Author: Rathish Rajan / Editor: Egidija Rainosalo

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CENTRIA UNIVERSITY OF APPLIED SCIENCES, 2023

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centria
University of Applied Sciences

PUBLISHER:
Centria University of Applied Sciences
Talonpojankatu 2, 67100 Kokkola

COVER PICTURE: Adobe Stock

Centria. Reports, 2.
ISSN 2814-8924
ISBN 978-952-7173-78-7

CONTENTS

1 ABOUT THE PROJECT

The Veneprint project's primary goal is to create conditions for boat industry companies to transform from a linear economic model to a circular. This transformation is envisaged through the utilization of partially or entirely bio-based, as well as recyclable, materials and robotized 3D printing production technology. The project's measures will reduce the carbon footprint of boat companies, improves working conditions for workers and therefore improves overall sustainability. The use of recyclable material with potential to reuse it strengthens companies' competitiveness and provides cost-effective and environmentally friendly solutions to customers, while 3D printing technology enables better customization of the boat features. Furthermore, Veneprint project activities accelerate business development by promoting investments in new modern technologies and pave the way for new value chains, which can be exploited locally.

2 LCA INFORMATION

The scope of the present study is to assess the potential environmental impact of the steering console production based on the Life Cycle Assessment methodology. A description of the functional unit, system boundaries, key assumptions and a flow chart describing the lifecycle stages of the product is given below.

The study aims to compare two manufacturing methods used for producing steering consoles to select the one based on overall environmental performance. Method one is a conventional thermoset hand lay-up process using glass fiber reinforced thermoset resin composite material (GFRP), and method two is a robot-assisted fused granular fabrication using thermoplastic matrix-based wood fibre reinforced composite material (WPC). The primary reason for the study is to identify the benefits of using 3D printing with bio-based and recyclable materials to replace synthetic materials in manufacturing components in the boat industry. The considered lifecycle is for cradle-to-gate phases, which includes raw material extraction, material manufacturing and manufactured product ready to leave the factory gate.

2.1 PRODUCT INFORMATION

Product name. Steering console
Geographical scope: Global

Product identification and description: The steering console (Figure 1) serves as the central hub for all essential boat controls components such as the steering wheel, ignition system, trim control, radio, various electronic devices and switches. Additionally, it may offer a modest allocation of storage space.

FIGURE 1: Steering console manufactured by robot-assisted fused granular fabrication

2.2 CONTENT DECLARATION

A finished steering console is installed in the boat. The specifications of steering console is tabulated in Table 1.

TABLE 1: Specifications of the two systems considered for LCA study

Specifications	Unit	WPC-3D printing	GFRP-Hand lay-up
Area	m2	1.8	1.8
Weight	kg	12.2	8.8
Fibre weight	%	50	35
Materials			
Polymer		Polypropylene	Orthopthalic polyester resin
Fibre		Wood flour	Glass fibre mat
Topcoat/gelcoat		Polyester based	Polyester based
Tools			
		No tool needed	Plug and mould

2.3 FUNCTIONAL UNIT AND REFERENCE FLOWS

The environmental impacts of a production system are evaluated based on the inputs/outputs of material and the energy utilization at each life cycle stage for a defined functional unit of the product. The functional unit is defined as the quantification of the identified function of the product. This study defines a functional unit as “steering console with a total area of 1.85 m2 for a boat with a lifetime of 20 years.”

The reference flow for a 3D-printed steering console made using wood plastic composite is 12.2 kg, and the reference flow for a glass fibre-reinforced composite-based steering console is 8.9 kg.

2.4 DESCRIPTION OF SYSTEM BOUNDARIES

The LCA is based on a ‘cradle to gate’ approach. The LCA covers the raw material extraction to the stage when the steering console is ready to leave the factory gate. The end-of-life allocation considered is 100-0 or upstream allocation, also known as cut-off approach (Figure 2). It allocates the burden from recycling activities and the benefits from avoided virgin material to the life cycle 2 (LC2) that using the recycled material as input. The wood plastic composite based steering console can be reused for minimum 2 more life cycles. Therefore, the burden from recycling and benefits from avoided products are accounted for in LC2 and are not modelled in LC1.

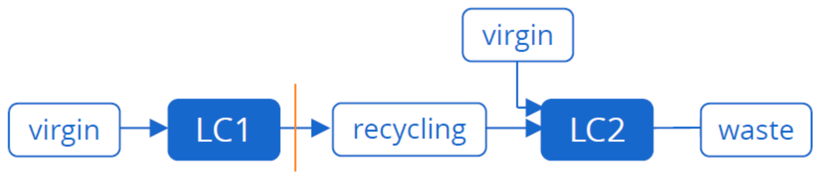

FIGURE 2: Cut-off approach is considered as end-of-life allocation.

The life cycle stages considered in the study presented in figure 3. Excluded life cycle stages are as follows:

1. Construction of building and machineries used in the production facility
2. Production and maintenance of machineries with more than five years estimated lifetime

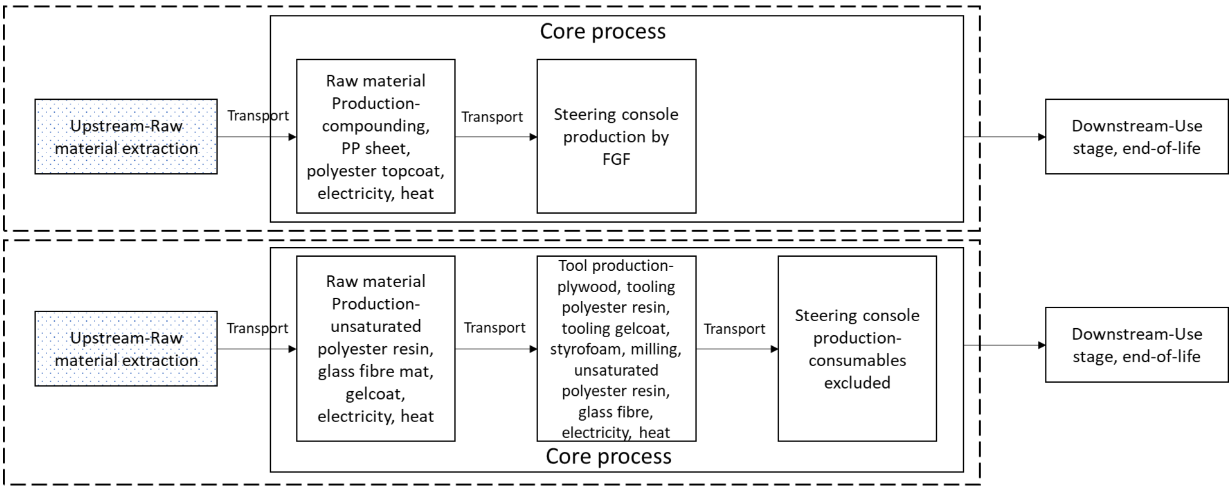

FIGURE 3: The life cycle stages considered in the study. The dotted boxes represent background data and the no-fill boxes represent foreground data

Ecoinvent datasets are used for background data, and foreground data is based on the measured data and expert estimates from the manufacturing sites. The foreground data has been collected from the partner involved in the project by visiting the boat company and through email communications. The environmental impact due to the production and use of energy (electricity) were based on data obtained from the company (GFRP) and Centria (WPC-3D printing). Data used is presented in APPENDIX 1.

All the background data is from the Ecoinvent database v.3.6, and the LCA is performed using Simapro 9.3. software. The LCIA methods used are ReCiPe 2016 Midpoint (H) V1.06 and ReCiPe 2016 Endpoint (H) available in Simapro.

3 ENVIRONMENTAL PERFORMANCE

The comparison of life cycle impact results calculated with the Recipe 2016 midpoint method for the steering console produced in two different manufacturing methods is seen in the image below. 3D printing with WPC shows lower impacts in 16 out of 18 categories (Figure 5).

The higher impact of 3D printing in the impact category of ionizing radiation is related to the electricity usage during 3D printing. The data used for modelling electricity for manufacturing by 3D printing is country mix data from the Ecoinvent database. Therefore, the results are affected by the share of electricity production sources.

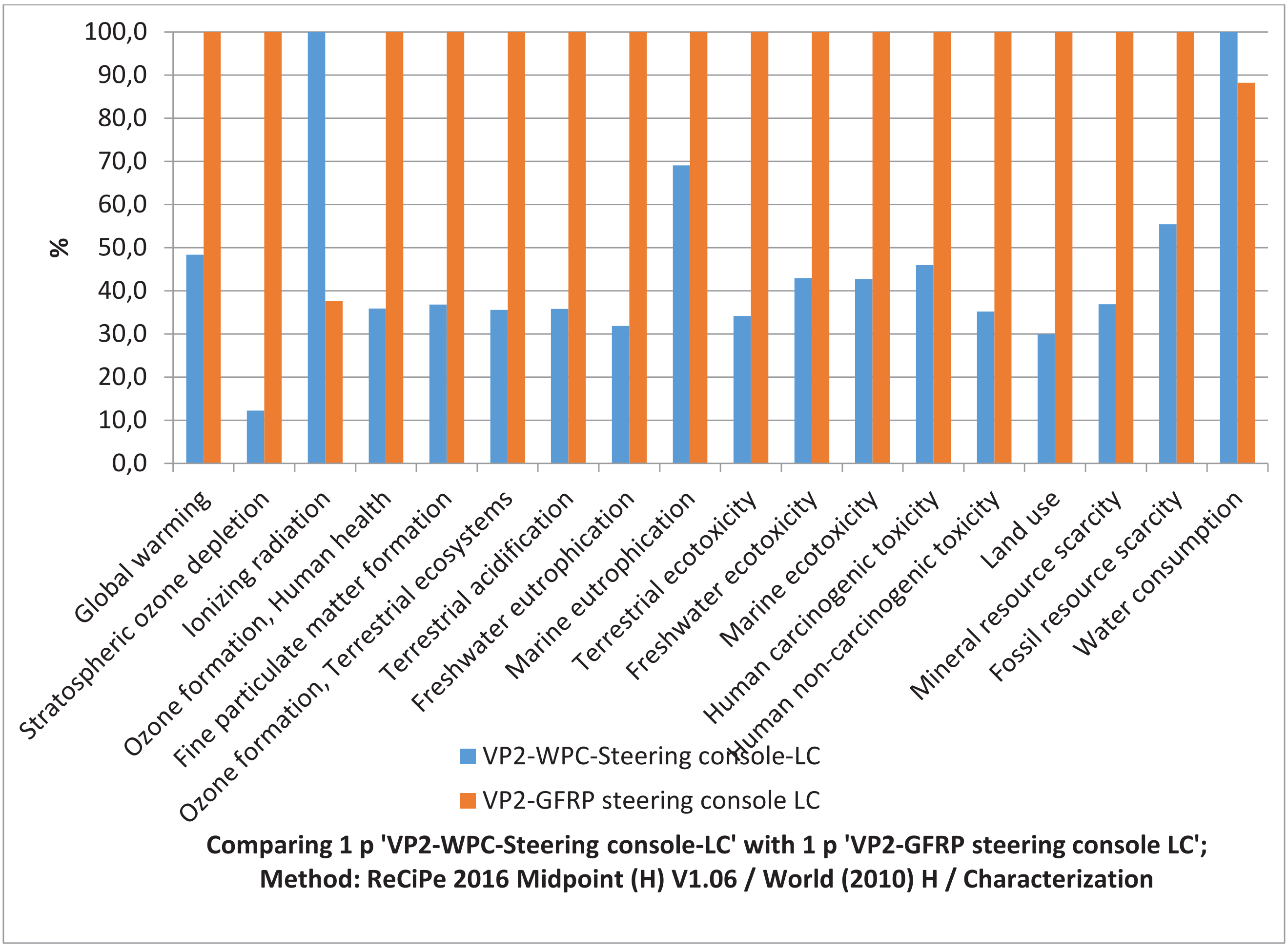

FIGURE 5: Impact categories of console 3D-printed using WPC and manufactured using conventional hand lay-up method and materials (GFRP); ReCiPe 2016 Midpoint (H) method.

According to Statistics Finland, in 2021 nuclear power accounted for 22,646 GWh out of total 69,324 GWh electricity produced (Figure 6). Nuclear power was the second largest source of electricity production in Finland. Ionizing radiation is an impact category included in most impact assessment methodologies to convey the potential impact due to radioactive emissions of materials, processes or products. Therefore, the higher impact in the ionizing category can be related to electricity consumption.

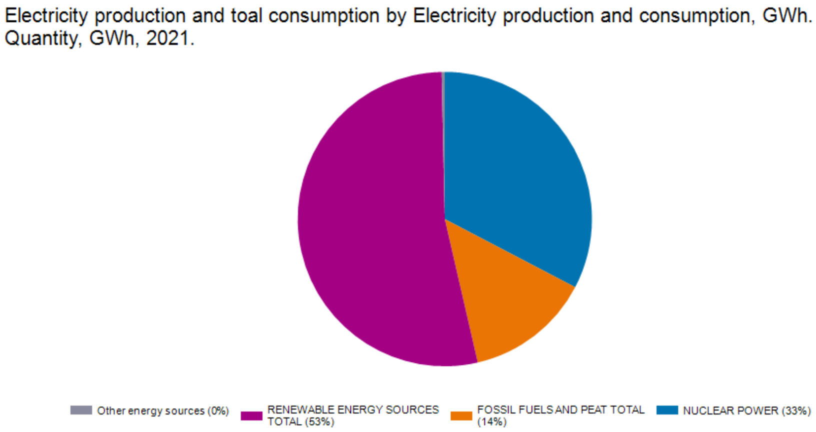

FIGURE 6: Sources for electricity production in Finland (Statistics Finland)

The higher impact in the water use category for 3D-printing can be attributed to higher amount of electricity needed and as sequence higher amount of water for cooling consumed. Nuclear power plants generate power in steam processes where most water is used for cooling.

In ReCiPe endpoint method, most of the midpoint impact categories are multiplied by damage factors and aggregated into three endpoint categories named (1) damage to human health, (2) damage to ecosystems (3) damage to resource availability.

The endpoint characterization factors used in ReCiPe can be described as follows:

(1) Human Health is expressed as the number of years life lost and the number of years lived disabled. These are combined as Disability Adjusted Life Years (DALYs), an index that the World Bank and WHO also use. The unit is years.

(2) Ecosystems are expressed as the loss of species over a certain area, during a certain time. The unit is years.

(3) Resource scarcity is the surplus costs of future resource production over an infinitive timeframe (assuming constant annual production), considering a 3% discount rate. The unit is USD2013. Note that fossil resource scarcity does not have constant mid-to-endpoint factor but individual factors for each substance.

The endpoint category results show low environmental impact for the steering console produced by the 3D-printing method in comparison to the conventional method (Figure 7). In terms of human health indicator, the low impact for 3D-printed steering console is due to low emissions compared to the conventional manufacturing method in which the workers are exposed to VOC emissions.

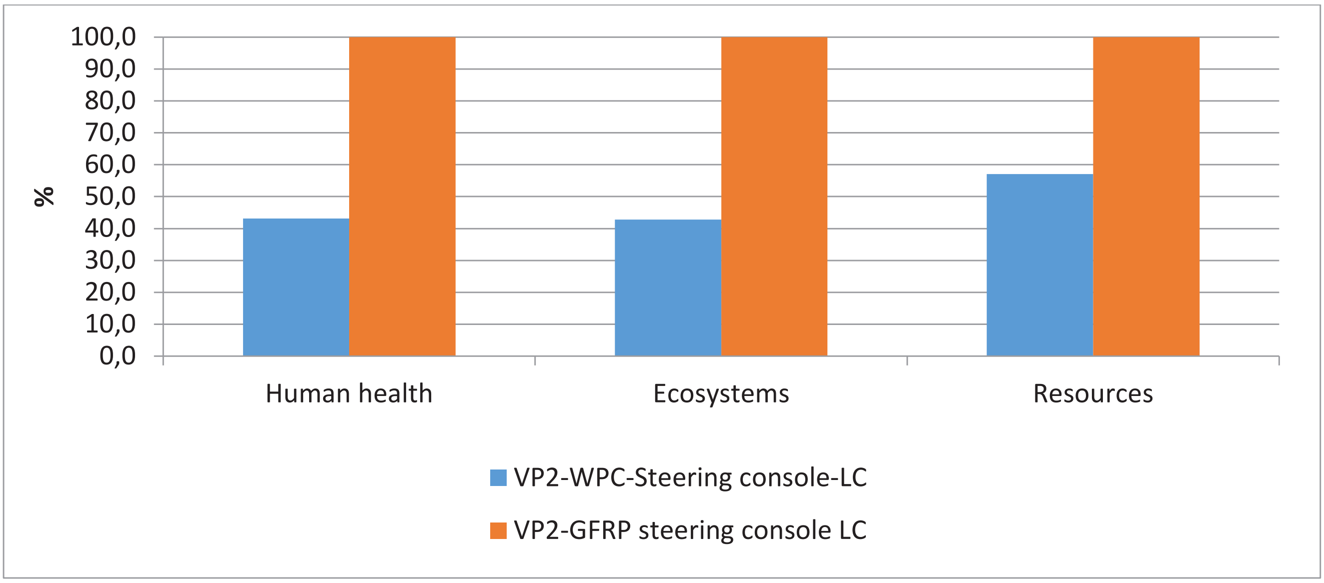

FIGURE 7: Comparing steering console made from 3D-printing and conventional method by ReCiPe 2016 endpoint (H) method

An overview of environmental impact results presented in terms of 3D printing method compared to conventional manufacturing method is in APPENDIX 2.

4 CONCLUSIONS

The main factors contributing to the environmental impact of robot-assisted fused granular fabricated steering console are the raw material, specifically polypropylene and the high electricity consumption during printing by the 3D printing extruder system and the robot. Compared to polypropylene, the orthopthalic acid-based resin used as matrix in GFRP composite show double the impact in all the midpoint impact indicators. As discussed above, the primary contributor to 3D printing in comparison to the hand lay-up method is electricity consumption. This result is affected because in Finland the nuclear power is the second largest source (33%), contributing to ionizing radiation, eutrophication and water use indicators.

Since the burden from recycling and benefits from avoided virgin raw materials are not accounted to the first life cycle, the recycling and usage of WPC in the second life cycle will have these shares. The environmental impact might have been even lower if the weight of the wood plastic composite could reach a similar weight as the GFRP composite-based steering console. This will reduce the impact of materials and printing time by generating savings from electricity. The effect of electricity during the 3D printing can be reduced using renewable sourced electricity. In addition, finding an alternative for similarly performing bio-based polymer to replace fossil-based polypropylene will reduce the environmental impact of the product considered for the study.

APPENDIX 1

Modelling of finished 3D printed steering console

Data used	Value	Unit
VP2-Compounding-Polypropylene-wood flour 50% composite	12.2	kg
VP2-Polypropylene - Sheet	0.675	kg
Orthophthalic acid based unsaturated polyester resin {RER}| production | Cut-off, U	1.1	Kg
Electricity, medium voltage {FI}| electricity voltage transformation from high to medium voltage | Cut-off, U	0.23	kWh
Electricity, medium voltage {FI}| electricity voltage transformation from high to medium voltage | Cut-off, U	32.52	kWh
Transport, freight, light commercial vehicle {Europe without Switzerland} | processing | Cut-off, U	0.675	tkm
Transport, freight, light commercial vehicle {Europe without Switzerland} | processing | Cut-off, U	0.224	tkm

Modelling of finished conventional steering console

Data used	Value	Unit
VP2-Glass fibre reinforced plastic, polyester resin, hand lay-up {RER}| production | Cut-off, U	7.7	kg
Orthophthalic acid based unsaturated polyester resin {RER}| production | Cut-off, U	1.1	kg
Acetone, liquid {RER}| market for acetone, liquid | Cut-off, U	3	Kg
Plug for GFRP mould	0.185	p
Mould for steering console	0.092	p
Transport, freight, sea, container ship {GLO}| transport, freight, sea, container ship | Cut-off, U	13.6	tkm
Transport, freight, sea, container ship {GLO}| transport, freight, sea, container ship | Cut-off, U	1.9	tkm
Transport, freight, lorry 16-32 metric ton, euro3 {RER}| market for transport, freight, lorry 16-32 metric ton, EURO3 | Cut-off, U	6.9	tkm

Modelling of 1 kg glass fibre reinforced plastic, polyester resin, hand lay-up

Data used	Value	Unit
Chemical, organic {GLO}| market for | Cut-off, U	0.025	kg
Glass fibre {GLO}| market for | Cut-off, U	0.35	kg
Orthophthalic acid based unsaturated polyester resin {RER}| production | Cut-off, U	0.65	kg
Emissions to air - Hydrocarbons, aromatic - high. pop.	6.25E-05	kg
Waste to treatment		
Waste mineral wool, for final disposal {CH}| market for waste mineral wool, for final disposal | Cut-off, U	0.00028	kg
Waste mineral wool, for final disposal {Europe without Switzerland}| market for waste mineral wool, for final disposal | Cut-off, U	0.052	kg

APPENDIX 2

An overview of environmental impact results presented in terms of 3D printing method compared to conventional manufacturing method. The midpoint indicator values are calculated using ReCiPe 2016 midpoint method and endpoint indicators are calculated by ReCiPe 2016 endpoint method