Blast and Fire Resistant Material

B A M

EXCELLENCE/0421/0137

DELIVERABLE D5.2

COST-BENEFIT ANALYSIS (CBA)

Co-funded by the European Union
Republic of Cyprus
RESEARCH & INNOVATION FOUNDATION

The project is implemented under the programme of social cohesion "THALIA 2021-2027" co-funded by the European Union, through Research and Innovation Foundation.

Project Information

Project Title	Blast and Fire Resistant Material
Project Acronym	BAM
Programme	EXCELLENCE HUBS
Grant Number	EXCELLENCE/0421/0137
Project Duration	01.04.2022 – 31.03.2024 (24 months) + 3 months extension

Document information

Deliverable Number	D 5.2
Deliverable Title	Cost-Benefit Analysis (CBA)
Version	1.0
Dissemination Level	Public
Work package	WP5
Authors	RECS
Contributing partners	FRC, UCY
Delivery Date	28.06.2024
Planned Delivery Month	M 24
Keywords	Cost, Benefit, Analysis, Life Cycle Assessment, Net Present Value, Benefit-Cost Ratio

Co-funded by the European Union

Republic of Cyprus

RESEARCH & INNOVATION FOUNDATION

The project is implemented under the programme of social cohesion "THALIA 2021-2027" co-funded by the European Union, through Research and Innovation Foundation.

Version History

No	Description	Author	Organization	Date
1	First draft	Konstantina Oikonomopoulou Marios Valanides	UCY RECS	19.03.2024
2	Second draft with the addition of Partners' contribution	Konstantina Oikonomopoulou Marios Valanides	UCY RECS	10.06.2024
3	Review of the document	Dr Demetris Nicolaides Dr Ourania Tsioulou Prof. Michael Petrou	FRC UBrighton UCY	20.06.2024
4	Final version with integration of the reviewers' feedback	Dr Demetris Nicolaides	FRC	28.06.2024

Co-funded by the European Union

Republic of Cyprus

RESEARCH & INNOVATION FOUNDATION

The project is implemented under the programme of social cohesion "THALIA 2021-2027" co-funded by the European Union, through Research and Innovation Foundation.

Table of Contents

Co-funded by the European Union

Republic of Cyprus

RESEARCH & INNOVATION FOUNDATION

The project is implemented under the programme of social cohesion "THALIA 2021-2027" co-funded by the European Union, through Research and Innovation Foundation.

List of Figures

List of Tables

Co-funded by the European Union
Republic of Cyprus
RESEARCH & INNOVATION FOUNDATION
The project is implemented under the programme of social cohesion "THALIA 2021-2027" co-funded by the European Union, through Research and Innovation Foundation.

List of Equations

Co-funded by the European Union
Republic of Cyprus
RESEARCH & INNOVATION FOUNDATION
The project is implemented under the programme of social cohesion "THALIA 2021-2027" co-funded by the European Union, through Research and Innovation Foundation.

1. Introduction

Deliverable 5.2 of Work Package 5 (D5.2 – "Cost-Benefit Analysis (CBA)") for the BAM project (EXCELLENCE/0421/0137) focuses on quantifying the overall net benefits derived from the BAM project. A Cost-Benefit Analysis (CBA) will identify and assess factors such as health and environmental benefits through a life cycle assessment analysis (LCA), alongside additional economic benefits assessed from a comprehensive analysis of the developed material. Costs were previously calculated and analyzed in Deliverable D5.1 – "Technoeconomic Analysis". Experimental results for the development of the Hybrid Laminated Material (HLM) were sourced from Deliverable D3.1 – "Designed and Developed Hybrid Laminated Material" and utilized in the LCA study.

This report provides an overview of CBA and LCA definitions, followed by a comprehensive analysis of the scope and methodology, functional unit, system boundaries, analysis time frame and data selection. It is worth mentioning that both the LCA and CBA must adhere to the same aforementioned parameters to ensure compatibility and integrate the external factors from the LCA into the CBA. Furthermore, this report will interpret the LCA findings, offering key environmental and health information regarding the industrial production of the HLM material. The CBA will assess the investment's viability, using key financial indicators such as the Net Present Value (NPV), Net Benefits (NB) and Benefit-Cost Ratio (CBR) to evaluate the financial performance of the project.

All consortium partners sincerely contributed to the successful completion of this deliverable by providing the required data and key information for the execution of the LCA and CBA. The information arise from the results will be valuable feedback considering further optimization in the product development, industrial transition and marker penetration.

Co-funded by the European Union
Republic of Cyprus
RESEARCH & INNOVATION FOUNDATION
The project is implemented under the programme of social cohesion "THALIA 2021-2027" co-funded by the European Union, through Research and Innovation Foundation.

2. BAM Project – Hybrid Laminated Material (HLM)

The BAM project focuses on developing a Hybrid Laminated Material (HLM) as illustrated in Figure 1. This innovative material combines fireproof and blast/impact resistance characteristics. HLM consists of two layers: a Fire-Resistance Geopolymer layer (FRG) and a Blast/Impact Resistance Ultra High-Performance Fiber Reinforced Concrete layer (UHPFRC).

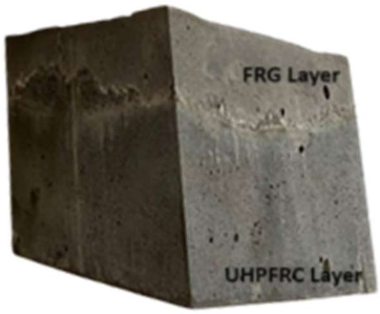

Figure 1: Hybrid Laminated Materials (HML) layers, on top the FRG Layer and at the bottom the UHPFRC Layer.

Given the high cost of already established fire or blast/impact products and their limitations such as the inability of some to provide fire protection due to spalling, there is a clear demand for an innovative solution that offers both properties simultaneously.

The primary aim of the project is to enhance the resilience of infrastructure against fire and blast impacts, thereby preventing structural collapses and their associated consequences. Successfully bringing this project to market would position Cyprus as a leader in infrastructure safety, create new jobs and providing cost-effective materials potentially up to 30% cheaper than current solutions. Environmentally, the HLM product will mitigate the severe local impacts of fire and blasts, while offering a greener alternative to Portland cement with significantly lower carbon emissions.

Further details regarding the development, validation and economic viability of HLM are analysed in the following chapters.

Co-funded by the European Union

Republic of Cyprus

RESEARCH & INNOVATION FOUNDATION

The project is implemented under the programme of social cohesion "THALIA 2021-2027" co-funded by the European Union, through Research and Innovation Foundation.

3. Cost-Benefit Analysis Overview

Cost-Benefit Analysis (CBA) is a methodology used to estimate, calculate and evaluate the positives (benefits) and negatives (costs) aspects of a project or investment to determine its viability. In simpler terms, it involves comparing the monetary value of costs and benefits to assess whether the advantages of a project outweigh its expenses.

The objectives of conducting a CBA include:

1. Assessing the Cost-Benefit Factors of the BAM product: This involves using a predetermined framework to identify and assign monetary values to costs and benefits, ultimately calculating the Net Present Value (NPV) (Equation 1), Net Benefit (NB) and Benefit-Cost Ratio (BCR) (Equation 2) of the investment. NPV is defined as the disparity between the present value of inflows and outflows over the entire investment period. Net Benefit is defined as the difference between the total NPV of benefits and Costs. A positive NB indicates that the project is economically viable and generates more value than its costs. BCR is calculated by dividing the NPV of benefits by NPV of costs. A BCR lower than 1 indicates a negative outcome, while a BCR higher than 1 signifies a positive outcome and the project viability.

$$NPV = \sum_{n=1}^{N} \frac{C_n}{(1+r)^n}$$

$$Where\ N = Total\ number\ of\ time\ periods, n = Time\ Period,$$

$$C_n = Net\ cash\ flow\ of\ time\ period\ and\ r = Discount\ rate$$

Equation 1: Net Present Value (NPV)

$$Net\ Benefit\ (NB) = \sum Present\ Value\ of\ Benefits - \sum Present\ Value\ of\ Costs$$

Equation 2: Net Benefit (NB)

$$Benefit - Cost\ Ratio\ (BCR) = \frac{\sum Present\ Value\ of\ Benefits}{\sum Present\ Value\ of\ Costs}$$

Equation 3:Benefit-Cost Ratio (BCR)

2. Comparison with alternative materials: Both the LCA and CBA aim to compare the overall performance (economic, environmental and health factors) of the innovative BAM product with equivalent materials used in scenarios requiring fire protection and blast/impact resistance. The comparison will focus on materials with equivalent fireproof performance

(1.5 hours of fire resistance) and blast/impact properties (ability to withstand 3.5 kg of TNT explosive). It is crucial that both properties are equivalent to ensure a valid comparison.

3. Recommendations for further improvement and optimization: As the product is in initial stages of development with a Technology Readiness Level (TRL) 4, there is a possibility that unforeseen costs may arise during the transition from laboratory to industrial production. Therefore, recommendations for further enhancement, improvement and optimization of the HLM product and the manufacturing process should be considered to incorporate them in a future higher TRL research project.

Co-funded by the European Union

Republic of Cyprus

RESEARCH & INNOVATION FOUNDATION

The project is implemented under the programme of social cohesion "THALIA 2021-2027" co-funded by the European Union, through Research and Innovation Foundation.

4. Life Cycle Assessment (LCA) Overview

Life Cycle assessment (LCA) is a methodology utilized for the evaluation of environmental impacts of products throughout their entire life cycle. Conducting an LCA helps to prioritize the enhancement of more eco-friendly products at various stages, including production, use, disposal and recycling. The LCA process adheres to ISO 14040, which outlines the principles and frameworks of LCA and ISO 14044, which defines the requirements and guidelines, both set by the International Organization for Standardization (ISO). Furthermore, the International Reference Life Cycle Data System (ILCD) handbook1 by the European Commission Joint Research Centre (JRC) provides further technical guidance in alignment with ISO standards.

The LCA framework is divided in four interlinked steps, where decisions at each stage impact the final results:

i. **Goal and Scope:** This step outlines the processes and environmental factors to assess, the economic and social benefits, technical challenges and the target audience for the LCA study.

ii. **Life Cycle Inventory (LCI):** This phase involves systematically compiling and quantifying inputs (such as materials, energy, chemicals and resources) and outputs (including emissions, solid waste) throughout the entire life cycle of the product system. It includes modeling, data collection and verification.

iii. **Life Cycle Impact Assessment (LCIA):** Inventory data are converted into impact indicators to assess the environmental impacts of the defined system. This step involves classifying (categorization inventory parameters and allocating them to impact categories) and characterizing (multiplying inventory parameters by equivalent factors) the burdens. The study may also include normalization and weighting to compare and prioritize different impacts, such as Climate Change, Ozone Depletion, Acidification, Eutrophication etc.

iv. **Interpretation:** This step ensures that the inventory analysis and impact assessment align with the initial "Goals and Scope". Conclusions and recommendations are made based on all prior LCA stages. According to ISO 14043 guidelines, this interpretation step identifies major environmental impact issues and evaluates the study's completeness, sensitivity and consistency. The LCA process is iterative, allowing for reevaluation and adjustments at each stage to ensure accuracy and comprehensiveness.

For the LCA study of the HLM product and the comparison with alternative model materials, the LCA software SimaPro5 (version 9.4.0.2), a registered trademark of PRé Sustainability B.V was utilized. SimaPro5 supports data collection, analysis and monitoring for sustainability performance across various applications including environmental impact measurement and hotspot identification throughout the product life cycle.

The project is implemented under the programme of social cohesion "THALIA 2021-2027" co-funded by the European Union, through Research and Innovation Foundation.

5. LCA Scope and Methodology

5.1 Goal and Scope definition

The goal of this LCA study for the HLM product is to evaluate the environmental impacts of the innovative fireproof and blast/impact material, covering aspects related to raw materials, development and manufacturing. The scope of this study adopts a cradle-to-gate approach (Figure 2), focusing on the impacts from the acquisition of raw materials to the point where the product leaves the production facility. In a future research project with higher TLR level, once more information on the end-of-life possibilities of the novel material becomes available, a cradle-to-grave approach will be considered.

An equivalent alternative model will be analyzed to provide comparative information on sustainability and environmental impacts between the HLM product and other similar materials. Throughout the study a standardized approach with consistent methodologies will be employed to ensure uniformity in system boundaries, functional unit, data accuracy and impact assessment indicators. This consistency will make the comparisons meaningful and support informed, sustainable decision-making.

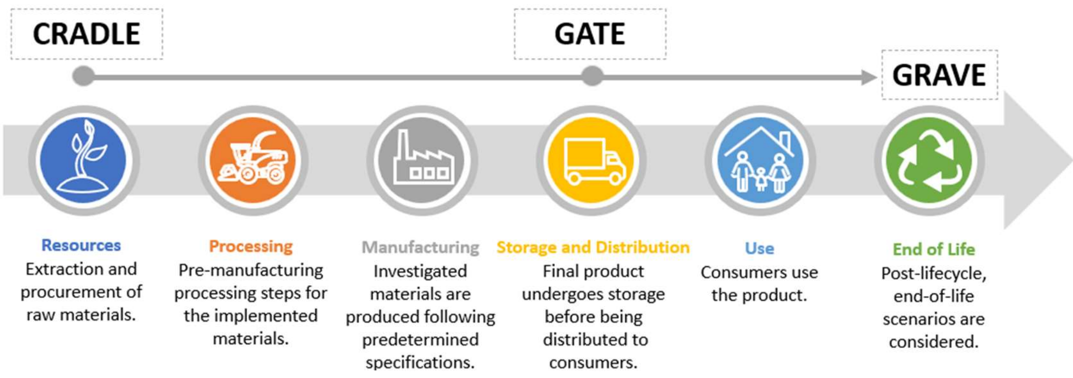

Figure 2: Cradle-to-Gate and Cradle-to-Grave approach for the LCA

5.1.1 Functional Unit

The focus of an LCA is defined by its function, functional unit, and/or reference flow. The primary function of the innovative material is to enhance safety during fire, blast and/or impact incidents. For this study, the functional unit was determined based on mass, a standard metric commonly utilized in the construction industry for reporting reserves and production data. This mass-based approach ensures clarity, enables straightforward comparison of LCA results and facilitates scaling across various production scales or time periods.

Regarding this LCA study, the functional unit is defined as the mass (in kg) of the HLM product required to produce predetermined amounts of boards (specifically the square meters produced each year), over a five-year period as examined in the technoeconomic analysis (Deliverable D5.1). Factors such as the thickness of each layer required to provide specific, predefined fire resistance time and blast/impact performance were also considered. This functional unit serves as a benchmark for comparing the environmental performance of the HLM product with equivalent products used in similar scenarios.

5.1.2 System Boundaries

In the cradle-to-gate approach, the system boundaries encompass the raw material acquisition, transportation, mixing, cutting and curing required for the development of the HLM product. This LCA study includes the A1-3 (Figure 3), Product Stage life cycle stages as described by CYS EN 15804:2012+ A1:2013[1]:

a) Life Cycle Stage A1 refers to Raw Material Supply that incorporates all the raw materials necessary for the manufacturing stage of both the fireproof and blast/impact resistance HLM product.
b) Life Cycle Stage A2 covers the Transportation of Raw Materials to the Manufacturing Plant and incorporates all impacts associated with transporting raw materials (by boat, truck or train) from their sources to HLM production unit. Freight transport amounts were calculated as accurately as possible, considering the location of the manufacturing plant in Nicosia, Cyprus.
c) Life Cycle Stage A3 reflects the Product Manufacturing. This stage includes all processes related to the production of the blast/impact resistance and fireproof composite, accounting for energy consumption, water usage and any emissions from the mixing, curing and cutting of the product.

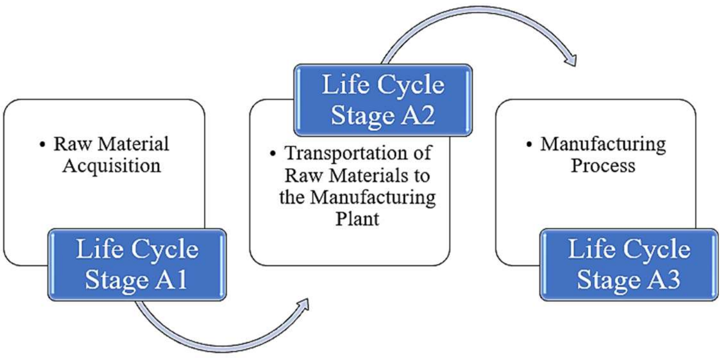

Figure 3: System Boundaries of the LCA.

[1] CYS EN 15804:2012+A1:2013/FprA2 - Sustainability of construction works – Environmental product declarations – Core rules for the product category of construction products.

Co-funded by the European Union
Republic of Cyprus
RESEARCH & INNOVATION FOUNDATION

The project is implemented under the programme of social cohesion "THALIA 2021-2027" co-funded by the European Union, through Research and Innovation Foundation.

5.1.3 Analysis Time Frame

The analysis time frame, according with ISO 14040:2006 and ISO 14044:2006, should be consistent with goal and scope of the LCA study, defining the period over which the environmental impacts of a product, process or service are assessed. Regarding this LCA study, the analysis time frame encompasses the initial five years of HLM production. It includes the calculation of environmental impacts for each year from raw material acquisition to the manufacturing process in line with the cradle-to-gate approach.

5.1.4 Interpretation and Limitations

The LCA study will carefully document data sources, assumptions and calculations to ensure transparency and reproducibility. Results will be critically interpreted, acknowledging and discussing limitations to provide a comprehensive understanding of the study's scope and reliability.

5.2 LIFE CYCLE INVENTORY (LCI)

Life Cycle Inventory (LCI) section incorporates all data flows for the A1-A3 life cycle stages in line with the goal and scope of the study and defined functional unit. The gathered data were imported to Simapro5 software through the LCI database Ecoinvent[2] (mainly for background data). LCI results were calculated of their environmental impact utilizing the LCIA method EPD (2018) V1.04 method, as required by the Declaration of Work (DoW).

5.2.1 Data Collection

As defined in section 5.1.5, the functional unit of the LCA study is the mass (in kg) of HLM product require to produce predetermined amounts of boards specifically the square meters produced each year over the five-year period in the technoeconomic study (Deliverable D5.1). The data used for the HLM product LCA study are detailed and presented in this section.

Table 1 presents the square meters of HLM produced each financial year and the corresponding number of boards. Each board (1 board) has dimensions of 0.5 m x 0.5 m corresponding to an area of 0.25 m^2. The thickness of each layer is as follows: 0.04 m for UHPFRC layer (with a volume of 0.01 m^3) and 0.02 m for the FRG Layer (with a volume of 0.005 m^3), as determined from the experimental and numerical validation of the materials in Work Packages 3 and 4.

[2] Ecoinvent Database: https://ecoinvent.org/the-ecoinvent-database/. Accessed 21/09/2023.

Table 1: Square Meters of HLM mixture and the corresponding number of boards produced.

Financial Year	FY1	FY2	FY3	FY4	FY5
m^2/year	5280	5703	6159	6651	7184
Number of boards/year	21120 boards	22810 boards	24634 boards	26605 boards	28734 boards

For Raw Material Acquisition (Life Cycle Stage A1), calculations were based on the final mixture designs provided in Work Package 3 and Deliverable D3.1-"Design and Development of Hybrid Laminated Material". Quantities (in kg) for producing 1 board were calculated and then as presented in Table 2, the quantities of each material needed were determined based on the number of boards produced each year.

Table 2: Materials (kg/year) required for the annual production of the UHPFRC and FRG Layer.

UHPFRC Layer						
		FY1	FY2	FY3	FY4	FY5
	1 board	21120 boards	22810 boards	24634 boards	26605 boards	28734 boards
Cement (kg/year)	8.80	185856.0	200728.0	216779.2	234124.0	252859.2
Microsilica (kg/year)	2.20	46464.0	50182.0	54194.8	58531.0	63214.8
Reference Sand (kg/year)	8.33	175929.6	190007.3	205201.2	221619.7	239354.2
Water (kg/year)	1.72	36326.4	39233.2	42370.5	45760.6	49422.5
Superplasticizer (kg/year)	0.67	14150.4	15282.7	16504.8	17825.4	19251.8
Steel Fibres 6 mm (kg/year)	0.80	16896.0	18248.0	19707.2	21284.0	22987.2
Steel Fibers 13 mm (kg/year)	0.80	16896.0	18248.0	19707.2	21284.0	22987.2
PVA Fibres (kg/year)	0.13	2745.6	2965.3	3202.4	3458.7	3735.4
FRG Layer						
		FY1	FY2	FY3	FY4	FY5
	1 board	21120 boards	22810 boards	24634 boards	26605 boards	28734 boards
Fly Ash (kg/year)	14.40	304128.0	328464.0	354729.6	383112.0	413769.6
GGBS (kg/year)	1.60	33792.0	36496.0	39414.4	42568.0	45974.4
NaOH Pellets (kg/year)	0.81	17160.0	18533.1	20015.1	21616.6	23346.4
Water (kg/year)	3.20	67584.0	72992.0	78828.8	85136.0	91948.8
Water Glass (kg/year)	1.76	37171.2	40145.6	43355.8	46824.8	50571.8

The project is implemented under the programme of social cohesion "THALIA 2021-2027" co-funded by the European Union, through Research and Innovation Foundation.

Life Cycle Stage A2- Transportation of Raw Materials to the Manufacturing Plant was measured in ton-kilometres (tkm), considering the location of each material supplier. For materials supplied from countries outside Cyprus, transportation of the supplies was considered in two stages: by boat from the supplier's country to the Limassol Port followed by truck transport to the production facility. For materials supply within Cyprus, transportation was calculated using trucks from the supplier's factory to the manufacturing plant.

Since material supply is required throughout the year, transportation was based on the amounts (in kg) of each material and the distance from the supplier. Multiple routes for supplying the necessary raw materials were considered Table 3 presents the origin of each material supplier and the ton-kilometres for each material per year.

Table 3: Transportation of raw materials to the production facility.

UHPFRC	**Distance (km)**	**Country**	**FY1 (tkm/year)**	**FY2 (tkm/year)**	**FY3 (tkm/year)**	**FY4 (tkm/year)**	**FY5 (tkm/year)**
Cement	85	Cyprus	3159.552	3412.376	3685.246	3980.108	4298.606
Microsilica	957	Egypt	8893.21	9604.835	10372.88	11202.83	12099.31
Reference Sand	65	Cyprus	1143.542	1235.047	1333.808	1440.528	1555.802
Water	0	Cyprus	0	0	0	0	0
Superplasticizer	20	Cyprus	56.6016	61.1308	66.01912	71.3014	77.00712
Steel Fibres 6 mm	2048	Slovenia	17301.5	18685.95	20180.17	21794.82	23538.89
Steel Fibres 13 mm	2048	Slovenia	17301.5	18685.95	20180.17	21794.82	23538.89
PVA	2120	Central Europe	5820.672	6286.436	6789.13	7332.338	7919.09
FRG	Distance (km)	Country	FY1 (tkm/year)	FY2 (tkm/year)	FY3 (tkm/year)	FY4 (tkm/year)	FY5 (tkm/year)
Fly Ash	957	Egypt	14552.52	15717	16973.81	18331.91	19798.88
GGBS	957	Egypt	6467.789	6985.334	7543.916	8147.515	8799.5
NaOH Pellets	2120	Central Europe	18189.6	19645.11	21216.03	22913.56	24747.16
Water	0	Cyprus	0	0	0	0	0
Water Glass	1060	Greece	19700.74	21277.17	22978.6	24817.14	26803.08
Total tkm/year			112587.2	121596.3	131319.8	141826.9	153176.2

The manufacturing processes for the HLM product (Life Cycle Stage A3) include mixing the UHPFRC and FRG Layer, curing the UHPFRC boards and cutting the FRG blocks.

Two industrial mixers (capacity 2 m^3/batch) each connected to an electric motor with energy consumption of 30 kWh (2.5 kWh/batch) was used for the mixing process. Given the volume of 1

The project is implemented under the programme of social cohesion "THALIA 2021-2027" co-funded by the European Union, through Research and Innovation Foundation.

UHPFRC board (0.01 m^3) and the number of boards that can be produced per session (with one month having 8 sessions) we calculated the number of batches required to produce the necessary cubic meters of mixture (Table 4).

It is important to note that the incorporation of steel fibers in the high-performance concrete mixture significantly limits the possibility of casting a UHPFRC block and then cutting it into 0.5 m x 0.5 m x 0.04 m boards. Therefore, multiple molds, each holding one UHPFRC block are utilized in the mixing process. Considering the number of batches, the duration of each mixing batch (12 minutes) and the energy consumption of the mixer (2.5 kWh), the amount of kWh per session was calculated. The cumulative yearly energy consumption for the UHPFRC Layer was measured at 144 kWh. On the other hand, the production of the FRG Layer, involves forming 0.5 m x 0.5 m x 1.5 m blocks, which are subsequently cut into the required size. Following a similar calculation methodology as for the UHPFRC Layer, the yearly energy consumption for the FRG Layer was calculated at 20 kWh. The energy consumption for the mixing process of both layers over the 5-year period was valued at **164.00 kWh**.

Table 4: Energy consumption for the mixing process of UHPFRC and FRG Layer.

m^2/year	5280	5703	6159	6651	7184
Boards/year	21120	22810	24634	26605	28734
UHPFRC	**FY1**	**FY2**	**FY3**	**FY4**	**FY5**
m^3/board	0.01	0.01	0.01	0.01	0.01
Boards/session	220	238	257	277	299
m^3/session	2.20	2.38	2.57	2.77	2.99
Number of batches/sessions	3	3	3	3	3
Mixing Time (min)	12	12	12	12	12
kWh/session	1.5	1.5	1.5	1.5	1.5
kWh/year	144	144	144	144	144
FRG	**FY1**	**FY2**	**FY3**	**FY4**	**FY5**
m^3/board	0.005	0.005	0.005	0.005	0.005
m^3/session	1.10	1.19	1.28	1.39	1.50
Number of batches/sessions	1	1	1	1	1
Mixing Time (min)	5	5	5	5	5
kWh/session	0.21	0.21	0.21	0.21	0.21
kWh/year	20.00	20.00	20.00	20.00	20.00
Total kWh/year	**164.00**	**164.00**	**164.00**	**164.00**	**164.00**

Co-funded by the European Union
Republic of Cyprus
RESEARCH & INNOVATION FOUNDATION

The project is implemented under the programme of social cohesion "THALIA 2021-2027" co-funded by the European Union, through Research and Innovation Foundation.

Following the mixing, the UHPFRC boards and FRG blocks undergo an initial curing of 24 h to develop the initial strength. The demoulding phase involves carefully removing the specimens from their molds. FRG blocks undergo curing for 6 days in ambient conditions to obtain their mechanical characteristics. However, the curing process is crucial for the blast/impact performance of the UHPFRC boards. This process requires the boards to be water cured in an accelerated curing tank for 14 days. From day 1 to day 3, the temperature gradually increases from 20 °C to 90 °C , maintained the temperature of 90 °C until day 11 and afterwards the curing tank is allowed to cool back 20 °C. Custom-made water curing tanks with dimensions of 9.0 m x 0.8 m x 0.8 m will be constructed and considering the energy required for heating the water during the curing period, the energy consumption is calculated at 406 kWh per tank. Each mixing session requires two curing tanks to accommodate all produced boards. Therefore, the annual energy consumption for the curing process of the UHPFRC boards at **77952 kWh**.

Table 5: Energy Consumption for the curing process of the UHPFRC boards.

UHPFRC	**FY1**	**FY2**	**FY3**	**FY4**	**FY5**
kWh/tank	406	406	406	406	406
kWh/session	812	812	812	812	812
kWh/month	6496	6496	6496	6496	6496
kWh/year	**77952**	**77952**	**77952**	**77952**	**77952**

Following ambient curing, the FRG blocks (with a volume of 0.375 m^3) need to be precisely cut into 0.5 m x 0.5 x 0.02 m boards. An industrial cutting machine with a total energy consumption of 11 kW will be utilized for cutting the blocks. Each block can produce 75 FRG boards and the cutting machine requires 2 hours to process each block. For each year of production, the numbers of blocks per batch were calculated based on block volume (0.375 m^3) and the m^3 of each produced batch. Considering the energy consumption of the cutting machine, the duration of the cutting process, the number of blocks per batch and the number of produced boards per block, we calculated the annual energy consumption as demonstrated in Table 6. `

Table 6: Energy Consumption for the cutting process of FRG blocks.

FRG	**FY1**	**FY2**	**FY3**	**FY4**	**FY5**
Boards/year	21120	22810	24634	26605	28734
m^3/block	0.375	0.375	0.375	0.375	0.375
m^3/batch	1.10	1.19	1.28	1.39	1.50
Block/batch	3	4	4	4	4
kWh/block	22	22	22	22	22
kWh/batch	66	88	88	88	88
kWh/panel	0.293	0.293	0.293	0.293	0.293
kWh/year	**6195.2**	**6690.9**	**7226.0**	**7804.1**	**8428.6**

Co-funded by the European Union

Republic of Cyprus

RESEARCH & INNOVATION FOUNDATION

The project is implemented under the programme of social cohesion "THALIA 2021-2027" co-funded by the European Union, through Research and Innovation Foundation.

During the LCI analysis, certain gaps or uncertainties in the data were addressed by making assumptions that are clearly documented and explained in Table 7.

Table 7: Uncertainties and assumption of this LCA study.

Functional Unit	The mass (in kg) of HLM product required to produce specific number of boards as defined in the technoeconomic analysis (Deliverable 5.1).
Limitation on Data	Raw materials such as the fly ash, retarder, steel fibres and PVA fibres were not defined in the Ecoinvent Library. Literature data from published LCA articles were used to build those models[3,4,5,6]
Curing of HLM boards	Custom made accelerated water curing tanks and not already commercially available tanks were assumed for the curing process of the UHPFRC boards.
Alternative Market Model	A hybrid model of gypsum fiberboard and reinforced conrete is designed to match the fire proofing and blast/impact properties of the HLM material.
Modification of Properties (Alternative Market Model)	To ensure a fair comparison based on the fire resistance of the HLM product, the dimensions of the Alternative Market Model were modified. The dimensions and density of gypsum fiberboard were taken from a datasheet of commercially available material[7]. Furthermore, reinforced concrete dimensions were modified to withstand 3.5 kg of TNT explosives.

As previously mentioned, each raw material and process requires to match its relevant data in the Ecoinvent library dataset for the LCI analysis. However, certain materials such as steel fibres and PVA fibres were not included in the database. In these cases, literature data were utilized from previously investigated research detailing raw materials, energy and/or transportation

[3] LCA Allocation procedure used as an initiative method for waste recycling: An application to mineral addition in concrete, C. Chen, G. Habert, Y. Bouzidi, A. Jullien, A. Ventura, Resources, Conservation and Recycling.
[4] Life cycle assessment of concrete made with high volume of recycled concrete aggregates and fly ash, Rawaz Kurda José D. Silvestre, Jorge de Brito, , Resources, Conservation and Recycling
[5] Compared environmental and economic impact from cradle to gate of concrete with natural and recycled coarse aggregates, Ana Margarida Braga, José Dinis Silvestre. Jorge de Brito, Journal of Cleaner Production
[6] Multicriteria performance evaluation of fiber-reinforced cement composites: An environmental perspective, Arslan Akbar, K.M. Liew, Composites Part B: Engineering
[7] Knauf Type X Fire Rated Gypsum Wall Board (GW-TX) Datasheet. Knauf 2019.

required for the production of 1 kg of the needed material. The selected datasets for each material and/or process are described in Table 8.

Table 8: Ecoinvent Library Dataset for the LCA study.

Constituent/Process included in HLM Product Manufacturing	Ecoinvent Library dataset used in HLM LCA study assembly
Cement	Cement Portland {Europe without Switzerland}, | market for | Cut-off, U
Micro Silica	Silica Fume, densified {GLO}, | market for | Cut-off, U
Reference Sand	Silica Sand {GLO}, | market for | Cut-off, U
Superplasticizer	Polycarboxylates, 40% active substance {RER}, | market for | Cut-off, U
Sodium Silicate	Sodium Silicate solid {RER}, sodium silicate production| market for | Cut-off, U
NaOH pellets	Sodium Oxide {RER}, sodium oxide production| market for | Cut-off, U
GGBS	Ground granulated blast furnace slag {RoW}| market for | Cut-off, U
PVA Fibers	Vinyl acetate {RER}| market for | Cut-off, U, Polyvinylchloride emission polymerized {RER}| market for | Cut-off, U, Methanol {GLO}| market for | Cut-off, U, Sodium Hydroxide without water in 50% solution state {RER}| market for | Cut-off, U, Tap Water {Europe without Switzerland}| market for | Cut-off, U, Lubricating Oil {RER}| market for | Cut-off, U, Heat district or industrial natural gas {Europe without Switzerland}| market for | Cut-off, U, Electricity medium voltage {Europe without Switzerland}| market for | Cut-off, U
Steel Fibers	Iron ore concentrate {GLO}| market for | Cut-off, U, Manganese {GLO}| market for | Cut-off, U, Sulfur {GLO}| market for | Cut-off, U, Phosphorus white liquid {GLO}| market for | Cut-off, U, Limestone crushed for mill {RoW}| market for | Cut-off, U, Electricity high voltage {Europe without Switzerland}| market for | Cut-off, U, Heat district or industrial other than natural gas {RoW}| market for | Cut-off, U

The project is implemented under the programme of social cohesion "THALIA 2021-2027" co-funded by the European Union, through Research and Innovation Foundation.

Fly Ash	Water deionized {Europe without Switzerland}| market for | Cut-off, U, Hard coal {Europe without Russia and Turkey}| market for | Cut-off, U, Electricity high voltage {RER}| market for | Cut-off, U, Heat district or industrial natural gas {Europe without Switzerland}| market for | Cut-off, U, Heat district or industrial other than natural gas {Europe without Switzerland}| market for | Cut-off, U, Transportation freight train {Europe without Switzerland}| market for | Cut-off, U, Transport freight lorry 7.5-16 metric ton EURO6 {RoW}| market for | Cut-off, U
Deionized Water	Water, deionized {Europe without Switzerland} | water production, deionized | Cut-off, U
Electricity for all processes	Electricity, low voltage {CY} | market for | Cut-off, U
Transport of raw materials (ship)	Transport, freight, sea, container ship {GLO}| market for transport, freight, sea, container ship | Cut-off, U
Transport of raw materials (road)	Transport, freight, lorry > 32 metric ton, EURO6 {RER}| market for | Cut-off, U

5.2 Life Cycle Impact Assessment (LCIA)

In the LCIA phase, all imported data for the HLM model are converted to equivalent environmental impact factors for each impact category using the selected impact assessment method. EPD 2018 was utilized, which is primarily focused on the European context and involves characterizing the environmental impacts of the innovative fireproof and blast/impact HLM product. The EPD 2018 method includes the following impact categories: Acidification potential, Eutrophication potential, Global warming potential, Photochemical oxidant creation potential, Abiotic depletion potential – elements, Abiotic depletion potential – fossil fuels, Water Scarcity Footprint (WSF), and Ozone depleting potential (Table 9). Further information about the EPD method is presented in Annex A.

Co-funded by the European Union
Republic of Cyprus
RESEARCH & INNOVATION FOUNDATION
The project is implemented under the programme of social cohesion "THALIA 2021-2027" co-funded by the European Union, through Research and Innovation Foundation.

Table 9: Impact indicators and unit description of the EPD impact method.

Impact category	Unit	Unit Description
Acidification (fate not incl.)	kg SO_2 eq	Kilograms of sulfur dioxide-equivalents
Eutrophication	kg PO_4 eq	Kilograms of phosphate-equivalents
Global warming (GWP100a)	kg CO_2 eq	Kilograms of carbon dioxide-equivalents
Photochemical oxidation	kg NMVOC	Kilograms of non-methane volatile organic compound-equivalents
Abiotic depletion, elements	kg Sb eq	Kilograms of antimony-equivalents
Abiotic depletion, fossil fuels	MJ	Megajoules
Water scarcity	m^3 eq	Cubic meters of consumed water-equivalents
Ozone layer depletion (ODP) (optional)	kg CFC-11 eq	Kilograms of trichlorofluoromethane-equivalents

5.3.1 HLM product - LCIA Results

This section analyzes the results from a comprehensive cradle-to-gate analysis for producing a predetermined number of HLM boards over a 5-year production period as detailed in Table 1. Figures 4-6 illustrate the flowchart for the 1st year of manufacturing the novel HLM material, presenting the quantities for each constituent and the energy/tkm per process. Red lines indicate a negative environmental impact with the thickness of the line representing the magnitude of the impact - the thicker the line, the greater the impact.

From the flowchart, it is evident that the inclusion of cement has the highest environmental impact among all raw materials and processes. Additionally, materials utilized in the production of FRG Layer such as the fly ash, sodium silicate and NaOH pellets, significantly contribute to the overall environmental impact of the end-product. It is also worth mentioning that the electricity required for the manufacturing processes (mainly the curing of the UHPFRC) is substantial. Therefore, investing in photovoltaics as part of the initial setup of the manufacturing plant was crucial for reducing the environmental impact.

Co-funded by the European Union
Republic of Cyprus
RESEARCH & INNOVATION FOUNDATION
The project is implemented under the programme of social cohesion "THALIA 2021-2027" co-funded by the European Union, through Research and Innovation Foundation.

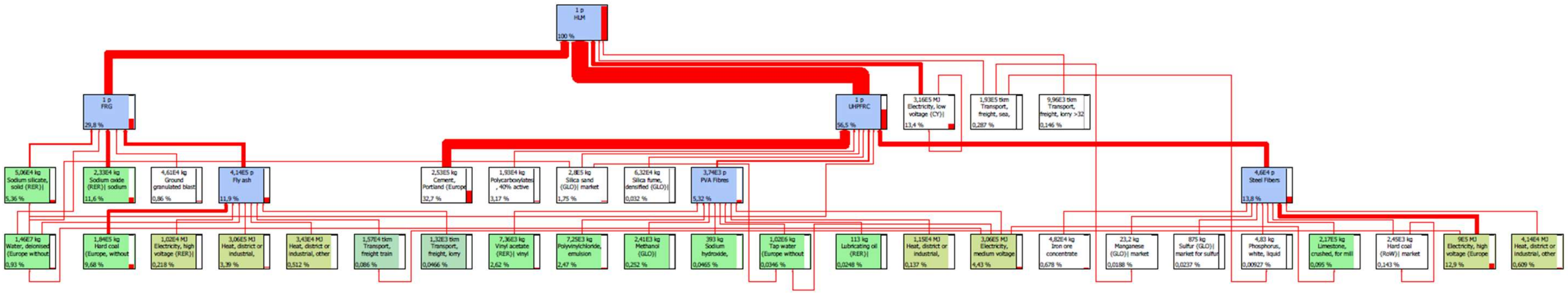

Figure 4: HLM flowchart (EPD Impact Method)

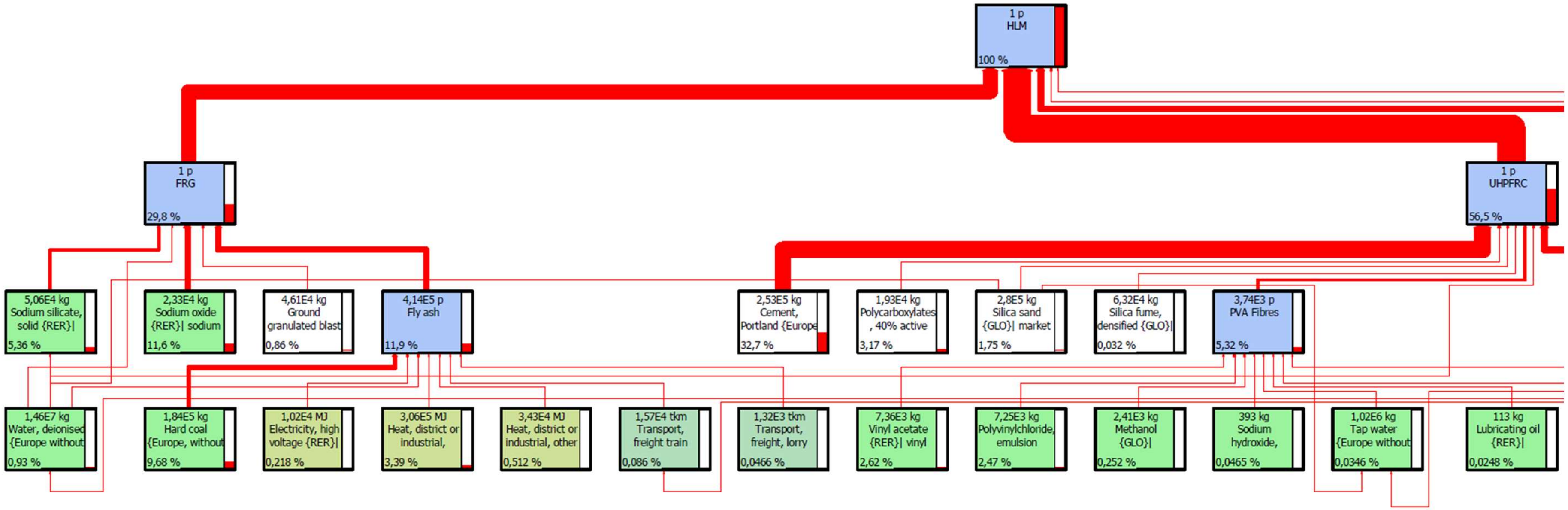

Figure 5: HLM flowchart (EPD Impact Method) – Section 1

The project is implemented under the programme of social cohesion "THALIA 2021-2027"
co-funded by the European Union, through Research and Innovation Foundation.

Co-funded by the European Union
Republic of Cyprus
RESEARCH & INNOVATION FOUNDATION

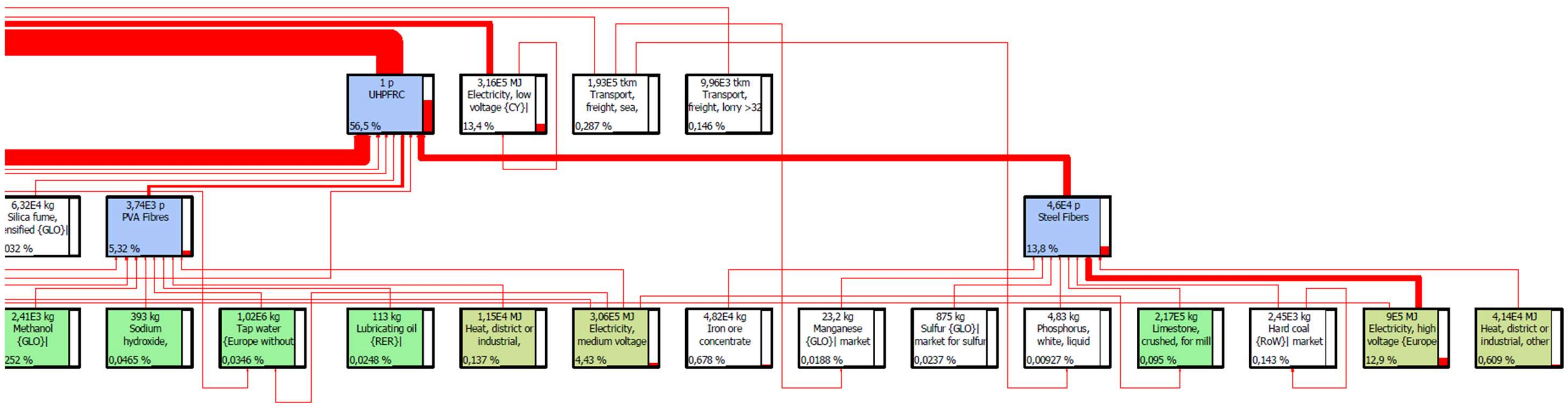

Figure 6: HLM flowchart (EPD Impact Method) – Section 2

The project is implemented under the programme of social cohesion "THALIA 2021-2027" co-funded by the European Union, through Research and Innovation Foundation.

Figures 7 and 8 illustrate the characterisation results of the EPD 2018 method for the HLM material for the 1st year and 5th year, respectively. Classification involves assigning, quantifying and analysing how the raw materials and processes associated with the examined elementary flows contribute to the relevant impact categories. The impact category indicator results are calculated by multiplying the classification factors with the corresponding LCI result. Furthermore, SimaPro normalizes the data from -1 to 1, instead of the standard 0 to 1 approach. For example, the highest positive impact is presented as -100%, while the highest negative impact is defined as 100%.

The EPD method, primarily a document based on ISO 14025[8], contains information regarding the impact on human health and environmental factors. Annex B presents a set of Tables that include analytical values for the 1st and 5th year of production for the HLM product, the Alternative Market Model and the comparison between the two models. Results from years 2 through 4 were used to obtain the necessary information for the CBA. Since the production units are increase by a percentage factor each year, the alteration in LCA results between each year is expected to be limited. Therefore, for the LCA discussion we will present and analyse the EPD method results from the first and last year of the 5-year production period.

Figure 7 shows that the materials required for the production of UHPFRC yields the highest environmental impact on Global Warming (54.13%) mainly due to the high quantities of cement. The combination percentages for the materials of both layers contribute the majority to the impact factors. The chemicals incorporated in the FRG layer exhibit the most significant water demand during the manufacturing process and contributes the largest percentage in Water Scarcity (80.59%). Furthermore, Photochemical Oxidation resulting from pollutants such as VOCs and NOx, yields significant impacts for the FRG Layer (22.74%), the UHPFRC Layer (47.86%) and Electricity (27.60%). As expected, in Figure 8, shows similar environmental impact with a variation of ±0.5-2% per subassembly and/or process for the last year of production.

[8] ISO (International Standards Organization). 2006. "ISO 14025:2006: Environmental labels and declarations — Type III environmental declarations — Principles and procedures". International Standards Organization, Geneva.

Co-funded by the European Union
Republic of Cyprus
RESEARCH & INNOVATION FOUNDATION
The project is implemented under the programme of social cohesion "THALIA 2021-2027" co-funded by the European Union, through Research and Innovation Foundation.

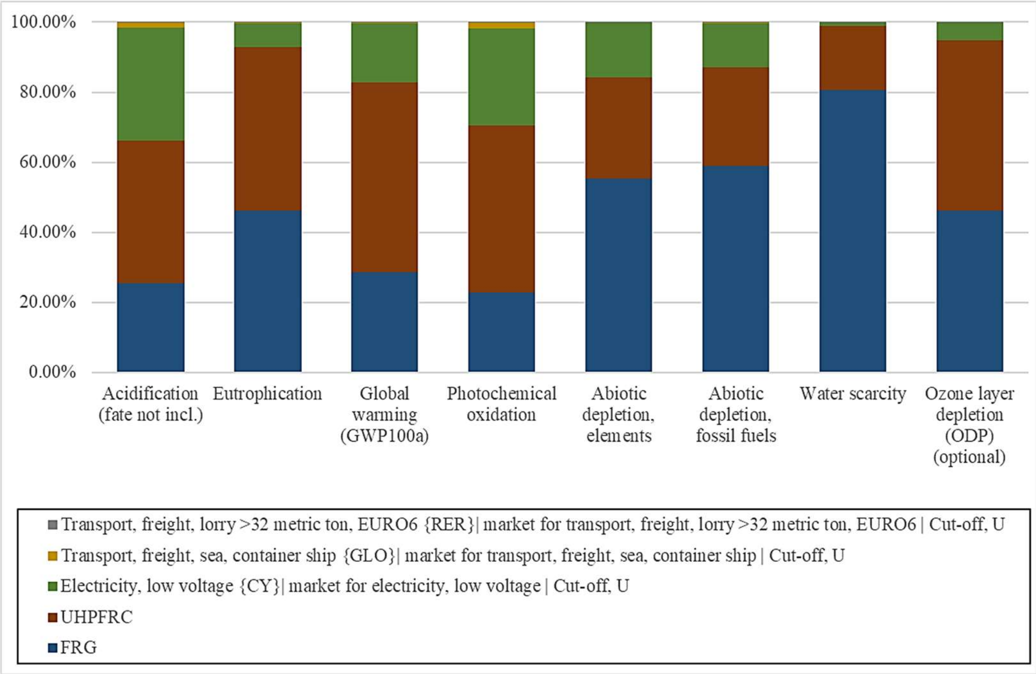

Figure 7: HLM product Characterization (EPD Impact Method) – 1st Year

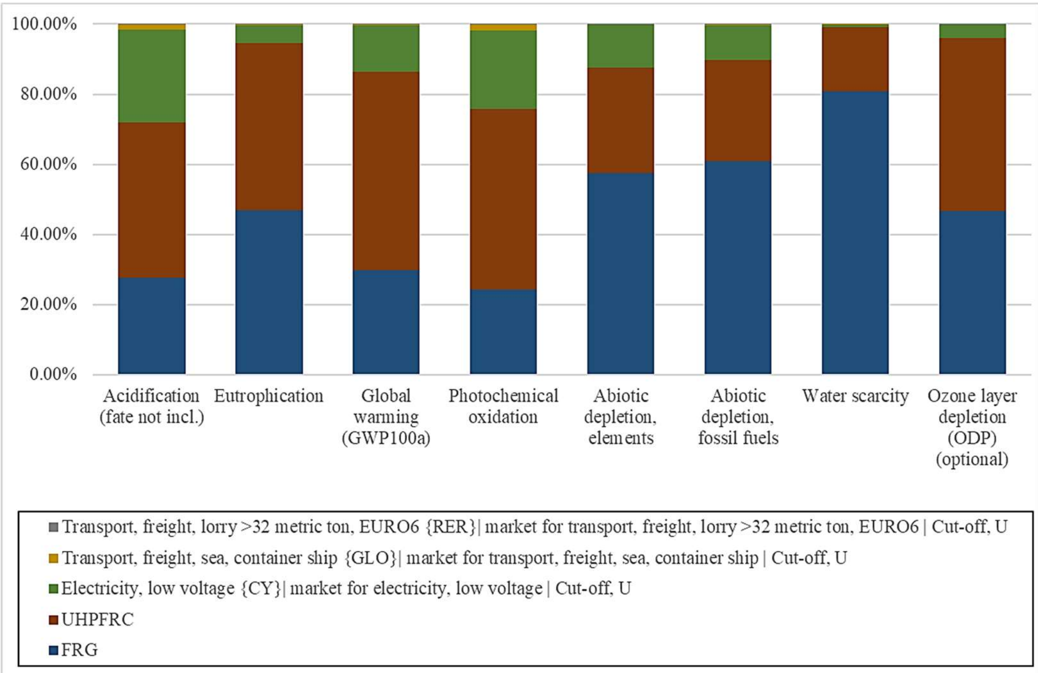

Figure 8: HLM product Characterization (EPD Impact Method) – 5th Year

5.3.2 Comparison with Alternative Market Model LCIA Results

To obtain the environmental impact and the valuation of those factors for the CBA of the HLM product, a comparison should be conducted with an equivalent material. However, the investigated product consists of two distinct layers with fireproof and blast/impact characteristics, respectively. Therefore, a hypothetical Alternative Market Model was created incorporating a gypsum fibreboard for the fire resistance layer and a reinforced conrete wall for the blast/impact performance. A mixture design for high strength concrete, obtained from industrial partners was utilized. The equivalent thickness of the high strength concrete wall which will be poured on-site is designed to withstand 3.5 kg of TNT explosives was determined at 0.03 m based from discussions of common practices with the army. Table 10 demonstrates all the necessary materials required per year of production based on the dimension of the high strength concrete mixture. For the steel reinforcement of the reinforced concrete, the maximum reinforcement limit specified in the EN 206-1 standard at 4% was utilized. Calculations were based on the m^3 required for each year of production and then, according to steel density (7850 kg/m^3), the steel mass (in kg) was defined. Calculation example for 1st year of production: 1584 m3 of concrete mixture in the 4% equivalents to → 0.04*1584 = 63.36 m^3 * 7850 kg/m^3 = **497.38 kg**

For the fire-resistance layer, the equivalent thickness was calculated for the gypsum fibreboard based on the performance of the FRG Layer. Considering that the HLM fireproof layer provides 1.5h of fire-resistance, while commercially available gypsum fibreboard (Knauf Type X Fire Rated Gypsum Wall Board) offers 1h (ASTM C1396), the thickness of 1.5 fibreboard was considered. Market available gypsum boards has a thickness of t_{GF} = 1.59 cm ⇒ 1.5 x 1.59 = 2.385 cm. Calculation example for 1st year of production: One board weight is 13.1 kg/m^2, therefore for 5280 m^2 area ⇒ 13.1 x 5280 x 1.5 = **103752 kg**

Table 10: Quantities (kg/year) required for the Alternative Market Model

High Strength Concrete				**FY1 (kg/year)**	**FY2 (kg/year)**	**FY3 (kg/year)**	**FY4 (kg/year)**	**FY5 (kg/year)**
	kg or l/m^3	1 board (0.25m^2)	1 m^2	5280 m^2	5703 m^2	6159 m^2	6651 m^2	7184 m^2
Cement	500	37.50	150.0	792000.0	855375.0	923775.0	997687.5	1077525.0
Microsilica	40	3.00	12.0	63360.0	68430.0	73902.0	79815.0	86202.0
Superplasticizer	5	0.38	1.50	7920.0	8553.8	9237.8	9976.9	10775.3
Retarder	3	0.19	0.8	3960.0	4276.9	4618.9	4988.4	5387.6
Aggregates 8/20	650	48.75	195.0	1029600.0	1111988.0	1200908.0	1296994.0	1400783.0
Aggregates 4/10	335	25.13	100.5	530640.0	573101.3	618929.3	668450.6	721941.8
Sand 4/10	28	21.00	84.0	443520.0	479010.0	517314.0	558705.0	603414.0
Limestone Sand 0/2	430	32.25	129.0	681120.0	735622.5	794446.5	858011.3	926671.5
Water	165	12.38	49.5	261360.0	282273.8	304845.8	329236.9	355583.3

Gypsum Fibreboard	Density (kg/m^3)	Equivalent Width (cm)	Equivalent Resistance Time (h)	FY1	FY2	FY3	FY4	FY5
	13.1	2.385	1.5	103752.0	112054.1	121014.5	130697.1	141155.8

Co-funded by the European Union

Republic of Cyprus

RESEARCH & INNOVATION FOUNDATION

The project is implemented under the programme of social cohesion "THALIA 2021-2027" co-funded by the European Union, through Research and Innovation Foundation.

Steel Reinforcement		FY1	FY2	FY3	FY4	FY5
	m^3/year	1584.00	1710.75	1847.55	1995.39	2155.05
	4% of Concrete Mass	63.36	68.43	73.90	79.82	86.20
	Quantity (kg)	497.38	537.18	580.13	626.55	676.69

For the transportation process, gypsum fibreboard and steel reinforcement incorporate the transportation in their dataset. However, for the materials required for the high strength concrete calculations similar to those for the HLM product were conducted. Table 11 presents the supplier origin of each material and the ton kilometres (tkm) of each material per year.

Table 11`: Transportation process for the Alternative Market Model.

High Strength Concrete	Distance (km)	Country	FY1 (tkm/year)	FY2 (tkm/year)	FY3 (tkm/year)	FY4 (tkm/year)	FY5 (tkm/year)
Cement	85	Cyprus	13464.0	14541.4	15704.2	16960.7	18317.9
Microsilica	957	Egypt	12127.1	13097.5	14144.8	15276.6	16499.1
Superplasticizer	20	Cyprus	31.68	34.22	36.95	39.91	43.10
Retarder	20	Cyprus	26.40	28.52	30.79	33.26	35.91
Aggregates 8/20	26	Cyprus	3346.20	3613.96	3902.95	4215.23	4552.54
Aggregates 4/10	26	Cyprus	1724.58	1862.58	2011.52	2172.47	2346.31
Sand 4/10	26	Cyprus	1441.44	1556.78	1681.27	1815.79	1961.10
Limestone Sand 0/2	21	Cyprus	1787.94	1931.01	2085.42	2252.28	2432.51
Water	0	Cyprus	0	0	0	0	0
Total tkm/year			33949.34	36665.93	39597.92	42766.21	46188.47

In addition to the transportation process, calculations are also required for the mixing of the high strength concrete. Utilizing an industrial mixer (capacity 2 m^3/batch) connected to an electric motor with energy consumption of 30 kWh (2.5 kWh/batch), we calculated the number of batches needed per year to produce equivalent amount of m^3 high strength concrete compared to the HLM product. Subsequently, the energy consumption for mixing was calculated for each annual period.

Table 12: Energy Consumption for the mixing process required for the high strength concrete.

High Strength Concrete	FY1	FY2	FY3	FY4	FY5
m^2/year	5280	5702.5	6158.5	6651.25	7183.5
m^3/year	1584	1710.75	1847.55	1995.375	2155.05
Mixer Capacity (m^3)	2	2	2	2	2

The project is implemented under the programme of social cohesion "THALIA 2021-2027" co-funded by the European Union, through Research and Innovation Foundation.

Mixing Time (min)	10	10	10	10	10
Batches/year	792	856	924	998	1078
kWh/year	330.00	356.41	384.91	415.71	448.97

The assemblies and the processes for the Alternative Market Model were matched with the Ecoinvent library dataset to conduct the LCI analysis. Nevertheless, certain materials such as the retarder utilized in the high strength concrete mixture, were not included in the database. For these materials, manufacturing data were used to build the model. Table 13 lists the selected database matches for the aforementioned materials and processes.

Table 13: Ecoinvent Library dataset applied in the LCA study for the Alternative Market Model.

Material/Process of Compared Alternative Market Model	Ecoinvent Library dataset
Cement	Cement Portland {Europe without Switzerland}| market for | Cut-off, U
Micro Silica	Silica Fume, densified {GLO}| market for | Cut-off, U
Superplasticizer	Polycarboxylates, 40% active substance {RER}| market for | Cut-off, U
Aggregates	Gravel crushed {RoW}| market for | Cut-off, U
Sand 0/4 mm	Sand {RoW}, gravel and sand quarry operation| market for | Cut-off, U
Limestone Sand 0/2 mm	Limestone crushed for mill {RoW}| market for | Cut-off, U
Retarder	Water deionized {Europe without Switzerland}| market for | Cut-off, U, Glucose {GLO}| market for | Cut-off, U, Sodium tripolyphosphate {RER}| market for | Cut-off, U, Electricity low voltage {CY}| market for | Cut-off, U
Water	Water, deionized {Europe without Switzerland} | water production, deionized | Cut-off, U
Electricity for all processes	Electricity, low voltage {CY} | market for | Cut-off, U
Transport of raw materials (ship)	Transport, freight, sea, container ship {GLO}| market for transport, freight, sea, container ship | Cut-off, U
Transport of raw materials (road)	Transport, freight, lorry > 32 metric ton, EURO6 {RER}| market for | Cut-off, U
Steel Reinforcement	Reinforcing steel {GLO}| market for | Cut-off, U
Gypsum Fibreboard	Gypsum fibreboard {GLO}| market for | Cut-off, U

Co-funded by the European Union
Republic of Cyprus
RESEARCH & INNOVATION FOUNDATION

The project is implemented under the programme of social cohesion "THALIA 2021-2027" co-funded by the European Union, through Research and Innovation Foundation.

Figure 9 illustrates the flowchart for the Alternative Market Model in the 1st year of production. It clearly shows the dominant negative impact of the large cement quantities in the high strength cement mixture. This dominance is further evidenced in the EPD impact method results for both the 1st (Figure 10) and the 5th year (Figure 11) of production. The Blast/Impact equivalent model accounts for over 90% of the total impact across all environmental factors, highlighting the significant emissions from the cement industry. Meanwhile, the Fire-Resistance equivalent alternative exhibits the highest impact on Acidification (9.81%) and Abiotic Depletion, fossil fuels (8.52%).

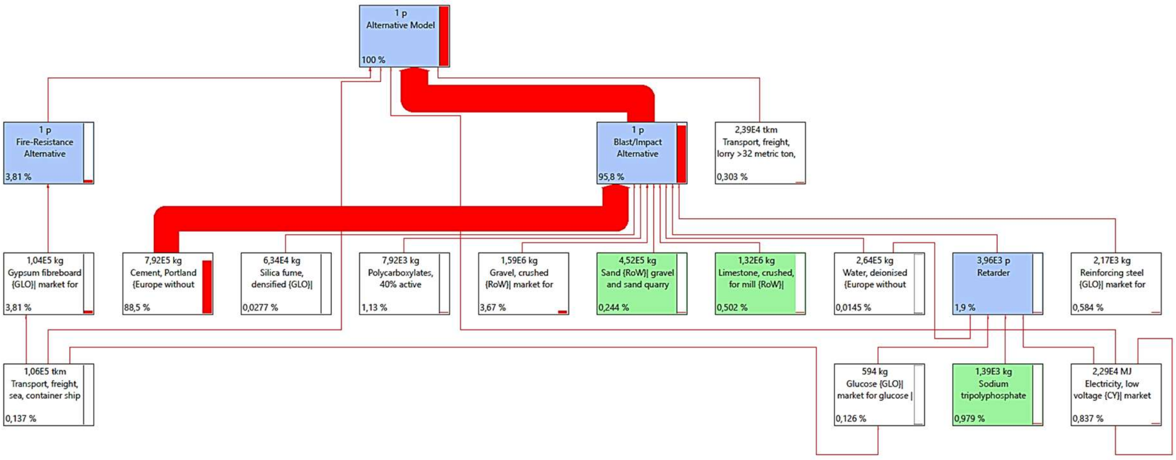

Figure 9: Alternative Market Model material flowchart (EPD Impact Method)

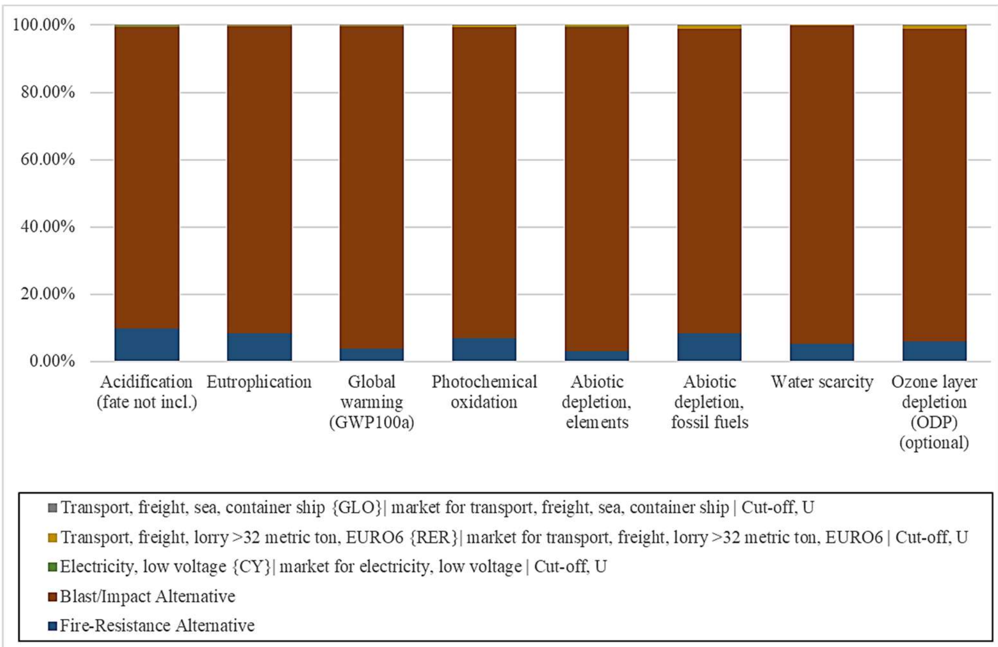

Figure 10: Alternative Market Model material Characterization (EPD Impact Method) – 1st year

Co-funded by the European Union

Republic of Cyprus

RESEARCH & INNOVATION FOUNDATION

The project is implemented under the programme of social cohesion "THALIA 2021-2027" co-funded by the European Union, through Research and Innovation Foundation.

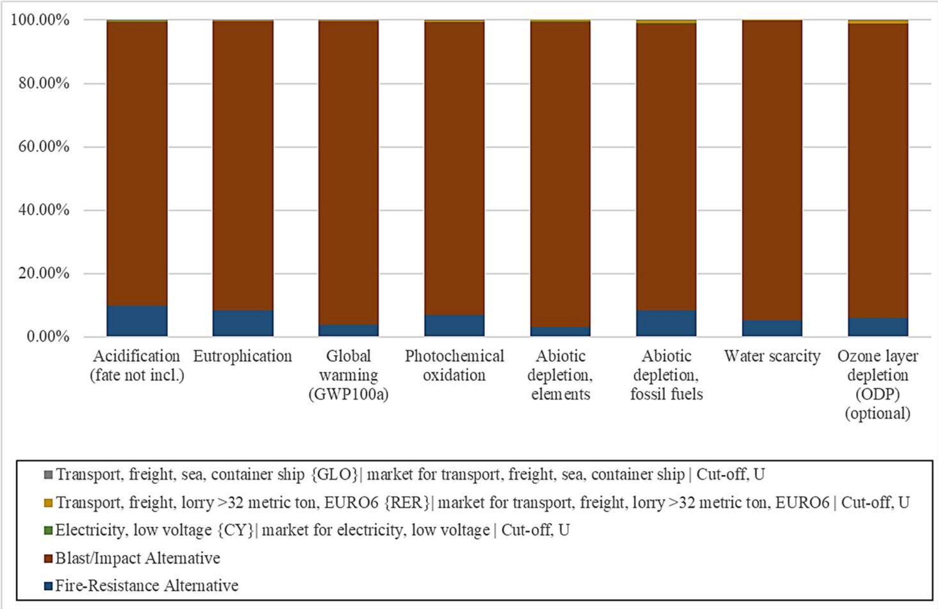

Figure 11: Alternative Market Model material Characterization (EPD Impact Method) – 5th Year

While the EPD impact assessment method provides valuable insights into the environmental impacts of the HLM product and the Alternative Market Model, it cannot alone determine the overall environmental friendliness or sustainability of these Models. A Comparison of the life cycle between the two models is necessary and the impact assessment results are presented in Figures 12 (1st year of production) and Figure 13 (5th year of production).

The HLM product demonstrates superior environmental performance in Global Warming (66.30%) and Photochemical Oxidation (81.14%) indicators compared to the equivalent Alternative Market Model, which conversely performs better in Water Usage (23.57%) and Ozone layer Depletion (22.08%). Additionally, the equivalent model exhibits lower kilograms of antimony-equivalents in both Abiotic depletion categories (59.00% for elements and 42.84% for fossil fuels).

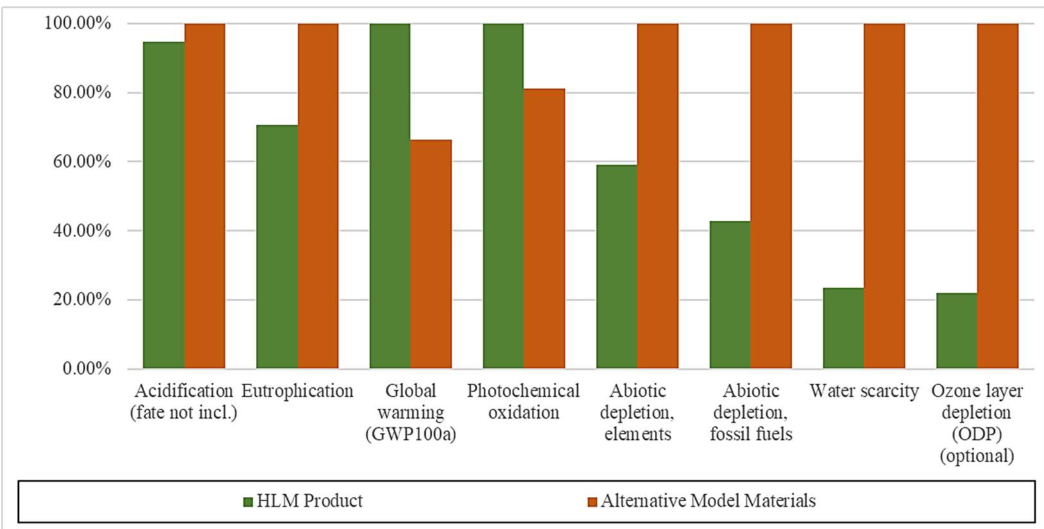

Figure 12: Comparison between HLM product and Alternative Market Model (EPD method – 1st year)

Co-funded by the European Union

Republic of Cyprus

RESEARCH & INNOVATION FOUNDATION

The project is implemented under the programme of social cohesion "THALIA 2021-2027" co-funded by the European Union, through Research and Innovation Foundation.

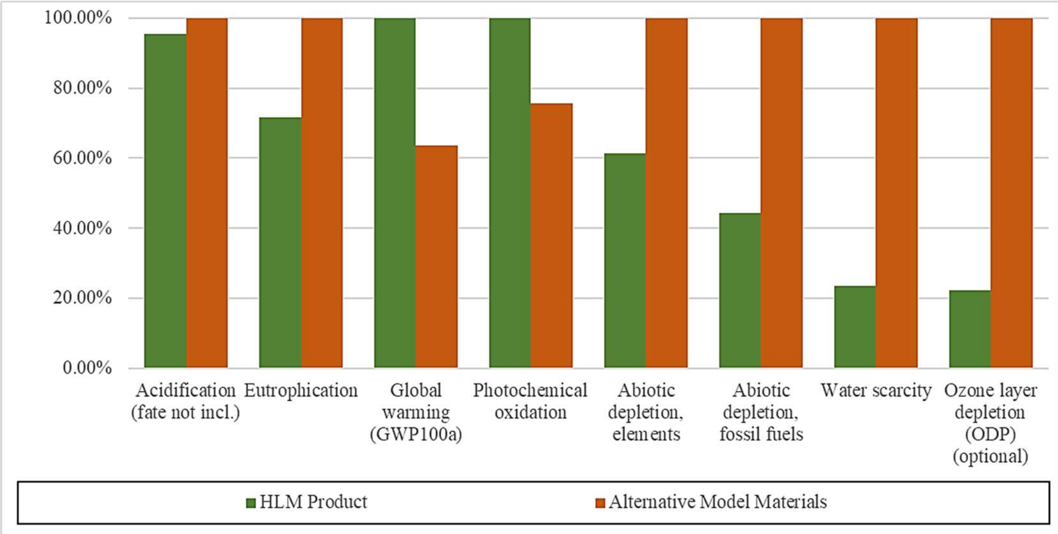

Figure 13: Comparison between HLM product and Alternative Market Model (EPD method – 5th year)

5.3.3 Interpretation of LCA

The goal of interpreting the LCA results is to pinpoint the major environmental impacts and critical areas of concern across the entire life cycle of the HLM fireproof and blast/impact resistance product. Chapter 5 of this report discusses these findings, presenting them in a straightforward and insightful way to provide a thorough understanding of the material's environmental performance.

6. LCIA results for the CBA

To integrate the results from the environmental indicators of the LCA analysis into the CBA, it is essential to assign monetary values to the emissions. Based on the social cost of environmental emissions provided from various sources[9,10], Table 14 summarizes the cost per unit for each impact indicator.

Table 14: Cost of impact indicator per unit for EPD impact assessment method.

Impact category	Unit	Cost of Impact Indicator (€/unit)
Acidification (fate not incl.)	kg SO_2 eq	4.00 €
Eutrophication	kg PO_4 eq	9.00 €
Global warming (GWP100a)	kg CO_2 eq	0.07 €
Photochemical oxidation	kg NMVOC	2.00 €
Abiotic depletion, elements	kg Sb eq	0.16 €
Abiotic depletion, fossil fuels	MJ	0.16 €
Water scarcity	m^3 eq	0.14 €
Ozone layer depletion (ODP) (optional)	kg CFC-11 eq	29.50 €

Following the comparison of impact indicators obtained from the EPD impact assessment method for each financial year, the differences in emissions between the Alternative Market Model and the HLM product were calculated as an example of this calculation is presented in Table 15. If the result was negative, the impact category was categorized as a cost; if positive, it was considered a benefit. For the HLM product, Global Warming and Photochemical Oxidation Valuation were categorized as benefits while the remaining indicators were categorized as costs.

The valuation of each indicator was calculated by multiplying the emission difference between the two models by the cost associated with each impact indicator. Table 16 presents all costs and benefits obtained for each of the 5-year production period as defined by the LCA study. It is worth mentioning that the monetary values for the Abiotic depletion, fossil fuels will not be incorporated into the CBA analysis because the purchase of photovoltaic systems was included in the initial investment. If the monetary values for fossil fuels were included, they would be classified as benefit due to the reduction in emissions.

[9] https://www.statista.com/statistics/1322214/carbon-prices-european-union-emission-trading-scheme/
[10] https://cedelft.eu/publications/environmental-prices-handbook-2023/

Co-funded by the European Union

Republic of Cyprus

RESEARCH & INNOVATION FOUNDATION

The project is implemented under the programme of social cohesion "THALIA 2021-2027" co-funded by the European Union, through Research and Innovation Foundation.

Table 15: Example of integrate the LCA results to monetary values for the CBA.

Impact category	Unit	Alternative Market Model	HLM Product	Difference	Valuation of Impact Indicator (€)
Acidification (fate not incl.)	kg SO_2 eq	1.88E+03	1.98E+03	-1.06E+02	-425.52 €
Eutrophication	kg PO_4--- eq	5.37E+02	7.61E+02	-2.24E+02	-2,015.33 €
Global warming (GWP100a)	kg CO_2 eq	7.86E+05	5.21E+05	2.65E+05	18,542.32 €
Photochemical oxidation	kg NMVOC	1.89E+03	1.53E+03	3.56E+02	712.16 €
Abiotic depletion, elements	kg Sb eq	1.31E+00	2.22E+00	-9.09E-01	-0.15 €
Abiotic depletion, fossil fuels	MJ	3.56E+06	8.30E+06	-4.75E+06	-759,404.99 €
Water scarcity	m^3 eq	1.37E+05	5.83E+05	-4.46E+05	-62,427.84 €
Ozone layer depletion (ODP) (optional)	kg CFC-11 eq	4.07E-03	1.84E-02	-1.43E-02	-0.42 €

Table 16: Costs and benefits from the LCA study to the CBA.

Impact category	FY1	FY2	FY3	FY4	FY5
Acidification (fate not incl.)	425.52 €	548.77 €	659.61 €	739.68 €	864.05 €
Eutrophication	2,015.33 €	2,142.77 €	2,280.33 €	2,474.30 €	2,589.52 €
Global warming (GWP100a)	18,318.27 €	20,486.52 €	22,584.86 €	24,741.95 €	27,310.57 €
Photochemical oxidation	712.16 €	832.02 €	961.37 €	1,034.42 €	1,252.14 €
Abiotic depletion, elements	0.15 €	0.15 €	0.16 €	0.17 €	0.18 €
Abiotic depletion, fossil fuels	759,404.00 €	807,654.89 €	859,730.99 €	918,995.99 €	976,786.44 €
Water scarcity	62,427.84 €	67,351.06 €	72,665.27 €	78,665.83 €	84,608.61 €
Ozone layer depletion (ODP) (optional)	0.42 €	0.46 €	0.49 €	0.53 €	0.57 €

7. CBA - Costs

Based on Deliverable D5.1 – “Technoeconomic Analysis”, two strategic approaches were considered: Plan A which involves granting a five-year exclusive license to distributors, complemented by more affordable license options for additional distributors. Plan B entails a a five-year period comprehensive financial analysis including direct sales, therefore requiring a detailed assessment of all the fixed and variable costs associated with the project.

A thorough analysis was conducted across five distinctive price scenarios including sensitivity analysis of the Internal Rate of Return (IRR), scenarios with dynamic pricing strategies and discount factor scenarios. The financial outcomes for the investigated analysis time frame are summarized in Table 17, which also incorporates the environmental impact costs from the LCA study. It is worth mentioning that both the LCA and CBA use the same time frame to ensure meaningful comparisons. Detailed information on each category of fixed and variable costs presented in Table 17 can be found in Annex C.

Table 17: Fixed, Variable and Environmental costs for the CBA study.

	COSTS				
	FY1	**FY2**	**FY3**	**FY4**	**FY5**
FIXED COSTS					
Advertising (1% on turnover)	5,649.60 €	6,272.64 €	6,959.21 €	7,715.48 €	8,548.22 €
Web hosts fees	1,000.00 €	500.00 €	500.00 €	500.00 €	500.00 €
Accounting, Legal	11,299.20 €	12,545.28 €	13,918.42 €	15,430.97 €	17,096.45 €
Depreciation	564.96 €	627.26 €	695.92 €	771.55 €	854.82 €
Insurance	5,000.00 €	5,000.00 €	5,000.00 €	5,000.00 €	5,000.00 €
Manufacturing (2% on turnover)	11,299.20 €	12,545.28 €	13,918.42 €	15,430.97 €	17,096.45 €
Rent	14,400.00 €	14,400.00 €	14,400.00 €	14,400.00 €	14,400.00 €
Utilities	10,560.00 €	11,404.80 €	12,317.18 €	13,302.56 €	14,366.76 €
Labor	24,000.00 €	24,000.00 €	24,000.00 €	24,000.00 €	24,000.00 €
Payroll	13,000.00 €	13,000.00 €	13,000.00 €	13,000.00 €	13,000.00 €
Supplies	253,440.00 €	273,715.20 €	295,612.42 €	319,261.41 €	344,802.32 €
Patent & CE Marking fees	10,000.00 €	10,000.00 €	10,000.00 €	10,000.00 €	10,000.00 €
VARIABLE COSTS					
Overhead (10% on turnover)	56,496.00 €	62,726.40 €	69,592.09 €	77,154.84 €	85,482.24 €
Cost of Goods Sold (2% on turnover)	11,299.20 €	12,545.28 €	13,918.42 €	15,430.97 €	17,096.45 €
Maintenance (2% on turnover)	28,248.00 €	31,363.20 €	34,796.04 €	38,577.42 €	42,741.12 €
ENVIRONMENTAL COSTS					

Co-funded by the European Union

Republic of Cyprus

RESEARCH & INNOVATION FOUNDATION

The project is implemented under the programme of social cohesion “THALIA 2021-2027” co-funded by the European Union, through Research and Innovation Foundation.

Valuation of SO_2 emissions (LCA)	425.52 €	548.77 €	659.61 €	739.68 €	864.05 €
Valuation of PO_4 emissions (LCA)	2,015.33 €	2,142.77 €	2,280.33 €	2,474.30 €	2,589.52 €
Valuation of Sb emissions (LCA)	0.15 €	0.15 €	0.16 €	0.17 €	0.18 €
Valuation of m^3 water usage (LCA)	62,427.84 €	67,351.06 €	72,665.27 €	78,665.83 €	84,608.61 €
Valuation of CFC-11 emissions (LCA)	0.42 €	0.46 €	0.49 €	0.53 €	0.57 €

Co-funded by the European Union

Republic of Cyprus

RESEARCH & INNOVATION FOUNDATION

The project is implemented under the programme of social cohesion "THALIA 2021-2027" co-funded by the European Union, through Research and Innovation Foundation.

8. CBA – Benefits

Just as costs represent potential disadvantages and often play a decisive role in the execution of a project and/or investment, benefits highlight the possible advantages followed that may follow the initiation of the production. Making informed decisions and developing a comprehensive strategic plan to mitigate risks and maximize innovation can significantly enhance the likelihood of positive outcomes. Benefits are expressed in monetary values and may encompass economic, environmental, health and social factors. It is worth mentioning that some potential benefits are difficult to quantify monetarily (etc. customer loyalty) and often require extensive data collection over several years market interactions.

The LCA study identified the prevention of carbon dioxide and NMVOC emissions, therefore the valuation of those environmental indicators was included as a benefit in the project's valuation. Additionally, revenue from the sales of the HLM product over the 5-year period, is a major benefit since it provides a positive financial performance and validates the initial investment.

Further benefits are related to the supply chain. By securing prior exclusive agreements with suppliers, we can potentially obtain a discount of around 5% on the cost of raw materials and therefore, considered as a benefit to the project. In addition, proper maintenance of the factory and efficient management of employee schedule can prevent production delays, thereby enhancing the project's revenue and success.

The social impact includes job creation which reduces unemployment and strengthens the economy by circulating money within various economic sectors. Taxes generated from the project contribute additional revenue to society and government, supporting public projects such as constructions of schools or hospitals.

Participation in workshops, seminars, partnerships with industry members and the development of innovative technologies or services can also significantly enhance the overall performance of the project and enhance the viability of the end-product. It is worth mentioning that the potential benefits from patenting the HLM product were not included in this study, due to insufficient information on potential outcomes and additional revenue.

Table 18: Benefits for the CBA study.

BENEFITS					
Category	**FY1**	**FY2**	**FY3**	**FY4**	**FY5**
Valuation of CO_2 emissions (LCA)	18,318.27 €	20,486.52 €	22,584.86 €	24,741.95 €	27,310.57 €
Valuation of NMVOC emissions (LCA)	712.16 €	832.02 €	961.37 €	1,034.42 €	1,252.14 €
Revenue from sales	528,000.00 €	598,752.00 €	677,445.12 €	764,897.13 €	862,005.81 €
Aggrement with suppliers for discount (5%)	12,672.00 €	13,685.76 €	14,780.62 €	15,963.07 €	17,240.12 €
Better Scheduling of employers (10%)	3,700.00 €	3,700.00 €	3,700.00 €	3,700.00 €	3,700.00 €
Sufficient maintenance (25%)	2,824.80 €	3,136.32 €	3,479.60 €	3,857.74 €	4,274.11 €
Social Impact from the employers	56,400.00 €	56,400.00 €	56,400.00 €	56,400.00 €	56,400.00 €
Taxes	0.00 €	96,445.25 €	133,808.51 €	176,104.49 €	223,883.29 €
Innovation and partnership	10,560.00 €	11,975.04 €	13,548.90 €	15,297.94 €	17,240.12 €

Co-funded by the European Union

Republic of Cyprus

RESEARCH & INNOVATION FOUNDATION

The project is implemented under the programme of social cohesion "THALIA 2021-2027" co-funded by the European Union, through Research and Innovation Foundation.

9. CBA results and discussion

Based on Equations 1-3 presented in Chapter 3, we first summarized all costs and benefits, and then considering a discount rate of 5%, we calculated the NPV for both factors. It was observed that the total NPV of benefits exceeds the corresponding NPV of costs, resulting in a positive Net Benefits for the project. This indicate that the project's costs are lower than its benefit. For instance, in the 1st financial year, the project generates an outcome of 106,725.53 € more than the calculated NPV of costs. By the end of the investment period, a Net Benefit of 281,087.81 € demonstrates a significant economic return relative to the initial investment of 160,000.00 € for the manufacturing plant. The BCR calculated using Equation 3 for the 1st year yielded an indicator of 1.22. This indicates that for every 1.00€ spent on the project, it generates 1.22€ in return, resulting in a profit of 0.22€. By the end of the analysis period the BCR is increased at 1.42. This suggests that executing the HLM manufacturing project will establish the business as viable and be economically stable of generating positive revenue.

Nevertheless, there are potential risks and uncertainties related to estimated costs that could affect the CBA outcome. To address these, a sensitivity analysis on cost variations in the FY5 profit and IRR was conducted, as explained and discussed in Deliverable D5.1 The analysis identified supplies as the most impactful parameter on the final project outcome. Furthermore, the potential benefits of patent revenue and the energy savings from photovoltaic use were not implemented in the initial benefits calculations. Incorporating these factors could results in a BCR factor greater than 4.0.

Further recommendations for improving the HLM production process which will be investigated at a higher TRL to enhance the financial stability of the project includes optimization of mixture designs in both layers to contain less chemicals, cement and water, alteration of the curing process of the UHPFRC layer to reduce energy consumption and increase curing sessions per month, alternative suppliers closer to the country of region to reduce transportation costs and emissions.

Table 19: CBA study final NPV, NB and BCR factors.

	FY1	FY2	FY3	FY4	FY5
NPV COST	496,309.92 €	533,989.10 €	575,460.93 €	620,815.88 €	669,569.30 €
NPV BENEFIT	603,035.46 €	730,533.25 €	800,526.07 €	873,707.35 €	950,657.12 €
NB	106,725.53 €	196,544.15 €	225,065.14 €	252,891.47 €	281,087.81 €
BCR	**1.22**	**1.37**	**1.39**	**1.41**	**1.42**

Co-funded by the European Union

Republic of Cyprus

RESEARCH & INNOVATION FOUNDATION

The project is implemented under the programme of social cohesion "THALIA 2021-2027" co-funded by the European Union, through Research and Innovation Foundation.

10. Conclusion

Deliverable 5.2 of Work Package 5 (D5.2 – "Cost-Benefit Analysis (CBA)") for the BAM project (EXCELLENCE/0421/0137) focuses on quantifying the overall net benefits derived from the BAM project. The LCA and CBA analyses for the HLM product provided valuable insights of the environmental impacts and economic viability of the project.

In general, the LCA study identified significant impacts in tha majority of impact categories for the HLM product except for the Global Warming Potential. More specific, the LCA highlighted that the cement usage is a major contributor to Global Warming for both Models, while FRG Layer of the HLM product. further affect Water Usage and Photochemical Oxidation. Furthermore, the Alternative Market Model performs better in Water Scarcity and Ozone Layer Depletion.

The CBA demonstrated positive net benefits and a favorable BCR suggesting the viability of the project. The total NPV of benefits surpasses the NPV of costs with the first financial year showing a positive outcome of 106,725.53 € and a substantial Net Benefit of 281,087.81 € at the end of the period. This positive outcome indicates that the project is profitable to the initial investment of 160,000.00 €. The BCR for the first year is 1.22 improving to 1.42 by the end of the analysis period, reflecting that the project is stable and profitable. Further recommendations were proposed for a future project with higher TRL to enhance both environmental performance and financial stability.

In conclusion, the HLM product considering the TRL 4 of the BAM project offers some valuable environmental benefits and a positive economic return and viability over the production of the HLM product.

Co-funded by the European Union
Republic of Cyprus
RESEARCH & INNOVATION FOUNDATION
The project is implemented under the programme of social cohesion "THALIA 2021-2027" co-funded by the European Union, through Research and Innovation Foundation.

Annex A

This section provides further information regarding the EPD 2018 impact assessment method used for the LCA study:

EPD (2018)

This method is the successor of EPD (2013) and is intended for the creation of Environmental Product Declarations (EPDs), as published on the website of the Swedish Environmental Management Council (SEMC). For more information see also General programme instructions for the international EPD System 3.0 of 11 December 2017. The latest update to the recommendations included in this method is from 2018-06-08 (adding Water Scarcity Footprint).

In the standard EPDs one only has to report on the following impact categories:

- Acidification potential (in SimaPro 'Acidification (fate not incl.)')
- Eutrophication potential (in SimaPro 'Eutrophication')
- Global warming potential (in SimaPro 'Global warming (GWP100a)')
- Photochemical oxidant creation potential (in SimaPro 'Photochemical oxidation')
- Abiotic resource depletion, elements (in SimaPro 'Abiotic depletion, elements')
- Abiotic resource depletion, fossil fuels (in SimaPro 'Abiotic depletion, fossil fuels')
- Water Scarcity Footprint (in SimaPro 'Water scarcity')
- Ozone-depleting gases (expressed as the sum of ozone-depleting potential in mass of CFC 11-equivalents, 20 years) (in SimaPro 'Ozone layer depletion (ODP) (optional)')

Most impact categories are taken directly from the CML-IA baseline method (eutrophication, global warming, ozone depletion and abiotic resource depletion) and CML-IA non-baseline method (acidification). Water scarcity category is based on AWARE method and Photochemical oxidation is based on ReCiPe 2008.

- Other adaptations

June 2022, version 1.04, SimaPro 9.4:

- Characterisation factors were added for regionalised substances based on the global substances in the following impact categories:

> Photochemical oxidation (NMVOC, non-methane volatile organic compounds)

Co-funded by the European Union

Republic of Cyprus

RESEARCH & INNOVATION FOUNDATION

The project is implemented under the programme of social cohesion "THALIA 2021-2027" co-funded by the European Union, through Research and Innovation Foundation.

> Water scarcity (Water, cooling, unspecified natural origin; Water, lake; Water, river; Water, turbine use, unspecified natural origin; Water, unspecified natural origin; Water; Water, well) for the regions ENTSO-E and UN-EUROPE

- Characterisation factors were added in the following impact categories:

> Global warming (GWP100a) (Carbon dioxide, peat oxidation; Methane, peat oxidation; Dinitrogen monoxide, peat oxidation)

> Photochemical oxidation (Methane, peat oxidation)

> Eutrophication (Dinitrogen monoxide, peat oxidation)

December 2021, version 1.03, SimaPro 9.3:

- Characterisation factors were added for regionalised substances based on the global substances in the following impact categories:

Acidification (fate not incl.) (Ammonia, Nitrogen dioxide, Nitrogen monoxide, Nitrogen oxides, Sulphur dioxide, Sulphur trioxide)

Eutrophication (Ammonia, COD (Chemical Oxygen Demand), Nitrate, Nitrogen, Nitrogen dioxide, Nitrogen monoxide, Nitrogen oxides, Phosphate, Phosphorus

Photochemical oxidation (Nitrogen dioxide, Nitrogen oxides, Sulphur dioxide, Sulphur oxides)

June 2021, version 1.02, SimaPro 9.2:

- Updated Water Scarcity to use values from AWARE 1.2c (Feb 2019 version)
- Updated Water scarcity impact category, to include latest list of regionalized water flows
- Added waste water, chemically and thermally polluted water with global average characterization factor for water withdrawal/emission
- Old water stress flows are removed from the database, they are largely unused by libraries
- Removed characterization for fossil water withdrawal

December 2019, version 1.01:

- Corrected characterisation factor of 'Methane, fossil' in 'Global warming (GWP100a)' from 30 to 28.

Co-funded by the European Union

Republic of Cyprus

RESEARCH & INNOVATION FOUNDATION

The project is implemented under the programme of social cohesion "THALIA 2021-2027" co-funded by the European Union, through Research and Innovation Foundation.

Annex B

This section provides all the results from the HLM product, Alternative Market Model and comparison of the conducted LCA study.

Table 20: HLM product – EPD Method – Year 1

Label	Units	Total	FRG	UHPFRC	Electricity, low voltage {CY}| market for electricity, low voltage | Cut-off, U	Transport, freight, sea, container ship {GLO}| market for transport, freight, sea, container ship | Cut-off, U	Transport, freight, lorry >32 metric ton, EURO6 {RER}| market for transport, freight, lorry >32 metric ton, EURO6 | Cut-off, U
Acidification (fate not incl.)	kg SO_2 eq	1.98E+03	5.04E+02	8.08E+02	6.43E+02	2.78E+01	1.64E+00
Eutrophication	kg PO_4 eq	7.61E+02	3.51E+02	3.56E+02	5.05E+01	2.92E+00	3.81E-01
Global warming (GWP100a)	kg CO_2 eq	5.21E+05	1.49E+05	2.82E+05	8.84E+04	1.09E+03	7.64E+02
Photochemical oxidation	kg NMVOC	1.53E+03	3.48E+02	7.33E+02	4.23E+02	2.44E+01	3.11E+00
Abiotic depletion, elements	kg Sb eq	2.22E+00	1.22E+00	6.42E-01	3.47E-01	1.06E-03	2.15E-03
Abiotic depletion, fossil fuels	MJ	8.30E+06	4.90E+06	2.33E+06	1.05E+06	1.34E+04	1.14E+04
Water scarcity	m^3 eq	5.83E+05	4.70E+05	1.06E+05	6.92E+03	3.05E+01	5.56E+01
Ozone layer depletion (ODP) (optional)	kg CFC-11 eq	-1.23E-04	8.49E-03	8.97E-03	9.21E-04	1.36E-05	1.43E-05

Co-funded by the European Union

Republic of Cyprus

RESEARCH & INNOVATION FOUNDATION

The project is implemented under the programme of social cohesion "THALIA 2021-2027" co-funded by the European Union, through Research and Innovation Foundation.

Table 21: HLM product – EPD Method – Year 5

Label	Units	Total	FRG	UHPFRC	Electricity, low voltage {CY}| market for electricity, low voltage | Cut-off, U	Transport, freight, sea, container ship {GLO}| market for transport, freight, sea, container ship | Cut-off, U	Transport, freight, lorry >32 metric ton, EURO6 {RER}| market for transport, freight, lorry >32 metric ton, EURO6 | Cut-off, U
Acidification (fate not incl.)	kg SO_2 eq	2.49E+03	6.86E+02	1.10E+03	6.60E+02	3.78E+01	1.98E+00
Eutrophication	kg PO_4 eq	1.02E+03	4.77E+02	4.85E+02	5.19E+01	3.98E+00	4.59E-01
Global warming (GWP100a)	kg CO_2 eq	6.79E+05	2.02E+05	3.84E+05	9.08E+04	1.49E+03	9.21E+02
Photochemical oxidation	kg NMVOC	1.94E+03	4.74E+02	9.97E+02	4.34E+02	3.33E+01	3.74E+00
Abiotic depletion, elements	kg Sb eq	2.90E+00	1.67E+00	8.73E-01	3.56E-01	1.45E-03	2.59E-03
Abiotic depletion, fossil fuels	MJ	1.09E+07	6.66E+06	3.17E+06	1.08E+06	1.82E+04	1.38E+04
Water scarcity	m^3 eq	7.91E+05	6.40E+05	1.44E+05	7.11E+03	4.15E+01	6.70E+01
Ozone layer depletion (ODP) (optional)	kg CFC-11 eq	2.47E-02	1.16E-02	1.22E-02	9.46E-04	1.85E-05	1.72E-05

Table 22: Alternative Market Model– EPD Method – Year 1

Label	Units	Total	Fire-Resistance Alternative	Blast/Impact Alternative	Electricity, low voltage {CY}| market for electricity, low voltage |	Transport, freight, lorry >32 metric ton, EURO6 {RER}| market for transport	Transport, freight, sea, container ship {GLO}| market for transport, freight,

Co-funded by the European Union
Republic of Cyprus
RESEARCH & INNOVATION FOUNDATION
The project is implemented under the programme of social cohesion "THALIA 2021-2027" co-funded by the European Union, through Research and Innovation Foundation.

					Cut-off, U	, freight, lorry >32 metric ton, EURO6 | Cut-off, U	sea, container ship | Cut-off, U
Acidification (fate not incl.)	kg SO_2 eq	1.88E+03	1.84E+02	1.68E+03	2.52E+00	4.76E+00	3.12E+00
Eutrophication	kg PO_4 eq	5.37E+02	4.52E+01	4.90E+02	1.98E-01	1.10E+00	3.27E-01
Global warming (GWP100a)	kg CO_2 eq	7.86E+05	2.99E+04	7.53E+05	3.46E+02	2.22E+03	1.23E+02
Photochemical oxidation	kg NMVOC	1.89E+03	1.30E+02	1.74E+03	1.65E+00	9.01E+00	2.74E+00
Abiotic depletion, elements	kg Sb eq	1.31E+00	4.20E-02	1.26E+00	1.36E-03	6.23E-03	1.19E-04
Abiotic depletion, fossil fuels	MJ	3.56E+06	3.03E+05	3.21E+06	4.11E+03	3.31E+04	1.50E+03
Water scarcity	m^3 eq	1.37E+05	7.17E+03	1.30E+05	2.71E+01	1.61E+02	3.41E+00
Ozone layer depletion (ODP) (optional)	kg CFC-11 eq	4.07E-03	2.43E-04	3.78E-03	3.61E-06	4.14E-05	1.52E-06

Table 23: Alternative Market Model– EPD Method – Year 5

Label	Units	Total	Fire-Resistance Alternative	Blast/Impact Alternative	Electricity, low voltage {CY}| market for electricity, low voltage | Cut-off, U	Transport, freight, lorry >32 metric ton, EURO6 {RER}| market for transport, freight, lorry >32 metric ton, EURO6 | Cut-off, U	Transport, freight, sea, container ship {GLO}| market for transport, freight, sea, container ship | Cut-off, U
Acidification (fate not incl.)	kg SO_2 eq	2.38E+03	2.41E+02	2.12E+03	3.42E+00	6.45E+00	4.24E+00
Eutrophication	kg PO_4 eq	7.30E+02	6.15E+01	6.67E+02	2.69E-01	1.49E+00	4.45E-01

Co-funded by the European Union

Republic of Cyprus

RESEARCH & INNOVATION FOUNDATION

The project is implemented under the programme of social cohesion "THALIA 2021-2027" co-funded by the European Union, through Research and Innovation Foundation.

Global warming (GWP100a)	kg CO_2 eq	1.07E+06	4.07E+04	1.02E+06	4.71E+02	3.00E+03	1.67E+02
Photochemical oxidation	kg NMVOC	2.57E+03	1.77E+02	2.37E+03	2.25E+00	1.22E+01	3.73E+00
Abiotic depletion, elements	kg Sb eq	1.78E+00	5.71E-02	1.71E+00	1.85E-03	8.44E-03	1.62E-04
Abiotic depletion, fossil fuels	MJ	4.84E+06	4.12E+05	4.37E+06	5.59E+03	4.48E+04	2.04E+03
Water scarcity	m^3 eq	1.87E+05	9.75E+03	1.77E+05	3.69E+01	2.18E+02	4.65E+00
Ozone layer depletion (ODP) (optional)	kg CFC-11 eq	5.53E-03	3.30E-04	5.14E-03	4.91E-06	5.60E-05	2.07E-06

Table 24:Comparison between HLM product and Alternative Market Model– EPD Method – Year 1

Label	Units	HLM Product	Alternative Model Materials
Acidification (fate not incl.)	kg SO_2 eq	1.98E+03	1.88E+03
Eutrophication	kg PO_4 eq	7.61E+02	5.37E+02
Global warming (GWP100a)	kg CO_2 eq	5.21E+05	7.86E+05
Photochemical oxidation	kg NMVOC	1.53E+03	1.89E+03
Abiotic depletion, elements	kg Sb eq	2.22E+00	1.31E+00
Abiotic depletion, fossil fuels	MJ	8.30E+06	3.56E+06
Water scarcity	m^3 eq	5.83E+05	1.37E+05
Ozone layer depletion (ODP) (optional)	kg CFC-11 eq	1.84E-02	4.07E-03

Table 25: Comparison between HLM product and Alternative Market Model– EPD Method – Year 5

Label	Units	HLM Product	Alternative Model Materials
Acidification (fate not incl.)	kg SO_2 eq	2.59E+03	2.38E+03
Eutrophication	kg PO_4 eq	1.02E+03	7.30E+02
Global warming (GWP100a)	kg CO_2 eq	6.79E+05	1.07E+06
Photochemical oxidation	kg NMVOC	1.94E+03	2.57E+03
Abiotic depletion, elements	kg Sb eq	2.90E+00	1.78E+00
Abiotic depletion, fossil fuels	MJ	1.09E+07	4.84E+06
Water scarcity	m^3 eq	7.91E+05	1.87E+05
Ozone layer depletion (ODP) (optional)	kg CFC-11 eq	2.47E-02	5.53E-03

Annex C

This section presents analytic description for all the fixed and variable costs applied in the technoeconomic analysis and CBA study.

Table 26: Fixed and variable costs categories for the financial analysis.

Category	Description
Web Host Fees	Costs related to the development and upkeep of the product website.
Accounting, Legal	Costs for accounting and legal services.
Depreciation	Spreading the cost of an asset over its useful life.
Insurance	Payments for insurance coverage.
Manufacturing	Expenses directly linked to manufacturing processes involving raw materials.
Payroll	Wages for office employees.
Rent	Payments for leasing and using a property or space for a specific period.
Supplies	Costs of materials and resources used in production. (Detailed described in on section 5.3 - Comparative Economic Analysis)
Taxes	Payments for corporate taxes.
Utilities	Costs for essential services like, water, gas, waste disposal and Telecommunications. Electricity cost excluded as photovoltaic installation required on initial investment.
Labor	Salaries for labor personnel.
Patent & CE Marking	Costs associated with obtaining and maintaining patents and CE marking certifications to ensure compliance with regulatory standards and protect intellectual property rights.

Co-funded by the European Union

Republic of Cyprus

RESEARCH & INNOVATION FOUNDATION

The project is implemented under the programme of social cohesion "THALIA 2021-2027" co-funded by the European Union, through Research and Innovation Foundation.

Acknowledgements

The project is implemented under the programme of social cohesion "THALIA 2021-2027" co-funded by the European Union, through Research and Innovation Foundation.

Το έργο υλοποιείται στο πλαίσιο του Προγράμματος Πολιτικής Συνοχής «ΘΑλΕΙΑ 2021-2027» με τη συγχρηματοδότηση της ΕΕ, μέσω του Ιδρύματος Έρευνας και Καινοτομίας.