Life Cycle Assessment

Environmental assessment of roofing systems

Using buildLCA to assess the performance of materials in roofing systems

worldsteel ASSOCIATION

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Executive Summary

This LCA study has been carried out to understand the environmental performance of different roofing systems in terms of the materials being used: steel, bitumen and concrete. The study covers the construction, use (maintenance) and end-of-life of the different roofing systems. buildLCA, a GaBi-based LCA model developed by worldsteel, has been used to benchmark the potential life cycle environmental performance of these roof designs.

The purpose of the study is to quantify the life cycle environmental performance of six roof solutions for a typical Scandinavian house (150m^2 roofing that is used for 60 years) and identify the solution with lowest environmental impacts from a life cycle perspective. The six roof solutions include two steel solutions (Monterrey and Classic) each with two options for batten types (wood or steel), a concrete roofing system and a bitumen roofing system.

This report acts as an initial assessment, to provide a first indication for the planning team of the roofing designs, based on generic data. Further optimisation, using more specific LCI data, for each further specified roofing design must be carried out in the context of the whole building. This is particularly important when taking into account the weight of the different roofing systems and their impact on the supporting systems within the building and the assumed lifetime of the building and service life of the roofing system. Each of these aspects can be further assessed using the buildLCA tool.

The study considers the roof construction stage (A1 – A5) including packaging materials, roof maintenance (B2, B4) and the end-of-life stage (C3, C4 and D) which includes consideration of the recycling, reuse, incineration, and disposal to landfill. A sensitivity analysis has been conducted to assess the variability of the results when different end-of-life assumptions are applied.

The CML method has been chosen as the main environmental impact assessment method for this study, and the selected indicators for this study are based on EN 15804 (EN15804, 2012+A1_2013) and EN 15978 (EN15978, 2011), which are: Abiotic Depletion, Acidification Potential, Eutrophication Potential, Freshwater Aquatic Ecotoxicity Potential, Global Warming Potential, Global Warming Potential excluding biogenic carbon, Photochemical Ozone Creation Potential, Ozone Layer Depletion Potential and Primary energy demand from renewable and non-renewable resources.

According to the results of the study, reflecting a first environmental assessment in an early design phase as a starting point for further optimisation, it is observed that the Monterrey steel solution with timber frame has less environmental impact than the other roof solutions in most of the impact categories. Bitumen roofing systems have the highest impact in most of the impact categories, except for impacts of Abiotic Depletion (ADP elements) and Ozone Layer Depletion Potential. The Monterrey steel roof solution saves nearly 60% of GWP compared with the bitumen solution. For the primary energy demand, bitumen has the highest energy demand, while the Monterrey steel solution with timber frame has the lowest energy demand.

It is noted that the Classic steel roof solutions have the lowest GWP in all solutions in terms of maintenance, which is more than 85% less than bitumen. The results also indicate that the steel roof solutions have more advantages at the end-of-life, in terms of reduced environmental impacts. In terms of the weight of the structure, the steel roof systems are the lightest: 50% less than the bitumen roof, and about 25% of the weight of the concrete roof.

Overall, the production of the construction materials contributes the largest proportion to the life cycle of the steel and concrete solutions, contributing more than 69% in terms of GWP. The impact of maintenance is more important for the bitumen roofing while less important for the steel roofing systems. Packaging contributes less than 3% of the total GWP. Transport does not have a big influence for any of the solutions other than concrete. Construction energy usage is negligible for all solutions.

1. Goal and Scope

Buildings and infrastructure are responsible for a high proportion of environmental impacts on a global level, which is a major concern for society. It is therefore important to understand the environmental performance of buildings/infrastructure at a very earlier stage (i.e. design phase) from a scientific and systematic perspective.

Life Cycle Assessment (LCA) is a well-used method to evaluate the potential environmental impact of buildings and building materials. worldsteel has developed a tool 'buildLCA' to quantify the environmental performance of buildings and building materials from a life cycle perspective and understand where improvements or benefits can be seen.

The goal of the study is to carry out a life cycle environmental evaluation of six, functionally equivalent, roofing solutions for a typical Scandinavian house, in an early-design phase. This report acts as an initial assessment, to provide a first indication for the planning team of the roofing designs, based on generic data. Further optimisation, using more specific LCI data, for each more finalised roofing design must be carried out in the context of the whole building. This is particularly important when taking into account the weight of the different roofing systems and their impact on the supporting systems within the building and the assumed lifetime of the building and service life of the roofing system. Each of these aspects can be further assessed using the buildLCA tool.

This study aims to identify a first indication of the environmental performance of roofing applications from the whole life cycle perspective. It helps the designers/users in an early design phase to understand the life cycle environmental performance of these three different roofing materials in Finland as a starting point for further optimisation for each design. Thus, the results represent intermediate results in the planning process and therefore no comparative assertion. This is based on the results of a pre-verified, neutral tool (buildLCA). This is then verified by an external review of the chosen parameter settings. Thus, the analysis of the impacts conducted is valid in the context of the buildLCA tool and the reviewed parameter settings associated to that, linked to the goal and scope. In this context the study is appropriate to be used for external communications.

Figure 1 (Ruukki, 2019) shows the structure of the roof. Only the roofing has been considered for this study. It is assumed that the items listed in table 1 (with the exception of the steel coatings) are similar in all roof solutions and have therefore been excluded from all roof designs.

Figure 1: Roof structure

Excluded items for the study
Original coating of steel roof systems
Rainwater system
Ladders
Snow guards
Roof bridge
Lead-ins
Chimney
Valley flashing and joint flashing
Waste nails and screws etc. from installation
Tapes and stickers for packaging
Cardboard packages for nails etc.

Table 1: Items excluded from the roof designs for this study

The functional unit is a roof of 150m^2, which is estimated to be used for 60 years. The key roofing materials considered are:

- Steel (Zinc coated steel)
- Bitumen felt
- Concrete tile

For the steel roofing, four designs have been included in the study, which are as follows:

- Monterrey steel roof with timber batten
- Monterrey steel roof with steel batten
- Classic steel roof with timber batten
- Classic steel roof with steel batten

Figure 2 and Figure 3 (Ruukki, 2019) are the Monterrey and Classic roofs respectively.

Figure 2: Monterrey steel roof

Figure 3: Classic steel roof

Table 2 gives an overview of the technical information for the two steel roof designs.

	Coating types	Structure
Ruukki Monterrey steel roof	Polyester 25 um	Tile sheet model
Ruukki Classic steel roof	GreenCoat Pural BT 50 um	Profile that resembles traditional seamed roof

Table 2: Overview of the two steel roof specifications

It should be noted that as no LCI data was available for the two different coating types, this was not included in the study. However, the painting required during the maintenance of these roofing systems was included.

For the concrete tile roof (Ormax, 2019) shown in Figure 4, only the timber batten option has been included. The coating of the concrete tile is Ormax protector, other coatings have not been considered in this study.

Figure 4: Concrete tile

Figure 5 shows the bitumen roof that has been chosen for this study: Katepal (Katepal, 2019) 3 T bitumen shingles. Only the timber batten option has been included for this design.

The parameters for the steel, concrete and bitumen roofing are described in Table 3, and the installation of all roof designs are summarised in Table 4.

Figure 5: Bitumen roof

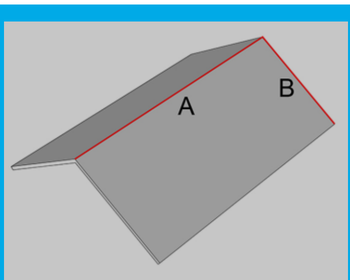
	A = 12 m
	B = 6.25 m
	Slope: 14 degrees or more (1:4)

Table 3: Roofing parameters for all roof designs

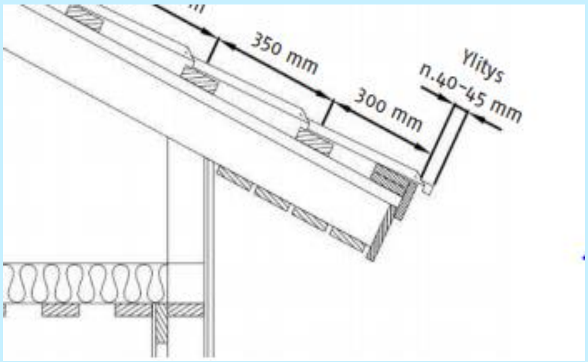
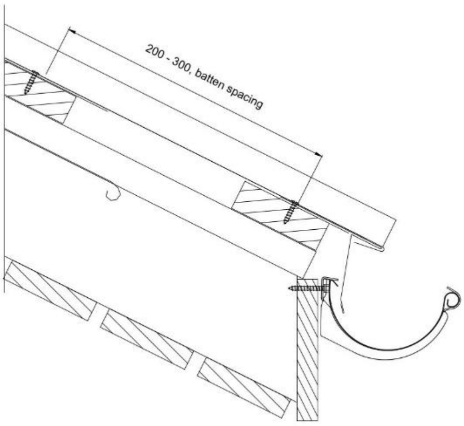
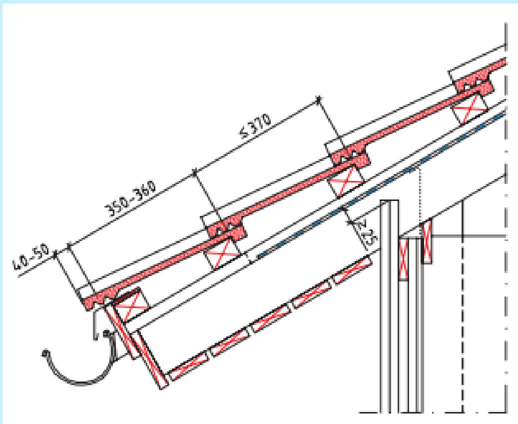
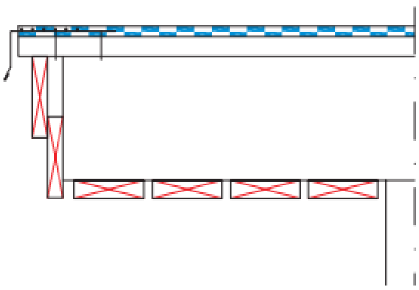
Roof types	Installations
Monterrey steel roofing	
Classic steel roofing	
Concrete tile roofing	
Bitumen sheet roofing	

Table 4: Roofing installations for all roof designs

The composition of the six roof designs are summarised in Figure 6 and listed in Appendix D. The mass of the concrete roof is more than eight tonnes, and the steel roof designs are the lightest options at less than a quarter of this weight. The bitumen roof is more than double the weight of the steel roof solutions. Timber accounts for about 50% of the total mass of the bitumen roofing and steel roofing with timber frame. The different mass for each of roofing designs will impact on the overall building requirements which should be considered in a further assessment of the building design.

Figure 6: Mass composition per m² of the roof designs

Table 5 shows the life cycle stages that have been included in the study:

Construction Stage (A1 - A5)	Use and maintenance (B2, B4)	End-of-life Stage (C3, C4, D)
- Production of all roof materials - Original coating for steel roofing systems were excluded due to lack of data. - Packaging materials - Transportation (included only for product transportation to construction site regarding truck load factors and estimated distances) - Energy associated with roof installation	- Paint - Bitumen - Detergent for cleaning - Transportation associated with paint and bitumen	- Recycling - Incineration - Landfill

Table 5: System boundary of the study

2. Software and data source

buildLCA is used as the tool for assessing the environmental performance of the six roof designs. The tool is modelled in the commercial software GaBi, using the appropriate life cycle inventory (LCI) data for different materials and transport and construction activities. A critical review of the model and methodology has been carried out to ensure the quality of the buildLCA tool, in line with ISO 14040: 2006 and ISO 14044: 2006 standards (14040, 2006) (14044, 2006). GaBi version 9.2.1.68 has been used together with service pack 40 database version 8.7 (GaBi, 2020). All the datasets used in this study are from the latest GaBi release in February 2020. Regional data for the key materials has been used. Steel LCI data is from worldsteel LCI data collection, released in 2018. Considering the geographical location of this case study, Finnish data is used for the electricity grid mix. European data is taken as the next best available data and where this is not possible, global data has been used. This is therefore a useful study during the early design phase, showing the relative order of magnitude for each life cycle stage. The data is selected based on the technology representativeness and the data availability and detailed information on the source and representation of the data is provided in Appendix A.

EN 15804 (EN15804, 2012+A1_2013) is the European standard which provides a structure to ensure that all Environmental Product Declarations (EPD) of construction products are developed following the same rules. It allows the complete information to be provided throughout the life cycle of the product in a harmonized way from the product level, which requires that data should be consistent, reproducible and comparable. Thus, upstream data that follows the EN 15804 standard is selected for this study where it is available.

3. Assumptions and limitations

In order to assess the end-of-life stage environmental performance, the following assumptions have been considered. All these assumptions are based on experts' estimation (particularly from those providing data for the BOM of the roofing systems) (Gaia Consulting Oy, 2019) and literature sources (e.g. EUROSTAT). It is assumed that no reuse of the materials takes place at this stage.

Materials	Recycling rate	Incineration	Landfill
Steel	85%	0%	15%
Timber	26%	50%	24%
Plastic	40%	50%	10%
Paper	26%	50%	24%
Concrete	75%	0%	25%
Bitumen	70%	0%	30%
Aluminium	94%	0%	6%

Table 6: End-of-life scenario settings

In addition to these end-of-life assumptions, the assumptions which have been made for the results calculation are listed in Table 7. For the non-steel solutions, a realistic approach has been taken to ensure that the steel solutions are not treated favourably. The figure for transportation and maintenance vary case by case. The scenarios for transport and maintenance included in the study are case-specific, and the final results and conclusions may be affected by uncertainties in these assumptions. For transport, the average Finnish specific transport figure is estimated based on the location of Ruukki's facilities. It is very difficult to obtain the frequency of the cleaning and the amount of cleaning detergent required as this depends on the user's choices and the environmental conditions, as well as the requirements of the specific roofing materials. Inclusion of these aspects will affect the impacts during maintenance. End-of-life is the most complex to assess as this will be affected by the different end-of-life scenarios and the uncertainty of the recycling methodology. Care should therefore be taken to set accurate scenarios for end-of-life. A sensitivity analysis is performed on this to investigate the changes to the environmental impacts with different end-of-life scenarios.

Categories	Items	Assumptions and limitations
Packaging	Plastic	Plastic type assumed (HDPE film or PE band). Amount of plastic film used for packaging special parts and battens assumed based on data for Steel sheets.
	Wood	Wood type assumed to be pine.
	Cardboard boxes for nails and screws etc.	Not included.
	Tapes and stickers	Not included.
Transportation in construction	Truck load factor	Load factors calculated assuming only the steel/concrete tile/bitumen sheet roofing material as load. In reality other materials used on site are also included in the load. Assumed 100% load.
	Truck transportation distances	Average transportation distances in Finland and Sweden estimated based on location of Ruukki facilities and transportation distances used by Ecoinvent database for steel and other similar product (for EU). Taking into account that average distances in Scandinavia are longer than average EU values. Assumed 500km transport distance for each material.
Construction	Battens	Wood type assumed to be pine. The highest density for pine used as an estimate.
	Underlay	Material type and density provided by Gaia by data from one possible product. Considering the specific requirements on site, the actual results may vary. Assumed the same materials are used for all solutions.
	Nails, screws, stables and other fastening articles	Weight and material of nails, screws and stables assumed by Gaia based on commercial data.
	Energy use on site	Assumed that only the power drill is used for installation, and no other processes on the construction site were considered. Use hours and drill power assumed.
	Waste from installation	In practice some material leftovers are used in other construction sites, which is not considered in the loss rates. For underlay, same loss rate assumed for concrete as for underlay of steel

		roofing. For bitumen battens, loss rate assumed from thesis, other parts from Katepal calculator.
Use and maintenance	Lifetime	Steel roofing estimate is based on Ruukki technical specifications/qualities of the used zinc coating.
		Concrete: According to Ormax, lifetime is 50-70 years, 60 years was used as the average lifetime for concrete tiles.
		Bitumen: Average technical service life for bitumen is 30 years for normal situation (Rakennustieto, 2008).
	Lifetime for wooden parts + underlay	Assumed new installations, where the lifetime of battens and underlay would be the same as for the steel cover.
	Cleaning (before painting) + painting	Corrosivity capacity for steel roofing is assumed to be C1-C3. The amount of water used for cleaning estimated by Ruukki.
		Density for a possible paint used as an estimate, and assumed the same paint applied for steel and concrete roofing.
		The amount of water used for cleaning assumed to be same for all roofing solutions.
	Cleaning/moss treatment	Recommended by Ormax to treat Ormax roof with washing detergents approximately every 5 years. Assumed the steel and bitumen roofings would be the same as the concrete roofing.

Table 7: List of assumptions and limitations (Gaia Consulting Oy, 2019)

The maintenance schedule over the 60-year period for each of the roofing systems is shown in Table 8.

	Cleaning / moss treatment	**Re-painting**	**Replacement**
Monterrey wood	11 times (every 5 years)	3 times (every 15 years)	No replacement (every 60 years)
Monterrey steel	11 times (every 5 years)	3 times (every 15 years)	No replacement (every 60 years)
Classic wood	11 times (every 5 years)	Once (every 30 years)	No replacement (every 60 years)
Classic steel	11 times (every 5 years)	Once (every 30 years)	No replacement (every 60 years)
Concrete	11 times (every 5 years)	Twice (every 20 years)	No replacement (every 60 years)
Bitumen	10 times (every 5 years)	(No re-painting)	1 time and assumed replace bitumen sheet only (every 30 years)

Table 8: Maintenance schedule for all roofing systems

4. Life Cycle Assessment results

In calculating the results, the following environmental indicators listed in Table 9 below have been used, based on EN 15804 (EN15804, 2012+A1_2013) and EN 15978 (EN15978, 2011).

Indicators	Indicators Abbreviation	Unit
Abiotic Depletion	ADP_{fossil}	[GJ]
Abiotic Depletion	$ADP_{elements}$	[kg Sb eq.]
Acidification Potential	AP	[kg SO2 eq.]
Eutrophication Potential	EP	[kg Phosphate eq.]
Freshwater Aquatic Ecotoxicity Potential	FAETP	[kg DCB eq.]
Global Warming Potential[1]	GWP	[tonnes CO2 eq.]
Global Warming Potential[1], excluding biogenic carbon	GWP_{excl}	[tonnes CO2 eq.]
Photochemical Ozone Creation Potential	POCP	[kg Ethene eq.]
Ozone Layer Depletion Potential	ODP[2]	[kg R11 eq.]
Primary energy demand from renewable and non-renewable resources	PED[3]	MJ

1. GWP 100 years 2. Steady state 3. Net calorific value

Table 9: Environmental indicators list

In accordance with ISO 14040: 2006 and ISO 14044: 2006 standards (14040, 2006) (14044, 2006), an end-of-life assessment method has been applied for this study. The end-of-life method looks at the full life cycle of the system being assessed and assesses the overall environmental impacts and credits between different product systems across the different life cycles. The environmental impact of the product system is dependent on the net recycling rate at end-of-life.

Recycling, reuse, incineration, and landfill impacts have been considered in the end-of-life scenarios. Energy recovery impacts of plastic, paper and timber have been considered in the study when the incineration of these materials is included.

Figure 7 shows the GWP per kg of each material (A1-A3) that have been used in this study. However, these figures should only be used in conjunction with the mass of material used in each roof design, as shown in Figure 6.

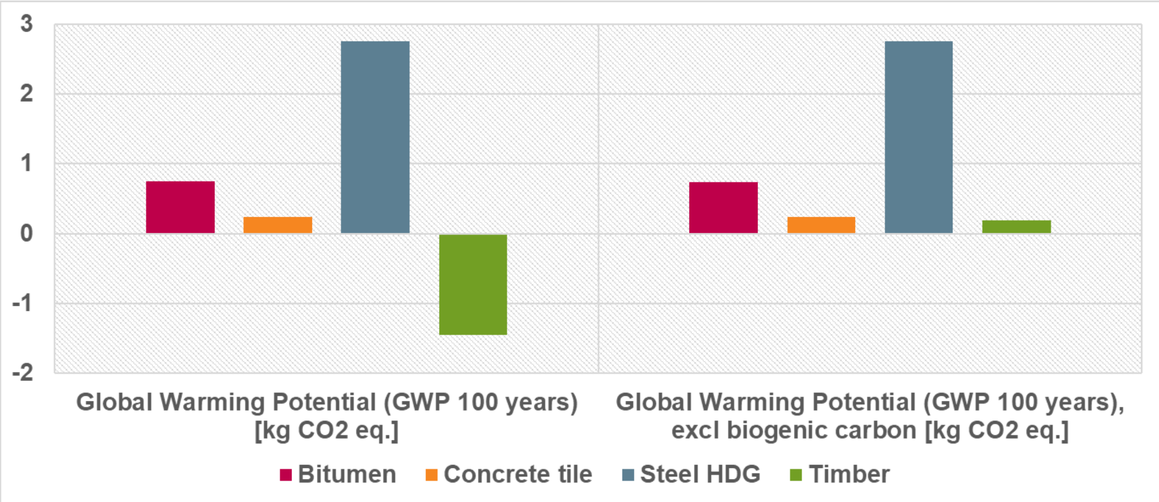


Figure 7: GWP per 1kg of each key roof material (A1-A3)

4.1 Overview of environmental impacts

An overview of the selected results is illustrated in Figure 8. The Bitumen roofing system is clearly the highest contributor to the Abiotic Depletion Potential (ADP fossil), Acidification Potential (AP), Eutrophication Potential (EP), Freshwater Aquatic Ecotoxicity Potential (FAETP), Global Warming Potential (GWP), Photochemical Ozone Creation Potential (POCP) and Primary energy demand from renewable and non-renewable resources (PED). The Monterrey steel roofing system with timber frame has the lowest impact in most of the categories except the Abiotic Depletion Potential (ADP elements), and Ozone Layer Depletion Potential (ODP).

Note that:

- MW = Monterrey steel solution with wood batten
- MS = Monterrey steel solution with steel batten
- CW = Classic steel solution with wood batten
- CS = Classic steel solution with steel batten.

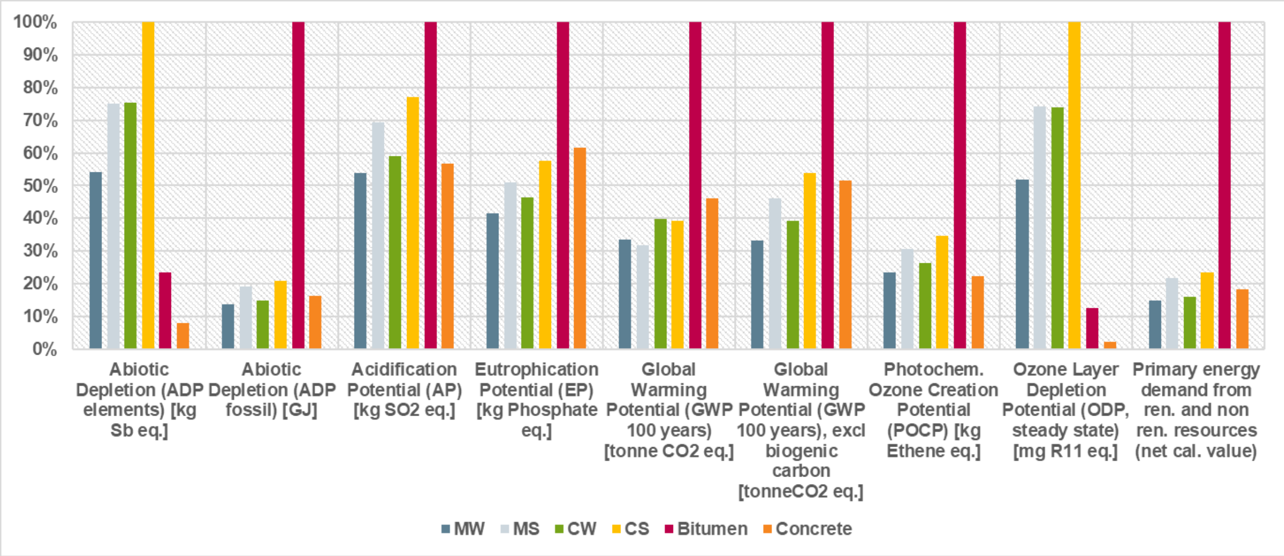


Figure 8: Cradle to grave environmental impacts for each roof design

4.2 Contribution analysis

The results for the impact of GWP are illustrated in Figure 9, Figure 11 and Figure 12, looking at different contribution categories.

For most of the roof solutions, the highest contribution, as shown in Figure 9, is clearly from the construction stage. However, unlike the other solutions, for the bitumen roof the operational (maintenance) stage is the highest contributor as this includes the replacement of the roof after 30 years and cleaning of the roofing system during the 60-year timeframe the bitumen roof needs 6 times more detergent than the other roofing systems each time it is cleaned. The detergent used for bitumen roof moss treatment is estimated based on Katepal's website (Katepal, 2019). Figure 10 shows the differences in impact from the use/maintenance phase for the roofing systems, which demonstrates the very large impact associated with the bitumen roof (Katepal, 2019), as the bitumen roof needs to be replaced after 30 years while the other roofs stays 60 years without any replacement (based on the life time of the materials). It also shows the difference in maintenance requirements between the Monterrey and Classic roofing systems which have the same cleaning requirements, but difference in painting requirements. The end-of-life stage is also a significant contributor and cannot be neglected; steel solutions bring more advantages in terms of recycling than the other solutions studied. It can also be observed that the steel frame has more advantages (about 2-3 times higher) in terms of recycling than the timber frame for steel solutions, which is due to the advantage of the potential recyclability of steel.

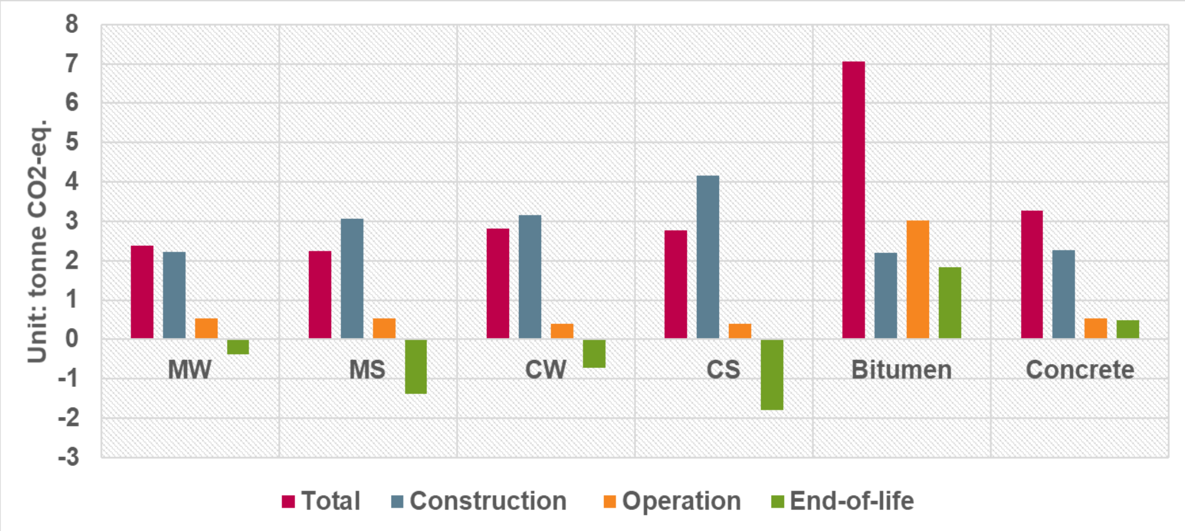


Figure 9: GWP per each life cycle stage

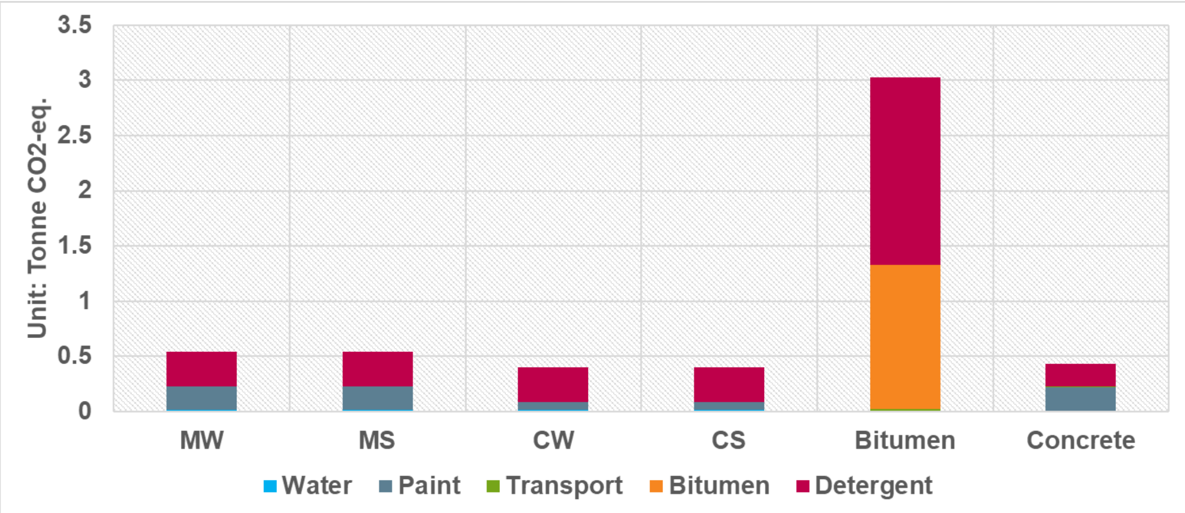


Figure 10: Breakdown of GWP for the maintenance phase only

Figure 11 shows the full life cycle of the roof systems (construction, transport, maintenance and end-of-life) and shows that for the vast majority of cases, the biggest GWP impact comes from the materials (including the packaging) used in the roof. For the steel roofing, the net impact from materials (including end-of-life), is over 74%. Maintenance has a much larger contribution to the life cycle GWP of the bitumen roofing system (43%) than the other roofing systems, as described above. Transportation, which is assessed based on the estimated average distance, accounts for around 7% of the impact for the concrete roofing system, while it is around 2% for the other roofing solutions. Packaging is not that important for bitumen and concrete roofing, which is less than 1%. However, it contributes around 3% to 4% for the steel roofing, due to the lower overall GWP of the steel roofing systems.

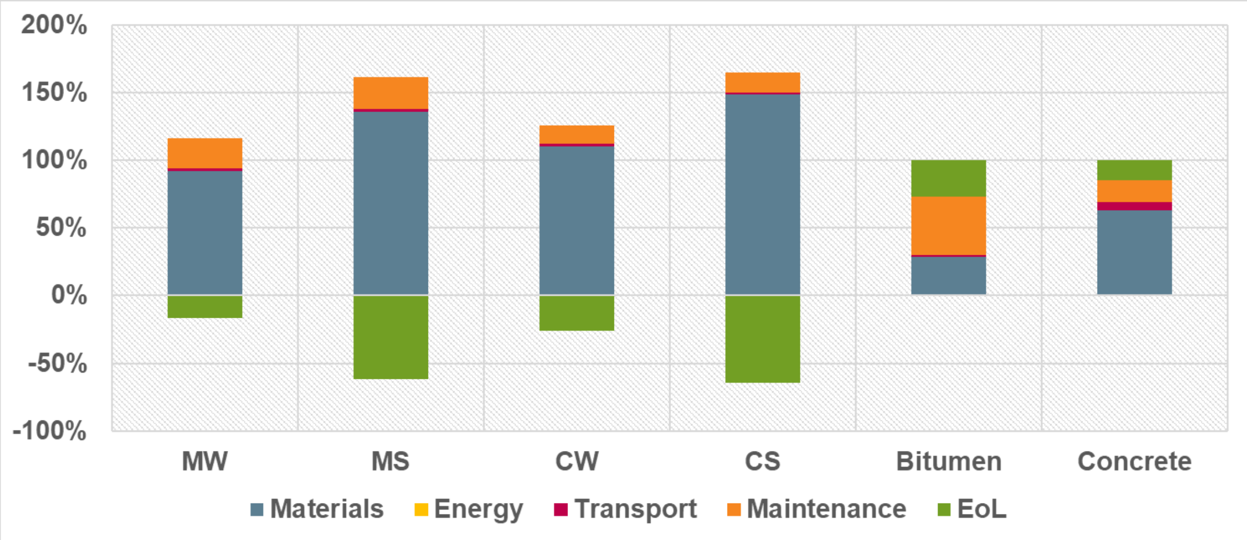


Figure 11: Cradle to grave GWP contribution per category

As seen in Figure 12, in terms of the contribution from the materials, the highest contributor is the main material used in the steel and concrete roofing systems, i.e. steel contributes more than 46% in the steel roofing system and concrete tiles contribute more than 54% in the concrete roofing system. Timber is the second largest contributor for the steel solution with timber frame, bitumen and concrete solutions, while detergent shows a bigger contribution to the GWP for the steel solution with steel frame. Paint is more important for Monterrey steel solutions (as the roof needs to be painted more often than the Classic steel roof), which accounts for about 10% of their total GWP impact. For the bitumen roofing system, detergent contributes around 24% of the GWP impact due to the large quantities of detergent (Katepal, 2019) that are needed for cleaning and moss treatment. The other roofing solutions require mainly water and less detergent usage for cleaning.

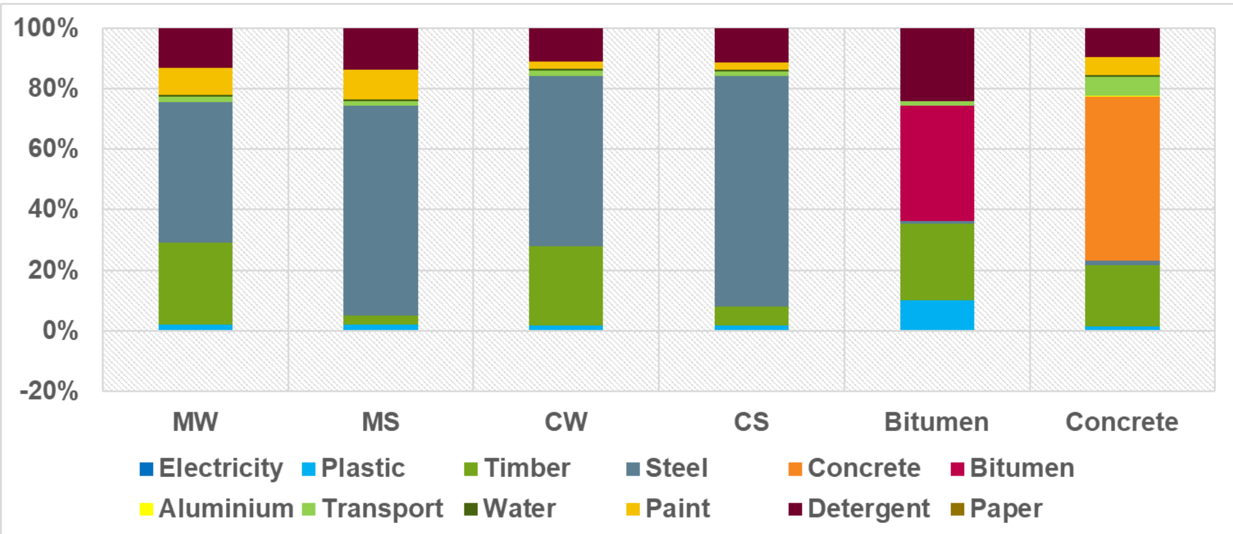


Figure 12: Cradle to grave GWP contribution per material

The contribution in relation to the Primary energy demand from renewable and non-renewable resources (PED) is illustrated in Figure 13, Figure 14, and Figure 15 according to different categories. Very similar conclusions can be taken in relation to PED as has been shown for the GWP impacts: the construction stage is the main contributor for all solutions except for the bitumen solution (where maintenance/operational stage is the main contributor). The end-of-life benefit in the bitumen roofing system is mainly due to the timber.

As shown in Figure 12 and Figure 14, the biggest contributor to the Primary energy demand from renewable and non-renewable resources (PED) is generally related to the roof materials. Maintenance is the largest contributor for the bitumen roof due to the fact that the roof needs to be replaced during the 60-year time frame and the significantly larger amount of detergent that is required. Considering the net impact from the materials (including end-of-life), maintenance also plays a large contribution to the Monterrey steel solution with timber frame, due to the additional paint requirements. The steel roofing systems using timber have a lower PED than the same systems with steel frames. This then leads to maintenance having a higher proportional impact to the overall life cycle of the timber framed steel solutions. Transport accounts for more than 12% of the PED for the concrete roofing system, while accounting for only about 3% of the steel roofing system, and 1% of bitumen roofing system. It should be noted that the impact of transportation is based on the estimated average distance.

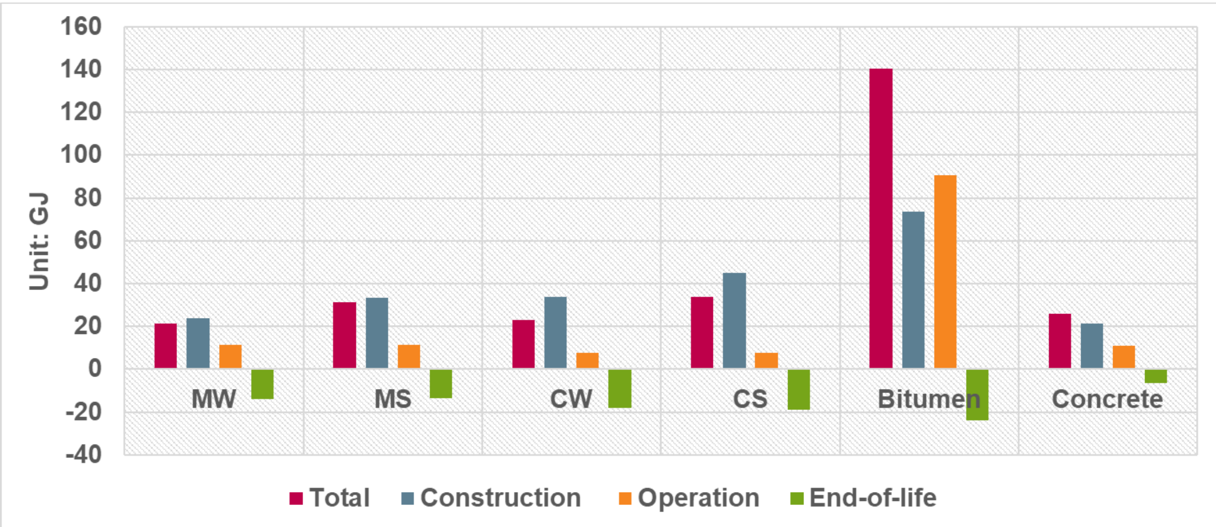


Figure 13: PED per each life cycle stage

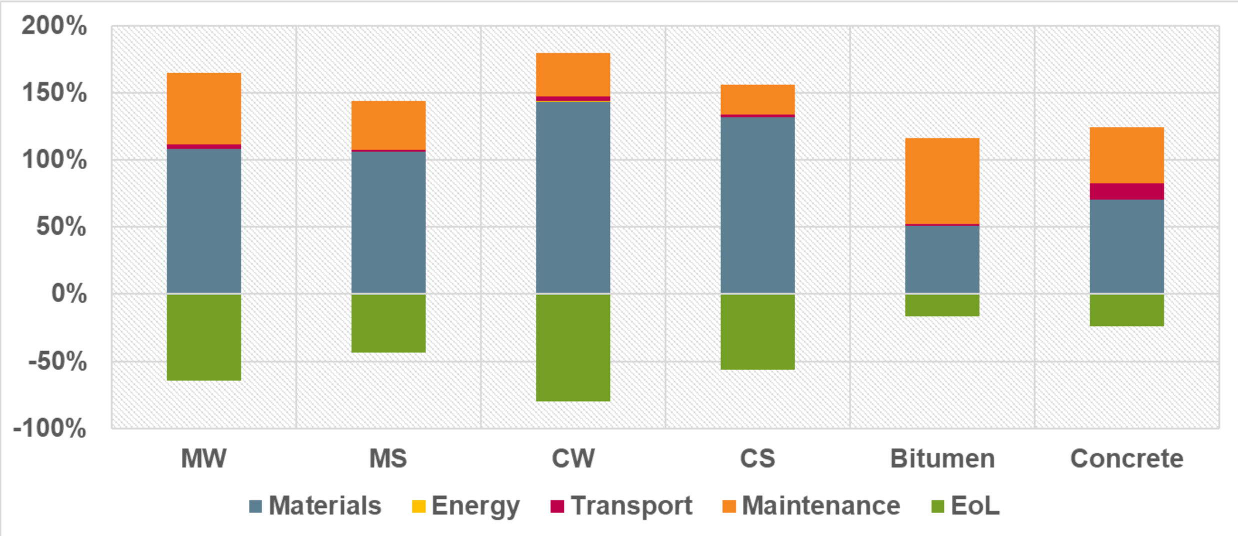


Figure 14: Cradle to grave PED contribution for each roofing system per category

Figure 15 illustrates the contribution of materials for Primary Energy Demand. The highest contributor is the main material used in each roofing solution, e.g. steel in the steel roofing system, bitumen sheet in bitumen roofing, as these contribute more than 60% of the PED. Timber has a high contribution to all roofing systems except the steel roofing system with steel battens (where there is very little timber used). It is observed from Figure 15 how important the use of detergent is in the roofing systems, which accounts for 16 to 26% of the PED. It is noted that the paint contributes more to the PED for the Monterrey steel roof (18%) rather than the Classic steel roof (6%), as it needs more frequent painting). These factors reflect the importance of the maintenance of each of the roofing systems.

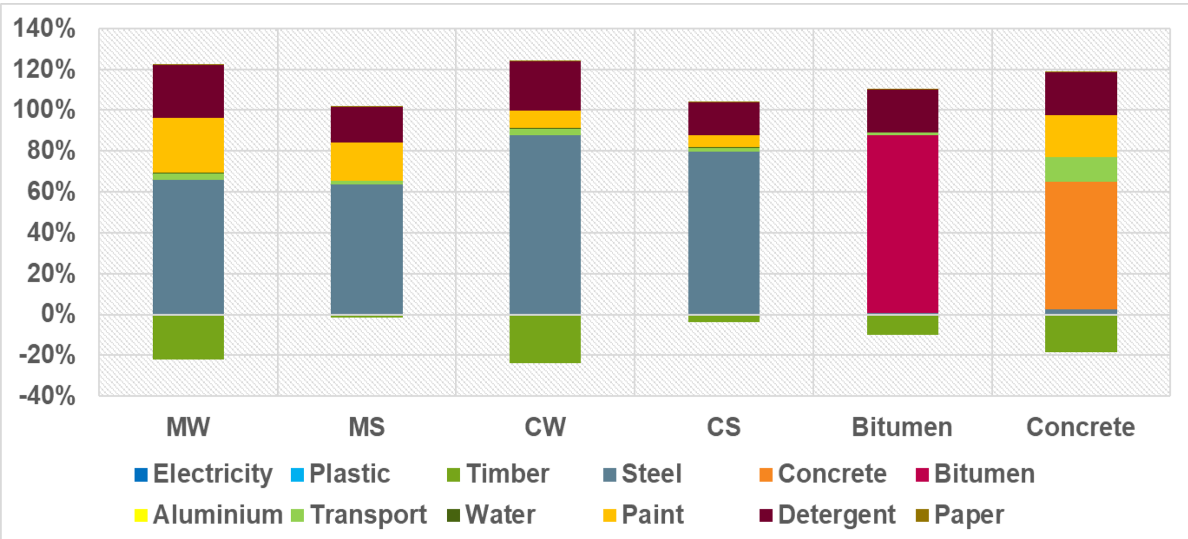


Figure 15: Cradle to grave PED of each roofing system per material used

4.3 Sensitivity analysis

A sensitivity analysis has been carried out on the upstream data to ensure that the most appropriate data has been selected, in particular in relation to the type of wood being used. A sensitivity analysis on transportation distances shows that transportation has a larger impact for the heavier roofing systems, i.e. concrete. Those systems which require a higher degree of cleaning (i.e. bitumen) will have more sensitivity to the detergent used for cleaning. Further analysis is therefore required once more appropriate detergent data is available.

A sensitivity analysis was also carried out on the end-of-life assumptions to assess the impact on the results of changing the end-of-life recycling rates from the base scenario presented above in section 3, scenario 1. Alternative end-of-life recycling rates have been applied for scenario 2. The aluminium and plastic underlay recycling rates have not been changed as they are already perceived to be quite high in the first scenario, based on discussions with construction experts. The amount of plastics used for packaging is quite negligible and changing the results makes very little difference to the overall impact of the roofing systems.

The results of the different scenarios are illustrated in Figure 16, and

Table 10. The end-of-life settings for scenario 1 and scenario 2 are described below in

Table 10.

Material	Scenario 1				Scenario 2			
	Recycling rate	Reuse rate	Incineration rate	Landfill rate	Recycling rate	Reuse rate	Incineration rate	Landfill rate
Steel	85%	0%	0%	15%	95%	0%	0%	5%
Timber	26%	0%	50%	24%	31%	0%	34%	35%
Plastic	40%	0%	50%	10%	10%	0%	50%	10%
Paper	26%	0%	50%	24%	31%	0%	34%	35%
Concrete	75%	0%	0%	25%	77%	0%	0%	23%
Bitumen	70%	0%	0%	30%	80%	0%	0%	20%
Aluminium	94%	0%	0%	6%	94%	0%	0%	6%

Table 10: End-of-life settings for two scenarios

Figure 16 compares scenario 2 with scenario 1. The difference in GWP between the two scenarios of the different roofing systems is between 7 and 14%. The results indicate that increasing the timber recycling rate and reducing the incineration rate will bring more benefits in GWP, especially for the steel solution with timber batten.

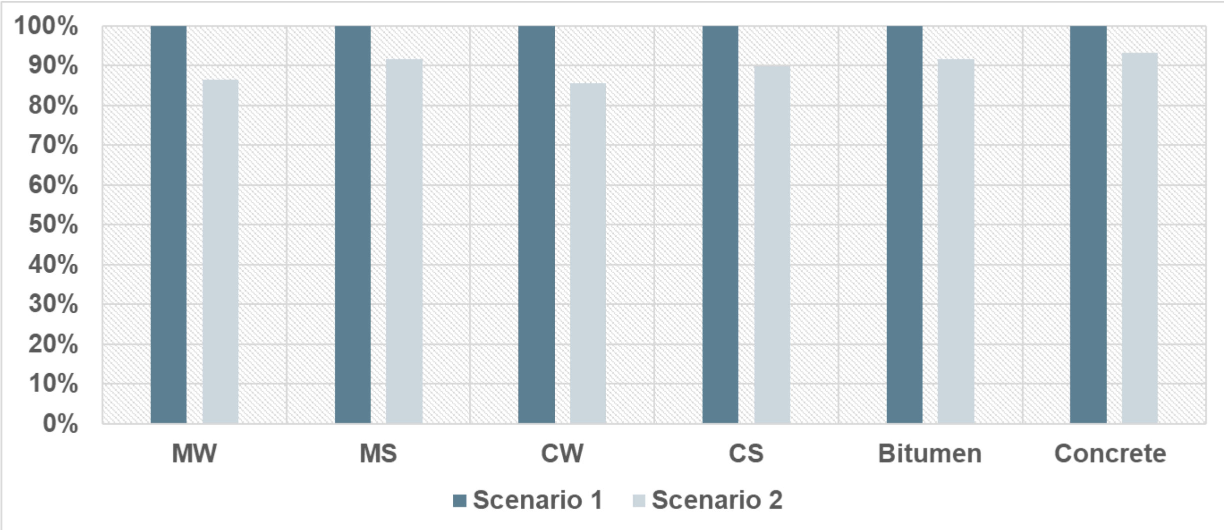


Figure 16: GWP of the roofing systems for the end-of-life sensitivity analysis

Figure 17 shows the Primary energy demand from renewable and non-renewable resources (PED) for the two scenarios. Unlike the figures for the impact of GWP, increasing the recycling rate for the materials does not bring more benefit for all roof solutions. The PED for the steel roofs with timber frame increased between 1 and 2%, while it decreased about 4 to 5% for the steel frame. For the bitumen and concrete roofing systems, the PED increased by about 2% and 6% respectively. This is mainly because of the high timber content in these roofing solutions which means that will have more energy demand due to the high embodied energy materials usage.

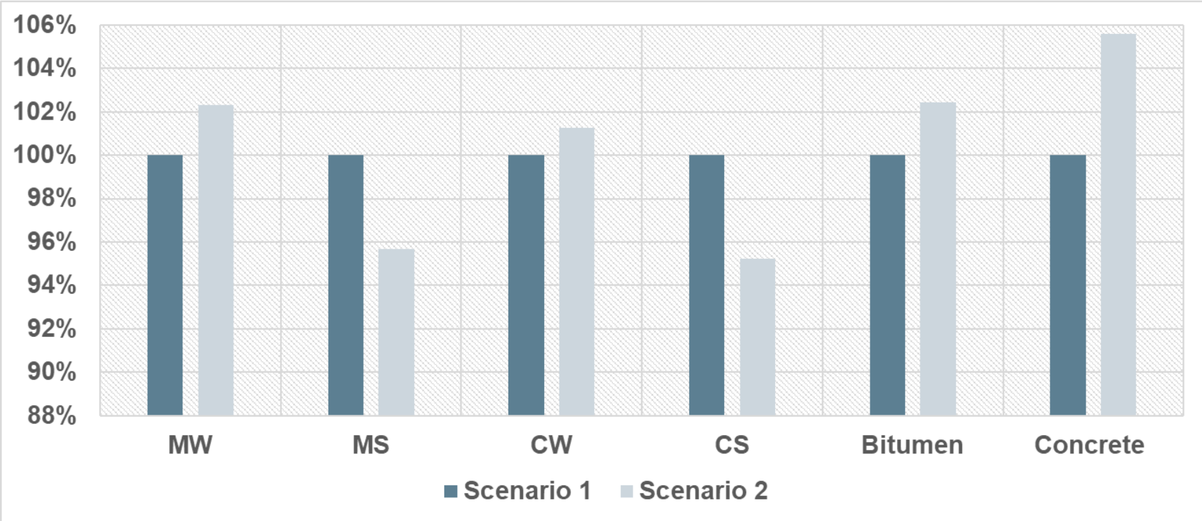


Figure 17: PED for the 2 scenarios for each roof system

In summary, while recycling is generally beneficial for the environmental performance of product systems, this is not always the case for all roof solutions for all environmental impact categories. For example, for roofing systems using a large amount of timber, an increase in recycling can lead to a reduction in the GWP of the roofing solution but an increase in the PED. However, changing the end-of-life recycling rates results in the same trend in the results for the different roofing systems.

5. LCA conclusions

This study has compared six different designs for a typical Scandinavian roofing using the worldsteel buildLCA tool. The results reflect a first indication of environmental performance as a starting point for further optimisation for each design. The study focused on the following environmental indicators:

- Abiotic Depletion (ADP elements)
- Abiotic Depletion (ADP fossil)
- Acidification Potential (AP)
- Eutrophication Potential (EP)
- Freshwater Aquatic Ecotoxicity Pot. (FAETP inf.)
- Global Warming Potential (GWP 100 years)
- Global Warming Potential (GWP 100 years), excluding biogenic carbon
- Ozone Layer Depletion Potential (ODP, steady state)
- Photochemical Ozone Creation Potential (POCP)
- Primary energy demand from renewable and non-renewable resources (PED)

As the results indicate, compared with other solutions, the steel roof solutions have more advantages at the end-of-life, in terms of reduced environmental impacts.

The Monterrey steel solution with timber frame has lower environmental impact than the other roof solutions in most impact categories. The timber frame versions have a slightly lower impact than the steel frame except for GWP (which is slightly higher for the timber frame, though only by about 2%). The difference between the steel and timber frame systems will narrow if the recycling rate of timber increases, and less timber is incinerated. Bitumen has the highest impact in most of the impact categories, except for impacts of Abiotic Depletion (ADP elements), and Ozone Layer Depletion Potential (ODP, steady state).

Considering PED, the bitumen roof solution has the highest energy demand, while the steel solutions with timber frame have the lowest energy demand. For the steel solutions, the steel frame requires about 10% more energy compared with the timber frame.

In terms of total GWP, steel roof solutions have the lowest overall GWP, which is 60% less than bitumen roofing system. Compared to the other roofing systems, the bitumen roof has the highest GWP contribution from maintenance (over 40%) due to the bitumen replacement and large quantity of detergent required for roof cleaning and moss treatment. The use of timber has less impact on the construction stage than the other materials considering the biogenic carbon, but more impact during the end-of-life stage.

In terms of the weight of the structure, the steel roof systems are the lightest: 50% less than the bitumen roof, and about 25% of the weight of the concrete roof.

Overall, the construction materials have the biggest contribution to the steel and concrete solutions, contributing more than 70% in terms of GWP. Maintenance is the highest contributor for the bitumen roofing system. According to an assessment of the estimated transport distance, transport does not have a big influence for any of the solutions other than concrete: it contributes over 7% in GWP for concrete, and over 12% for PED. Packaging materials contribute about 3 to 4% for the steel solutions, the majority of which comes from the timber and steel packaging (brown paper, and plastic packaging are also required but have a minimal contribution to the GWP). This steel packaging has a higher impact than the packaging used in other roofing solutions which is due to the low overall GWP impact of the steel roofing systems.

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7. Appendices

Appendix A – List of background data sources

Appendix B – List of the data sources for end-of-life assumptions

Appendix C – List of construction yields for different materials

Appendix D – Bill of materials (BOM) for all roofing solutions

Appendix A: List of background data sources

Input material	Dataset name in GaBi	Data source	Reference Year	Geography
Concrete ridge tile	Concrete roof tile (A1-A3)	thinkstep	2019	EU-28
Concrete verge tile	Concrete roof tile (A1-A3)	thinkstep	2019	EU-28
Concrete ridge seal	Concrete roof tile (A1-A3)	thinkstep	2019	EU-28
Steel Drip edge flashing	Steel hot dip galvanized	worldsteel	2018	GLO
Zinc coated steel sheet	Steel hot dip galvanized	worldsteel	2018	GLO
Steel screws	Steel hot dip galvanized	worldsteel	2018	GLO
Steel stables	Steel Electrogalvanized	worldsteel	2018	GLO
Steel verge trims	Steel hot dip galvanized	worldsteel	2018	GLO
Steel ridges	Steel hot dip galvanized	worldsteel	2018	GLO
Steel batten	Steel hot dip galvanized	worldsteel	2018	GLO
Timber underlay	Timber pine (12% moisture; 10.7% H2O content) (EN15804 A1-A3)	thinkstep	2019	EU-28
Timber batten	Timber pine (12% moisture; 10.7% H2O content) (EN15804 A1-A3)	thinkstep	2019	EU-28
Brown paper	Kraft paper (EN15804 A1-A3)	thinkstep	2019	EU-28
Detergent	Sodium hypochlorite solution	thinkstep	2019	US
Water	Tap water from groundwater	thinkstep	2019	EU-28
Waste water treatment	Municipal waste water treatment (mix)	thinkstep	2019	EU-28
Aluminium ridge tile fastener	EU-28: Aluminium frame profile, powder coated (EN15804 A1-A3)	thinkstep	2019	EU-28
Stainless steel nails	Stainless steel sheet (EN15804 A1-A3)	thinkstep	2018	EU-28

Stainless steel screws	Stainless steel sheet (EN15804 A1-A3)	thinkstep	2019	EU-28
Bitumen	Bitumen sheets PYE-PV 200 S5 ns (slated) (EN15804 A1-A3)	thinkstep	2019	EU-28
Paint	Water based paint white (EN15804 A1-A3)	thinkstep	2019	EU-28
Steel corner cover	Steel hot dip galvanized	worldsteel	2018	GLO
Plastic film (PP, PE, PVC)	Plastic Film (PE, PP, PVC)	thinkstep	2019	GLO
Plastic for packaging	Plastic Film (PE, PP, PVC)	thinkstep	2019	GLO
Steel scrap	Value of scrap v3	worldsteel	2018	GLO
Bitumen torching	Torch applied installation of APP-modified bitumen (asphalt) roofing membrane - ARMA (A5)	EPD	2012	RNA
Stainless steel scrap	Recycling potential stainless steel sheet	thinkstep	2019	DE
Aluminium recycling credits	Recycling potential aluminium sheet	thinkstep	2019	DE
Timber incineration with energy recovery	Wood (natural) in waste incineration plant	thinkstep	2019	DE
Polyethylene (PE) incineration with energy recovery	Polyethylene (PE) in waste incineration plant	thinkstep	2019	EU-28
Waste incineration of timber	Waste incineration of untreated wood (10.7% H2O content)	thinkstep	2019	EU-28
Waste incineration of PE	Waste incineration of plastics (PE, PP, PS, PB)	thinkstep	2019	EU-28
Brown paper incineration with energy recovery	Paper and board (water 0%) in waste incineration plant	thinkstep	2019	EU-28
Waste incineration of brown paper	Waste incineration of paper fraction in municipal solid waste (MSW)	thinkstep	2019	EU-28

Electricity	Electricity grid mix	thinkstep	2016	FI
Steam	Thermal Energy from Natural Gas	thinkstep	2016	EU-28
Diesel	Diesel mix at refinery	thinkstep	2016	EU-28
Large truck	Truck-trailer, Euro 6, 28 - 34t gross weight / 22t payload capacity	thinkstep	2019	GLO

Appendix B: List of the data source for end-of-life assumptions

Materials	Source
Steel	World Steel Association Life Cycle Assessment Methodology Report Steel Recycling Institute (https://www.steelsustainability.org/construction) Estimated average value for roof based on the construction recycling rate for steel products.
Timber	https://ec.europa.eu/eurostat/documents/3217494/6975281/KS-GT-15-001-EN-N.pdf/5a20c781-e6e4-4695-b33d-9f502a30383f
Plastic	Eurostat data (https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Packaging_waste_statistics)
Paper	https://ec.europa.eu/eurostat/documents/3217494/6975281/KS-GT-15-001-EN-N.pdf/5a20c781-e6e4-4695-b33d-9f502a30383f
Concrete	https://link.springer.com/chapter/10.1007/978-3-319-66981-6_24
Bitumen	Gaia Oy, Finland
Aluminium	Construction experts' estimation based on European Aluminium Association's end-of-life recycling rate for construction from Circular Aluminium Action Plan (https://european-aluminium.eu/media/2929/2020-05-13-european-aluminium_circular-aluminium-action-plan.pdf)

Appendix C: List of construction yields for different materials

For the purpose of this study, construction yields used in the model have been provided by the construction experts at Ruukki. A construction yield of 1.1 means that 1.1 tonnes of material are required to be bought in order to have 1 tonne of that material in the roof, or in other words, a 10% loss in the manufacturing/construction process.

Materials	Construction yield
Steel	1.025 - 1.1
Timber	1.04 - 1.06
Plastic	1.01 - 1.02
Paper	1.01
Concrete	1.05 - 1.07
Bitumen	1.02
Aluminium	1.1

Appendix D: Bill of materials (BOM) for all roofing solutions

Monterrey Steel with wooden batten:

Name	Amount	Unit
Colour coated steel roof Monterrey (sheets)	670.5	kg
Roof batten (wood)	680.4	kg
Counter batten (wood)	129.6	kg
Nails (for battens)	2.7	kg
Screws	3.75	kg
Underlay, thin watertight film, assuming 100% PE	23.1	kg
Staples to attach underlay	0.012	kg
Ridge capping (see figure 1 item no. 6)	18	kg
Verge trims (see figure 1 item no. 7)	36	kg
Screws to attach ridge capping and verge trims	0.5	kg
Energy usage for installation (Battery power drill)	2.2	kWh
Total roof mass	1565	kg

Monterrey Steel with steel batten:

Name	Amount	Unit
Colour coated steel roof Monterrey (sheets)	670.5	kg
Roof batten (steel)	321.0	kg
Nails (for battens)	0.9	kg
Screws	3.6	kg
Underlay, thin watertight film, assuming 100% PE	23.1	kg
Staples to attach underlay	0.012	kg
Ridge capping (see figure 1 item no. 6)	18	kg
Verge trims (see figure 1 item no. 7)	36	kg
Screws to attach ridge capping and verge trims	0.5	kg
Energy usage for installation (Battery power drill)	2.2	kWh
Total roof mass	1074	kg

Classic Steel with wooden batten:

Name	Amount	Unit
Underlay, thin watertight film, assuming 100% PE	23.1	kg
Staples to attach underlay	0.012	kg
Steel roof Classic (sheets)	946.5	kg
Roof batten (wood)	793.8	kg
Counter batten (wood)	129.6	kg
Nails (for battens)	3.15	kg
Screws	3.24	kg
Ridge capping (see figure 1 item no. 6)	18	kg
Verge trims (see figure 1 item no. 7)	36	kg
Screws to attach ridge capping and verge trims	0.5	kg
Eaves flashing	30	kg
Screws to attach eaves flashing	0.125	kg
Energy usage for installation (Battery power drill)	2.2	kWh
Total roof mass	1984	kg

Classic Steel with steel batten:

Name	Value	Unit
Underlay, thin watertight film, assuming 100% PE	23.1	kg
Staples to attach underlay	0.012	kg
Steel roof Classic (sheets)	946.5	kg
Roof batten (steel)	375	kg
Counter batten (wood)	129.6	kg
Nails (for battens)	3.15	kg
Screws	3.105	kg
Ridge capping (see figure 1 item no. 6)	18	kg
Verge trims (see figure 1 item no. 7)	36	kg
Screws to attach ridge gapping and verge trims	0.5	kg
Eaves flashing	30	kg
Energy usage for installation (Battery power drill)	2.2	kWh
Total roof mass	1565	kg

Bitumen roofing:

Name	Value	Unit
Roof batten (wood)	2448.264	kg
Underlay, thin watertight film	384.0	kg
Bitumen shingles	1600.0	kg
Nails (for battens)	27.2	kg
Nails (for bitumen and underlay)	13.8	kg
Eaves shingles	72.0	kg
Drip edge flashing	48.0	kg
Screws to attach drip edge flashing	0.125	kg
Energy usage for installation (Battery power drill)	1.1	kWh
Total roof mass	4593	kg

Concrete roofing:

Name	Value	Unit
Ormax protector + concrete tiles	6843.72	kg
Roof batten (wood)	628.4	kg
Counter batten (wood)	116.9	kg
Nails (for battens)	8.1	kg
Nails (for tiles)	1.6	kg
Screws (for verge tiles)	0.8	kg
Ridge tile fastener	0.6	kg
Underlay, thin watertight film	23.5	kg
Staples to attach underlay	0.012	kg
Ridge tiles	163.8	kg
Ridge seal	77.5	kg
Verge tiles	242.6	kg
Drip edge flashing	21.6	kg
Screws to attach drip edge flashing	0.125	kg
Energy usage for tile installation (Battery power drill)	1.1	kWh
Total mass	8129	kg

Packaging:

Name	Plastic for packaging	Brown paper	Galvanized Steel for packaging	Timber for packaging	Total	Unit
Monterrey Steel with wooden batten	2.37	0.87	10.01	74	87	kg
Monterrey Steel with steel batten	2.44	0.87	10.01	86	99	kg
Classic Steel with wooden	3.06	0.99	19	95	118	kg
Classic Steel with steel batten	3.18	0.99	19	107	130	kg
Bitumen roofing	0	0	50	1.97	52	kg
Concrete roofing	0	0	160	2.39	162	kg

Maintenance:

Name	Water	Detergent	Paint	Bitumen replacement	Total	Unit
Monterrey Steel with wooden batten	11330	110	135	0	11575	kg
Monterrey Steel with steel batten	11330	110	135	0	11575	kg
Classic Steel with wooden	11330	110	45	0	11485	kg
Classic Steel with steel batten	11330	110	45	0	11485	kg
Bitumen roofing	0	600	0	1705.44	2305	kg
Concrete roofing	11550	110	125	0	11785	kg

Appendix E: Critical Review Statement

Commissioner	World Steel Association
Reviewer	Adolf Daniel Merl Daxner & Merl GmbH
References	ISO/TS 14071 (2014) ISO 14040 (2006) ISO 14044 (2006)

Scope of the Critical Review

This independent review covers the environmental Life Cycle Assessment (LCA) study of six roofing systems for a typical Scandinavian House in an early design phase: "Life Cycle Assessment - Environmental assessment of roofing systems" conducted by the World Steel Association (worldsteel) applying the reviewed buildLCA tool, developed by worldsteel. The study includes four designs based on steel, one design based on concrete tiles and one design based on bitumen felt. The results reflect an initial environmental assessment providing a first indication for the planning team of the roofing designs in an early design phase, in a life cycle perspective based on generic data in a pre-verified neutral tool. Thus, the study does not aim for a comparative assertion and the review was conducted according to ISO 14044, section 6.2 "Critical review by internal or external expert". The review did not include the analysis and verification of the tool or individual datasets. This should therefore be clearly and transparently highlighted in any communication.

The critical review process ensures

- the compliance of the study and its methodological choices with the requirements of the international standards ISO 14040 and ISO 14044,
- the technical validity of the data collection, data set selection within the tool as well as assumptions and limitations according to the goal and scope of the study,
- the plausibility of results,
- the used data are reasonable and appropriate with respect to the goal and scope of the study,
- the study documents the goal of the study and its limitations,
- the transparency and consistency of the methodology.

This review statement is valid for the report “Life Cycle Assessment - Environmental assessment of roofing systems. Using buildLCA to assess the performance of materials in roofing systems”. For LCA calculation the separately reviewed buildLCA tool modelled in GaBi software system was applied. (Version 9.2.1.68 based on the 2019 LCI database, SP39, together with service pack 40 database version 8.7) (GaBi 2020).

The review covers the methodologies applied to conduct the study including its documentation. It does not include the verification of individual datasets applied in this case study. The quality of results is consistent with the goal and scope of the study providing a first indication of environmental impacts in an early design phase over the whole life cycle.

The independent review was commissioned by worldsteel. It followed the requirements of ISO 14071, 2014.

Review Process

The review process covered a time frame from 29th of June 2020 until 9th of September 2020 and was coordinated between worldsteel and Daxner & Merl.

It started on 29th of June 2020 with the first screening of the version of the report from 18th of May. Also, additional background information of the data collection documented in a presentation for the considered roofing designs, carried out by the Finnish consultancy Gaia Oy in 2019, was viewed. In the kick-off meeting via web-conference on 30th of July 2020 the first feedback from the reviewer was discussed. After that, the first revised version of the report was submitted to the reviewer.

Further feedback provided by the reviewer especially with distinction to a possible comparative assertion, data collection and inventory of data for the various roofing systems was discussed during an online review meeting on 20th of August 2020. Data inventory including the insertion into the buildLCA tool and parameter setting was checked via provided screenshots covering all data used in the study. Subsequently the comments were integrated in an ongoing process including several iteration loops. These loops included the detailed evaluation of open issues and further clarifications to address all comments thoroughly. After the pending topics concerning the report were resolved (until end of August 2020), a final check of the inventory and results generated through the buildLCA tool was conducted. This final check included the review of plausibility of results as well as limitations and assumptions. Throughout the entire process, worldsteel was open for feedback and reacted to questions and recommendations of the reviewer as comprehensively as possible considering the scope of the study.

After the final version of the methodology report was provided by worldsteel on 1st of September 2020, the review process was concluded.

General Evaluation

worldsteel conducted the study to provide a first indication of environmental impacts considering the whole life cycle in an early design phase. The goal of the study is to carry out a life cycle environmental evaluation of six, functionally equivalent, roofing solutions for a typical Scandinavian house in Finland applying the pre-verified buildLCA tool (in accordance with ISO 14040/44). It aims to support designers in understanding the potential environmental impacts in an early design phase from a life cycle perspective. Results are based on generic data reflecting a starting point for further optimisation for each considered design. Thus, the results represent intermediate stages in the planning process and represent therefore no comparative assertion. Further optimisation, using more specific LCI data, for each further specified roofing design must be carried out in the context of the whole building. This is particularly important when considering the weight of the different roofing systems and their impact on the supporting systems within the building, the assumed lifetime of the building and service life of the roofing system. Further specifications of each design in the whole building context may also lead to modifications of the functional unit regarding building physics. In the communication of results of the study this aspect must be considered. In the report this aspect is addressed in an appropriate way and clearly described.

Methodological choices of the study comply with the requirements specified in ISO 14040 and ISO 14044. The critical reviewer did not find any significant deviations in the LCA report with the ISO 14040 (2006) and 14044 (2006) standards. The defined and achieved scope of this LCA study was found to be appropriate to achieve the stated goals.

The mass calculation of the inventory was provided by a Finnish consultancy for each roofing design and is together with limitations and assumptions well documented. The insertion of the inventory tool was done carefully and double-checked during the review process. The selected generic data sets on European or global level implemented in the tool are appropriate for environmental life cycle information in an early planning phase. Regional Finnish data were only available for the grid mix which is a limitation in regionalisation. The results of the study also show the impact of selected scenarios for the use phase and end of life phase which are reflecting Finnish conditions. The system boundaries follow the approach of EN 15804 covering construction stage (A1-A5), maintenance (B2, B4), and end of life (C3, C4, and D – considering the substitution potential for primary material net flows). The period under consideration is 60 years. The contribution analysis shows the environmental impacts in each life cycle stage and the contributions from each material. This information is important for designers for further optimisation of each roofing system.

Sensitivity analysis for various selection of data and end of life scenarios was performed to show the impacts on overall results.

The selection of life cycle impact assessment follows the European standard EN 15804+A1 implemented accordingly in the buildLCA tool.

The LCA conclusion includes the interpretation of results, which is representing a first indication of environmental performances and can be used as a starting point for further optimisation of each design.

Summarising, the review covered a comprehensive check of the inventory data inserted into the buildLCA tool including the methodology report provided with it. The reviewer confirms the applied methodology as appropriate. Underlying data and applied tools for LCA modelling provide an elaborate approach for the life cycle assessment of the roofing designs in an early design phase and deliver plausible results.

Conclusion and Review Statement

The reviewer acknowledges the conduction of a profound study demonstrating the usefulness of potential environmental impacts of building components in an early design phase. The study is considered suitable and delivers plausible results for its application in assessing the environmental impact over the whole life cycle in an early design phase. The methodology report offers a comprehensive and transparent documentation of its goal and scope. The methodological aspects of the study, the selection and definition of the technical parameters have been within the scope of the critical review.

Applied procedures and methods follow the requirements of the international standards ISO 14040 and ISO 14044. The reviewer considers the chosen approach as appropriate regarding the intended goal and scope of the study.

This review statement is only to be used in the context of the "Life Cycle Assessment - Environmental assessment of roofing systems" in the delivered version.

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