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Development of environmental assessment tool

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Abstract

This report describes the development of a lifecycle assessment (LCA) screening tool that allows environmental consequences to be considered, together with other design factors such as cost, manufacturing processes, material availability, etc, during the development of fire protection systems in the LASH FIRE project.

The platform for the LCA screening tool is an excel® spreadsheet file; expert knowledge of environmental impacts is not needed to use it. The tool is based on output from SimaPro® software, in which detailed LCA models of the risk control measures are created. The SimaPro® results are scaled so that comparisons can be made between alternative RCMs and a reference case.

Fire models provide important data about the type and amount of fire effluents going to the air as smoke and surface water as fire water run-off. The fire models used in a previous version of the tool will be modified in the spring of 2022 when fire experiments for Actions 6-D and 10-B are conducted.

A tour of the user-accessible worksheets is presented to allow users to understand what they see and how to manage the output from the tool. Detailed descriptions are given about how each part of the tool works and case studies describe how the tool was developed to fit the needs of Actions 6-D and 10-B. This document provides a limited amount of background information about the science of life cycle assessment as needed to support user understanding of the tool.

The results are presented in terms of: Fine particulate matter formation, Freshwater ecotoxicity, Global warming, and Marine ecotoxicity. Bar graphs showing the total impacts, normalized to the highest impact in each category, are provided next to the input area so that users can interactively see how the impacts change with new input. Detailed results are presented on a separate worksheet so that users can see both the numerical results and the graphical results showing the relative contributions from manufacturing, installation, use, end of life, fire emissions, and fire response to the overall impacts in each category. All the other worksheets in the tool are hidden and protected so that the calculations cannot accidentally be corrupted.

It is hoped that this tool will help the partners involved in this project become more aware of the environmental consequences of their design decisions, both for the LASH FIRE project and for other future work.

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Content

1 Executive summary

1.1 Problem definition

As our society changes due to the development of new materials, fire protection systems, construction codes and regulations, and as resources become scarcer, organisations responsible for fire safety are increasingly compelled to consider which response strategies are most effective, while minimizing the negative consequences on people, property and the environment. Unfortunately, few fire protection practitioners have the training and expertise necessary to understand the environmental consequences of fire protection systems and operations, which makes it difficult to include environmental impacts in fire protection decisions.

The LCA screening tool was created to allow environmental consequences to be considered, together with other design factors such as cost, manufacturing processes, material availability, etc, during the development of fire protection systems in the LASH FIRE project. A focussed description of the functionality of the LCA screening tool can be found in the D05.04 report. Tools of this nature have been developed by the author for other projects. There are similar tools found in the literature that do not include fire but were usually developed for a very specific purpose and sometimes incorporate more than one type of analysis. For example, tools can be found that combine life cycle assessment with life cycle costing, risk assessment, energy analysis and/or social life cycle assessment.

1.2 Method

The platform for the LCA screening tool is a very simple excel® spreadsheet file; users do not need expert knowledge of environmental impacts. The tool is based on output from SimaPro® software, in which detailed LCA models of the risk control measures are created. The SimaPro® results are scaled to the functional unit of the analysis (protection of a ship from shipboard fires for the life of the ship) in the LCA screening tool so that comparisons can be made on an equal basis between alternative RCMs and a reference case.

Fire models provide important data about the type and amount of fire effluents going to the air as smoke and surface water as fire water run-off. The fire models used in a previous version of the tool will be modified in the spring of 2022 when fire experiments for Actions 6-D and 10-B are conducted.

A tour of the user-accessible worksheets is presented to allow users to understand what they see and how to manage the output from the tool. Detailed descriptions are given about how each part of the tool works and case studies describe how the tool was developed to fit the needs of Actions 6-D and 10-B. This document provides a limited amount of background information about the science of life cycle assessment as needed to support user understanding of the tool.

The LCA screening tool has the same basis of calculations as the LCC tool, also developed in WP5, which makes it possible to consider the results of each tool together, i.e., the cost and environmental impacts of an RCM are derived from the same definition of the system. Therefore, partners can consider various aspects of the cost and the environmental consequences of creating, using, and disposing of an RCM.

There is an important connection with the formal safety assessment (FSA) developed in WP4. The FSA provides an estimate of the frequency and, to a limited degree, the severity of fire in various parts of a ship. This information is needed to scale the SimaPro® results to the functional unit so that valid comparisons can be made between RCMs.

1.3 Results and achievements

The LCA screening tool is as complete as it can be until the fire experiments for Actions 6-D and 10-B have been conducted in spring of 2022 and the fire models have been modified. When the fire models are complete the tool can be used to compare RCMs with each other and with a reference case that represents the current state-of-the-art for manual firefighting and weather deck fire protection operations. The comparison with the reference case is especially important because it indicates whether the proposed RCM is better or worse than existing fire protection methods.

The tool results are presented in terms of these environmental impact categories: Fine particulate matter formation, Freshwater ecotoxicity, Global warming, and Marine ecotoxicity. Bar graphs showing the total impacts, normalized to the highest impact in each category, are provided next to the input area so that users can see how the impacts change with new input. Detailed results are presented on a separate worksheet so that users can see the numerical results and the graphical results showing the relative contributions from manufacturing, installation, use, end of life, fire emissions, and fire response to the overall impacts in each category.

1.4 Contribution to LASH FIRE objectives

This work is part of Action 5-A: Define generic ro-ro ships for evaluation of risk control measures, with basis in characteristic ship types in the world fleet and provide for life cycle assessment. Action 5-A supports the overall project Objective 2: LASH FIRE will evaluate and demonstrate ship integration feasibility and cost of developed operational and design risk control measures for all types of ro-ro ships and all types of ro-ro spaces.

1.5 Exploitation

Documenting the development of the LCA screening tool helps project partners in Actions 6-D and 10-B, and any other interested partner, understand how the tool works and how the inventory data is used. It also provides evaluation criteria regarding the ranking of the RCMs.

It is hoped that this tool will serve as an example for how both internal and external parties can become more aware of the environmental consequences of their design decisions, both for the LASH FIRE project and for future work.

2 List of symbols and abbreviations

BEV	Battery electric vehicle
CAF	Compressed air foam
CO	Carbon monoxide
CO_2	Carbon dioxide
D&D	Development and demonstration
ERA	Environmental risk assessment
FR	Flame retardant
FSA	Formal safety assessment
HCl	Hydrogen chloride
HCN	Hydrogen cyanide
HRR	Heat release rate
LCA	Life cycle assessment
LCC	Life cycle costing
PAH	Polyaromatic hydrocarbon
PM	Particulate matter
RCM	Risk control measure
RCO	Risk control option
SO_2	Sulphur dioxide
VOC	Volatile organic compound

3 Introduction

Main author of the chapter: Francine Amon, RISE

As our society changes due to the development of new materials, fire protection systems, construction codes and regulations, and as resources become scarcer, organisations responsible for fire safety are increasingly compelled to consider which response strategies are most effective, while minimizing the negative consequences on people, property and the environment. Unfortunately, few fire protection practitioners have the training and expertise necessary to understand the environmental consequences of fire protection systems and operations, which makes it difficult to include environmental impacts in their fire protection decisions.

Fires contribute to contamination of the atmosphere and to surface water, groundwater, sediment, and soil in the natural and built environments [1-3] although for the LASH FIRE project we are primarily concerned with contamination of the atmosphere from smoke and surface water from fire debris and fire water run-off that goes overboard during and after a fire on a ship. The impact of responding to fires, including tactics and use or choice of suppression media, can also have a negative effect on the environment [4]. The environmental consequences of fighting fires are related to the fire size, degree of ventilation and fuel, which affect the type and amount of contaminants in the fire effluent and residue.

Even without using additives in fire suppression water, the burning objects can produce effluents containing toxins and pollutants that are harmful to people and the environment. Fire effluents from burning vehicles, enclosures and various contents or furnishings have been characterized by many researchers. The Swedish Civil Contingencies Agency commissioned a large project in which fire effluents to air, soil, and water from large fires were analysed [5]. These studies have provided much useful information about species such as polyaromatic hydrocarbons (PAHs), flame retardants (FR), volatile organic compounds (VOCs), acid gases, halogenated compounds, metals, dioxins and furans, and other toxic compounds that have short- and long-term impacts on the environment. Also, the choice of suppression media and how it is applied, contained, and disposed of is a very important factor when considering the environmental impact of fires and their suppression [6-9].

While much research has been devoted to characterizing the contaminants found in fire effluents (see for example [10-11], very little work has been done to bring this complex body of knowledge to responsible authorities, fire protection engineers and first responders in a form that enables them to understand the environmental consequences of choices made to protect people, ships and the environment from fires.

Lifecycle assessment (LCA) is a growing scientific field in which the environmental impacts of a system[1] are estimated. The LASH FIRE environmental assessment tool (referred to as the LCA screening tool from this point forward) was created to allow environmental consequences to be considered, together with other design factors such as cost, manufacturing processes, material availability, etc, during the development of fire protection systems in the LASH FIRE project. Tools of this nature have been developed by the author for other projects [12, 13]. A methodology for including fire in LCA was created by Andersson et al. in 2004 [14]. This methodology, called Fire-LCA, is a way of accounting for fire effluents produced in given situations and can be used in conjunction with standard LCA procedures. Some aspects of this methodology have been incorporated into the LCA screening tool.

[1] A system can be almost anything, more details about LCA are provided in the following sections.

There are similar tools found in the literature, that do not include fire, but usually were developed for a very specific purpose and sometimes incorporate more than one type of analysis [15-20]. For example, tools can be found that combine life cycle assessment with life cycle costing (LCC), risk assessment, energy analysis and/or social life cycle assessment. Commercial software packages that can be applied to a wider range of systems are available, but they are typically expensive and require users to have a deep knowledge of both the analysis methodology and the system being analysed.

3.1 Objectives of this document

This report describes the development of the LCA screening tool and provides information about the underlying principles of LCA as applied to fires and fire protection systems aboard ships. The LCA screening tool was created to allow environmental consequences to be considered during the development of fire protection systems in the LASH FIRE project. The LCA screening tool provides information about the relative environmental impacts of selected risk control measures (RCMs) to support decision-making activities around which of the RCMs to include in the risk control options (RCOs) for protection of ro-pax, ro-ro cargo, and vehicle carrier ships from fires.

While basic information about LCA concepts is provided in the following sections, a detailed description is beyond the scope of this report; however, references are provided for readers interested in knowing more about LCA.

3.2 What is Life Cycle Assessment?

LCA is an analytical tool for considering environmental impact during the lifetime of a system. A system can be nearly anything that entails making decisions that could have an impact on the environment, e.g., creating a new product, changing a manufacturing process, or implementing new policies and regulations, although usually it is the creation of a product. The process of performing an LCA was standardised in 2006 in ISO 14040 and ISO 14044 [21-22]. The EU Joint Research Centre published an LCA handbook in 2010 [23] that describes in detail the process by which LCAs should be conducted to comply with the ISO standards. Since the two original standards mentioned above were published, six additional ISO standards[2] have been published to provide further guidance about conducting LCA studies.

Life cycle thinking is a concept that follows the same basic principles of LCA, except it is not a standardised process. Life cycle thinking involves creatively making a holistic evaluation of the environmental impact of a system using whatever tools or methods are relevant for the situation. The LCA screening tool is an example of life cycle thinking.

Two fully ISO compliant LCAs will be conducted on selected Action 6-D and 10-B RCMs as required by Task 5.9 and reported in IR05.65 and IR05.66. The LCA screening tool results for these RCMs provide the foundation for the full LCAs, however, the treatment of the results in Task 5.9 is much more comprehensive.

3.2.1 The LCA process

The process of conducting an LCA begins with defining the goal and scope of the assessment. Establishing a functional unit is part of the goal and scope. For the LASH FIRE project, the functional unit is protection[3] of a ship[4] from shipboard fires for the life of the ship. The next step is to collect and analyse the necessary data (referred to as “inventory”) to create models of the components of

[2] See https://www.iso.org/committee/54854/x/catalogue/p/1/u/0/w/0/d/0 for further information.

[3] Following the objectives af Actions 6-D and 10-B, protection is manual firefighting or weather deck fire protection

[4] The ship is a ro-pax or ro-ro cargo ship.

the system being studied. The next step is to assign environmental impacts to the components of the system. The last step is to interpret the results. As shown in Figure 1, these steps are very interconnected; new information discovered during one step of the process usually requires alterations in other steps, so it is normal for several iterations of the overall process to be performed before the work can be considered complete.

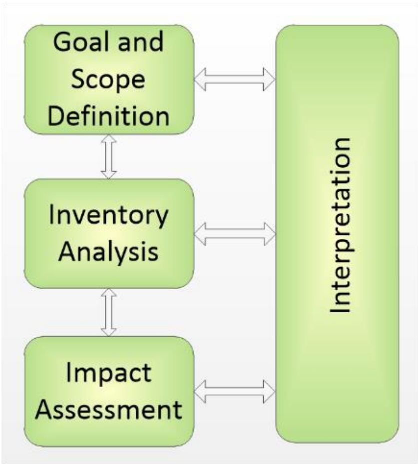

Figure 1: Steps in the process of conducting an LCA.

Typically, LCA studies are conducted from cradle to gate(s) to grave; the number of gates depend on the system being studied. Figure 2 illustrates how the structure of the LASH FIRE LCA screening tool fits within the typical lifecycle phases. The LASH FIRE phases are:

- Extraction of raw materials (cradle)
- Manufacturing- creation of the RCM hardware (gate)
- Installation activities- on newbuilding or existing ships (gate)
- Use- maintenance and potential RCM activation in case of fire during service life (gate)
- Fire- includes emissions to the air and water (part of Use phase)
- End of life- recycling, incineration, landfill, or other fate of RCM system (grave)

Figure 2: Typical lifecycle phases and LASH FIRE LCA screening tool structure

Extraction of raw materials from the earth is the beginning of the lifecycle for systems comprised of materials. Manufacturing and installation of the RCMs, for example, the hoses and water curtains of Action 6-D or the piping and monitors of Action 10-B, include impacts associated with transport of materials, waste streams, energy used, emissions from production processes, etc. The Use phase contains the impacts of testing, inspecting, and maintaining the RCMs during their service life and using them if there is a fire. It may be that the RCM is be destroyed while it is used during a fire, in which case it must be replaced. The fire itself is not really a lifecycle phase but is treated as a separate step so that the impacts of fire (both emissions from the fire and impacts from using the RCMs) can be compared with the impacts of the other lifecycle phases of the RCM systems.

Models of the lifecycle phases are created using SimaPro® LCA software [24] for each of the selected RCMs. The inventory data for the models are collected from various sources, such as LCA databases, the literature, and test reports for background data and directly from the project partners for the RCM foreground data.

The output from SimaPro represents estimates of the environmental impacts of one unit of the RCM of interest. This output is imported to the LCA screening tool, where it is scaled to the functional unit of the analysis (protection of a ship from shipboard fires for the life of the ship) and normalized so that comparisons can be made of RCMs having different service lives.

3.3 Connections with LCC and FSA

The LCA screening tool has the same basis of calculations as the LCC tool, also developed in WP5, which makes it possible to consider the results of each tool together, i.e., the cost and environmental impacts of an RCM are derived from the same definition of the system. Therefore, partners can consider various aspects of the cost and the environmental consequences of creating, using, and disposing of an RCM.

There is an important connection with the formal safety assessment (FSA) developed in WP4. The FSA provides an estimate of the frequency and, to a limited degree, the severity of fire in various parts of a ship. This information is needed to scale the SimaPro® results to the functional unit so that valid comparisons can be made between RCMs.

4 Approach

Main author of the chapter: Francine Amon, RISE

Following the structure and data flow of the LCA screening tool as shown in Figure 3, the fire scenarios created in the development activities of Actions 6-D and 10-B determine the fire protection challenge(s) to be overcome, the optimal type of RCMs to consider, and the design of fire experiments to evaluate the efficacy of the chosen RCMs. The RCM specifications include activities, material and energy requirements of interest to the LCA screening tool. Information from the fire experiment results and the RCM specifications, together with information from other sources such as relevant experiments from other projects and the literature is used to create the fire models and is also used directly as inventory data for some of the LCA models.

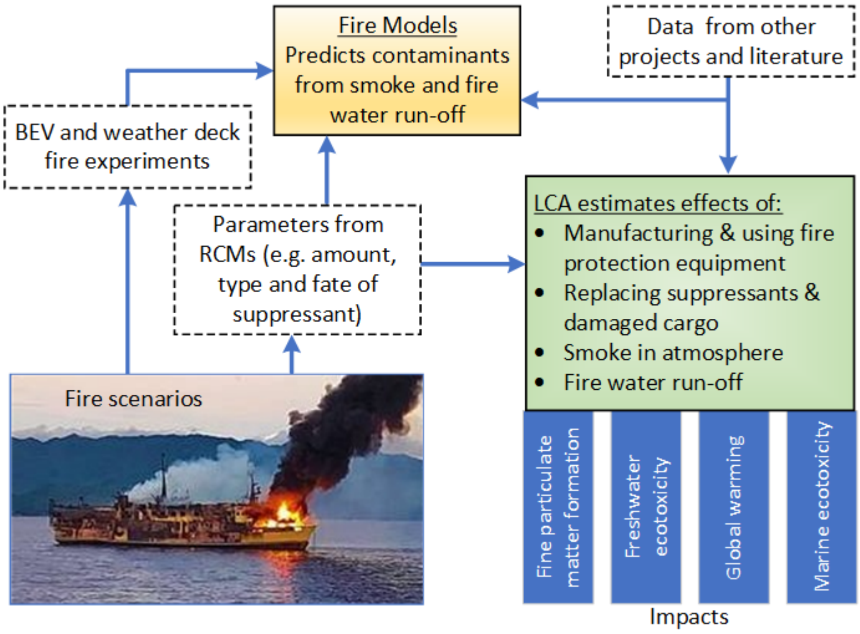

Figure 3: Structure of LCA screening tool and flow of data

4.1 Goal and scope

The fire models predict the amount and type of contaminants from smoke and fire water run-off. The LCA models estimate the impacts to the environment resulting from the fire effluents, manual firefighting operations (Action 6-D) and weather deck fire protection systems (Action 10-B), and replacement/disposal of fire suppressants and damaged cargo. The LCA models to not include replacing damaged parts of the ship, which is beyond the scope of this project.

Reference cases are used to compare the environmental impacts of the LASH FIRE RCMs with the state of the art that complies with minimum SOLAS regulations (if any exist) for the type of ship, corresponding to the action under investigation.

4.1.1 Description of the LCA screening tool

The LCA models are comprised of information about the materials, transport, energy, waste, and emissions related to a "system", such as an RCM. The SimaPro® software calculates environmental impacts based on the chosen impact assessment method and assigns the impacts to the appropriate impact categories. The results are exported to the LCA screening tool, scaled in various ways, and presented as key results in the RCM input worksheet and in the detailed results worksheets.

4.1.1.1 Adaptation of previous LCA screening tools

The LCA screening tool was originally developed as a combined LCA and LCC screening tool. This tool was intended to estimate the environmental and economic benefits/costs of firefighting operations for warehouse fires [13]. A similar combined environmental/cost approach was used on two later projects, in which LCA/LCC screening tools were adapted to the needs of innovation projects for graphene-filled polymeric materials [25] and non-halogenated flame retarded polymers [26]. Meanwhile, the LCA part of the screening tool was improved and extended to apply to vehicle fires and enclosure fires [12]. This revised tool, called the Fire Impact tool, has again been improved and extended to apply to the ship fire scenarios specified in Actions 6-D and 10-B of the LASH FIRE project.

The Fire Impact tool platform is an excel® file with a few user interface worksheets and many hidden calculation worksheets. It allows users to define two fire scenarios for two types of fires: vehicle fires and enclosure fires. The user-defined scenarios are compared with a reference case (one for vehicles and one for enclosures) in which the fire occurs and first responders arrive at the incident but only prevent the fire from spreading beyond the original vehicle or enclosure. While the excel® platform and concept of using reference cases for comparisons were retained for the LASH FIRE project, the user-defined scenarios have been replaced by the RCMs. This reduces the amount of user input significantly.

The Fire Impact tool has three main components: time-resolved fire models to predict the effluents produced by the fire; environmental risk assessment (ERA) models to predict the local environmental impacts; and LCA models to predict the global environmental impacts. The ERA model results are focussed on contamination of surface water, groundwater, and soil. Contamination of groundwater and soil are not relevant for the LASH FIRE application, and since the LCA component of the existing tool can adequately handle contamination of surface water, the ERA component of the tool was not included in the LASH FIRE version of the LCA screening tool.

4.1.1.2 Fire model adaptation

The fire model used for vehicle fires in the Fire Impact tool was based on fire experiments conducted by Lönnermark and Blomqvist in 1998 on a medium-sized, internal combustion passenger vehicle [27]. Detailed, time-resolved data were collected on the heat release rate (HRR) and smoke emissions.

The vehicle fire model predicts the amount of VOCs, aldehydes, isocyanates, PAHs, dioxins, furans, particulate matter (PM), carbon monoxide (CO), carbon dioxide (CO_2), hydrogen chloride (HCl), hydrogen cyanide (HCN), and sulphur dioxide (SO_2) emitted to the atmosphere based on the time elapsed since the fire started. It was assumed that the fire is extinguished 5 minutes after intervention started. Emissions to fire water run-off were also collected at the point of extinguishment and analysed for 25 species. It was assumed that the accumulation of contaminants in the fire water run-off generally followed the HRR curve. A detailed description of this methodology is found in [28].

Ongoing projects at RISE have generated new time-resolved data on smoke emissions from battery electric vehicle (BEV) fires [29] and will also produce new fire water run-off contamination data in the spring of 2022. This new data is much more representative of modern vehicles, especially BEV, which were chosen as the worst-case scenario for Action 6-D, so the vehicle fire model will be updated using the new data as soon as they are available. Meanwhile, the old fire model can be used in the LCA screening tool. The functionality of the screening tool will remain the same from the user perspective.

The fire model used for enclosures in the Fire Impact tool was based on work performed by Blomqvist et al. for the smoke [30] and experiments conducted at FM Global for the fire water run-off [31-32]. Furnished rooms were burned in both sets of experiments. Considering that there is no feasible way to know what kind of cargo is being transported by lorry on the weather deck of a ro-ro cargo ship, the above-mentioned experiments were retained in the LCA screening tool for Action 10-B. The reason is three-fold: first, there is high confidence in the quality of the data from these experiments; second, furnished rooms contain a range of materials and could be representative of many types of cargo; and third, the LCA screening tool results are relative, i.e., they are presented as a comparison of two RCMs against a reference, the ranking of the results do not depend on the type of fuel.

An understanding of the efficacy of the RCMs proposed by Actions 6-D and 10-B is needed to fully adapt the existing tool to the LASH FIRE LCA screening tool because it cannot be assumed that all the RCMs will extinguish the fire within 5 minutes. Experiments will be conducted in the spring of 2022 to test the efficacy of the RCMs, determine the feasibility of including fire spread as a parameter, and establish the most reasonable end point condition of the fires (control, containment, extinguishment). This is especially important for the reference case because it cannot be assumed that the current state-of-the-art techniques or the new RCMS of Actions 6-D and 10-B can keep the fire from spreading.

The fuel for the Action 10-B experiments will be wooden EURO pallets, which are frequently used as a surrogate fuel in large-scale fire tests. A fire growth curve for wooden EURO pallets in tunnel fires, based on work by Ingason and Li [33], together with the experimental results will be used to scale the fire effluents in both the smoke and the fire water run-off.

For both Actions, fire spread beyond the vehicle or enclosure is of interest to the LASH FIRE project but is not included in the Fire Impact tool. The feasibility of including fire spread, and thus the time to reach the desired endpoint of the fire using the RCMs, will be explored during the fire experiments conducted during the spring of 2022.

4.1.1.3 LCA model adaptations

The appearance of the existing LCA tool was changed to conform with the overall graphical theme of the LASH FIRE project. The amount of user input has been significantly reduced because the comparisons are between individual, complete RCMs. The fire protection parameters, e.g., type and amount of fire suppressant used, will be determined by the RCM efficacy experiments in spring of 2022. Rather than keeping separate input worksheets for vehicle fires and enclosure fires, the user input and key overall results for Actions 6-D and 10-B are both found in the RCM input worksheet. Likewise, the detailed results for both actions are presented in the Detailed results worksheet. A tour of the visible portion of the LASH FIRE LCA screening tool is provided in Chapter 5.

4.1.2 Assumptions & limitations

As the LCA models are developed there will be situations in which assumptions must be made about the inventory data and model structure. Assumptions are used to overcome gaps in the models. Usually this happens when the LCA database does not have a dataset that matches the materials and/or processes to be modelled. Another common example is the transport distance between suppliers and manufacturers, which might be unknown. For the sake of transparency, the assumptions made for each model will be explained in Deliverable D05.8.

The fire model for Action 10-B has some important assumptions. It is assumed that the cargo on the weather deck can be adequately modelled using data from fire tests of furnished rooms. It is also assumed that this data can be fit to a fire curve for burning EURO pallets. Considering that the results are relative, and that each RCM is exposed to the same design fire, these assumptions will not make a difference in the ranking of the RCMs.

A thorough investigation of the environmental consequences of shipboard fires would include damage to the ship. It is a limitation of this LCA screening tool that ship damage is not included. The amount of work necessary to include ship damage, which would require a full inventory of all the ship's materials and construction processes, is far beyond the scope of the LASH FIRE project.

4.2 Inventory analysis

Most of the complexity of developing the LCA screening tool lies in collecting inventory data and building the LCA models from it. Most of the inventory data about the RCMs came directly from the responsible LASH FIRE partners (SAS, UNI, F4M). A questionnaire was sent to these partners and interviews were conducted to make sure they understood what was needed. Decisions about how to handle the reference cases and fire models were made with the Action 6 and Action 10 leaders. A blank questionnaire is provided in Annex A.

Additional information was acquired from the literature and from fire experiment reports. The Ecoinvent® database (34], which is included in the SimaPro® software, was used to link the individual components of the LCA models. Sub-models were created in cases where there was no entry in the database that adequately described a part of an LCA model. The details of the LCA models will be reported in D05.8; they are not reported here because many important aspects of the models will be determined during the fire experiments conducted in spring 2022.

The inventory data includes:

- Manufacture, use, disposal of fire protection equipment (monitors, hoses, blankets, etc)
- Fire effluents as produced by the fire models
- Replacement of suppressants and damaged cargo
- Fate of used suppression media

4.2.1 Scaling of RCM Input

The SimaPro® results are imported to the LCA screening tool in a standardised format, each occupying a worksheet. These results are scaled and combined in the Plotting calcs worksheet to produce the graphical and numerical results in terms of the functional unit in the RCM input and Detailed results worksheets. The basis is the lifetime of the ship, which is listed in

Table 1 for the ships considered in this project. Note that, at this time, no Actions for vehicle carriers are included in the LCA screening tool.

The service life of the RCMs is currently required input, although this is something that can be hardwired into the calculations, thus reducing the amount of user input to nothing. The expected number of relevant fires during the life of the ship is an output of the FSA and, together with the RCM service life, is used to scale the SimaPro® results so that they can be compared on an equal basis. Replacement of all or part of an RCM that is destroyed by fire is also accounted for in the scaling calculations. For example, the handheld fire extinguishers in Action 6-D must be refilled every time they are used.

Table 1. Ship lifetimes used as a basis for RCM comparisons

Ship type	Newbuilding (yr)	Existing (yr)
Ro-pax	43	23
Ro-ro cargo	40	23
Vehicle carrier	29	17

4.2.2 Reference cases

The reference case for Action 6-D is the current state-of-the-art technology and standard operating procedures for manual firefighting of a vehicle fire on a ro-pax ship that meet the requirements of SOLAS. As a worst case, a BEV fire was chosen. The ship used to design the fire response and experiments is the Stena Flavia, which is the selected generic ro-pax ship for the LASH FIRE project.

For Action 10-B, there are currently no fire protection requirements for the weather deck of a ro-ro cargo ship. The ship used to design the fire response and experiments is the Magnolia Seaways, which is the selected generic ro-ro cargo ship for the LASH FIRE project The configuration of the Magnolia Seaways weather decks is used for the reference case. The reference fire starts in a cargo container and spreads across the forward weather deck but a deluge sprinkler system prevents the fire from spreading to the aft weather deck.

4.3 Impact assessment using SimaPro LCA software

The impact assessment method chosen for the LCA screening tool is ReCiPe 2016 Midpoint (H) V1.02/Europe Recipe H [35]. It was chosen because it contains the impact categories of interest to the LASH FIRE project and because it is a well-regarded European impact assessment method. The impact categories described below were chosen for their relevance to the project (fine particulate matter formation and global warming are related to fire effluents among other things, freshwater and marine ecotoxicity are related to ship effluents).

- **Fine particulate matter formation** (kg $PM_{2.5}$ eq) is air pollution that causes primary and secondary aerosols in the atmosphere that can have a substantial negative impact on human health, ranging from respiratory symptoms to hospital admissions and death [35].
- **Freshwater ecotoxicity** (kg 1,4-DCB) accounts for the environmental persistence (fate), accumulation in the human food chain (exposure), and toxicity (effect) of a chemical, leading eventually to damage to ecosystems and human health via freshwater pathways [35].
- **Global warming** (kg CO_2 eq) models the damage caused by emission of a greenhouse gas that will lead to an increased atmospheric concentration of greenhouse gases which, in turn, will increase the radiative forcing capacity, leading to an increase in the global mean temperature. Increased temperature ultimately results in damage to human health and ecosystems [35].
- **Marine ecotoxicity** (kg 1,4-DCB) accounts for the environmental persistence (fate), accumulation in the human food chain (exposure), and toxicity (effect) of a chemical, leading eventually to damage to ecosystems and human health via marine pathways [35].

The LCA models created in SimaPro® are for one unit of each system, e.g., one RCM, one kg of each fire effluent, one kg of suppressant used, one kg of damaged cargo replaced. Some of the models are comprised of sub-models so that the results are generated with the desired level of detail.

4.4 Interpretation of tool output

The results of the RCMs can be compared with the reference cases and with each other. The idea of using a reference case allows the users to consider whether the proposed RCM is better or worse for the environment than the existing state-of-the-art method. Of course, there are other factors to consider when designing new fire protection systems, but this tool allows users to include environmental impacts in their decision-making process.

The results are presented in four environmental impact categories because there is no single overall measure of "environmental friendliness". Each impact category is measured in its own way and represents a different type of impact on the environment. Most people have become somewhat familiar with the concept of global warming but may be less familiar with the other impact categories selected for this project.

There is no difference between the newbuilding and existing ships for Action 6-D so the results are generic in this regard. For Action 10-B, it is likely that more piping and possibly more monitors would be required for existing ships because the layout of the fire protection systems would need to accommodate the existing configuration of the ships to provide coverage for all areas, whereas the fire protection systems would be integrated into the design of a newbuilding ship. Therefore, the results for Action 10-B are given for both newbuilding and existing ships.

It is possible that the results will show a trend that an RCM has the lowest or relatively low impacts across all categories, which is an indication that the RCM is the best solution from an environmental perspective. More likely, the RCM results will be a mix of higher and lower relative impacts. In this case it is up to the user to decide how to interpret the results. It may be that some of the categories are felt to be more important than other categories, depending on the situation and the views of the user. For example, if the results show that an RCM has relatively low impacts in all categories except Freshwater ecotoxicity, but the ship only operates in marine waters, then the higher Freshwater ecotoxicity impact may not matter as much as the other impacts.

5 Tour of the LCA screening tool

Main author of the chapter: Francine Amon, RISE

The excel® spreadsheet-based tool has only three worksheets that are accessible by the users, which are described in the following sections. There are many worksheets that are hidden from users to prevent accidental corruption. Among these are worksheets for each RCM, each reference case, vehicle smoke, cargo smoke, vehicle fire water run-off, cargo fire water run-off, the fire models, and the plotting/scaling calculations. Most of these worksheets contain the output from the SimaPro® software and are called upon by the plotting calculations worksheet.

5.1 Instructions Worksheet

The instructions worksheet is where the user should go first. It describes where and how to enter data in the RCM input worksheet and provides a glossary of terms, as shown in Figure 4. It also has a list of the RCMs for reference, a list of the assumptions and limitations associated with modelling the RCMs, and a description of the reference case used for each action.

Legislative Assessment for Safety Hazards of Fire and Innovations in Ro-Ro Ship Environment

Introduction Life Cycle Assessment (LCA) Tool

Function : This tool allows environmental consequences to be considered, together with other design factors such as cost, manufacturing processes, material availability, etc, during the development of fire protection systems in the LASH FIRE project.

How to Use the tool

Select white cells to input the service life of the RCM

Step

1. Enter the service life of each RCM you want to compare in the RCM input sheet
2. Enter zero service life to remove an RCM from the comparison
3. Look at the key overall comparison results
4. Absolute and relative values of the numerical results can be found on the Detailed results sheet

LASH FIRE

Glossary

Fine particulate matter formation- (kg $PM_{2.5}$ eq) is air pollution that causes primary and secondary aerosols in the atmosphere that can have a

Freshwater ecotoxicity- (kg 1,4-DCB) accounts for the environmental persistence (fate), accumulation in the human food chain (exposure), and toxicity (effect) of a chemical, leading eventually to damage to ecosystems and human health via freshwater pathways

Global warming- (kg CO_2 eq) models the damage caused by emission of a greenhouse gas that will lead to an increased atmospheric concentration of greenhouse gases which, in turn, will increase the radiative forcing capacity, leading to an increase in the global mean temperature. Increased temperature ultimately results in damage to human health and ecosystems

Marine ecotoxicity- (kg 1,4-DCB) accounts for the environmental persistence (fate), accumulation in the human food chain (exposure), and toxicity (effect) of a chemical, leading eventually to damage to ecosystems and human health via marine pathways

Reference case- The reference cases assume the ship is equipped with fire protection systems that meet the minimum SOLAS requirements relevant to each action. Each reference case is described below.

Figure 4: Section of Instructions worksheet. Note that the glossary and the D&D, assumptions, and reference case lists are also provided on this worksheet.

5.2 RCM input worksheet

The only input needed is the service life of the RCMs. The user can enter zero for the service life to remove an RCM from the comparison. The reference cases are always included in the comparisons. Figure 5 shows the input cells for Actions 6-D and 10-B with fictional numbers entered as service lives and the key overall results for the 8 RCMs and the reference case in Action 6-D. Note that the results are fictional at this time because the LCA models have not been completed yet.

The key overall results are normalized to the highest impact in each impact category. The reason for presenting the results this way is that most of the impact categories are measured using different sets of units (kg $PM_{2.5}$ eq, kg 1,4-DCB, or kg CO_2 eq) and the absolute values of the results can differ by several orders of magnitude, which makes it hard to see all the data if it is plotted on the same graph unless it is normalized.

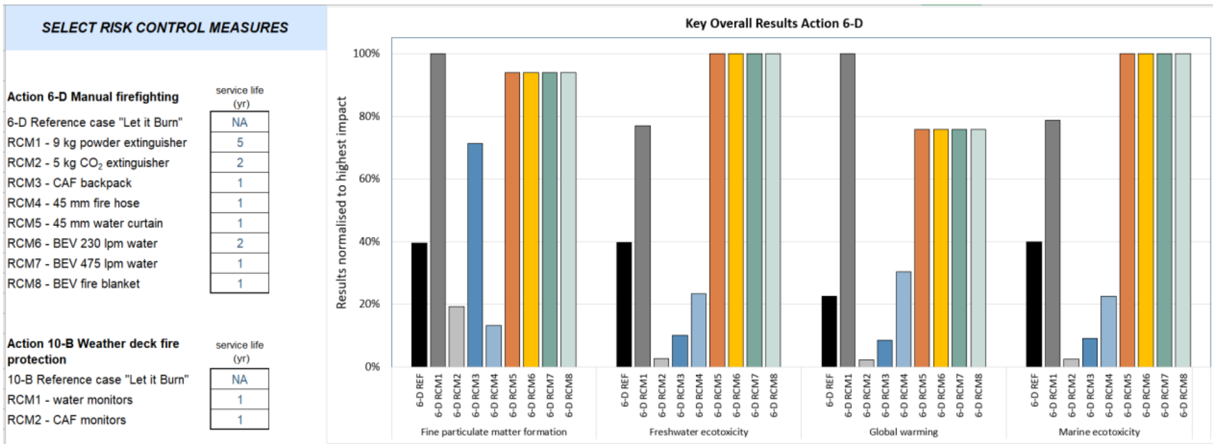

Figure 5: User input and key overall results for Action 6-D in the RCM input worksheet

5.3 Detailed results worksheet

Both the absolute values of the results and the detailed breakdown of the contributions of each part of the RCM life cycle to the total results are found in the Detailed results worksheet. The breakdown of contributions graphs show the results divided into the life cycle phases so that users can see which phases contribute the most (or least) to the overall relative impact in each category. An example of these results is provided in Figure 6. This information can help users identify “hotspots” or indicators of areas in which targeted improvements could lead to better overall results.

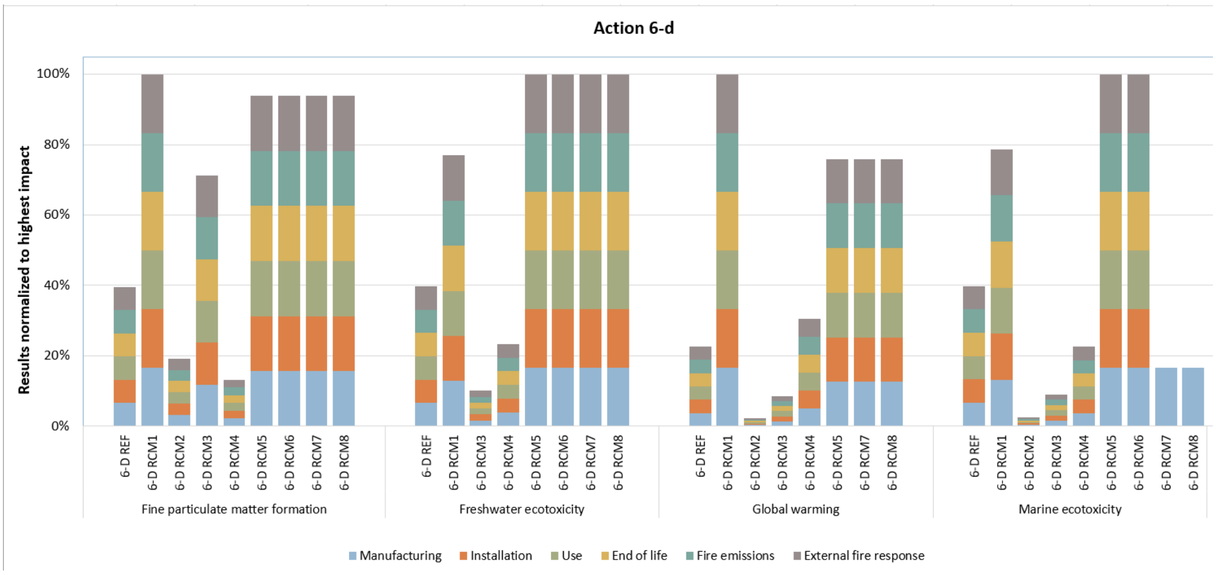

Figure 6: Example of breakdown of contributions results using fictional data

The life cycle phases in the breakdown are manufacturing, installation, use, end of life, fire emissions and fire response. The fire response refers to any additional response coming from outside the boundaries of the RCM being investigated.

The numerical results are also available on the Detailed results worksheet. They are provided in the units associated with each of the impact categories and can be copy/pasted by the user if it is desired to track changes in an RCM over time. It is incumbent upon the user to ensure that changes to the RCM have been incorporated into the LCA model currently used by the screening tool. As a matter of convenience, the relative numerical results have also been added to the Detailed results worksheet.

6 Case studies

Main author of the chapter: Francine Amon, RISE

The development of the LCA screening tool was influenced by the specific requirements of Actions 6-D and 10-B, which are fundamentally different. Action 6-D depends heavily on the first responders using equipment (the RCMs) to control a BEV fire; the tool compares the choice of tactics to use. Action 10-B is comprised of two self-contained fire protection systems that may or may not be controlled by a person; the focus is on the equipment rather than the actions of the first responders.

A challenge for both Actions is to define the desired endpoint of the fire, which will be determined during the fire experiments. It is possible that controlling the fire (preventing it from spreading to other fuels) is the best outcome that can reasonably be expected. It is also likely that the endpoints will be different for the two Actions. The burning time, which determines the progression along the fire curve and thus the amount of contaminants generated by the fire, is an important factor in the LCA screening tool results.

6.1 Action 6-D

There are 8 solutions under consideration for Action 6-D; this number may change after the fire experiments are conducted in spring of 2022. None of these RCMs are dependent on the age of the ship (newbuilding vs existing ship). It is possible that some of the solutions will be combined, e.g., the first person at the fire may use a handheld extinguisher and the next people to arrive may bring a fire hose or blanket. The LCA screening tool will be modified if the RCMs change after the fire experiments.

The fire model for smoke and fire water run-off will be created from fire experiments on BEVs. Fire spread to other vehicles is of interest to the Action 6-D leader, as is time to reach the endpoint of the fire. The reference case is a BEV fire. The first responders will use standard equipment (handheld extinguisher, various fire hoses, blanket) to suppress the fire. These tactics will be compared with the new RCMs developed in the project (CAF backpack and water curtain).

6.2 Action 10-B

There are two RCMs under consideration for Action 10-B. It is not expected that this will change after the fire experiments. The degree to which these RCMs are dependent on the ship's age will be estimated based on recommendations from fire protection engineers with experience installing these systems on newbuilding and existing ships.

Much of the materials used in the two RCMs is common to both systems. They both require the same size water tank and piping and can even use the same monitors. The major difference in the LASH FIRE project is the fire suppressant: water vs compressed air foam (CAF). The RCM that uses CAF also requires specialized equipment to create the foam.

The fire model for smoke and fire water run-off will be created from fire experiments on furnished rooms and EURO pallets. Fire spread to other fuels (cargo containers) is of interest to the Action 10-B leader, as is time to reach the endpoint of the fire. The reference case is a severe fire that spreads across the entire forward weather deck and back as far as the superstructure, where it is stopped by a deluge sprinkler system.

7 Conclusions

Main author of the chapter: Francine Amon, RISE

This report documents the development of the LASH FIRE environmental assessment tool (LCA screening tool). The LCA screening tool was created to allow environmental consequences to be considered, together with other design factors such as cost, manufacturing processes, material availability, etc, during the development of fire protection systems in the LASH FIRE project. It provides a limited amount of background information about the science of life cycle assessment as needed to support user understanding of the tool.

The LCA screening tool was designed to fit the needs of Actions 6-D and 10-B. Modifications will be necessary to include other Actions if there is the desire, time and resources available to further expand the tool.

The next, and final, step in the environmental impact work for the LASH FIRE project is to conduct two full, ISO-compliant LCAs, one on each of the highest ranked RCMs in Actions 6-D and 10-B, which will be reported in D05.8.

It is hoped that the LCA screening tool will help the partners involved in this project become more aware of the environmental consequences of their design decisions, both for the LASH FIRE project and for other future work.

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9 Indexes

9.1 Index of tables

9.2 Index of figures

10 ANNEX A – Blank questionnaire for collection of inventory data

1. GENERAL INFORMATION

Product/component

Name	Article no
LASH FIRE	

Sender

Company	RISE Research Institutes of Sweden
Contact person	Francine Amon
Address	Box 857
Tel	+46 105 16 51 66
Fax	
E-mail	francine.amon@ri.se

Receiver

Company	
Contact person	
Address	
Tel	
Fax	
E-mail	

Dispatch date	2021-04-27	Latest date for return	2021-05-24

2. INFLOWS AND OUTFLOWS

The manufacturing of a product involves inflows of material and energy resources and outflows such as emissions to air, water and ground, waste and material for recycling. The product itself is also an outflow.

In order to carry out an environmental Life Cycle Assessment (LCA) of a product, all flows relevant for the product must be declared.

To make the declarations, please use the tables below. You may ignore any resources/emissions in the tables which are not relevant for your product. If necessary you can increase the number of rows in the table so that all your information can be included.

One source of information could be an environmental report which is required annually by the environmental authorities.

2.1 ALLOCATION OF INFLOWS- AND OUTFLOWS

Often data is available annually at a site for the whole production but not for one specific product. To be able to estimate the inflows and outflows per product an allocation of the resource consumption and emissions between different products needs to be undertaken.

We recommend that the allocation is undertaken according to the following two steps:

1) Allocation between the different types of products should be calculated in proportion to the workshop area used for the product type.

Example:

In a workshop product “A” and “B” are manufactured. For the manufacturing of product “A”, 70 % of the workshop area is used and for product “B”, 30% of the workshop area is used. Emissions of volatile organic compounds (VOC) during one year are 1000 kg. The allocation of inflows and outflows is calculated using these proportions, i.e. product “A” is allocated 700 kg VOC and product “B” is allocated 300 kg VOC.

2) Within a product type the allocation is calculated as the quotient between the weight of the product and the sum of the weight of all products manufactured during one year.

Example:

To allocate inflows and outflows to one product “A”, the quotient between the weight for product “A” and the sum of the weight for “all products A” manufactured during one year should be calculated. If the weight of product “A” is 50 kg and the weight of “all products of type A” manufactured during one year is 100000 kg, then one product “A” represents (50/100000) x 700 = 0.35 kg VOC.

In the case the allocation is carried out in another way please describe the allocation below. It is OK to do a different sort of allocation as long as it is reasonable and understandable.

Alternative allocation:

2.2 INFLOWS

Materials in 1 whole system

Materials (polymers, tubing, machined parts, etc)	Weight (kg)	Transport type (lorry, train, plane, ship, etc)	Distance (km)

Consumption of materials/chemicals etc during production of system

(These are items consumed in production that are not part of the product)

Materials (solvents, cleaners, etc)	Allocated weight (kg)	Transport type (lorry, train, plane, ship, etc)	Distance (km)

Energy consumption during production of system

Energy (electricity, heating fuel, coal, gas, etc)	If electricity, is it from national grid?	Allocated quantity (kWh, kg, m^3)

2.3 OUTFLOWS

Emissions to air during production of system

Type of emission	Allocated quantity (kg)	Comments (how measured, estimated, calculated, etc)
CO Carbon monoxide		
CO_2 Carbon dioxide		
SO_x Sulphur oxides		
SO_2 Sulphur dioxide		
NO_2 Nitrogen dioxide		
NO_x Nitrogen oxides		
N_2O Dinitrogen oxide		
NH_3 Ammonia		
CFC/HCFC Freons		
HCl Hydrogen chloride		
Cl_2 Chlorine		
HF Hydrogen fluoride		
F_2 Fluorine		
CH_4 Methane		
NMVOC Non-methane volatile organic compounds		
NMVOC-Cl Chlorinated NMVOC		
PAH Polyaromatic hydrocarbons		
Other (specify)		

Emissions to water during production of system

Type of emission	Allocated quantity (kg)	Comments (how measured, estimated, calculated, etc)
COD Chemical oxygen demand		
BOD Biological oxygen demand		
TOC Total organic content		
TOCl Chlorinated TOC		
AOX Adsorbable organic halogens		
NO_3 Nitrate		
NH_4-N Ammonium nitrogen		
Acid as H^+		
N-total Total nitrogen		
P-total Total phosphorous		
Sulphur		
Phenol		
Oil		
Suspended solids		
Hydrocarbons		
Metals (specify which metal/metals)		

Emissions to ground during production of system

Type of emission	Allocated quantity (kg)	Comments (how measured, estimated, calculated, etc)

Waste

Type (hazardous, industrial, etc)	Allocated quantity (kg)	Receiver (specify type of waste treatment)	Transport type (lorry, train, plane, ship, etc)	Distance (km)

Materials to recycling

Type (metals, plastics, etc)	Allocated quantity (kg)	Receiver	Transport type (lorry, train, plane, ship, etc)	Distance (km)

4. OTHER INFORMATION *(for other information or comments)*

Is there any other process or emission or transport, etc. involved in your role in producing the prototype?