NÝSKÖPUNARSJÓÐUR NÁMSMANNA

Circularity of Raw Materials in Iceland

RANNIS reference: 2210490-1101

I) Life Cycle Assessment of Icelandic Wool

II) Life Cycle Assessment of Icelandic Forest Products

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Abstract

The purpose of this research was to identify a method to determine the circularity of raw material in Iceland, specifically wool and wood. Life Cycle Assessment, or LCA, was the chosen method and utilized a combination of foreground data collected from primary sources in Iceland and international literature reviews, and background data which included detailed processes on manufacturing and production of energy, resources, and transportation. In total, 31 different government agencies, NGOs and private businesses in Iceland were contacted in June and July 2022, from which the local foreground data was sourced.

While the LCA of wood and wool in Iceland provides an introductory study into the circularity of raw material, this method is more suited to assessing negative environmental impacts. For both wool and wood, primary data on waste varied depending on the source of information. From available data, wool was determined to be ~95% circular in Iceland while wood waste was found to be negligible. Both results are subject to a high margin of error due to the limited information and absence of quantitative data. Future research into the circularity of raw materials would best be focused on collecting primary data on the total wasted materials for both wood and wool.

I) Life Cycle Assessment of Icelandic Wool

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1. Introduction

In the textile sector, wool is a niche product consisting of approximately 1.2% of the market share of the global textile market (Wiedemann et al., 2020). In Iceland, wool is an additional resource from sheep farming which has a long tradition in the country. In recent years however, the price for wool has declined, and for sheep farmers it is often not profitable to sell the sheared wool. Furthermore, the price depends on different quality categories provided by Ístex, the largest wool processing company in Iceland. The aim of this study is to collect data on the amount of wool that is processed in Iceland per year and calculate the environmental impact of each wool category. Overall, the goal is to determine the circularity of Wool in Iceland and propose alternative uses to keep this local resource in Iceland.

2. Goal and Scope

The goal is to present the environmental impacts of each wool category to the public in the form of a calculator published on a website at a future date. The results are especially of interest for Ístex and the farmers. These results can help the public to identify and implement new ways to keep more wool in Iceland through usage in other products and manufacturing sectors.

The study was conducted in accordance with ISO 14044 for Environmental management — Life cycle assessment. However, the scope of the LCA, as part of a 3-month research project on Icelandic raw materials, required simplifying data, resulting in a higher margin of error in the results.

The functional unit (FU) for this study was 1kg of wool. The decision for the FU was based on comparative studies such as “Greenhouse gas emissions profile for 1 kg of wool produced in the Yass Region, New South Wales: A Life Cycle Assessment approach” (Brock et al., 2013).

The reference flow was based on data from 2019 in which 881.101 kg of unwashed wool, collected from farms around the country, resulting in 677.624 kg of clean wool which was then further processed into various products (Ullarmat, 2019). The reference flow for this LCA serves as a starting point for the following processes, quantifying the amount of wool that is handled in one year (Consequential LCA, 2017).

The impact categories used for this assessment were: climate change (global warming in openLCA), water consumption, marine ecotoxicity and freshwater ecotoxicity. Land-use was not taken into consideration due to the limited scope of the LCA, however, it is clear that land-occupation through sheep grazing has a large impact (Arnalds & Barkarson, 2003). Due to declining prices of wool in Iceland, meat and milk are the main purpose of sheep farming, and wool is a byproduct (S. Jökulsdóttir, personal communication, July 5th, 2022).

The system boundaries for this study are farm to gate, excluding land use, impacts related to sheep farming and end of life for wool products. Figure 1 shows the system boundaries for this study. The boundary excluded the raising and feeding of sheep, up until the point when shearing occurs. Wool shearing occurs two times a year, in the spring and in the fall. The wool in fall has higher quality and a better value (S. Jökulsdóttir, personal communication, July 5th, 2022). The data available has no distinction between the two sheering events. For future research, a distinction might be useful to apply to get higher accuracy in the results.

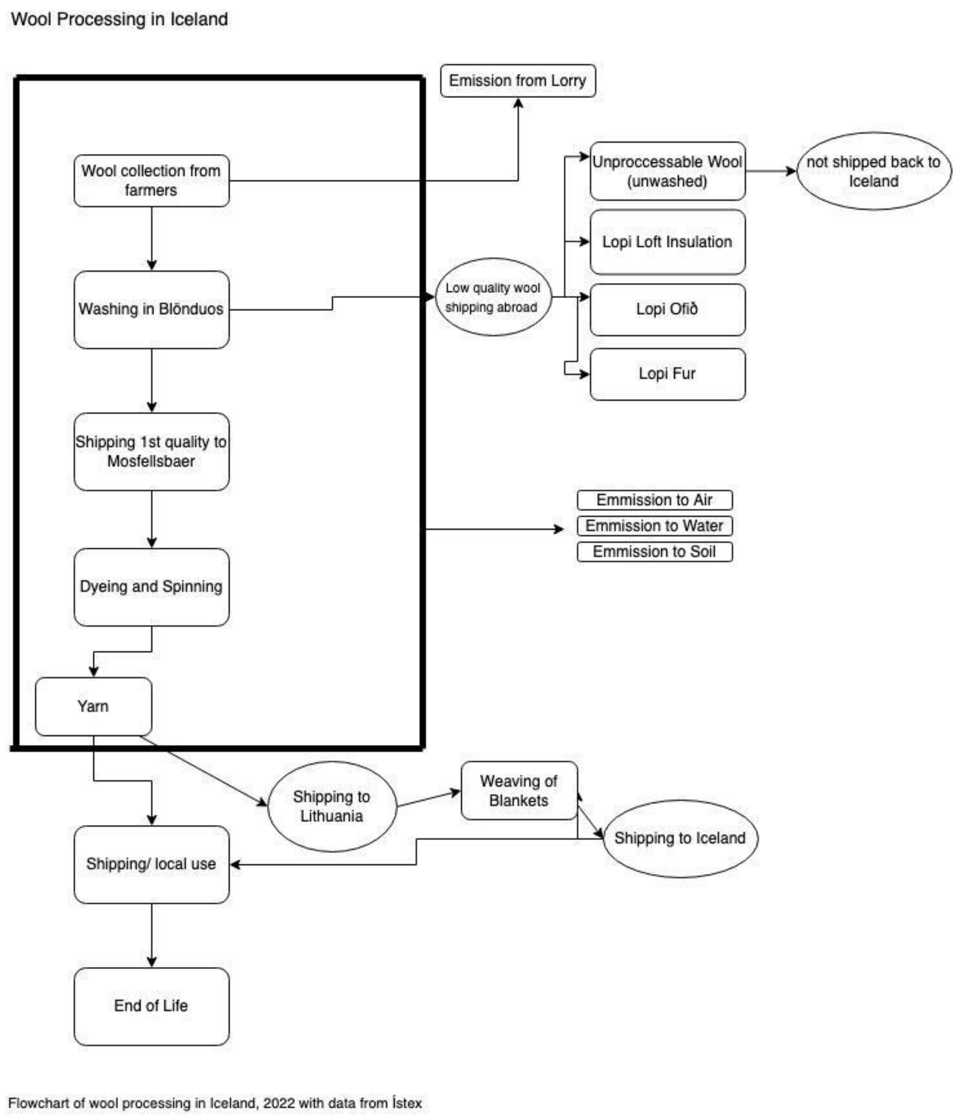

Figure 1: Wool processing in Iceland flowchart

3. Life Cycle Inventory Analysis

The life cycle of wool in this research is divided into 4 processes: (1) Collection of Wool from farmers around Iceland, (2) Washing of Wool in Blönduós (except low quality wool that is shipped abroad without being washed, (3) Shipping washed wool to Mosfellsbær, (4) Dyeing, spinning and further sub-processes depending on the end product: (A) Yarn, (B) Blankets, (C) Other.

Figure 2 shows the categories for which Icelandic wool is categorized. Data for wool usage within each category was obtained, however, detail into specific products was not possible in the scope of this project.

Further study of specific products is a potential opportunity for future research.

Wool categories					Usage
	Icelandic	English		Clean (kg)	
690	Snoð Hvítt	White Wool	78.367	54.857	30%
691	Hvít heilsársull	White all year wool	95.78	67.046	20%
695	H-Lamb	lamb	18.588	14.871	100%
696	H-1 Flokkur		172.465	137.972	100%
697	H-2 Flokkur		228.968	183.008	25%
698	H-2 Flokkur Lamb (lítið gölluð)		40.85	32.68	100%
715	M-Svart	Black	31.502	24.455	100%
716	M-Grátt	Grey	24.695	19.173	100%
717	M-Mórautt	red?	14.257	11.053	100%
718	M-2 Flokkur		105.739	80.588	65%
720	M-2 Lamb mislit		4.321	3.455	100%
Sum			815.532	629.158	

Figure 2: Wool categories according to Ullarmat and Istex

The numbers for this LCA regarding yearly wool processing were taken from the most recent report in 2019.(Ullarmar, 2019). It should be noted that data for 2020 and 2021 may differ because of the COVID-19 pandemic. For this research, it was relevant to find the average weight of wool, in kilograms) that one sheep produces per year. According to Ístex, the average is 2 kg (S. Jökulsdóttir, personal communication, July 5th, 2022). Further confirmation of this data came from the National Inventory Report, 2021 (*Figure 3*). Lambs and mature ewes produce differing amounts of wool. The weight of wool was multiplied by the number of sheep and divided by 4. This resulted in 21,125 kg of wool, and an average of 2 kg of wool per sheep. To determine the amount of leftover, unprocessed wool, the number of sheep in 2019 (416 sheep) was multiplied by 2 kg, resulting in 831.989 kg. The amount of wool received by Ístex in 2019 was 881.101 kg. Accounting for a specific margin of error, this suggests that no significant amount of Icelandic wool is being wasted or left unprocessed. Therefore, the assumption for this research, and according to the data obtained, no significant amount of wool is "wasted" or left unprocessed in Iceland.

Wool Production according to the National Inventory Report 2021.			Nr. in KG
Mature ewes	Other mature sheep	Animals for replacement	Lambs
2.5	3	1.5	1.5

Figure 3: Wool production according to the National Inventory Report 2021

3.1 Collection of Wool

The primary wool collection data for this research was obtained from Ístex. Seven different trucks collect the wool around the country. Each truck has the capacity to hold 6-7 tons of wool. Polypropylene bags, holding 20-25 kg of wool per bag are used for the transport. These bags are not reusable due to contamination. Exact information on the total kilometers' wool is transported could not be obtained, therefore, this study is based on assumptions and averages. The longest trucking route is from South Iceland to Blönduós in the North measuring around 500 km. The average used for this study is 250km. Data for the weight of the polypropylene bags used in packaging, was obtained from Amazon, with an average weight of

130g. (Amazon, 2022). These bags were not available in the Ecoinvent database, therefore the flow *polypropylene granulate* was used.

Collection of Wool		
Average Distance to Blönduós	227.00	km
Raw unwashed Wool for collection (2019)	881,101.00	kg
Polypropylene bags (20-25kg per bag)	40,050	bags
Diesel truck transport		
Bags per Truck	6-7 tons per truck (raw wool). 7 different truck drivers for different parts of the island each with their truck.	
Weight of Poly bags	130	g
Total weight of bags	5,206,505.91	g

Figure 4: Collection of Wool process according to data from Ullarmat

3.2 Washing of Wool in Blönduós

For the washing process, data was obtained from Ístex and the washing facility in Blöndous (*see Appendix*). The raw wool is washed with water, soda ash, and wool sourcing soap. Around 30% of the weight is washed off in the form of dirt, sand, and vegetable matter. The water then goes into a septic tank outside of the plant where the sand and dirt settles. The water goes into a sewage plant in Blönduós where it is purified before discarding it. Where the water is discarded was not specified. The process also includes 3000 liters of DMA (Marine Distillate Diesel Fuel) to operate the machine. This process was included with *machine operation, diesel, < 18.64 kW, generators* for which liters were converted to kwh. There was no information on how much wastewater is produced. In a comparative study, approximately 80% of the water that ends up as wastewater (Wiedemann et al., 2020).

Washing of Wool	***From Ístex***	per year
Cold Water	8,822.00	m3
Warm Water	30,554.00	m3
Total water	39,376.00	m3
Water in KG (*1000)	39,376,000.00	kg
Electricity	414,000.00	kwh
DMA (Diesel) Fuel for Engines	3,000.00	L
Clean Wool	677.62	kg
Wastewater	31,500,800.00	kg
Water water in m3	31,500.80	m3
Soda Ash	18,000.00	kg
Wool scouring soap (polyglycol ether)	9,000.00	L

Figure 5: Washing of Wool data provided by Ístex

Collection of Wool	FU 1 kg	
Average Distance to Blönduos	227.00	km
Raw unwashed Wool for collection (2019)	1.00	kg
Polypropylene bags (20-25kg per bag)	0.0455	bags
Weight of Poly bags	130	g
Total weight of bags	5.91	g
Washing of Wool for FU of 1 kg	***From Istex***	per year
Cold Water	0.0100	m3
Warm Water	0.0347	m3
Total water	0.0447	m3
Water in KG (*1000)	44.6895	kg
Electricity	0.4699	kwh

DMA (Diesel) Fuel for Engines	0.0034	L
Clean Wool	0.7691	kg
Wastewater	35.7516	kg
Water Water in m3	0.0358	m3
Soda Ash	0.0204	kg
Wool scouring soap (polyglycol ether)	0.0102	L
677626 divided by 881101 is 76,91 percent		

Figure 6: Data with the FU of 1kg of wool

3.3 Shipping washed wool to Mosfellsbær

At this stage of the process, only a part of the washed wool is sent back to Mosfellsbær. The other part, which data could not be obtained for this study, is shipped abroad for further processing. At this point the available data is limited, so general processes available through the Ecoinvent database were used in place of Icelandic processes.

Processing in Mosfellsbaer	***ecoinvent***	per year
bleaching and dyeing, yarn	0.7691	kg of wool
diesel, burned in diesel-electric generating set, 10MW	0.2230	MJ
electricity, high voltage	1.6500	kWh
transport, freight, lorry 16-32 metric ton, EURO2	0.7691*229	kg*km

Figure 7: Processing the Wool in Mosfellsbær

3.4 Dyeing and Spinning

Specific data and input for the dyeing and spinning process could not be obtained from Ístex, therefore processes from the Ecoinvent database were used:

For Dyeing: market for bleaching and dyeing, yarn | bleaching and dyeing, yarn | Cutoff, U

For Spinning: no comparable process was found. However, data was obtained from a process named: yarn production, cotton, open end spinning | yarn, cotton | Cutoff, U in which data for electricity and diesel fuel was found (see Fig. 7).

3.5 Assumptions

Several assumptions were made to fill data gaps for the life cycle assessment:

- The type of truck that picks up the wool was not clear, a general freight lorry EURO1 was used in openLCA
- The distance that one truck covers when picking up the bags was not clear. An average distance was assumed according to Google Maps
- The polypropylene bags could not be found in openLCA. *polypropylene, granulate* was used in openLCA
- Soda ash, and wool sourcing soap as process were not found in the ecoinvent database. Similar processes were used: polycarboxylates, 40% active substance for soap and soda ash, dense for soda ash.
- It was not clear how the water from the washing process was discarded, although it was stated (email Exchange with Sunna Jökulsdóttir,) that it was purified after the processing.
- DMA (Marine Distillate Diesel Fuel) was not available in the ecoinvent database. Instead, *machine operation, diesel, < 18.64 kW, generators* was used.
- It was not clear how much wastewater from the washing process is produced. 80 percent from a comparative study was used (Wiedemann et al., 2020).
- Processes for spinning of wool were not available in the ecoinvent database. Data for electricity and diesel fuel use from a similar spinning process for a different kind of garment was used.

Finally, data was unavailable for post yarn manufacturing processes, like blankets, sweaters and other textile products and were not included in this study.

3.6 Limitations and data gaps

The most significant data gaps in this research appear in the dyeing and spinning processes. In these cases, processes from other parts of the world were used to fill these gaps when Icelandic process data was not available. Spinning for wool was not available in ecoinvent and no comparable process was found. Data was used from a comparable process (yarn production, cotton, open end spinning | yarn, cotton | Cutoff). This resulted in results with a higher margin of error.

4. Life Cycle Impact Assessment

The software openLCA version 1.10.3 on Macbook was used to conduct the life cycle assessment. The ecoinvent database version 36_cutoff_unit_20191212 was used for the data sets. Below is an overview of the results for the four impact categories.

Global warming	kg CO2 eq	0,041347674
Marine ecotoxicity	kg 1,4-DCB	0,003184022
Water consumption	m3	0,084842879
Marine eutrophication	kg N eq	1,74344E-05
Human carcinogenic toxicity	kg 1,4-DCB	1,818298195
Human non-carcinogenic toxicity	kg 1,4-DCB	1,540700192

Figure 8: Impact categories and their results

The impact of global warming is 0,041 kg CO2 eq per 1kg of unwashed wool. Other studies on wool, like Wiedemann et al. (2020) state that the largest impact from garments come from the use-phase, which was excluded in this study. In the paper by Wiedemann et al. (2020), the GHG emission for 1 garment (single wear) is ca. 0.05 kg CO" eq, comparable to the result of this study. Studies that include impacts by retail for using leftover wool conclude 6 kg CO2 eq per sweater from cradle-to-gate (Martin, 2021).

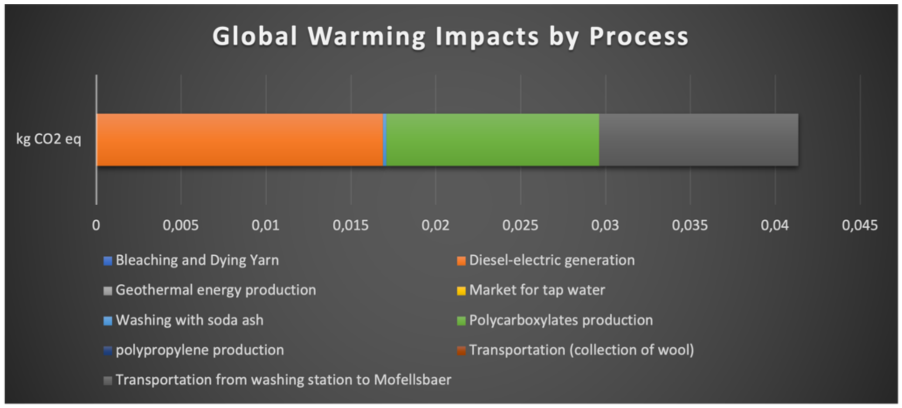

Figure 9: Global Warming Impacts by Process

The largest impact for global warming is Diesel (DMV) used for the generator followed by the soap (polycarboxylates) used for washing the wool. Transportation presents the third largest impact.

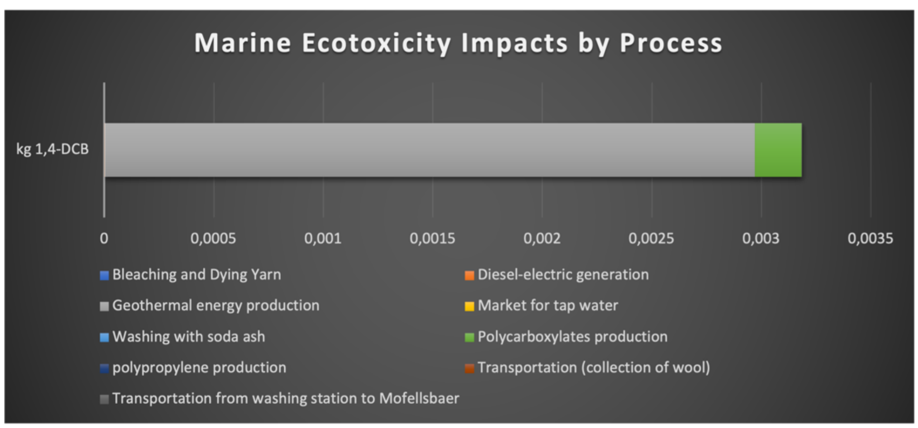

Figure 10: Marine Ecotoxicity Impacts by Process

Geothermal energy production presents the largest impact on marine ecotoxicity. This result can be explained by the large electricity needed in the washing and processing of wool.

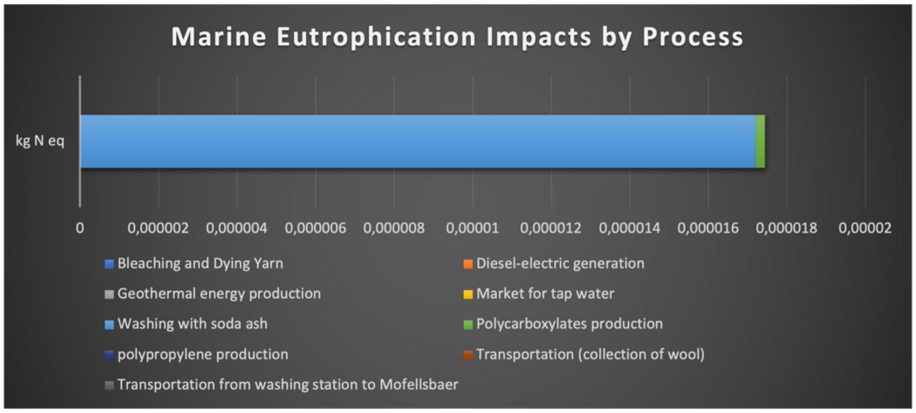

Figure 11: Marine Eutrophication Impacts by Process

Washing with soda ash has the highest impact on marine eutrophication. Ístex was not able to provide this study with numbers on wastewater, therefore the impact might change depending on the water treatment after use.

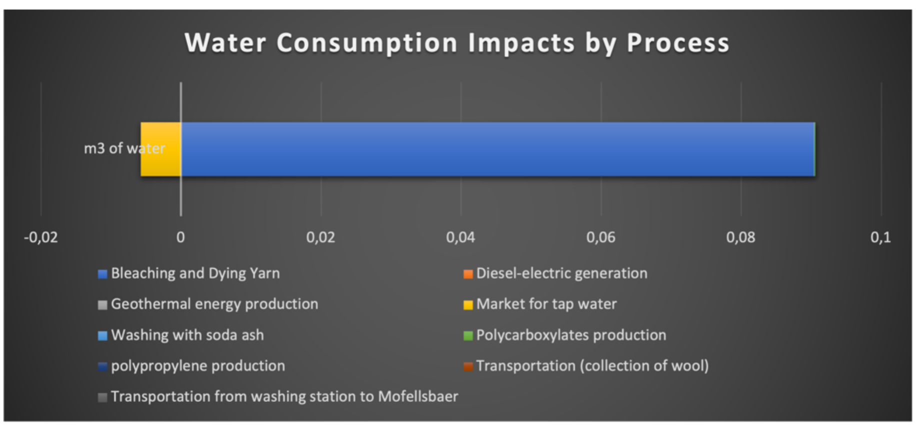

Figure 12: Water Consumption Impacts by Process

This graph regarding use of tap water does not show a significant result, as the water is presented as a negative value. The reason is most likely a problem with the calculations in openLCA.

This data does show that the washing, bleaching and dyeing processes for wool have the highest impact on water consumption.

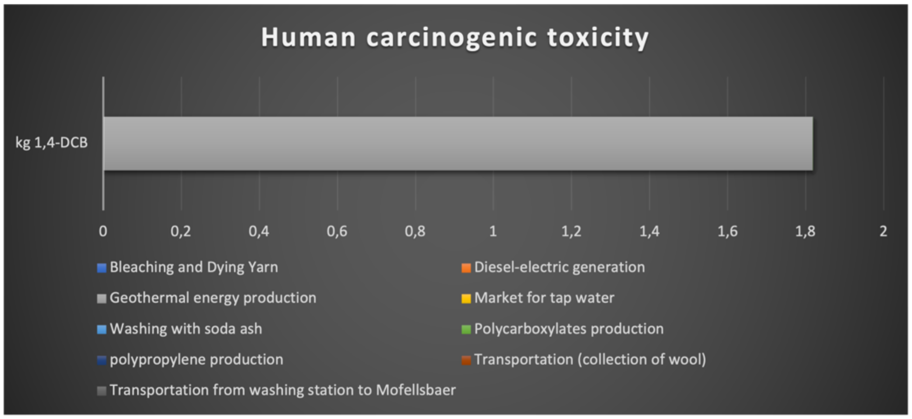

Figure 13: Human carcinogenic toxicity

Originally, human carcinogenic toxicity was not included in the relevant impact categories in the goal and scope of this study. However, showing the largest impact in kg 1,4-DCB, the graph is included in the results. As Fig. 10 shows, the large impact on this category derives from geothermal energy production. The same results shows in Fig. 14, the human non-carcinogenic toxicity.

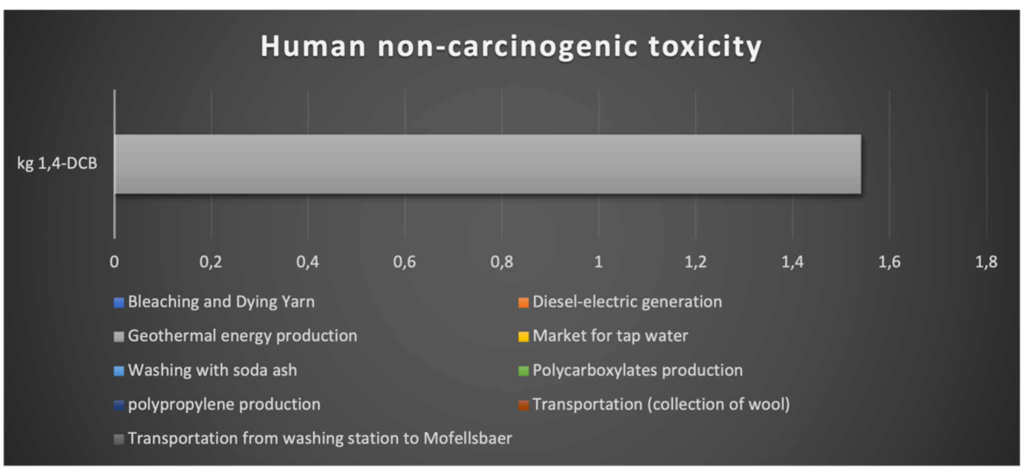

Figure 14: Human non-carcinogenic toxicity

5. Interpretation and Discussion

This study shows environmental impacts of wool processing in Iceland, with the largest impacts coming from water and electricity use, and use of certain chemicals during the washing process. It does not show the circularity of wool in Iceland and perhaps, the life cycle assessment is not the right tool to present circularity in this context. Another result of this project is that the circularity of a product is not necessarily in line with the lowest environmental impact. Making Icelandic wool into products has an impact and those impacts are accounted for in the results. If wool became 100 percent circular, that could also result in higher environmental costs.

Although other products sold by Ístex, such as blankets, could not be included in this study, the emission from overseas production would most likely have increased the environmental impact. This area is one where future research could identify if there are ways to use Icelandic wools that have a smaller negative environmental impact.

The results show high impacts from the use of soap, transport, and electricity. Possible adjustment on transport and usage of different soaps could reduce those impacts. However, several assumptions and data gaps allow only a general view on the impacts, something that can be better specified in further future research. Furthermore, if the impact of wool categories mentioned in *Figure 2* would be included in future research, it could give a better understanding for farmers and other stakeholders to make informed decisions.

At this moment, considering the nature of the study and data gaps/ assumptions, it was decided to postpone the publishing of a calculator online. This can be done when results are refined and further research is conducted.

6. Recommendations for future research

To build on this research and increase the accuracy of the results, data could be collected on the amount of wool discarded by farmers before processing by Ístex. Additionally, the potential for discarded wool to be used as a more economical source for agricultural fertilizer could be explored. These ideas could help increase the economic value, and therefore circularity of wool in Iceland. If wool loses economic value in the textile market, research into alternative uses, like fertilizer production, could be a way to increase wool’s circularity.

II) Life Cycle Assessment of Icelandic Forest Products

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7. Introduction

Traditional use of Icelandic forests was limited to firewood and charcoal production, and many forested areas were cleared for agricultural use from the time of settlement through the 20th century. In 1908 the Icelandic Forest Service was established, protecting existing woodland and planting new forests. Modern Icelandic Forest products are a relatively new and emerging industry in Iceland. Birchwood served as the first source of Icelandic Forest products, serving as fuelwood, building materials, fodder for livestock and charcoal from the time of human settlement though the 20th century. (Sigurmundsson et al., 2014)

Since the late 20th century, softwood trees like larch, spruce and pine have been added into the mix of raw materials to use in forest product manufacturing. These new species have supplemented the use of birch in the production of products like roundwood, sawn lumber, firewood, woodchips, and fence posts. Wood chips currently make up the largest percentage of products with 68% of all Icelandic Forest products. These wood chips are primarily by silicon smelters in Iceland, where they are used as a carbon source in combination with imported wood chips. Even with a greater variety of species, and a growing number of products, the Icelandic Forestry Industry is still fledgling, and data and information on production processes is limited. (Eysteinsson, 2017)

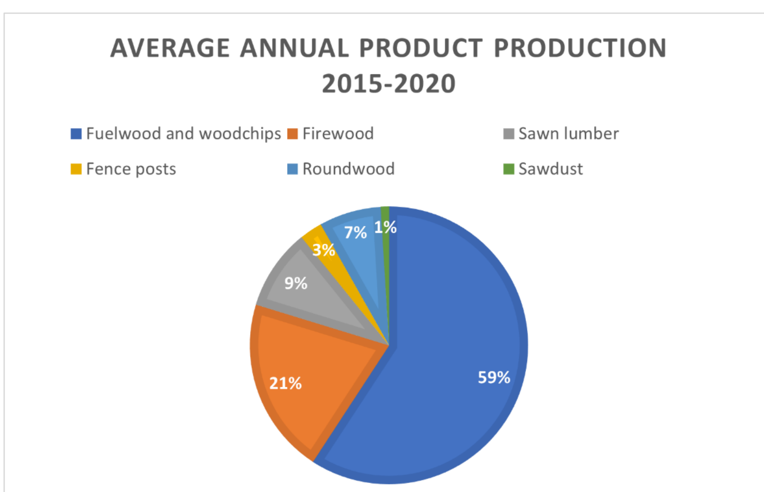

Figure 15: Average product makeup of Icelandic forest products from 2015-2020. (Skógræktin, 2020)

8. Goal and Scope

The goal of this research is to provide an introductory analysis into the circularity of the newly emerging forest product sector in Iceland using Life Cycle Assessment methodology and serve as a baseline study for future research. While this research aims to use data specific to Iceland where possible, the nature of the new forest product industry in Iceland means that for most processes, general data and data from other international sources were used. This, however, is in line with the goal of identifying areas for future research into the circularity of wood in Iceland and providing an academic foundation for that research.

The scope of this study is cradle-to-gate (shown in *Figure 16*) and includes all processes and materials from the harvesting of live trees to the transportation to retailers or industrial or private customers. With the exception of 2.76 and 1.38 cubic meters of wood chips sent to the Faroe Islands in 2016 and 2019 respectively, all sales of Icelandic Forest products were domestic. In line with other LCA research on forest products, the functional unit was determined to be 1 cubic meter of final product. Sawn lumber was chosen to be the final product due to the need for the most processing. Firewood and roundwood are considered inputs for sawn lumber and wood chips are a co-product.

The reference flows were based on data received from Skógræktin (the Icelandic Forest Service) spanning the years 2015 to 2020.

The impact categories used for this assessment were: Climate change, freshwater ecotoxicity, human toxicity, marine ecotoxicity, marine eutrophication, particulate matter formation, photochemical oxidant formation, terrestrial acidification, and terrestrial ecotoxicity.

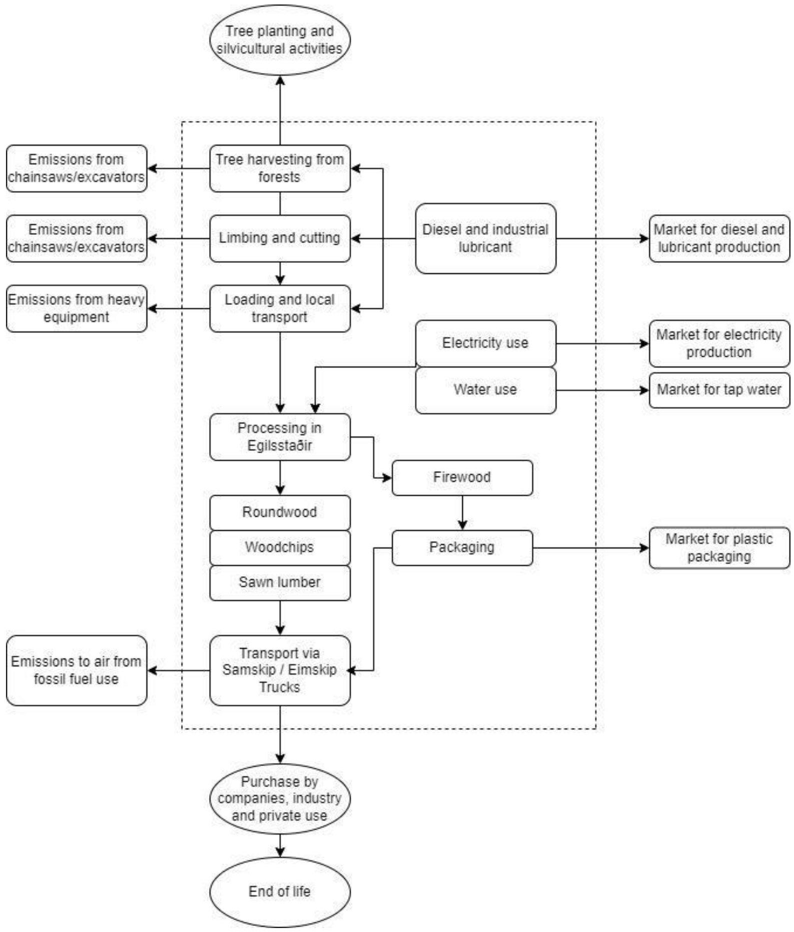

Figure 16: LCA system boundary is shown here within the dotted line. Processes and Technosphere inputs are shown within the dotted line. Environmental emissions are shown on the left and markets shown on the right while the processes excluded from this study are at the top (cradle) and bottom (grave).

9. Data Collection

For this Life Cycle Assessment (LCA) of Icelandic Forest products, 16 different government agencies, NGOs and businesses were contacted to provide information regarding the harvesting, processing, manufacturing, and transportation of Icelandic wood.

Primary data collection for Icelandic Forest products were received from Skógræktin, the Icelandic Forest Service. This data included total cubic meters of forest products sold each year from 2015 to 2020. Product data was categorized into 22 different products, falling into one of 5 categories: roundwood, sawn lumber, firewood, woodchips, and fence posts. These categories included product data for each species of relevant tree. For this research, 4 product categories were selected for inclusion in the LCA: Birch firewood (7%); Softwood roundwood (13%); Softwood sawn lumber (2%) and Woodchips (68%). These categories make up 90% of all forest products produced for the years 2015 to 2020. (Skógræktin, 2020)

Further primary data specific to Icelandic Forest products was gathered from emails and phone interviews during the months of June and July 2022 (Halldórsson, 2022). With all Icelandic Forest product data collected, there was still a need for data to fill in gaps to complete the LCA. While possible to obtain local data, the cost to do so was not available for this study. To overcome this lack of specific data, a literature review was conducted to fill in the missing data gaps with previous research from around the world. Data points were chosen based on similarity in species composition to Icelandic Forest products as well as similar harvesting, processing, manufacturing, and transportation methods. Where multiple sources for data were available, the newest source of data was used.

Harvesting, processing, and manufacturing of Icelandic Forest products is primarily conducted in the east of Iceland, and all manufacturing processes are done at the same location (Halldórsson, 2022). Transportation data (given in tones*kilometers) reflects an estimate of the distance traveled by final products from the main processing facility in Egilsstaðir to other municipalities across Iceland.

Background data for transportation fuel, electricity, and water production as well as excavator-based processes were taken from the Ecoinvent 3.6 database though Open LCA software version 1.110.

10. Life Cycle Inventory Analysis

Life Cycle Analysis was done for 4 different products, and includes harvesting of trees, sawing of roundwood, drying and planning for sawn lumber. Processes for roundwood and firewood were created first, as they required the least processing out of the 4 product categories. For sawn lumber and wood chips, the process for roundwood was used as an input in addition to other necessary inputs. The output was the respective product and any solid waste.

10.1 Roundwood and Firewood

Inputs for firewood and roundwood production include delimbing and sorting as an excavator-based process, electricity for drying, forwarder for loading and hauling, packaging for the individual bundles, skidder operations for removing the logs from the forest, tap water for washing and transport to the point of sale. Roundwood had these same inputs, excluding the packaging used for firewood. Outputs include birch firewood, recycling waste, inorganic waste to landfills and unspecified wood waste. Delimbing was listed as an excavator-based process, however in Iceland this is currently done by chainsaw (Halldórsson, 2022). The literature review was based on excavator-based processes, and while using chainsaw data would provide more accurate results for Iceland, the process system for chainsaws was not included in the OpenLCA database, so the existing excavator-based process was used instead.

Both processes for softwood roundwood and birch firewood are very similar, however due to the difference in density between hardwood birch and softwood, the input amounts between these two categories differed. These small differences were reflected in the final LCA results.

10.2 Sawn lumber

Making up only 2% of Icelandic Forest products, sawn lumber was the smallest product category in this study. Although fence posts currently make up a higher percentage of the market, sawn lumber was chosen as a product category in this study due to the potential for market growth. As import costs for lumber are high, the newly maturing Icelandic Forest will likely become a cheaper, more circular source for building materials in Iceland. For this reason, sawn lumber was included as its own category.

Sawn lumber used the process created for Icelandic softwood roundwood as an input in addition to electricity use and land transportation via 16-32 tonne lorry. The outputs for sawn lumber include bark and sawdust. Packaging data was not available, and it was assumed that minimal amounts of packaging (<0.1% of total product mass) was used in the transportation of sawn lumber (Milota et al., 2005).

10.3 Wood Chips

Woodchips represent the largest product category for Icelandic Forest products, and their use is largely as a carbon source for local silicon smelters. This product category has great versatility due to the ease of production from a variety of sources. Forest waste like limbs and bark can be used as inputs for woodchip production as well as other products like soft and hardwood roundwood. Due to the unavailability of data for forest waste products, only roundwood was used as an input for wood chips in this study, however both hardwood and softwood were used as the primary input. Because the process of producing woodchips does not significantly different between species, no changes were needed to differentiate between softwood roundwood and hardwood roundwood (Halldórsson, 2022). Outputs for wood chip production include wood chips and sawdust.

11. Results and Discussion

Climate change represented the largest impact category for all four products assessed in this research. Firewood and roundwood showed noticeable differences in effects across the assessed categories. It is likely that the excavator-based processes, skidding and forwarding included for roundwood and firewood harvesting are the primary cause of this difference. These machines were linked with both diesel and industrial lubricant markets which particularly impacted freshwater ecotoxicity, human toxicity, marine ecotoxicity and terrestrial ecotoxicity.

The database used for this research only included forestry processes for industrial, large-scale production. As the Iceland forest product sector is extremely small, many of these processes may differ. Felling of trees is done with chainsaws rather than excavators, so the results of this study could be improved by including chainsaw processes, however as the Icelandic Forest product market grows, the use of chainsaws may be eventually replaced by excavator-based processes.

Figures 17 through 25 show the relative impact of each product in all impact categories included in this research.

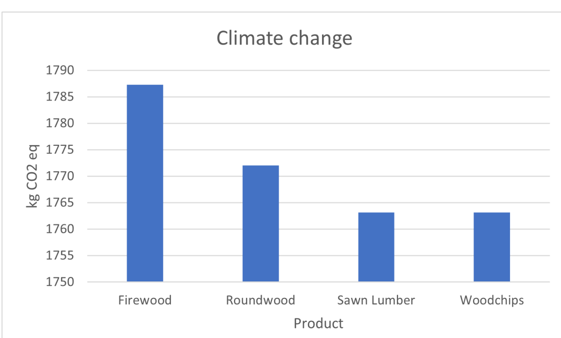

Fig. 17

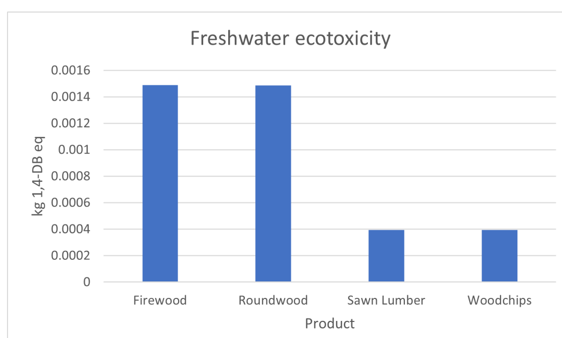

Fig. 18

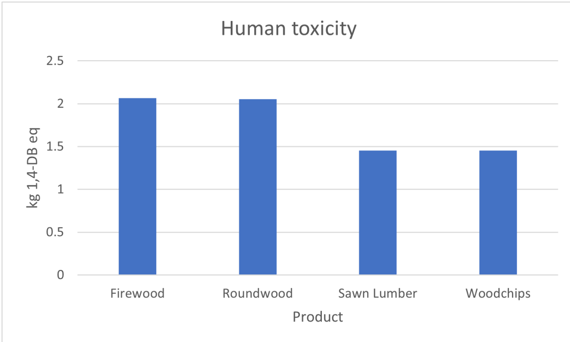

Fig. 19

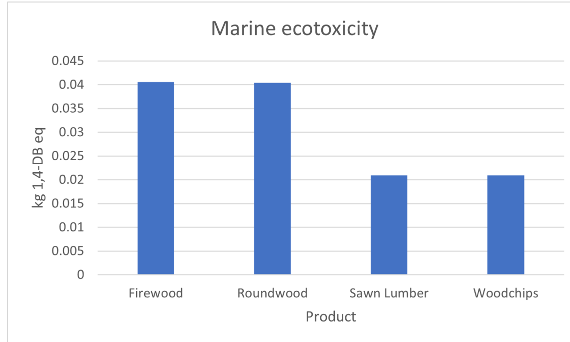

Fig. 20

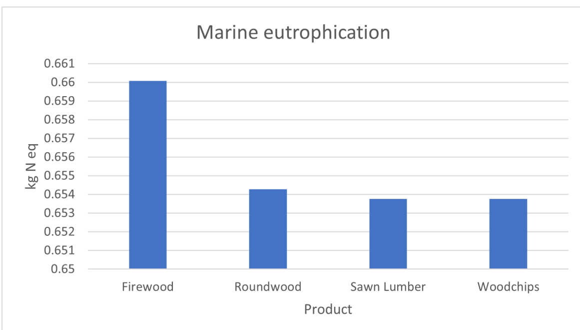

Fig. 21

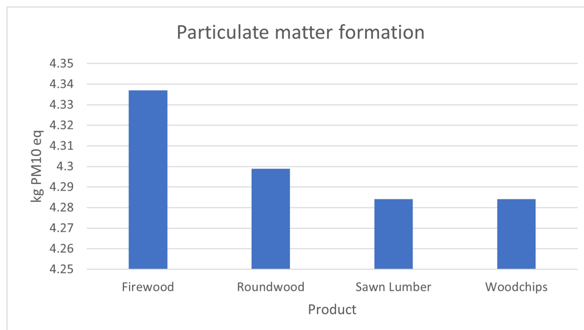

Fig. 22

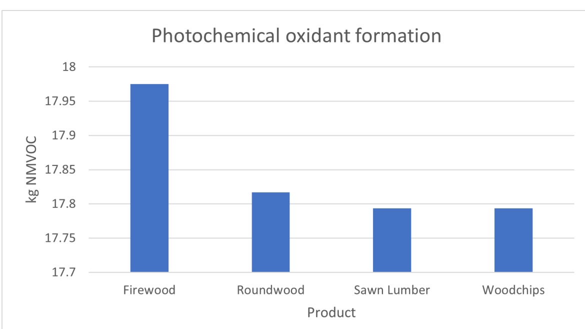

Fig. 23

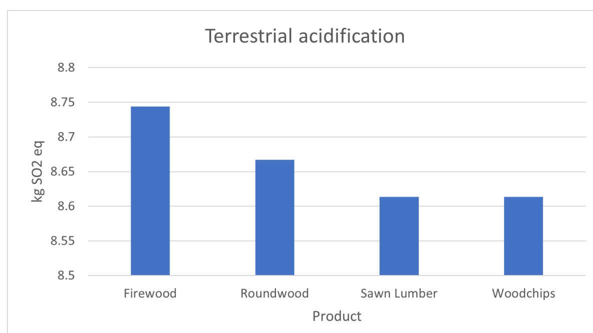

Fig. 24

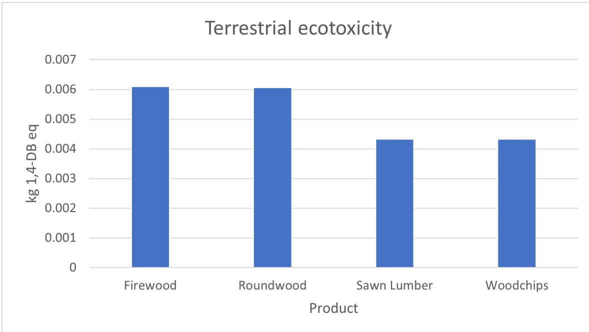
Terrestrial ecotoxicity
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
kg 1,4-DB eq
Firewood
Roundwood
Sawn Lumber
Woodchips
Product

Fig.25

The most notable difference with these results compared with the results of similar studies is the significant effect of transportation on almost all categories. Differences in system boundaries and functional units make direct comparison of international studies difficult (Puettmann et al., 2010), and the studies used for this LCA did not include transportation to industry in their scope. In similar studies, the on-site transportation of timber as well as fossil fuel machine operation has made important contributions to overall emission (Murphy et al., 2015). This research aims to include the effect of transportation and estimated an average distance of 250 km per cubic meter. This number aims to represent the distance between the largest manufacturing facility in Egilsstaðir and Reykjavik (~650km) as well as markets in other municipalities around Iceland, however this is one area where many assumptions were made, and future research could provide a more accurate assessment. Shown in *Figure 26* are the effects of transportation on each assessed category.

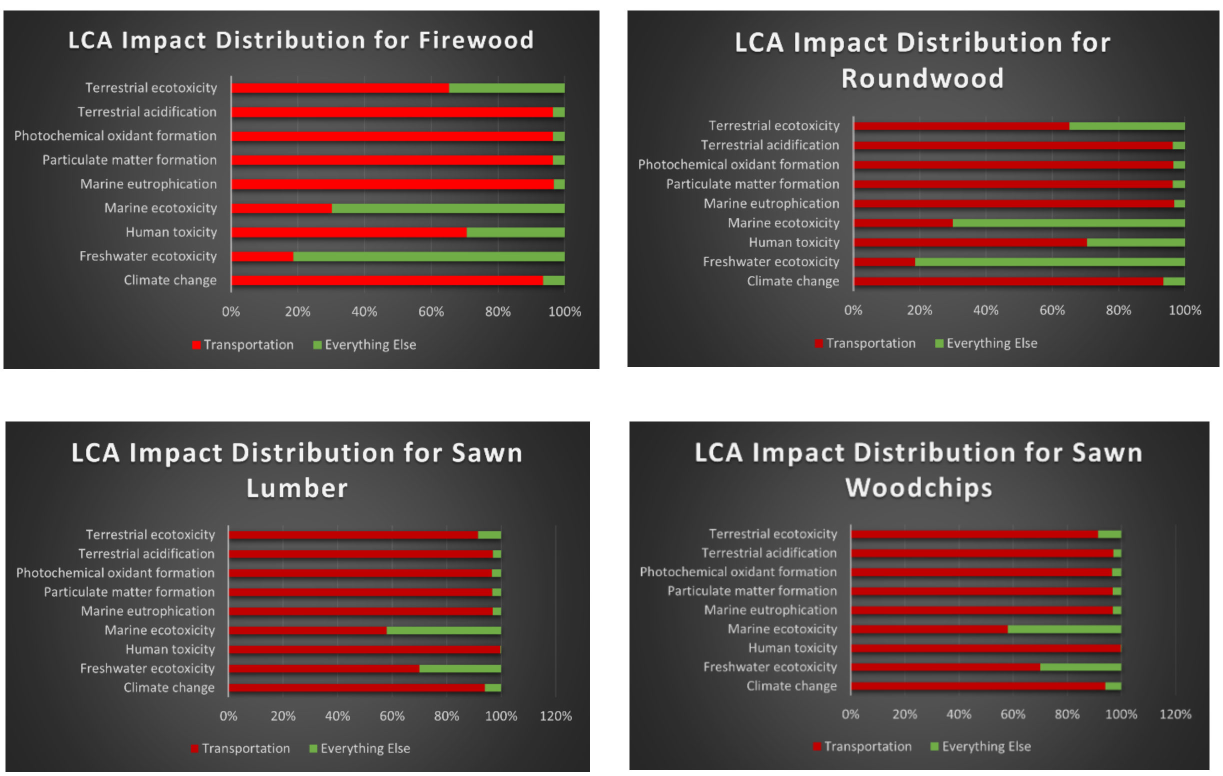

Figure 26: Percentage change in impact categories from transportation.

When the data does not include transportation, the results become very similar to other studies. The use of renewable energy and geothermal heated water also means there is likely an even lower impact across all categories compared to other studies where fossil fuels are a percentage of the off-site energy mix and where wood is used as a fuel source for boilers to kiln dry lumber. The small Icelandic market combined with renewable energy and geothermal heated water suggests that Iceland may have the potential to be one of the lowest impact countries when it comes to forest product manufacturing. The biggest impact currently comes from fossil fuel powered harvesting machinery and transportation vehicles. If these were to convert to electric, the impacts, particularly in carbon emission to the air, could be reduced.

12. Future Research

The Icelandic Forest product industry is a new and emerging sector, and though this research provides a general look at the circularity of forest products in Iceland, there are numerous opportunities to further this research and provide a more holistic view of forest products in Iceland.

The most feasible area for immediate LCA research would be in the silvicultural activities that go into planting and growing trees in Iceland. There have been many LCA studies done in other European countries, as well as around the world that could serve as a basis for assessing the impact of tree nurseries, tree planting, and thinning of forest stands. This is also a very active sector in Iceland with the possibility to collect enough data to serve as an accurate assessment of Icelandic forestry activities.

Second, further research could be done into the specifics of equipment used in Iceland, like chainsaws, transport vehicles, sawmills and all the inputs and output relative to those processes. This study gives a broad overview, mainly reliant on data from international research, but could be used as a guide to further increase the accuracy of forest products in Iceland.

Lastly, as the Icelandic Forest product market grows over the coming decades, product diversity will likely grow as well. This gives way to opportunities to investigate specific products like framing timber, pallets, and mass timber. Research into these products could then be compared to imported forest products, and potentially serve as a driver for increased circularity in Iceland.

Conclusion

The original purpose to determine the circularity of wool in Iceland could not be fully explored. Ístex receives around 95% of wool in Iceland for further processing but the actual numbers for wool that stays with the farmers could not be obtained. Additionally, the economic aspect of wool circularity in Iceland was not considered in this LCA. The results of the LCA show that global warming's impact is in line with other studies, showing that transport, electricity use, and the use of chemicals during the washing process have the largest impacts.

Based on the numbers received by Ístex and other sources, the raw material wool is around 95% circular in Iceland. Not considered in the scope of this research were end-of-life and products potentially going to landfills. For products like yarn, sweaters or blankets that are exported, it is even more difficult to obtain data on end-of-life processes. According to an interview with Ístex, yarn and other Icelandic wool products are shipped worldwide. That adds more embedded emission not included in this paper.

Similarly, the original goal of determining the circularity of wood in Iceland could not be fully explored either. Data from phone interviews suggest that most all forms of forest products are used and there is no quantitative data on forest product waste in Iceland. The forest product industry in Iceland is fledgling, so the high utilization of raw materials aims to maximize economic value, however it is likely there is still waste that has not been accounted for.

The results of the forest product LCA show that transportation of forest products to the various markets has the largest negative environmental impact, and particularly in the category of climate change (kg of CO_2). Other harvesting processes based on diesel-run machinery account for the next highest contribution to negative environmental impacts, while electric based sawing and processing accounted for the smallest impact due to off-site geothermal energy production. The results of this LCA are largely in line with results from other forest product LCAs from around the world, however one notable difference is the inclusion of transportation to markets in this LCA that increase the overall environmental impacts.

Overall, these LCAs were useful for introductory purposes, but are limited in their capacity to provide an assessment of raw material circularity in Iceland. Future research for LCAs would be best focused on the collection of data specific to Icelandic processes while future research into the circularity of raw materials would be better served by a different method, one more focused on identifying and quantifying waste throughout all stages of raw material processing.

Bibliography

I) Life Cycle Assessment of Icelandic Wool

Amazon. (2022). Amazon.com: Secbolt FIBC bulk bag. Amazon.com. https://www.amazon.com/Secbolt-2200lbs-Duffle-Bottom-Polypropylene/dp/B07D3P6351/ref=sr_1_27?

Arnalds, O., & Barkarson, B. H. (2003). Soil erosion and land use policy in Iceland in relation to sheep grazing and government subsidies. *Environmental Science & Policy*, *6*(1), 105-113. https://doi.org/https://doi.org/10.1016/S1462-9011(02)00115-6

Brock, P., Graham, R., Madden, P., & Alcock, D. (2013). Greenhouse gas emissions profile for 1 kg of wool produced in the Yass Region, New South Wales: A Life Cycle Assessment approach. *Animal Production Science*, *53*, 485-508. https://doi.org/10.1071/AN12208

Consequential LCA. (2017, May 22). Determining reference flows. https://consequential-lca.org/clca/the-functional-unit/determining-reference-flows/

Martin, M., & Herlaar, S. (2021). Environmental and social performance of valorizing waste wool for sweater production. *Sustainable Production and Consumption*, *25*, 425-438. https://doi.org/https://doi.org/10.1016/j.spc.2020.11.023

Ullarmat. (2019). Ársskýrsla vegna ullarsöfnunar 2019. Ullarmat . https://ullarmat.is/wp-content/uploads/2020/10/skyrsla_ullarsofnun_2019.pdf

Wiedemann, S., Biggs, L., Nebel, B., Bauch, K., Laitala, K., Klepp, I., Swan, P. G., & Watson, K. (2020). Environmental impacts associated with the production, use, and end-of-life of a woolen garment. *The International Journal of Life Cycle Assessment*, *25*. https://doi.org/10.1007/s11367-020-01766-0

II) Life Cycle Assessment of Icelandic Forest Products

Alibaba.com. (2022). *Wholesale used plastic 1 cubic meter big bag firewood*. https://www.alibaba.com/product-detail/Wholesale-used-plastic-1-cubic-meter_60651625729.html

Bergman, R. D. B. (2008). Environmental impact of producing hardwood lumber using life-cycle inventory. *Journal*, *40*(3), 448-458.

Eysteinsson, T. (2017). Forestry in a Treeless Land. *Skógræktin*. https://www.skogur.is/static/files/2017/Forestry_in_treeless_land_BKL_210x260mm.pdf

Halldórsson, P. (2022). Phone communication on Icelandic forestry processes. In P. Hill (Ed.).

Milota, M., & Puettmann, M. E. (2017). Life-cycle assessment for the cradle-to-gate production of softwood lumber in the pacific northwest and southeast regions. *Forest products journal*, *67*(5-6), 331-342.

Milota, M. R., West, C. D., & Hartley, I. D. (2005). Gate-to-gate life-cycle inventory of softwood lumber production. *Wood and fiber science*, 47-57.

Murphy, F., Devlin, G., & McDonnell, K. (2015). Greenhouse gas and energy based life cycle analysis of products from the Irish wood processing industry. *Journal of cleaner production*, *92*, 134-141.

Puettmann, M. E., Bergman, R., Hubbard, S., Johnson, L., Lippke, B., Oneil, E., & Wagner, F. G. (2010). Cradle-to-gate life-cycle inventory of US wood products production: CORRIM Phase I and Phase II products. *Wood and fiber science. Vol. 42, suppl. 1 (2010): p. 15-28.*, *42*(suppl. 1), 15-28.

Sigurmundsson, F. S., Gísladóttir, G., & Óskarsson, H. (2014). Decline of birch woodland cover in Þjórsárdalur Iceland from 1587 to 1938. *Human ecology*, *42*(4), 577-590.

Skógræktin. (2020). *Forestry in a Treeless Land*.

Appendix

I) Life Cycle Assessment of Icelandic Wool

a) Meeting with Sunna Jökulsdóttir, Quality manager at Ístex

Visit of the factory: Steffi Meisl and Paul Hill (no photos taken)

Place: Völuteigur 6, 270 Mosfellsbær

The higher quality wool arrives in Mosfellsbær and is washed, dyed, spun and made into yarn (Lopi)

- Collection of Wool happens two times a year: Autumn (around November after the sheep round up) and Spring before the sheep are let out to roam
- Wool quality when shearing in spring is higher
- Different classes of wool can be seen here: https://ullarmat.is/ullarflokkar/
- Pure colors are best for dying and spinning into yarn
- Secondary quality wool can be used in Istex duvet line: https://lopidraumur.is/
- More products for instance for icewear jackets are here: https://istex.is/en/other-products/lopi-loft-og-lopi-fur/
- According to Sunna, at least 95% if wool in Iceland is processes by Istex
- “Waste” can go to Insulation products (for instance short hair)
- Unprocessable wool such as felted and heavily soiled is shipped abroad
- Blönduos receives the wool and from there it is shipped abroad. Around 30% goes for processing to Istex

b) Email Exchange with Sunna Jökulsdóttir, Head of Quality and Development Ístex

Wed, Jul 13, 12:47 PM

Hi Steffi and Paul,

I can answer some of your questions now, others will have to wait.

The bags are polypropylene bags and take 20-25 kg

It is a formality that we are required to process at least 30% of the wool in Iceland. We are closer to 50%, in 2019 it was 45%.

Our blankets are woven in Lithuania. We spin the yarn in Mosfellsbær and then ship it to be woven and shipped back.

The wool for our duvets and pillows is shipped from Blönduós and then processed and part of it is sent back.

Hagstofan has data about how many sheep there are. A gross estimate is that each sheep gives 2 kg of wool with 70% purity (around 30% of the weight washes off in form of dirt, sand, vegetable matter, ...)

https://px.hagstofa.is/pxis/pxweb/is/Atvinnuvegir/Atvinnuvegir__landbunadur__landbufe/LAN10102.px/chart/chartViewLine/?rxid=448fa79f-647e-4bdc-a038-c69900d8c7bf

I will get back to you on the other answers.

Kind regards,

Sunna

Jul 26, 2022, 9:55 AM

Hello again,

6-7 tons per truck (raw wool). 7 different truck drivers for different parts of the island each with their truck.

Found this information for Blönduós about electricity and water use.

Let me know what you need next.

Sunna

Blönduós – scouring plant

Hve mikið rafmagn er notað (KWh)?

2018	2019	2020
465000	414000	368000

Er annað eldsneyti notað? Bensín, dísel eða eitthvað þessháttar? Hve mikið?

3000L/mán olía (average over the whole year)

Hve mikið vatn er notað?

Kalt vatn (m3)

Year	2018	2019	2020
Total	13467	8822	

Heitt vatn (m3)

Year	2018	2019	2020
Total	37120	30554	30127

Aug 4, 2022, 4:16 PM

Hi,

I have answered your questions below. Could you send me the excel file again?
Our goal is to no longer sell scoured wool, that all the wool that we buy gets transformed in some way before being sold. We have been working towards that goal for a few years and how the wool is used evolves year to year but the information I have shared gives an idea of the situation.

All the best
Sunna

Thank you, Sunna. We are getting closer :)

The data from Blönduós helps a lot to get a precise result.

- When you say olía does that mean diesel or any specific oil that is used for the machine?

Pretty sure it is DMA

- In the washing process, is there any soap used?

We use soda ash and a wool scouring soap (polyglycol ether). About 18 tons of soda ash and 9000 L of soap /year.

- Is there information on the wastewater from the washing process - for instance is it going to the sewage together with the dirt and sludge from the wool or is it somehow filtered and reused?

The water goes to a setþró (settling tank?) just outside the plant. There the sand and dirt settles. Then the water goes to the sewage plant of Blönduós who purify it before discarding it.

About the polyethylene bags, I found in the lopapeysur paper that the bags are reused and at another point in the paper that the bags cannot be reused because of contamination? Which one is correct?

The bags used for the raw wool from the farmers can not be reused because of contamination issues. The bags used to pack the scoured wool are reused.

Thank you for the percentages. Everything that is not 100% used in Iceland is shipped abroad? Is it shipped to a specific port in mainland Europe?

Most of the wool is shipped from Sauðarkrókur.

II) Life Cycle Assessment of Icelandic Forest Products

Table 1: Raw data on all Icelandic forest products produced for the years 2015-2020, given in cubic meters (Skógræktin, 2020).

Product	Species	2015	2016	2017	2018	2019	2020	Total
Fuelwood and chips (industry)		3171	1825	1296.55	1285.7	886.7	1641.4	10106.4
Firewood	Birch	318	513	700.96	592.226	485.77	169.5	2779.46
Wood chips	Spruce/Pine	160	225.5	400.5	260.585	385.3	485	1916.88
Firewood	Conifer	182	345.4	183.38	394.09	189.45	332.67	1626.99
Sawn lumber	Spruce	31	47.8	1084	28.1486	56.54	54.95	1302.44
Fuelwood and chips (energy production)		422	590	124	25	0	0	1161
Fence posts		20.95	7.34905	409	26.5885	132.85	33.0181	629.756
Sawn lumber	Other	3	17.6645	583	0.02959	0		603.694
Wood chips	Larch	81.8	68	188	90.2136	84.34	81	593.354
Round wood	Larch	27	26.1	45.6	39.8239	151.06	284.01	573.594
Round wood	Spruce	53	94.22	165.45	58.9821	55.56	90.92	518.132
Firewood	Aspen/Other	56	7	153	24	140.14	72.45	452.59
Round wood	Pine	72		10	109.14	66.02	79	336.16
Sawn lumber	Larch	21	48.7	89.67	72.1075	12.28	20.59	264.347
Round wood	Other	0	97.4	142.8	0	0		240.2
Wood chips	Birch/Other	6	0	29.24	3.75689	0	193	231.997
Sawdust		39.5	112.5	22	37.49	8.09	0	219.58
Sawn lumber	Aspen	1.6	10	13	14.425	6.06	0.4	45.485
Round wood	Birch	3.53	3.5	6	4.28913	2	1.97	21.2891
Round wood	Aspen	4	1.2	5.66	2	1	2	15.86
Sawn lumber	Pine	6	5.6	1	0	1		13.6
Sawn lumber	Birch	1	2.2	0.5	4.18298	0	0.98	8.86298
Totals		**4680.38**	**4048.134**	**5653.31**	**3072.779**	**2664.16**	**3542.858**	**23661.62**

Table 2: Inputs and sources gathered from Literature review and online marketplace data. (Alibaba.com, 2022; Bergman, 2008; Milota & Puettmann, 2017; Milota et al., 2005; Murphy et al., 2015; Puettmann et al., 2010)

	Number	Unit	Source
Resources			
Water, process, surface	2.24	kg	Milota 2017
Waterm process, well	2.02	kg	Milota 2017
Total water use	4.26	kg	Milota 2017
Materials and fuels			
Transport, diesel freight	98.9	t*km	Milota 2017
Delimbing, excavator based	1	h	
Forwarding, forwarder	1	h	
Packaging film	200	g	Alibaba 2022
Solid waste			
Landfill, inorganics to	0.00271	kg	Milota 2017
Recycled	0.000235	kg	Milota 2017
Wood scraps	2.61	g	Milota 2005
Bark	7.31	g	Milota 2005
Electricity			
Electricy use from grid	417.48	kWh	Bergman 2008
Electricity use produced on site	7.13	kWh	Bergman 2008
Total electricy use	424.61	kWh	Bergman 2008
Co-products			
Bark	58.41	kg	Milota 2005
Sawdust	55.33	kg	Milota 2005
Woodchips	200.68	kg	Milota 2005
Rough, green roundwood	427.38	kg	Milota 2005

Table 3: Impact category details for Firewood production

Firewood impact category	Reference unit	Result	Normalized
Climate change - ReCiPe Midpoint (I)	kg CO2 eq	1787.262	0.126359454
Freshwater ecotoxicity - ReCiPe Midpoint (I)	kg 1,4-DB eq	0.001489	0.000135488
Human toxicity - ReCiPe Midpoint (I)	kg 1,4-DB eq	2.067559	0.005913218
Marine ecotoxicity - ReCiPe Midpoint (I)	kg 1,4-DB eq	0.040552	0.005352816
Marine eutrophication - ReCiPe Midpoint (I)	kg N eq	0.660081	0.065216038
Particulate matter formation - ReCiPe Midpoint (I)	kg PM10 eq	4.336936	0.291008401
Photochemical oxidant formation - ReCiPe Midpoint (I)	kg NMVOC	17.97513	0.316362266
Terrestrial acidification - ReCiPe Midpoint (I)	kg SO2 eq	8.743804	0.270183539
Terrestrial ecotoxicity - ReCiPe Midpoint (I)	kg 1,4-DB eq	0.006101	0.000738176

Table 4: Impact category details for Firewood production excluding transportation processes.

Firewood impact category (transportation excluded)	Reference unit	Result	Normalize
Climate change - ReCiPe Midpoint (I)	kg CO2 eq	115.161095	0.008142
Freshwater ecotoxicity - ReCiPe Midpoint (I)	kg 1,4-DB eq	0.001210774	0.00011
Human toxicity - ReCiPe Midpoint (I)	kg 1,4-DB eq	0.607242812	0.001737
Marine ecotoxicity - ReCiPe Midpoint (I)	kg 1,4-DB eq	0.028313849	0.003737
Marine eutrophication - ReCiPe Midpoint (I)	kg N eq	0.021403215	0.002115
Particulate matter formation - ReCiPe Midpoint (I)	kg PM10 eq	0.155568791	0.010439
Photochemical oxidant formation - ReCiPe Midpoint (I)	kg NMVOC	0.631288389	0.011111
Terrestrial acidification - ReCiPe Midpoint (I)	kg SO2 eq	0.316441654	0.009778
Terrestrial ecotoxicity - ReCiPe Midpoint (I)	kg 1,4-DB eq	0.002112145	0.000256

Table 5: Impact category details for Roundwood production

Roundwood impact category	Reference unit	Result	Normalized
Climate change - ReCiPe Midpoint (I)	kg CO2 eq	1772.046144	0.125283662
Freshwater ecotoxicity - ReCiPe Midpoint (I)	kg 1,4-DB eq	0.001486337	0.000135257
Human toxicity - ReCiPe Midpoint (I)	kg 1,4-DB eq	2.053786296	0.005873829
Marine ecotoxicity - ReCiPe Midpoint (I)	kg 1,4-DB eq	0.040439972	0.005338076
Marine eutrophication - ReCiPe Midpoint (I)	kg N eq	0.654269317	0.064641808
Particulate matter formation - ReCiPe Midpoint (I)	kg PM10 eq	4.298885072	0.288455188
Photochemical oxidant formation - ReCiPe Midpoint (I)	kg NMVOC	17.81716634	0.313582128
Terrestrial acidification - ReCiPe Midpoint (I)	kg SO2 eq	8.667114017	0.267813823
Terrestrial ecotoxicity - ReCiPe Midpoint (I)	kg 1,4-DB eq	0.006064299	0.00073378

Table 6: Impact category details for Roundwood production excluding transportation processes.

Roundwood impact category (excluding transportation)	Reference unit	Result	Normalize
Climate change - ReCiPe Midpoint (I)	kg CO2 eq	115.161095	0.008142
Freshwater ecotoxicity - ReCiPe Midpoint (I)	kg 1,4-DB eq	0.001210763	0.00011
Freshwater eutrophication - ReCiPe Midpoint (I)	kg P eq	8.34566E-06	2.01E-05
Human toxicity - ReCiPe Midpoint (I)	kg 1,4-DB eq	0.606759543	0.001735
Marine ecotoxicity - ReCiPe Midpoint (I)	kg 1,4-DB eq	0.028313551	0.003737
Marine eutrophication - ReCiPe Midpoint (I)	kg N eq	0.021403215	0.002115
Particulate matter formation - ReCiPe Midpoint (I)	kg PM10 eq	0.155568791	0.010439
Photochemical oxidant formation - ReCiPe Midpoint (I)	kg NMVOC	0.631156654	0.011108
Terrestrial acidification - ReCiPe Midpoint (I)	kg SO2 eq	0.316441654	0.009778
Terrestrial ecotoxicity - ReCiPe Midpoint (I)	kg 1,4-DB eq	0.002112111	0.000256

Table 7: Impact category details for Sawn lumber production

Sawn lumber impact category	Reference unit	Result	Normalized
Climate change - ReCiPe Midpoint (I)	kg CO2 eq	1763.128145	0.12465316
Freshwater ecotoxicity - ReCiPe Midpoint (I)	kg 1,4-DB eq	0.000394105	3.58636E-05
Human toxicity - ReCiPe Midpoint (I)	kg 1,4-DB eq	1.451700576	0.004151864
Marine ecotoxicity - ReCiPe Midpoint (I)	kg 1,4-DB eq	0.020916768	0.002761013
Marine eutrophication - ReCiPe Midpoint (I)	kg N eq	0.653754316	0.064590926
Particulate matter formation - ReCiPe Midpoint (I)	kg PM10 eq	4.284080733	0.287461817
Photochemical oxidant formation - ReCiPe Midpoint (I)	kg NMVOC	17.7933788	0.313163467
Terrestrial acidification - ReCiPe Midpoint (I)	kg SO2 eq	8.613674204	0.266162533
Terrestrial ecotoxicity - ReCiPe Midpoint (I)	kg 1,4-DB eq	0.004320727	0.000522808

Table 8: Impact category details for Sawn lumber production excluding transportation processes.

Sawn lumber impact category (excluding transportation)	Reference unit	Result
Climate change - ReCiPe Midpoint (I)	kg CO2 eq	106.2430954
Freshwater ecotoxicity - ReCiPe Midpoint (I)	kg 1,4-DB eq	0.00011853
Human toxicity - ReCiPe Midpoint (I)	kg 1,4-DB eq	0.004673823
Marine ecotoxicity - ReCiPe Midpoint (I)	kg 1,4-DB eq	0.008790347
Marine eutrophication - ReCiPe Midpoint (I)	kg N eq	0.020888215
Particulate matter formation - ReCiPe Midpoint (I)	kg PM10 eq	0.140764452
Photochemical oxidant formation - ReCiPe Midpoint (I)	kg NMVOC	0.607369113
Terrestrial acidification - ReCiPe Midpoint (I)	kg SO2 eq	0.263001841
Terrestrial ecotoxicity - ReCiPe Midpoint (I)	kg 1,4-DB eq	0.000368539

Table 9: Impact category details for Woodchip production

Woodchip impact category	Reference unit	Result	Normalized
Climate change - ReCiPe Midpoint (I)	kg CO2 eq	1763.128145	0.12465316
Freshwater ecotoxicity - ReCiPe Midpoint (I)	kg 1,4-DB eq	0.000394105	3.58636E-05
Human toxicity - ReCiPe Midpoint (I)	kg 1,4-DB eq	1.451700576	0.004151864
Marine ecotoxicity - ReCiPe Midpoint (I)	kg 1,4-DB eq	0.020916768	0.002761013
Marine eutrophication - ReCiPe Midpoint (I)	kg N eq	0.653754316	0.064590926
Particulate matter formation - ReCiPe Midpoint (I)	kg PM10 eq	4.284080733	0.287461817
Photochemical oxidant formation - ReCiPe Midpoint (I)	kg NMVOC	17.7933788	0.313163467
Terrestrial acidification - ReCiPe Midpoint (I)	kg SO2 eq	8.613674204	0.266162533
Terrestrial ecotoxicity - ReCiPe Midpoint (I)	kg 1,4-DB eq	0.004320727	0.000522808

Table 10: Impact category details for Woodchip production excluding transportation processes.

Woodchip impact category (excluding transportation)	Reference unit	Result	Normalized
Climate change - ReCiPe Midpoint (I)	kg CO2 eq	106.2431	0.007511387
Freshwater ecotoxicity - ReCiPe Midpoint (I)	kg 1,4-DB eq	0.000119	1.07863E-05
Human toxicity - ReCiPe Midpoint (I)	kg 1,4-DB eq	0.004674	1.33671E-05
Marine ecotoxicity - ReCiPe Midpoint (I)	kg 1,4-DB eq	0.00879	0.001160326
Marine eutrophication - ReCiPe Midpoint (I)	kg N eq	0.020888	0.002063756
Particulate matter formation - ReCiPe Midpoint (I)	kg PM10 eq	0.140764	0.009445295
Photochemical oxidant formation - ReCiPe Midpoint (I)	kg NMVOC	0.607369	0.010689696
Terrestrial acidification - ReCiPe Midpoint (I)	kg SO2 eq	0.263002	0.008126757
Terrestrial ecotoxicity - ReCiPe Midpoint (I)	kg 1,4-DB eq	0.000369	4.45932E-05