are compatible with their products, which argues in favour of HVO implementation, spatial availability and economic aspects may be an obstacle. Although HVO manufacturers aim to deliver a product compatible with most diesel engines, inferior grades of biodiesel have been shown to have technical limitations. The usage of certain biodiesel forms may increase the frequency of maintenance (e.g. filter replacement; see Appendix A2.4). Furthermore, sulphur is normally a greasing agent in general diesel fuels but is scant in HVO, resulting in increased use of alternative greasing agents. In addition, the energy density of 100% HVO fuel is approximately 5% less than for conventional diesel, which leads to the price difference (Valeika et al. 2021).

An example of an unconsidered yet potentially key social dimension is the public attitude towards the handling of the food consumption subsystem. The SAIL identifies that a change in the dietary composition could reduce the impact of the food consumption subsystem. The subsystems inventory has been compared to an average Danish diet and a plant-based diet, which resulted in the inference that a food-related impact reduction is feasible for the RCSA. Consequently, a shift towards a plant-based diet is suggested in the last steps of the SAIL. However, as the SAIL does not include a social dimension in its framework, the solutions presented are solely technical. Nevertheless, interviews conducted onboard the CSA identified that certain stakeholders are not ready to switch to a completely plant-based diet.

Furthermore, the output of the fast-track LCA analysis depends on the selection of impact categories, of which the SAIL framework suggests a limited set of three categories. The SAIL’s outcomes are therefore comparatively assessed using a subjective scale: choosing other categories (e.g. relating to acidification, resource use, land use or social factors) was reflected in the outcomes. For the implementation of HVO as a sustainable alternative for conventional marine diesel, its environmental benefits must be properly assured. Where first-generation renewable fuels (i.e. nonrecycled input) are produced from oily crops, land-use, transportation and social externalities can potentially outweigh other environmental benefits. Implementing low-impact substitutes therefore strongly depends on the reliability of suppliers, which may be another obstacle for globally operating vessels.

The SAIL highlights the major contributors and provides a quantification of the low-impact alternative's capability of reducing a highlighted subsystem's impact. Minor contributors are, however, left out of the scope, as the initial systemwide focus is continuously filtered towards major culprits. This characteristic of the framework could distract stakeholders from making gradual changes. For example, the SAIL computations found that the maintenance subsystem did not considerably influence the total combined systemwide impacts, as impacts were below 5%. Nevertheless, certain impacts may still deserve consideration, for example, biocide use in antifouling is known to harm marine ecosystems but is left out of the SAILs impact reduction scope (Van de Steenhoven, 2022). Nevertheless, impacts that have been computed as having an 'inconsiderable' quantitative contribution might still deserve consideration based on availability, durability or socioeconomic characteristics.

The techno-ecological scope of the SAIL analysis does not include the assessment of social low-impact innovations. However, interviews onboard the CSA noted that there are various opportunities for limiting environmental impacts in social dimensions. Energy usage can be reduced by implementing procedures to reduce the mixing of outside airflow with inside HVAC controlled air, and hot water consumption can be regulated. Quantification of the potential of these social environmental improvements to reduce impacts is currently undetermined.

Additionally, the on-board conducted interviews revealed certain socio-environmental trade-offs. Captain Moritz stated that, in general, the world trades environmental impacts for human safety (see Appendix A2.10.). The polypropylene lines onboard the CSA are safe to use but release numerous microfibers as they degrade due to the sun and salt. This adds up to trade-offs between luxury and environmental impacts, as setting high expectations for luxury and time management increases material and energy dependency.

Lastly, the type of fast-track data management in the SAIL framework forms a trade-off with accuracy. Since LCA databases are networks of available data on systemic impacts, the number of assumptions increase with computational system size. Each dataset is based on its corresponding assumptions. In the case of hotel operation or ship maintenance and production, material or energy inputs and correlated impact categorisations are considerably case specific. One should be cautious when generalising its assumptions to other cases. Due to the systemic dimension of LCA analysis, it is inherently dependent on assumptions, which in turn are debatable on a plethora of system abstraction levels. Propelling a debate on the implications of assumptions and quantified outputs of the SAIL might be one of its key capabilities, which in turn can contribute to low-impact strategies. Analysing a system with the SAIL effectively reduces complexity, but trade-offs are an intrinsic part of any intervention.

10. Conclusion

The SAIL framework provides a useful systemwide lifecycle perspective for the determination of impacts and solution based pathways in sailing cruise lifecycle systems. It has shown to be successful in clarifying the distribution of environmental impacts related to a sailing cruise holiday and to provide a quantification of the feasible impact reduction when substituting elements of major contributing subsystems. The SAIL successfully integrates multiple impact indicators and various system properties of a manageable lifecycle approach. This report thus forms a generalisable template for impact quantification and mitigation in the sailing cruise tourism sector.

Additionally, the SAIL delivers new insights in the potential of sailing cruises to be a low-impact alternative to conventional cruise tourism. In sailing cruise lifecycle systems, the share of non-fuel related impacts are greater on the CSA than estimated for Oasis-class cruise ships. Nevertheless, for the assessed impact categories, fuel-related impacts remain the greatest contributor to environmental damage of sailing cruise tourism. When relating the carbon footprint of a sailing cruise holiday on the CSA to two previously assessed conventional cruise holidays, a total reduction of 17% (Norwegian Gem) and 28% (Oasis-class) have been estimated, whereas the fuel related footprint was reduced up to 49%. This stresses the fact that, notwithstanding the efficiency advantages of more competitive economies of scale on extensive cruise ships, smaller scale sailing cruise holidays are a low-impact alternative.

In established fields of study, a fast-track LCA approach would be limited in contributing to novel insights, yet to assess the understudied sailing cruise service systems with the SAIL, it is advantageous to start with a systemwide lifecycle perspective, as impacts are less likely to be ascribed to a single point source. A subsystem's relative contribution to product and service related impacts can thus form the basis for impact-mitigating policies. The improvement-focused dimension of 'ascending' the SAIL increases its usability for estimations of feasible impact reduction. The computational focus on relative contribution of a subsystem serves as a proxy for the sensitivity of the aggregate system to a specified subsystem, which is relevant to (sailing) cruise ships, where the distribution of energy, material and service-related impacts differ from the rest of the shipping sector.

This report notes that the focus of large-scale complex service models for sustainability policies should be on usefulness rather than accuracy. Furthermore, the SAIL's principal aim to inform sailing cruise holiday stakeholders of the technical possibilities for environmental impact reduction was realised for the case study. The focus on fast-track LCA of the SAIL tool improves its actionability in sailing cruise lifecycle systems, where an impact assessment knowledge base is missing.

In the case study, fuel usage was a major contributor to the total impact of the implemented characterisation. Currently existing methods such as the EEOI or LCA-based methods on fuel use could thus also form a useful indicator to estimate the carbon footprint of the diesel combustion subsystem. These existing methods thus provide an effective approach to determining the fuel-related impacts, which is a major impact contributor for many ships. Nevertheless, in the sailing cruise sector, fuel consumption will not necessarily be the major culprit. Presumably, when different sailing cruise operators have varying fuel requirements or sail more often, relative contributions between subsystems will show divergent distributions. Furthermore, differences in systemic characteristics could lead to the formation of new subsystems for other sailing cruise operators or make existing subsystems more dynamically featured on the impact ladder. For example, when a sailing cruise operator plans to build another ship, the ship production subsystem will be a recurring event. Performing a SAIL analysis for other cruise operators would thus provide another set of meaningful insights.

Although the SAIL succeeds in comprehensibly forming focal points for impact reduction, this report finds that an exclusive focus on a set of three impact indicators may overlook other systemic factors needed to establish an SOI. Furthermore, the SAIL explores impact reduction in the techno-ecological dimension for subsystems which all bear, to a certain extent, social and economic characteristics. Consequently, this limitation of the SAIL leaves the formation of a socioeconomic interpretation up to the sailing cruise operator, in this case the RCSA.

Reiterating over the SAIL steps can however form an additional systemic dimension for the proposed interventions. Repeating the SAIL computations after system properties have changed could provide an iterative experimental design of sustainable innovations. Especially for more extensive sailing cruise systems, multiple SAIL computations benefit the coverage of the scope. Naturally, for a small system (i.e. sailboat) a single SAIL would be sufficient, whereas a larger system (i.e. tall ship) will sail well by systemic use of multiple SAILs. Subsequently, further usage of the SAIL in other case studies, with a focus on iterative experimental improvements, will provide valuable insights into the systemic realisation of impact reduction and sustainable innovation in the sailing and cruise tourism sector. Nevertheless, the SAIL successfully integrates multiple impact indicators and various system properties in a manageable lifecycle approach. A useful and generalisable design for impact quantification and mitigation in sailing cruise lifecycle systems is thus established.

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A1. Tables and figures

A1.1. Ship production

Type	*Full rigged Tallship*
Deck lenght	60.5
Length overall (LOA)	76
Beam	10.5
Air draught	46.3
Draught	4.8
Sail area	2200 m2
Crew	32
Water displacement	1083 m3
Tonnage (LWT)	922
Engine	Caterpillar C32
Speed under engine	11 knots
Speed under sail	16.5 knots
Passenger daytrips	120 max
Passengers multi day trips (ex-crew)	28

Table 17. General information CSA.

Type	DWT (t)	Lightweight tonnage (t)	Total displacement (t)				
Container ship*	43000	18429	61429		*See input dataset		
Stad Amsterdam complete	110	922	1032				
Bare tonnage clipper		659					
Sum additional categories		263					
Factorized Clipper/Carrier	**0.050**						
Factorized Non-Sail/Carrier	**0.0357**						
Sail specific category	kg	Used category	Database/Project	Location	Lifetime (weeks)	Persons	Net input kg/pp/week
Interior Wood joinery	108400	Teak FSC PEFC 665	IDEMAT 2.1	SEAsia-Rotte	2600	28	1.489
Insulation	14579	Stonewool	IDEMAT 2022	Global	2600	28	0.200
Upholstery	2054	Fiber, Cotton	Ecoinvent 3.8	Global	2600	28	0.028
Exterior wood work	18866	Iroko FSC PEFC 650	IDEMAT 2.1	SEAsia-Rotte	2600	28	0.259
Spars	23046	Aluminium extrusion profi	ELCD	EU	2600	28	0.317
Standing rigging	8181	Steel wire rod	Industry Data 2.0	EU	2600	28	0.112
Running rigging	4489	Polypropylene fibers	ELCD	EU	2600	28	0.062
Sails (stowed)	3355	PET	Idemat 2022	EU	2600	28	0.046
Ballast in box keel	80000	Lead	IDEMAT 2.1	EU	2600	28	1.099
Category	p	Used category	Database/Project	Location	Lifetime (weeks)	Persons	Net input p/pp/week
Bare ship production	0.0357	Container ship production	Ecoinvent 3	Global	2600	28	0.000000491

Table 18. LCI ship production, for input reference see tables below.

Ship parts	*mass (kg)*
Hull construction	308118
Steering gear	1525
Engine	11375
Bow Thruster	1200
Generator	7680
Fresh Water system	2242
Seawater system	1587
Bilge system	3343
Sewage System	2718
Hydraulic system	1400
Fuel System	772
Lubrification system	293
Firefighting system	3970
Cooling and freezing system	490
Ventilation system	1580
Climate control	8316
Electrical systems	17200
Navigation/communication	900
Cathodic and Lightning protection	150
Interior Wood joinery	108400
Galley/Laundry & Gas system	3853
Insulation	14579
Upholstery	2054
Deck equipment	8261
Anchor and mooring system	10208
Exterior wood work	18866
Spars	23046
Standing rigging	8181
Running rigging	4489
Sails (stowed)	3355
Inventory	13337
Owners options	37000
Safety equipment	13316
Miscellenous	12000
Soakage & system fluids	12232
Paint systems	8500
Ballast in box keel	80000
Trimballast inside hull	165000
Total (ex crew/guest/provision)	**921536**

Table 19. Mass balance CSA. Note: a detailed material and maintenance description is considered confidential and excluded from table.

Inputs from technosphere	Amount original	Conversion 1	Conversion 2	Final	pp/week
alkyd paint, white, without solvent, in 60% solution state	1.33E+05	0.035736	72800	6.53E-02	kg
aluminium, wrought alloy	9.87E+03	0.035736	72800	4.84E-03	kg
asbestos, crysotile type	1.54E+05	0.035736	72800	7.56E-02	kg
bronze	2.80E+04	0.035736	72800	1.37E-02	kg
copper, cathode	2.88E+04	0.035736	72800	1.41E-02	kg
electricity, medium voltage	5.87E+06	0.035736	72800	2.88E+00	kWh
electronic component machinery, unspecified	90.7	0.035736	72800	4.45E-05	unit
glass wool mat	1.54E+05	0.035736	72800	7.56E-02	kg
glued laminated timber, average glue mix	5.48E+02	0.035736	72800	2.69E-04	m3
heat, district or industrial, other than natural gas	7.11E+06	0.035736	72800	3.49E+00	MJ
marine engine	1.13E+03	0.035736	72800	5.55E-04	unit
polyethylene, high density, granulate	4.36E+04	0.035736	72800	2.14E-02	kg
polypropylene, granulate	4.36E+04	0.035736	72800	2.14E-02	kg
polystyrene, expandable	4.36E+04	0.035736	72800	2.14E-02	kg
polyurethane, flexible foam	4.36E+04	0.035736	72800	2.14E-02	kg
polyvinylidenchloride, granulate	4.36E+04	0.035736	72800	2.14E-02	kg
reinforcing steel	1.83E+07	0.035736	72800	8.98E+00	kg
sanitary ceramics	1.54E+05	0.035736	72800	7.56E-02	kg
welding, arc, steel	1.17E+07	0.035736	72800	5.74E+00	m
welding, gas, steel	8.86E+07	0.035736	72800	4.35E+01	m
zinc	1.25E+05	0.035736	72800	6.14E-02	kg

Table 20. LCI table of the background input dataset* on *container ship production*. Conversions for use were made based on LWT (conversion 1) and lifetime + passenger week (conversion 2).

A1.2. Hotel operation

Economic flows, in:						
Amount	*Unit*	*Product*	*Activity*	*Location*	*Data source*	*Aditional documentation*
7.00	guestnight	Hotel operatior	Building operation, hostel	Global	Ecoinvent 3	Impact of operation small hostel

Table 21. LCI hotel operation (7 background dataset units).

Overarching process	Amount	Information
Building operation hostel	7 Guestnight	Operation of hostel in Rio de Janeiro, accounted for all material and resource use
Input from technosphere	**Per guestnight**	**Reflection**
building, hostel	2.12e-06 unit	Not relevant: the building of a hostel is different from a ship, which is accounted for in construction
cleaning consumables, without water, in 13.6% solution state	0.00777 kg	Relevant
coffee maker	3.17e-05 unit	Relevant
compact fluorescent lamp	0.00433 unit	Relevant
computer, laptop	7.94e-05 unit	Relevant
cookstove	1.06e-05 unit	Relevant
electricity, low voltage	1.72 kWh	Not relevant: Electricity use is covered in fuel usage (by generators)
furniture, wooden	0.0272 kg	Relevant
heat, district or industrial, other than natural gas	0.809 MJ	Not relevant: Heat is produced by HVAC, energy input is fuel and electricity
mattress	0.000952 unit	Relevant
microwave oven	1.98e-05 unit	Relevant
non-ionic surfactant	0.019 kg	Relevant
nylon 6	0.000794 kg	Relevant
refrigerator	6.35e-05 unit	Relevant
steel, low-alloyed, hot rolled 0.0019 kg		Relevant
tap water	26.7 kg	Partially relevant: a share of water is made with water maker (indirect diesel input)
television	3.17e-05 unit	Relevant
textile, knit cotton	0.00262 kg	Relevant
tissue paper	0.0105 kg	Relevant
vacuum cleaner	1.98e-05 unit	Relevant
washing machine	1.59e-05 unit	Relevant
water, completely softened	0.0494 kg	Partially relevant: a share of water is made with water maker (indirect diesel input)
water, completely softened	0.0494 kg	Relevant

Table 22. Background dataset input for *building operation hostel*. Unit process related commentary is presented in the third column.

A1.3. Food consumption

Category on orderlist	kg	Category in database	Database/Project	Net input (kg/pp/week)	Location
Meat	233.25	beef fillet	LCA Food DK	3.24	Denmark
Fish	79	fish sticks hake	Ecoinvent 3	1.10	Global
Meat substitutes	12.5	Tofu	LCA Food DK	0.17	Denmark
Vegetables/herbs	330.4	Tomato, Standard	Ecoinvent 3	4.59	Global
Fresh fruit	289	Banana	Ecoinvent 3	4.01	Global
Frozen plant based	246.01	Potatoes, in supermarket	LCA Food DK	3.42	Denmark
Pasta, rice, bread and cereal	139	Bread, wheat conventional fresh	LCA Food DK	1.93	Denmark
Dairy	596	Full milk, from dairy	LCA Food DK	8.28	Denmark
Dairy substitute (soy)	33.5	Soybean meal	Ecoinvent 3	0.47	Global
(natural) Oil based products	52.3	Rapeseed oil, in supermarket	LCA Food DK	0.73	Denmark
Toppings/spreads	18	Palm oil, refined	Ecoinvent 3	0.25	Global
Snacks	72.79	Milk chocolate, at plant	World Food LCA dat	1.01	Local
Drinks (non-alchohol)	448	Apple pomace, from concentrated juic	World Food LCA dat	6.22	Local
Beer	253.44	Barley, Malted	World Food LCA dat	3.52	Local
Cleaning and disposables	201.3	Cleaning consumables	Ecoinvent 3	2.80	Global

Table 23. LCI for food consumption subsystem.

A1.4. Maintenance stad amsterdam

Economic flows, in:						
Amount	*Unit*	*Product*	*Activity*	*Location*	*Data source*	*Aditional documentation*
1.373E-06	p	Container ship maintenance	Maintenance	Global	Ecoinvent 3	corrected for lifetime and LWT

Table 24. LCI Maintenance in first iteration. Conversion input based on LWT, background dataset unit processes are presented in Table 25 below.

Inputs from technosphere
alkyd paint, white, without solvent, in 60% solution state
diesel, burned in building machine
reinforcing steel
sand

Table 25. Background dataset unit process inputs.

Per two years		Dataset		g/L	L	kg	kg/week/guest
Antifouling ingredient (741.84 g/L)	Copper oxide	Copper oxide (kg)	antifouling	741.84	184	136.50	4.69E-02
Antifouling ingredient (39.48 g/L)	C10H8CuN2O2S2	Copper rich materials (kg)	antifouling	39.48	184	7.26	2.49E-03
Antifouling ingredient (41.36 g/L)	Zineb	Zinc Sulfide (kg)	antifouling	41.36	184	7.61	2.61E-03

Table 26. Revised maintenance regime based on foreground processes. Inputs from technosphere (part 1).

Per 6 years	Dataset	6 yr	pp/week		
Epoxy based protective layers and primers	Epoxy resin, liquid (L)	602.5	6.90E-02		
Paint, above waterline	Alkyd paint (60% solution)(kg)	125	1.43E-02		
Third of deck replaced	Iroko FSC/PEFC (kg)	6288.67	7.20E-01		
Running rigging (lines)	Polypropylene (recycled) (kg)	4489	5.14E-01		
Sails (Dacron)	PET (kg)	3355	3.84E-01		
Per 20 years	Dataset	20 yr	pp/week		
Standing rigging (e.g. stays)	Steel wire rod (kg)	8181	2.81E-01		
One percent of steel (hull)	Reinforcing steel (kg)	3081.18	1.06E-01		
Marine engine	Marine engine (p)	1	3.43E-05		
Generator (2*100kW)	Generator, 200kW (p)	1	3.43E-05		
Electronics, for control units	Electronics, for control units (kg)	100	3.43E-03	Simons (2021)	

Table 27. Revised maintenance regime based on foreground processes. Inputs from technosphere (part 2).

Emissions to air	kg/pp/week			
NMVOC, non-methane organic compounds	1.99E-02	30% of paint in	Friedrich et al. (1999)	
Emissions to water	kg/pp/week			
Zineb	2.61E-03			
Copper oxide	4.69E-02			

Table 28. Revised maintenance regime based on foreground processes. Emissions from paint and antifouling (part 3).

A1.5. Crew flights

Economic flows, in:						
Amount	*Unit*	*Product*	*Activity*	*Location*	*Data source*	*Aditional documentation*
1241.43	person km	Crew flights	Transport, passengers, aircraft, long haul	Global	Ecoinvent 3	Weekly mean 2018

Table 29. LCI crew flights based on background dataset. Input is corrected for foreground consumption (booking list 2018).

A1.6. Diesel combustion

Amount	Unit	Product	Activity	Location	Data source	Aditional documentation	Conversion L to MJ	Source Additional
7759	MJ/pp/week	Diesel	Diesel, burned in fishing vessel	Global	Ecoinvent 3	Mean March 2019	38.7	Hofstrand (2007)

Table 30. LCI diesel combustion. Conversion based on Hofstrand (2007) and foreground datasets on fuel consumption.

Reference product	**Amount**	**unit**
Diesel, burned by CSA	1	MJ
Inputs from technosphere		
Diesel	0.0234	kg
Emissions to air	**Amount**	**unit**
Arsenic	9.37E-10	kg
Benzene, hexachloro-	1.87E-09	kg
Cadmium	2.34E-10	kg
Carbon dioxide, fossil	0.0742	kg
Carbon monoxide, fossil	0.000173	kg
Chromium	1.17E-09	kg
Copper	2.06E-08	kg
Lead	3.04E-09	kg
Mercury	7.03E-10	kg
NMVOC, non-methane volatile organic compounds, unspecified origin	0.0000656	kg
Nickel	2.34E-08	kg
Nitrogen oxides	0.000368	kg
Particulates, < 2.5 um	0.00001181	kg
Particulates, > 2.5 um, and < 10um	0.00001264	kg
Polychlorinated biphenyls	0.00000089	kg
Selenium	2.34E-09	kg
Sulfur dioxide	0.0001004	kg
Sulfur oxides	0.00006686	kg
Zinc	2.81E-08	kg

Table 31. Revised LCI diesel combustion based on the dataset revision described in Section 8.3.6. Adjustments are made according to SCR functioning, IMO sulphur standards and fuel reduction since refit.

A2. Interviews

In this part of the appendix interview takeaways relatable to the research are presented. Most interviews however, are partially or completely left out of the appendix due to confidentiality agreements. Certain exceptions are made for statements that are directly present in the textual part of the report and for which a reference is made to the related interview. Notes are ordered chronologically.

Meeting	Function	Topics	Frequency
Reinoud van der Heijden	Operations manager RCSA	Progress meetings internship	Weekly meeting
Evert van Dishoeck	Director RCSA	Internship projects for RCSA	Periodically
Gijsbert Korevaar	Professor TU Delft TPM	Progress meetings thesis	Every two weeks
Jeroen Pruyn	Professor TU Delft 3mE	Progress meetings thesis	Periodically

Table 32. Meetings for thesis and internship.

Interview	Function	Topics	Date(s)
Ernst de Haan	Logistics Manager RCSA	Maintenance regime	02-03-2022 15-06-2022
Bart van Liempt	Hospitality manager RCSA	Hospitality regime	17-03-2022
Andrew Simons	Researcher Ecoinvent, director SailLink and 3SP	LCA, databases and sailing cargo	01-06-2022
Robin Snouck Hurgronje	Director Tall Ships Races Europe	Sailing cruises, history CSA.	02-06-2022
Marlou Leenders	Global head sustainability Randstad	Carbon reporting, corporate sustainability	20-06-2022
Various crewmembers	Various positions: deckhand, bosun, chef, hospitality	Visions, assumptions and innovations.	23-06-2022 till 27-06-2022
Moritz Kuhlenbäumer	Captain CSA	The CSA and sustainability	24-06-2022
Marleen van Moorsel	Hospitality manager RCSA	Hospitality regime and social innovation	25-06-2022
Wesley van Dommelen	Mechanical engineer CSA	Technical overview and innovations	26-06-2022
Haakon Vatle	Director Statsraad Lehmkuhl	Intercompany opportunities, sustainable innovation	Planned, to be completed

Table 33. Interviews for thesis and internship.

A2.1. Minutes interview logistics

Interviewee: Ernst de Haan
Function: Logistics manager
Date: 02-03-2022
Time: 11:00-13:00
Location: Randstad HQ, Diemermere 25
Topics: General ship structure and outline maintenance process

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Confidential thus undisclosed.

Partial data reference: see second interview with Ernst (A2.5.)

A2.2. Minutes interview hospitality

Interviewee: Bart van Liempt
Function: Hospitality Manager
Date: 17-03-2022
Time: 10:00-11:00
Location: Google Meets online meeting
Topics: General structure hospitality system
Provided documents: Order list Crossing Las Palmas 2018 (.xlsx), Calculation sheet provisioning adventurous sailing (.xlsx)

Confidential thus undisclosed.

Partial data reference:

Generally, food and drinks are bought in bulk when in ports. In Europe, and especially in the Netherlands, certain food types and products are extensively gathered. Among these are specialty goods and goods which are hard to find in other locations (e.g. *bitterballen: fried meat balls*). The trip for which the order list is provided lasted 18 days and was sold out (28 passengers onboard.

A2.3. Minutes interview 3SP sustainability

Interviewee: Andrew Simons
Function: LCA specialist
Date: 01-06-2022
Time: 10:00-10:45
Location: Google Meets online meeting
Topics: LCA Practice for sailing ships
Provided documents: Cargo sailing LCA (.pdf)

Introduction
Andrew Simons runs a sustainability consulting practice (3SP) and has conducted an LCA study on a to be-constructed sail cargo ship of 500t: The Eco-clipper (Simons, 2021). He has experience working as a researcher for the Paul Scherrer institute in Switzerland, which includes contributions to the Ecoinvent database. Among his contributions are the datasets on container ship production and maintenance that are used in this report.

Key meeting takeaways
The services provided by the Eco Clipper case study are expressed in the functional units *ton km* and *passenger km.* In this way the functional unit it mainly focused on transport, which means that this differs from the single guest one-week voyage used in the SAIL, which mainly focuses the experience.
For general commercial vessels, like a sailing cargo vessel, the drydocking maintenance period is estimated at once every 5 years, as this is minimally required by shipping regulations. When choosing indicators on the 'burden side', the chances of misinterpreting the results are smaller, as you are giving an indications rather than an exact result. It was therefore chosen to use Carbon footprint, Environmental footprint and Human health impact. Andrew states that outcomes are often an underestimation of 'real' impacts, but can form the basis for a useful interpretation. Consequently, it is not worth making an LCA model too detailed. The data points given in Ecoinvent, such as container ship production/maintenance, are also based only on a few datapoints. Assumptions are unavoidable, thus interpretations should always be made with care.

One of the greatest challenges for the realization of the sustainable image of sailing, and competing with large scale fuel based scenarios, is the challenge of economies of scale.

A2.4. Minutes meeting maritime engineering

Present: Jeroen Pruyn, Tom de Ruyter
Date: 02-06-2022
Time: 12:00-12:45
Location: 3Me faculty, TU Delft
Topics: Ship maintenance, antifouling paints, (bio)diesel and innovation

Antifouling
When specific background data on environmental effects of alternative forms of antifouling paints are not present, an assumption based on the main active component can be made.

General alkyd paints are present as a category within the Ecoinvent database, providing the basis for assuming its usage for general non-antifouling ship application.

Jeroen names several alternatives for antifouling paints: Hard coatings that can be periodically cleaned are currently studied by another TBM student, Lotte van de Steenoven. She studies the effectivity and environmental interactions of this type of antifouling.

Sharkskin, a biomimetic type of structure that resembles the texture of a shark's skin. Tests of this product gained positive results, it has however not been implemented on a larger commercial scale (yet).

Most antifouling alternatives need periodical cleaning, instead of repainting.

Fuel alternatives
The usage of most types of biodiesel can increase the frequency that filters need to be changed. Sulphur is generally a greasing agent in conventional diesel fuels. Reducing sulphur concentrations will increase the usage of alternative greasing agents.

Lifetime/maintenance assumptions
For a general container ship, the interval for large technical maintenance/refit is around 15 years. This is due to ongoing sector-wide efficiency improvements, combined with wear and tear of parts.

As the provided services by the CSA differ from the provided services on a container ship, one could state that 20 year lifetime of technical equipment is a decent assumption for the CSA. As long as the requirements provided services will be fulfilled, it is likely that the currently installed equipment (from 2019) will remain sufficient for another 20 years. Nevertheless, bear in mind that before 2050 large changes will be required for the emissions of the marine industry, it is therefore likely that by 2040 another major technical refit is required.

A2.5. Minutes interview logistics

Interviewee: Ernst De Haan
Function: Logistics manager
Date: 15-06-2022
Time:10:00-11:00
Location: Google Meets online meeting
Topics: General ship structure, maintenance assumptions
Provided documents: maintenance order lists

Confidential thus undisclosed.

Partial data reference:

Ernst agreed upon the following proposed assumptions for the maintenance subsystem: the main periodical maintenance activities for the CSA differ in their frequency. There is a *continuous* replacement of small parts, as well as an upkeep of paint, woodwork and machinery. *Every two years,* periodic drydock maintenance takes place, where antifouling is renewed. In addition, the rigging is checked and updated as needed. *Every six years*, larger maintenance occurs. Certain parts of the ship needed replacement in 2006, 2013 and 2019, for which material demand was relatively high. *Every 20 years,* a large refit takes place to update the ship to modern standards and (sustainable) innovations. Among the replaced materials are the main engine, generators and electronic equipment.

A2.6. Minutes interview sustainability and sailing cruises

Interviewee: Robin Snouck Hurgronje
Function: Director Tall ship races Europe, retired captain CSA, retired captain royal navy
Date: 15-06-2022
Time: 14:30-16:00
Location: Google Meets online meeting
Topics: History of CSA and a sustainable future

Confidential thus undisclosed.

No partial data reference.

A2.7. Minutes interview corporate sustainability

Interviewee: Marlou Leenders
Function: Global head sustainability at Randstad
Date: 20-06-2022
Time: 15:00-16:00
Location: Google Meets online meeting
Topics: Sustainability, carbon reporting and Randstad's ambitions

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Confidential thus undisclosed.

Partial data reference:

Marlou proposed that she that replacing all short distance flights (< 750 km) with train journeys could become one of Randstad's sustainability strategies.

A2.8. General onboard interview questions

Date: 24-06-2022 – 26-06-2022
Stores & preparations + empty delivery (Nice-Marseille)

Goal
This interview is composed to get an insight in the environmental interactions of the Rederij Clipper Stad Amsterdam and the personal view of some of its crew onboard. Besides acquiring quantifiable data for calculation purposes, I am interested in general observations regarding sustainability. Furthermore is of great interest to me to gain first hand insights in how the Clipper is built, exploited and maintained. The interviews are semi-structured and chiefly to receive a wider stakeholder (data) input.

Personal view
What is your personal view on the environmental interactions of the Clipper and (the surrounding) nature?
What crosses your mind when thinking of sustainability?

Life time of equipment and sails
What is the durability of sails?
What parts are most subject to wear and tear and need to be replaced often?
Do you think that durability of some parts could be improved? If yes, which parts?

Waste and waste management
Can you give an indication of the amount of waste that is produced?

Engine policy
When is motoring preferred over sailing?
What factors influence the usage of the engine? (e.g. wind, schedule, type of cruise)

Generator, shore power and electricity
What is your opinion on the current improvements in the electrical system since the refit of 2019?
Is the electrical system efficient in its current state?
If electricity could be saved, what would be a strategy?
Do you expect changes in the usage of shore power/electricity/generator?

Provisioning
What are the main factors that influence the choices for provisioning?
What are the main differences between types of cruises and provisioning?

Is there a policy on food waste?
What do you think of implementing more plant based provision?

Cruise types
Considering the previous questions, what are the main differences between the types of cruises?

Ambition & vision
If you could choose anything, what part of the ship/system would you choose to improve in order to reduce its environmental impacts?

A2.9. Minutes meetings various crew onboard

Interviewee: various crew members
Function: chef, deckhand, bosun, sailor and hospitality crew members
Date: 23-06-2022 till 27-06-2022
Time: varying
Location: Nice, Marseille, Mediterranean sea
Topics: general sustainability related topics and assumptions for report

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Confidential thus undisclosed.

No partial data reference.

A2.10. Minutes interview captain

Interviewee: Moritz Kuhlenbäumer
Function: Captain
Date: 24-06-2022
Time: 23:00-23:45
Location: Onboard the CSA. Stern deck, Mediterranean Sea, France.
Topic: General sustainability on board

Confidential thus undisclosed.

Partial data reference:

Captain Moritz stated that, in general, the world trades environmental impacts for (short term) human safety. The polypropylene lines onboard the CSA are safe to use but release numerous microfibers as they degrade due to the sun and salt. This adds up to trade-offs between luxury and environmental impacts, as setting high expectations for luxury and time management increases material and energy dependency.

A2.11. Minutes interview hospitality manager

Interviewee: Marleen van Moorsel
Function: Hospitality manager
Date: 25-06-2022
Time: 12:00-12:45
Location: Onboard the CSA. Stern deck, Mediterranean sea, France.
Topic: Hospitality

Confidential thus undisclosed.

Partial data reference:

Marleen stated that many local suppliers rely on imports for their products, which vary by location. The demanded goods are generally not adapted to the visited country, but rather tailored to the guest's demand onboard. She thinks that moving to more locally sourced products is generally a good idea, the CSA could make a statement by taking the lead in the composition of local menu's.

A2.12. Minutes interview mechanical engineer

Interviewee: Wesley van Dommelen
Function: Mechanical engineer
Date: 26-06-2022
Time: 19:00-20:00
Location: Onboard the CSA. Middle deck, Marseille, France.
Topic: General ship and company

Confidential thus undisclosed.

No partial data reference

A3. Additional documents

A3.1. KPIs – sustainability

Confidential thus undisclosed.

Partial data reference:

Since the refit of the CSA in 2019, the following emission reduction and efficiency improvements are expected:
NO_x reduction 80%
PM reduction 64%
SO_x remains low
Fuel consumption 15-20% reduced

A4. Projects for company

A4.1. Advisory report antifouling

Drafted: 20 June 2022
Author: Tom de Ruyter van Steveninck

Confidential thus undisclosed.

No partial data reference.

A4.2. Advisory report biofuel

Drafted: 10 May 2022
Author: Tom de Ruyter van steveninck

Confidential thus undisclosed.

Partial data reference:

A commercial party who sell this type of second-generation HVO in various blends is available in the Netherlands. Goodfuels offers renewable marine fuel (HVO) in four blends (20%, 30%, 50% and 100%). They can provide LCA substantiated data on reduction in CO_2, SOx, NOx and PM for their products.

A4.3. Advisory report carbon compensation

Drafted: 29 March 2022
Author: Tom de Ruyter van steveninck

Confidential thus undisclosed.

No partial data reference.