Horizon 2020

Project acronym: **LASH FIRE**

Project full title: **Legislative Assessment for Safety Hazard of Fire and Innovations in Ro-ro ship Environment**

Grant Agreement No: **814975**

Coordinator: **RISE Research Institutes of Sweden**

Deliverable D05.4

Environmental assessment tool

February 2022

Dissemination level: **Public**

Abstract

This report describes the functionality of the lifecycle assessment (LCA) screening tool used as guidance during the development of fire protection systems in the LASH FIRE project. A more comprehensive description of the LCA screening tool is presented in deliverable D05.5.

The excel® spreadsheet-based LCA screening tool is comprised of fire models, output from SimaPro® LCA software, and scaling calculations. The fire models provide data about the type and amount of fire effluents going to the air as smoke and to surface water as fire water run-off. The SimaPro® output is in terms of these environmental impact categories: Fine particulate matter formation, Freshwater ecotoxicity, Global warming, and Marine ecotoxicity. The calculations within the LCA screening tool are used to scale the results so that they can be compared graphically.

The results are presented in bar graphs showing the total impacts, normalized to the highest impact in each category, which 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.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 814975

Document data

Document Title:	D5.4 – Environmental assessment tool		
Work Package:	WP5 – Ship Integration		
Related Task(s):	T5.4		
Dissemination level:	Public		
Deliverable type:	OTHER, Environmental assessment tool		
Lead beneficiary:	1 – RISE		
Responsible author:	Francine Amon		
Co-authors:	n/a		
Date of delivery:	2022-02-28		
References:	D05.5		
Approved by	Vito Radolovic on 2022-01-17	Martin Carlsson on 2022-01-31	Maria Hjohlman on 2022-01-18

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Document history

Version	Date	Prepared by	Description
01	2021-02-25	Francine Amon	Draft of structure
02	2022-01-15	Francine Amon	Draft of final report, circulated to reviewers
03	2022-02-08	Francine Amon	Final report

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1 Executive summary

1.1 Problem definition

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. 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 LCA screening tool is comprised of four parts: data from fire experiments, fire models built from this data, LCA models of fire effluents and RCMs, and the screening tool itself, in which everything comes together.

Information about the type and amount of contaminants in fire effluents comes from fire experiments conducted by RISE and FM Global for other projects, and from testing performed by Actions 6-D and 10-B. The fire experiments performed by Actions 6-D and 10-B also provide information about how long it takes to reduce the fire to its endpoint (control, containment, extinction) for each of the RCMs.

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 the tool will be further modified in the spring of 2022 according to the Actions 6-D and 10-B fire experimental results. A comprehensive description of the LCA screening tool is presented in deliverable D05.5.

1.3 Results and achievements

The results are presented graphically as key overall results and detailed results. The graphical results are relative and have been normalized to the highest impacts in each of the impact categories. Detailed absolute numerical results are also provided.

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.

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

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
HRR	Heat release rate
LCA	Life cycle assessment
LCC	Life cycle costing
RCM	Risk control measure
RCO	Risk control option

3 Introduction

Main author of the chapter: Francine Amon, RISE

3.1 Background

This report describes the lifecycle assessment (LCA) screening tool, which 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.

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 [1-6]. 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.

3.2 Description of the LCA screening tool

Main author of the chapter: Francine Amon, RISE

The excel®-based LCA screening tool has three worksheets that are visible to users. These worksheets provide instructions, a user input area, and the key overall and detailed results. At this time the only input from the user is the service life of the RCMs; this may change in a future version of the tool. The functionality of the LCA screening tool lies in the many worksheets that are hidden from users to prevent accidental corruption. The structure of the tool and the calculations performed in these hidden worksheets are described in Chapter 4. The three visible worksheets that are accessible by the users are described in Chapter 5.

4 Hidden worksheets

Main author of the chapter: Francine Amon, RISE

The structure of the tool can be divided into four main pieces: the fire experiments, fire models, SimaPro® LCA models, and the LCA screening tool, as shown in Figure 1. The description of the tool is organised organized according to Figure 1 in the following sections.

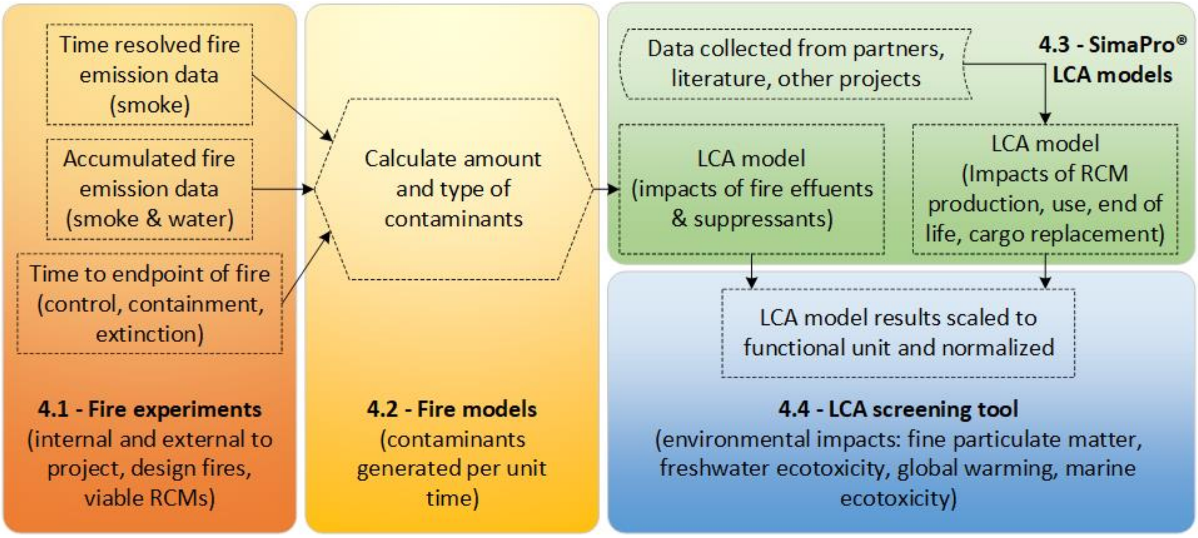


Figure 1: Structure of the LCA screening tool

4.1 Fire experiments

Information about the type and amount of contaminants in fire effluents is critical for the predicting the environmental impacts of fire. This information can come from a variety of sources; for the LASH FIRE project it comes from fire experiments conducted by RISE and FM Global for other projects [7-11], and from testing performed by Actions 6-D and 10-B. The fire experiments performed by Actions 6-D and 10-B also provide information about how long it takes to reduce the fire to its endpoint (control, containment, extinction) for each of the RCMs.

The data acquired from fire experiments is either time-resolved or from batch samples of contaminants accumulated during the fire. If it is accumulated the heat release rate (HRR) is used to distribute the contaminants over the time the fire burns. An example of the time-resolved data used in the smoke fire model for vehicle fires is given in Figure 2.

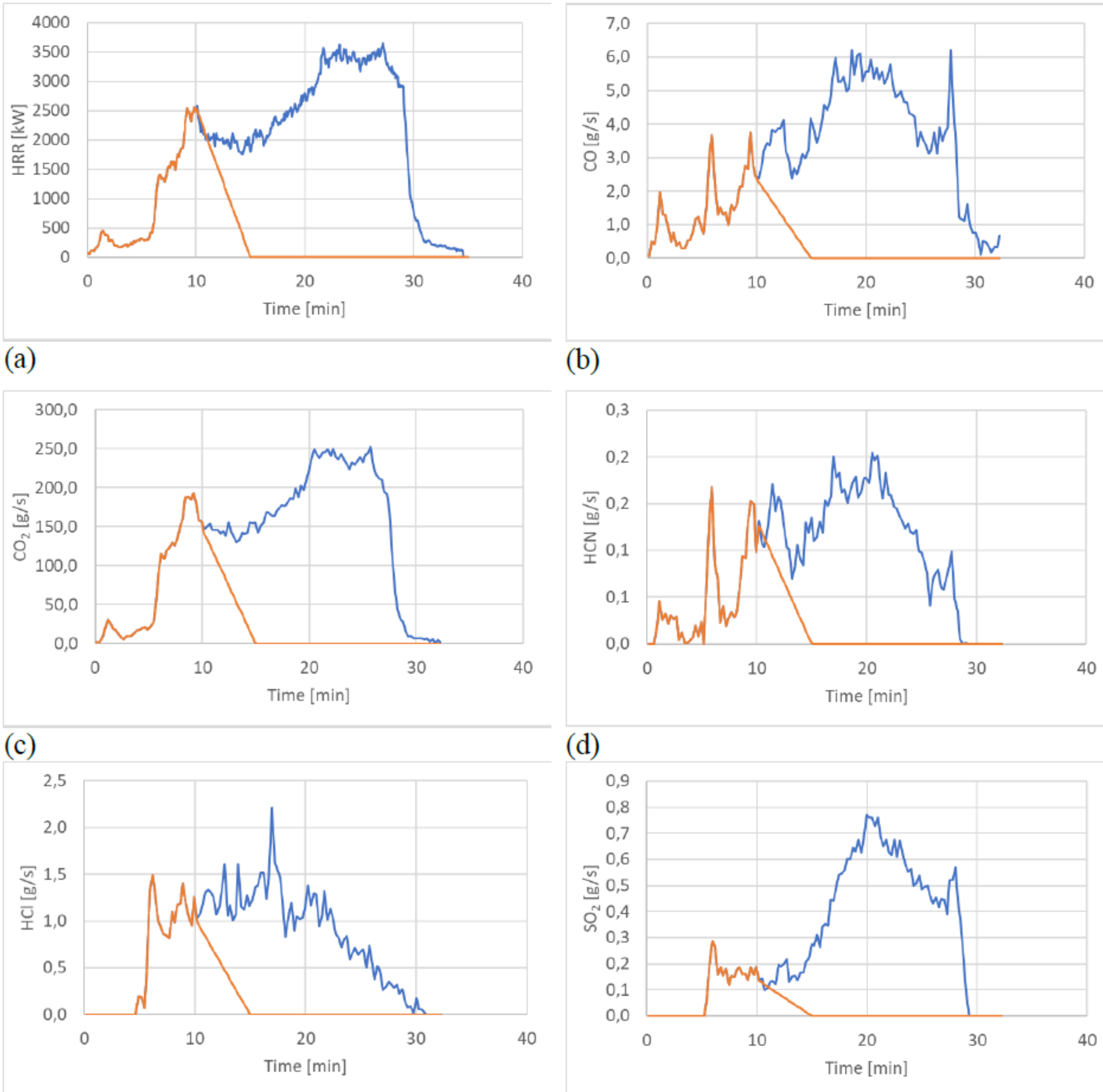


Figure 2: Example of HRR and five vehicle smoke contaminants with (orange lines) and without (blue lines) the use of RCMs.

The data used to build these plots, together with the accumulated data for 25 species found in the fire water run-off, occupies 7 of the worksheets in the LCA screening tool and is called by the fire model to predict the type and amount of contaminants in smoke and fire water run-off for a vehicle fire burning for a specified time. A screenshot showing some of the accumulated species is given in Figure 3. Note that the source of this data will be updated in spring of 2022 when battery electric vehicle (BEV) fire experiments are conducted. For cargo fires, the same types of worksheets are in the LCA screening tool, except they have been created from fire experiments on furnished rooms.

REFERENCE: Table 12 AND Table 13: A Lönnermark, P. Blomqvist, Chemosphere 62 (2006), pp 1043-1056

Yields in extinguishing water - car fire

Approx volume run-off water	200 l used to extinguish, 105 l collected fo		200
Analysis	**Result**	**Unit**	**Total amt (g)**
pH	9,1		-
Conductivity	760,0	mS/m	-
Particulates	1600,0	mg/l	320
P	19,0	mg/l	3,8
N	50,0	mg/l	10
TOC	1300,0	mg/l	260
T(aliphatic)OC	86,0	mg/l	17,2
T(aromatic)OC	<1,0	mg/l	<0,11
Non-polar aliphatics	70,0	mg/l	14
Non-polar aromatics	<1,0	mg/l	<0,11
AOX (Absorbable organic halogens)	0,8	mg/l	0,166
EOX (Extractable organic halogens)	0,0	mg/l	0,001
BOD (Biological oxygen depletion)	3100,0	mg/l	-
COD (Chemical oxygen depletion)	5300,0	mg/l	-
Nititox (measure of reduction potential on denitrification bacteria)	0,8		-

... Vehicle run-off water | Vehicle Smoke | LCA calcs | HRR | CO2 | CO | F ...

Figure 3: Screenshot of worksheet for fire water run-off for vehicle fires showing some of the accumulated species

4.2 Fire models

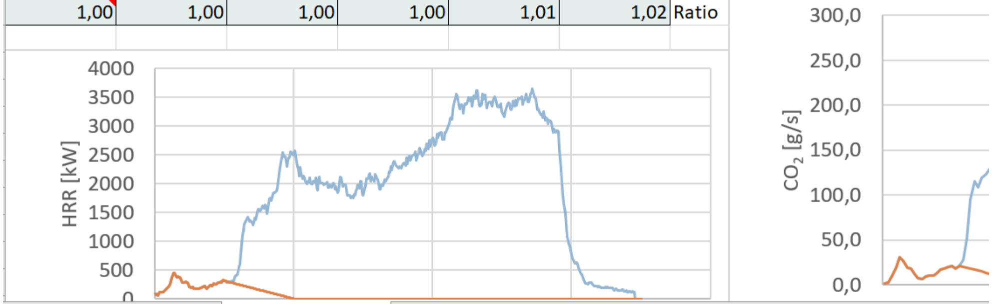
There are four fire models altogether: smoke and fire water run-off models for vehicle fires and for enclosures (cargo) fires. A screenshot of the vehicle fire model for smoke gases is shown in Figure 4. For illustration purposes only, the fire model shows that the smoke gases are reduced when an RCM is used, although the data shown will not be updated to the Action 6-D RCM test results until spring of 2022. The gases shown in Figure 4 are from the time-resolved data, although results also exist for the accumulated data. Similar fire model worksheets exist for the other three fire models.

RCM

HRR	CO2	CO	HCN	HCL	SO2	
311	22	0,71	0,07	0,19	0,06	Value at intervention
3737	251	5,74	0,17	1,44	0,54	Total amount late intervention
117	8	0,34	0,01	0,03	0,01	Total amount with intervention
0,03	0,03	0,06	0,09	0,02	0,01	Ratio

Reference case

HRR	CO2	CO	HCN	HCL	SO2	
2925	16	1,13	0,00	0,13	0,09	Value at intervention
3737	251	5,74	0,17	1,44	0,54	Total amount late intervention
3737	252	5,77	0,17	1,45	0,55	Total amount with intervention
1,00	1,00	1,00	1,00	1,01	1,02	Ratio



... Vehicle run-off water | Vehicle smoke model | HRR | CO2 | CO | ...

Figure 4: Screenshot of fire model for vehicle fire smoke. Similar models are included in the tool for vehicle fire water run-off and cargo fire smoke and run-off water.

The fire models predict the amount and type of contaminants in the smoke and fire water run-off. This information is then combined with the environmental impacts of these contaminants in the LCA screening tool. The process of creating LCA models in SimaPro® to assign the environmental impacts will be discussed next.

4.3 SimaPro® LCA models

The LCA models are created in SimaPro®. An example of a simple LCA model for a fire blanket is shown in Figure 5. These models can be constructed in many different ways and can include sub-models; they can quickly become quite complicated. There are two sub-models in the fire blanket model: one for the materials used and one for destruction (incineration) of a used fire blanket.

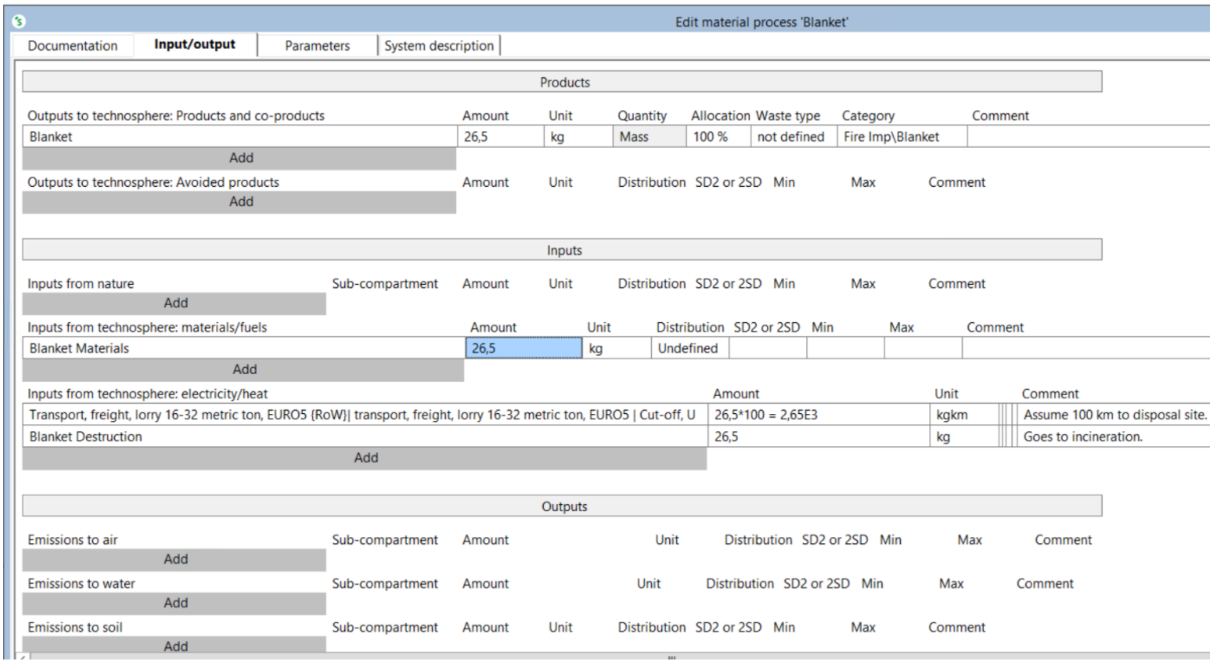


Figure 5: LCA model of a fire blanket

Information about the waste streams and emissions associated with a system (in this case producing a fire blanket), energy used, transport of materials, etc are all optional parts of the LCA model. The emissions section, at the bottom of Figure 5 is used to create LCA models of smoke and fire water run-off.

The output from SimaPro® can be exported to excel® as an .xlsx file. It has a consistent format that permits relatively easy retrieval of data by the Plotting calcs worksheet. The LCA model output for the fire blanket is shown in Figure 6.

SimaPro 8.5.2.3	Impact asses	Date:	2019-03-25	Time:	0,567368808	
Project	Fire Imp					
Calculation:	Analyze					
Results:	Impact assessment					
Product:	**26,5 kg Blanket**					
Method:	Ecological Scarcity 2013 V1.05 / Ecological scarcity 2013					
Indicator:	Characterization					
Skip categories:	Never					
Exclude infrastructure pro	No					
Exclude long-term emissic	No		Reference:			
Sorted on item:	Impact category					
Sort order:	Ascending					
		(Replace blanket)	(Destruction)			
Impact category	Unit	Blanket Materials	Transport, fre	Blanket Destr	Total Destruction	
Global warming	UBP	109195	206	31817	32023	
Air Pollution	UBP	44679	120	6724	6844	
Water Pollution	UBP	11723	26	1230	1256	
POP into Water	UBP	327	14	167	181	
Energy Resources	UBP	12944	25	1031	1056	

... | Vehicle run-off water | **Blanket** | Vehicle smoke model | HRR | C(...

Figure 6: LCA model output for fire blanket

4.4 LCA screening tool

Everything comes together in the LCA screening tool. The fire model results are scaled to the size of the fire and suppression efficacy of the RCMs and the environmental impacts from the LCA model results are assigned to the scaled effluents. The impacts of replacing vehicles, cargo and suppressant are scaled to the fire size and functional unit of the analysis. The results are normalized to the highest impact in each impact category to facilitate seeing all the results in one plot. All of these calculations take place in the Plotting calcs worksheet. A screenshot of part of the Action 6-D calculations is shown in Figure 7.

Input		
Action 6-D Manual firefighting	service life (yr)	
6-D Reference case "Let it Burr	NA	
RCM1 - 9 kg powder extinguish	5	recharge powder
RCM2 - 5 kg CO2 extinguisher	2	recharge CO2
RCM3 - CAF backpack	1	recharge CAF
RCM4 - 45 mm fire hose	1	OK- nothing to do after use
RCM5 - 45 mm water curtain	1	replace water
RCM6 - BEV 230 lpm water	2	replace water
RCM7 - BEV 475 lpm water	1	replace water
RCM8 - BEV fire blanket	1	replace after use

	Ship type	Newbuilding (yr)	Existing (yr)	Frequency (fire/yr)	
Action 6-D	Ro-pax	43	23	1,28	Ref D04.2, p.
Action 10-B	Ro-ro cargo	40	23	0,59	Ref D04.2, p.
	Vehicle carrier	29	17	0,83	Ref D04.2, p.

Action 6-d				
		Abs value	Scaled to ship life	Normalized
Fine particulate matter formation				
	6-D REF	0,00367016	0,202762906	0,39641976
	6-D RCM1	0,00925826	0,51148537	1
	6-D RCM2	0,00178331	0,098521568	0,19261855
	6-D RCM3	0,00659811	0,36452188	0,71267313
	6-D RCM4	0,00122898	0,06789661	0,13274399
	6-D RCM5	0,00869637	0,48044297	0,93930931
	6-D RCM6	0,00869637	0,48044297	0,93930931
	6-D RCM7	0,00869637	0,48044297	0,93930931
	6-D RCM8	0,00869637	0,48044297	0,93930931
Freshwater ecotoxicity				
	6-D REF	0,0619124	3,420436939	0,39785987
	6-D RCM1	0,1197259	6,614425072	0,76937957
	6-D RCM2	0,00426967	0,235883731	0,02743763
	6-D RCM3	0,01572017	0,868482634	0,10102054

Action 6-D					
Fine particulate matter formati		per service life			per service lif
		Manufacturi	Installation	Use	End of life
	6-D REF	0,066070	0,066070	0,066070	0,066070
	6-D RCM1	0,166667	0,166667	0,166667	0,166667
	6-D RCM2	0,032103	0,032103	0,032103	0,032103
	6-D RCM3	0,118779	0,118779	0,118779	0,118779
	6-D RCM4	0,022124	0,022124	0,022124	0,022124
	6-D RCM5	0,156552	0,156552	0,156552	0,156552
	6-D RCM6	0,156552	0,156552	0,156552	0,156552
	6-D RCM7	0,156552	0,156552	0,156552	0,156552
	6-D RCM8	0,156552	0,156552	0,156552	0,156552
Freshwater ecotoxicity		Manufacturi	Installation	Use	End of life
	6-D REF	0,066310	0,066310	0,066310	0,066310
	6-D RCM1	0,128230	0,128230	0,128230	0,128230
	6-D RCM2	0,004573	0,004573	0,004573	0,004573
	6-D RCM3	0,016837	0,016837	0,016837	0,016837

Instructions | RCM input | Detailed results | **Plotting calcs** | 6-D REF | 6-D RCM1 | 6-D RCM2 | 6-D RCM3 ...

Figure 7: Screenshot of part of the Action 6-D plotting calculations

5 Worksheets accessible to users

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 8. 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

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 8: 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 9 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 will not be completed until the fire experiments have been conducted in spring of 2022.

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.

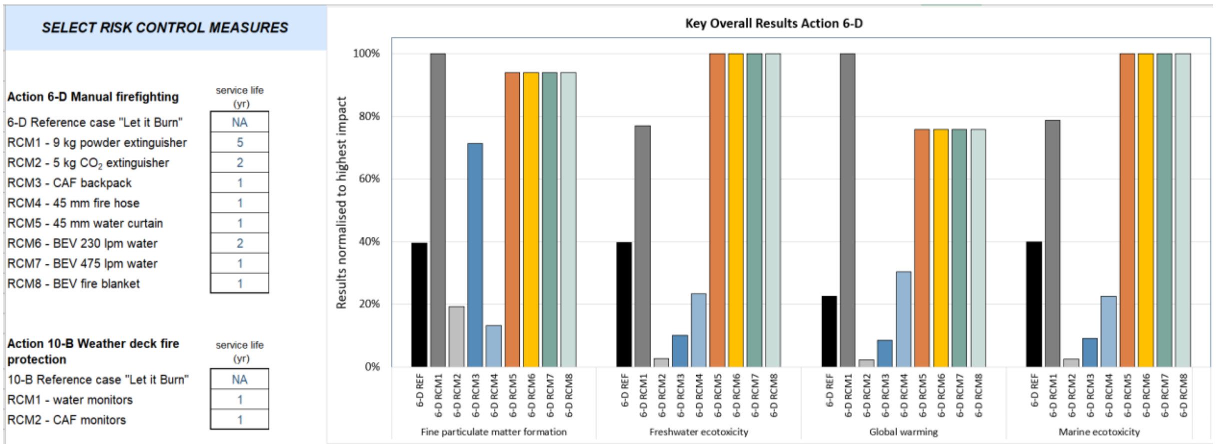


Figure 9: User input and key overall results for Action 6-D in the RCM input worksheet

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 lifecycle to the total results are found in the Detailed results worksheet. The breakdown of contributions graphs show the results divided into the lifecycle 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 10. This information can help users identify "hotspots" or indicators of areas in which targeted improvements could lead to better overall results.

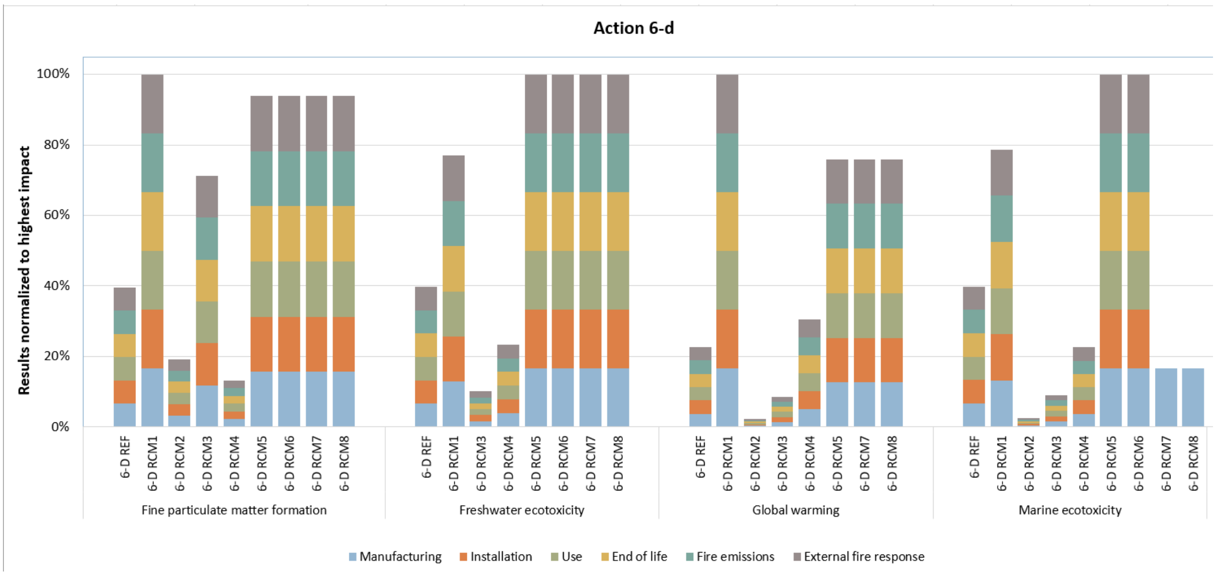


Figure 10: Example of breakdown of contributions results using fictional data

The lifecycle 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 Conclusion

Main author of the chapter: Francine Amon, RISE

This report documents the existence 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.

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.

7 References

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