Eco-Hestia: A comprehensive building environmental assessment scheme, based on Life Cycle Assessment: White Paper

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Introduction

EcoHestia is a comprehensive environmental building assessment tool, whose operation is based on a standardized, transparent, verifiable and internationally recognized approach life cycle approach (ISO 14040 series). **EcoHestia** performs whole- building Life Cycle Assessment (LCA), taking into consideration all inputs and outputs, whether in the form of materials and/ or energy, requires for the construction of any building located in Cyprus. The database of **EcoHestia** includes an extensive range of construction materials and building elements that are or were typically employed in the built environment of the island .

EcoHestia is about presenting in a quantitative way the environmental impacts that come with the establishment of a building and identifying how, and where the building design can be altered in order to improve its overall friendliness. The ultimate intention of the environmental building assessment tool is to contribute to the drastic lowering of the carbon footprint of the built sector by choosing alternative 'greener' building materials, such as the sustainability of the construction industry is promoted.

Recommended Application of EcoHestia

The straightforwardness and user- friendliness operation of the environmental building assessment tool **EcoHestia** provides the users with several options for the utilization of the generated results. Although the results generated by **EcoHestia** do not predict absolute or precise values for the environmental performance of a building, they address the potential

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environmental impacts caused by the construction of the building. The **EcoHestia** impact results, which are calculated on a Key Performance Indicators (KPIs) basis, enable the objective assessment of the sustainability level and the environmental performance of different buildings or building designs by quantitative indicating which performs better. The environmental building assessment tool also facilitates the evaluation of the energy efficiency of buildings which share similar designs characteristics but incorporate different insulating materials. Through the most efficient use of resources or energy and by allowing the identification of alternative options, **EcoHestia** also achieves the lowering of the overall construction costs, as well as contributes to the cost savings. Furthermore, EcoHestia may also supports decision- making based on the key objectives of the project and the involved stakeholders.
Taking into consideration the numerous benefits of **EcoHestia**, possible applications include:
<u>**EcoHestia** for the industry.</u> The industry, including civil engineers, quantity surveyors (QS), and environmental building design experts, employs **EcoHestia** for the assessment of alternative technical building design options and systems for the realization of the most sustainable building projects.
<u>**EcoHestia** for research purposes.</u> **EcoHestia** is a reference point for the research community on the application of LCA in the construction industry. It supports researchers in the implementation of whole- building LCA through the exploitation of the generated results or through providing validation to the results of their study.
<u>**EcoHestia** for policy- making.</u> Governmental and regulative bodies use **EcoHestia** in a policy making context, as quantitative data can be used for the development of strategies on building designs and decisions about introducing subsidies for construction materials and building systems.

Methodology

EcoHestia is the state of the art environmental building assessment tool for the implementation of whole- building LCA. **EcoHestia** performs ‘cradle- to- site’ LCA, taking into consideration the pre- utilization phase of the building, comprised of the following stages:

- Extraction/ acquiring of the raw materials
- Transportation of the raw materials to the manufacturing/ processing plant
- Transformation or manufacturing of the raw materials into the final product (construction materials or building element)
- Transportation of the final product to the construction site

The operation of **EcoHestia** is conducted according to the principles described in the ISO 14040 series on Life Cycle Assessment, providing transparency and reliability of its generated results. It employs the Life Cycle Impact Assessment (LCIA) - CML 2001 methodology. CML is the methodology of the Centre for Environmental Studies of the University of Leiden, whose results are expressed in terms of emissions to the environment on a series of environmental impact categories. Accordingly, **EcoHestia** generates the impact of the investigated building on the following impact categories, also described in detail in Table 1:

- Global Warming Potential (GWP 100 years),
- Acidification Potential (AP),
- Eutrophication Potential (EP),

- Ozone layer Depletion Potential (ODP, steady state),
- Abiotic Depletion Potential of elements and fossils (ADP Elements and ADP Fossils),
- Human Toxicity Potential (HTP),
- Photochemical Ozone Creation Potential (POCP).

Additionally, **EcoHestia** also generates the following:

- Building' s embodied energy
- Building' s carbon footprint.

Impact CategoryIndicators	Characterization Model	Unit
Global Warming Potential (GWP)	This value deals with all greenhouse gases (arises from emissions of *CO_2*, and *methane*) that may cause the earth's temperature to rise and have negative effect on the ecosystem, human health and material welfare.	**kg CO_2- Eq.**
Acidification Potential (AP)	This impact is caused by deposition of acidifying pollutant on soil, water, organisms, ecosystems & materials such as *sulphur* and *nitrogen*.	**kg SO_2- Eq.**
Eutrophication Potential (EP)	This category cover all impacts of high environmental levels of macronutrients (*phosphorous* and *nitrogen*) causing high biomass production in aquatic and terrestrial ecosystems. For example air pollutants, wastewater etc.	**Kg phosphate-Eq.**
Ozone Depletion Potential (OZP)	This impact arises with the increased ultraviolet radiation from the sun which depletes the ozone layer when *CFCs* and *HCFCs* reach the stratosphere.	**kg R11- Eq.**
Abiotic Depletion Elements (ADP Elements)	This category describes the reduction of the global amount of non-renewable raw materials. It covers the availability of natural elements in general.	**kg Sb-Eq.**
Abiotic Depletion Fossil (ADP Fossil)	This category indicator is related to the use of fossil fuels (oil, coal and natural gas) lost from reserves.	**MJ**
Human Toxicity Potential (HTP)	This category covers the impact on human health of all toxic substances emitted to air, water and soil.	**kg DCB-Eq.**
Photochemical Ozone Creation Potential (POCP)	This impact is caused by releases of hydrocarbons to atmosphere where produce ozone and can arise at any stage of the life cycle.	**kg Ethene- Eq.**

Table 1 Impact categories indicators generated by **ECOHESTIA**

The reliability of the **EcoHestia** results originates from the fact that its database is based on the characteristics of the local construction industry and on primary data provided by local product manufacturers. Additionally, the impact from the energy consumed for the manufacturing of the building materials is also representative of the country's energy mix, whereas the fuel required for the transportation of the materials is also according to the country's specifics.

If it is to be used effectively, it is also important to understand the limitations of **EcoHestia**. Primarily, the **EcoHestia** values reflect the fact that the impact category results are based on a relative approach and that they present potential environmental effects, rather than predict actual impacts. At the present phase, the database of **EcoHestia** is comprised of 21 LCAs of construction materials and building elements. These represent a very limited number of LCAs of building elements for the implementation of whole- building analysis, however additional LCAs of construction materials and building elements are anticipated to be developed and incorporated into **EcoHestia**.

How to use EcoHestia

EcoHestia determines the level of sustainability of any building in a four step process:

1. **Introduction of the construction materials' quantities (in kg)** required for the construction of the whole building
2. **Computation of the environmental impacts** of the building by **EcoHestia**
3. **Assessment of different technical building design options**
4. **Optimisation of building design** according to the objectives.

Inputs	Quantities	Units
Raw materials		
Clay	0.740	kg
Red Clay	0.260	kg
Water	0.130	kg
Additives	0.020	kg
Energy		
Electricity from HFO (KWh)	0.908	kWh
Diesel	0.00064	kg
Transportation		
Transport(ELCD) of Clay	4.75	km
Transport(ELCD) of Red Clay	18.20	km

Table 2 Data Inventory for the production of 1 kg of clay brick - Input

Outputs		
Materials		
Product (Brick)	1	kg
Emissions		
Inorganic emissions to air		
Carbon dioxide (CO2)	0.373	kg
Carbon monoxide (CO)	1.2×10^{-4}	kg
Nitrogen oxides (NO_x) (eq. NO_2)	7.21×10^{-4}	kg
Nitrogen (atmospheric nitrogen)	4.29×10^{-6}	kg
Oxygen	2.99×10^{-5}	kg
Sulphur dioxide (SO_2)	0.00206	kg
Water vapour	0.482	kg
Water (evapotranspiration)	0.0833	kg
Organic emission to air (group VOC)		
Methane (CH4)	3.61×10^{-4}	kg
Other emission to air		
Exhaust	1.47	kg
Particle to air		
Dust (PM2,5-PM10)	2.2×10^{-5}	kg
Dust (PM2,5)	3.95×10^{-5}	kg

Table 3 Data Inventory for the production of 1 kg of clay brick - Output

The methodology followed for the implementation of the LCA of a single building element for its incorporation in the **EcoHestia** database is presented for the case of clay brick. Table 2 presents the Life Cycle Inventory (LCI) for the production of 1 kg of clay brick (Functional unit). The LCI consists of a detailed tracking of all the in- and out- flows of the system under investigation. Input flows typically consist of raw materials and energy in different forms, while the output flows may include useful products, solid and water- borne wastes, atmospheric emissions, and other waste streams. Figure 1 present the Sankey diagram indicating the processes involved in the manufacturing of clay brick, as well as the mass balance for the manufacturing of 1 kg of clay brick.

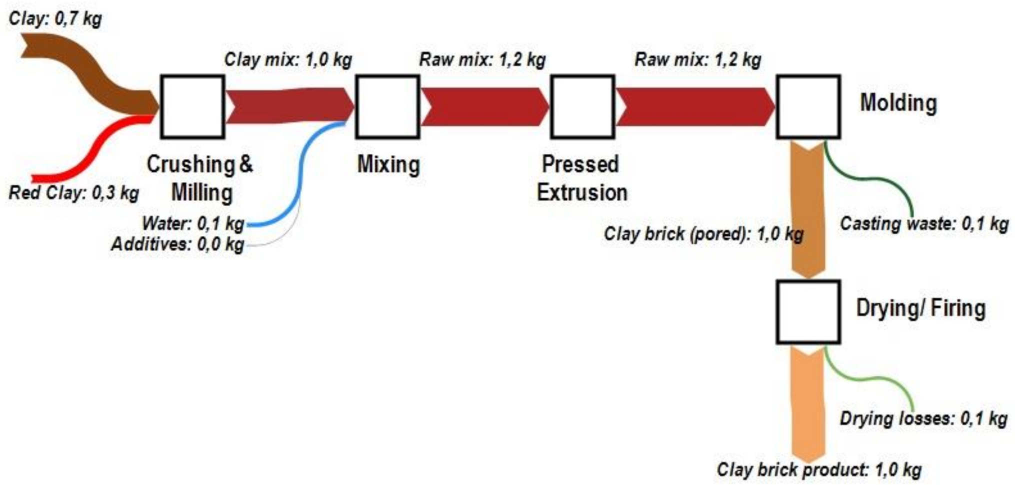


Figure 1 Sankey diagram of the mass balances for the production of 1 kg of clay brick

Case Studies

Provided as examples of the effectiveness and usefulness of the environmental building assessment tool **EcoHestia**, two case studies of whole- building LCAs are presented.

Case Study 1

The LCA of a level- ground, two- storey residential building located in Paralimni, Cyprus was implemented using **EcoHestia**. The total useful floor area of the building is 374 m^2, including both covered and uncovered areas, while the total height of the building is 7.5 m. According to the Bill of Quantities (BoQ), the main construction consists of concrete, brickwork, and plaster. Polystyrene was employed for building insulation purposes, and plasterboard was used between the internal walls. Also, the building has a flat roof with asphalt membrane polyester. The **EcoHestia** generated results for the case study building 1 are presented in Table 3. The table indicates the life- cycle impact of each of the building's element for the selected impact categories, based on the quantities provided by the user and the KPIs of the tool.

A/A	Description	Quantity	Unit	GWP [kg CO2-Equiv.]	AP [kg SO2-Eq.]	EP [kg Phosphate-Eq.]	ODP [kg R11-Eq.]	ADP Elements [kg Sb-Eq.]	ADP Fossils [MJ]	HTP [kg DCB-Eq.]	POCP [kgEthene-Eq.]
A	**Concrete Works**										
	C20-25 (p=2400)	173	m^3	3.43E+05	2.80E+06	9.96E+05	1.66E+06	1.33E+05	4.24E+06	3.50E+04	1.49E+06
	C30-35 (p=2400)	100	m^3	2.02E+05	1.65E+06	5.88E+05	9.55E+05	7.73E+04	2.50E+06	2.07E+04	8.76E+05
B	**Reinforcement**	21807	kg	4.23E+04	2.51E+02	1.13E+05	2.03E+05	5.71E+04	8.22E+05	3.10E+03	1.44E+05
C	**Brickwork**										
	Brick 30cm thermal /14.20kg	148	m^2	9.03E+03	6.69E+04	8.61E+03	1.77E+05	2.74E+04	1.12E+05	9.33E+02	3.67E+04
	Brick 25cm thermal / 13.90kg	39	m^2	2.78E+03	2.06E+04	2.66E+03	5.46E+04	8.44E+03	3.47E+04	2.88E+02	1.13E+04
	Brick 20cm / 5.45kg	122	m^2	4.28E+03	3.17E+04	4.08E+03	8.39E+04	1.30E+04	5.33E+04	4.42E+02	1.74E+04
D	**Plasterboard (10cm)**	10.20	m^2	1.11E+04	9.14E+01	3.12E+03	5.12E+03	8.93E+02	1.39E+05	1.15E+03	4.88E+03
F	**Insulation**										
	Polystyrene (5cm)	519	m^2	6.38E+04	1.34E+05	1.35E+05	4.17E+04	1.84E+05	2.51E+06	2.71E+03	2.44E+05
G	**Plaster**	1013	m^2	5.93E+03	3.29E+04	1.25E+05	1.28E+05	1.62E+03	5.45E+04	4.13E+02	1.75E+04
H	**Interior Painting**	717	m^2	3.69E+01	1.03E+02	1.29E+02	1.08E+02	1.17E+02	1.16E+03	1.53E+00	2.03E+02
I	**Exterior Painting**	388	m^2	3.37E+01	8.85E+01	1.18E+02	1.04E+02	1.16E+02	1.08E+03	1.33E+00	1.86E+02
J	**Windows**	47.5	m^2	1.72E+03	8.27E+03	6.60E+03	2.29E+03	7.14E+03	2.30E+04	8.83E+01	5.59E+03
K	**PVC**	93	m^2	2.57E+01	6.62E+01	6.61E+01	1.23E+02	1.00E+02	5.30E+02	1.19E+00	8.09E+01
	TOTAL			6.85E+05	4.74E+06	1.98E+06	3.32E+06	5.10E+05	1.05E+07	6.48E+04	2.84E+06

Table 3 ECOHESTIA results for case study building 1

A/A	Description	Quantity	Unit	GWP [kg CO2-Equiv.]	AP [kg SO2-Equiv.]	EP [kg Phosphate-Equiv.]	ODP [kg R11-Equiv.]	ADP Elements [kg Sb-Equiv.]	ADP Fossils [MJ]	HTP [kg DCB-Equiv.]	POCP [kgEthene-Equiv.]
A	**Concrete Works**										
	C20-25 (p=2400)	163	m^3	3.23E+05	2.64E+06	9.39E+05	1.57E+06	1.25E+05	3.99E+06	3.30E+04	1.40E+06
	C30-35 (p=2400)	221	m^3	4.46E+05	3.64E+06	1.30E+06	2.11E+06	1.71E+05	5.52E+06	4.57E+04	1.94E+06
B	**Reinforcement**	51000	kg	9.89E+04	5.87E+02	2.63E+05	4.75E+05	1.34E+05	1.92E+06	7.24E+03	3.37E+05
C	**Brickwork**										
	Brick 30cm thermal /14.20kg	109	m^2	6.65E+03	4.93E+04	6.34E+03	1.30E+05	2.01E+04	8.28E+04	6.87E+02	2.70E+04
	Brick 25cm thermal / 13.90kg	133	m^2	9.50E+03	7.04E+04	9.05E+03	1.86E+05	2.88E+04	1.18E+05	9.82E+02	3.86E+04
	Brick 20cm / 5.45kg	171	m^2	1.80E+04	1.33E+05	1.71E+04	3.53E+05	5.45E+04	2.24E+05	1.86E+03	7.32E+04
D	**Plasterboard (10cm)**	208	m^2	2.26E+05	1.86E+03	6.36E+04	1.04E+05	1.82E+04	2.82E+06	2.34E+04	9.94E+04
F	**Insulation**										
	Polystyrene (5cm)	227	m^2	2.79E+04	5.86E+04	5.92E+04	1.82E+04	8.03E+04	1.10E+06	1.19E+03	1.07E+05
G	**Plaster**	1920	m^2	1.12E+04	6.24E+04	2.37E+05	2.43E+05	3.07E+03	1.03E+05	7.83E+02	3.32E+04
H	**Interior Painting**	615	m^2	3.17E+01	8.87E+01	1.11E+02	9.30E+01	1.01E+02	9.99E+02	1.31E+00	1.74E+02
I	**Exterior Painting**	485	m^2	4.21E+01	1.11E+02	1.48E+02	1.30E+02	1.45E+02	1.36E+03	1.66E+00	2.32E+02
J	**Aluminium**	92	m^2	1.74E+04	1.32E+02	1.32E+02	4.71E+03	7.26E+03	4.22E+03	2.10E+05	1.25E+04
K	**Windows**	54	m^2	1.68E+03	8.09E+03	6.45E+03	2.24E+03	6.98E+03	2.25E+04	8.63E+01	5.46E+03
L	**PVC**	87	m^2	2.41E+01	6.19E+01	6.18E+01	1.15E+02	9.37E+01	4.96E+02	1.12E+00	7.57E+01
	TOTAL			1.19E+06	6.67E+06	2.90E+06	5.20E+06	6.49E+05	1.59E+07	3.25E+05	4.07E+06

Table 4 ECOHESTIA results for case study building 2

Case Study 2

The second case study building is also level- ground, two- storey residential building located in Strovolos area, Nicosia. The useful floor area is 315 m^2, including covered and uncovered areas. The building height is 11.5 m. The masonry of the building is made up of concrete, brickwork and plaster. Furthermore, polystyrene was used as an insulation material, and plasterboard as a roof in all the building's floors. Also, the building's doors and windows are made from aluminium. The generated **EcoHestia** results for the LCA of the case study building are presented in Table 4.

References

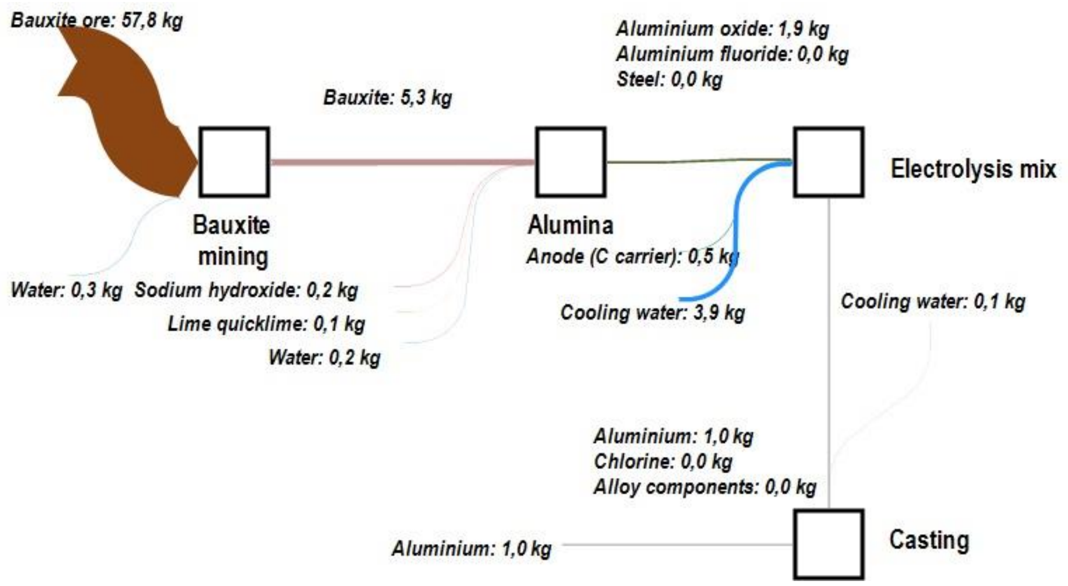
ISO (International Organization for Standardization). 2006. ISO 14040:2006– Environmental Management- Life Cycle Assessment- Principles and Framework.

GaBi. 2015. Software-System and Databases for Life Cycle Engineering. Version 6.0.Stuttgart,Echterdignen.

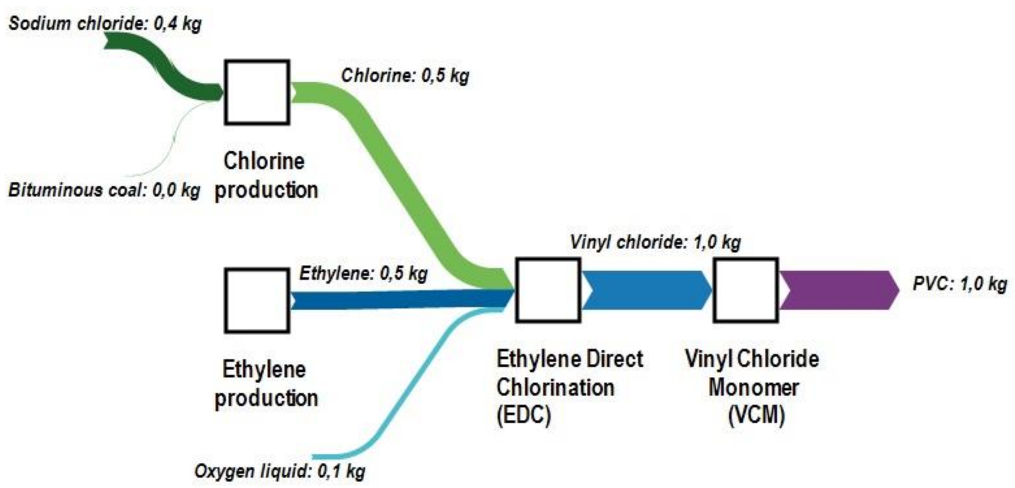
Annex

Mass Balances of selected building materials

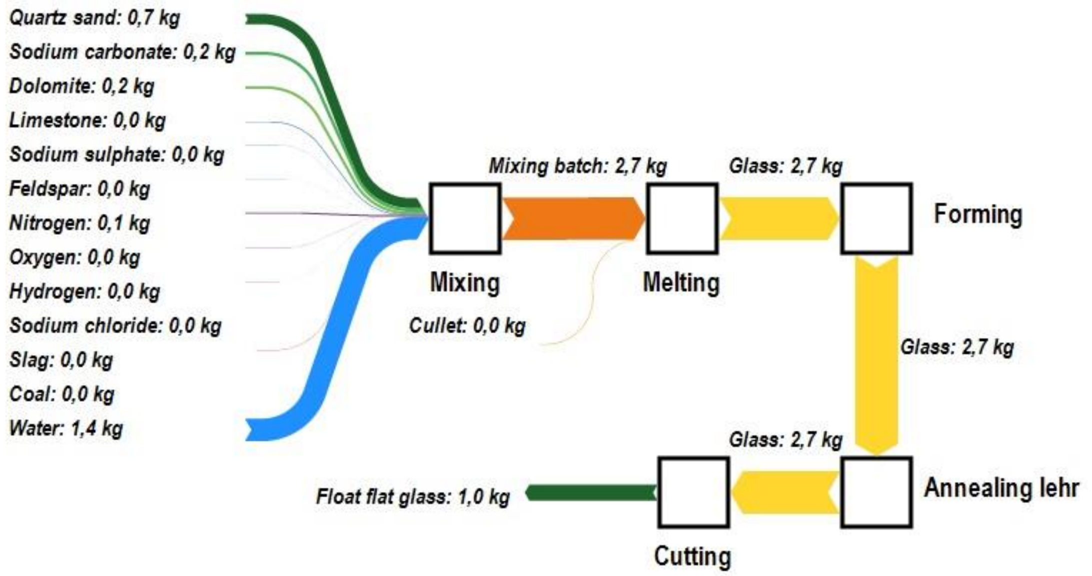
Aluminium



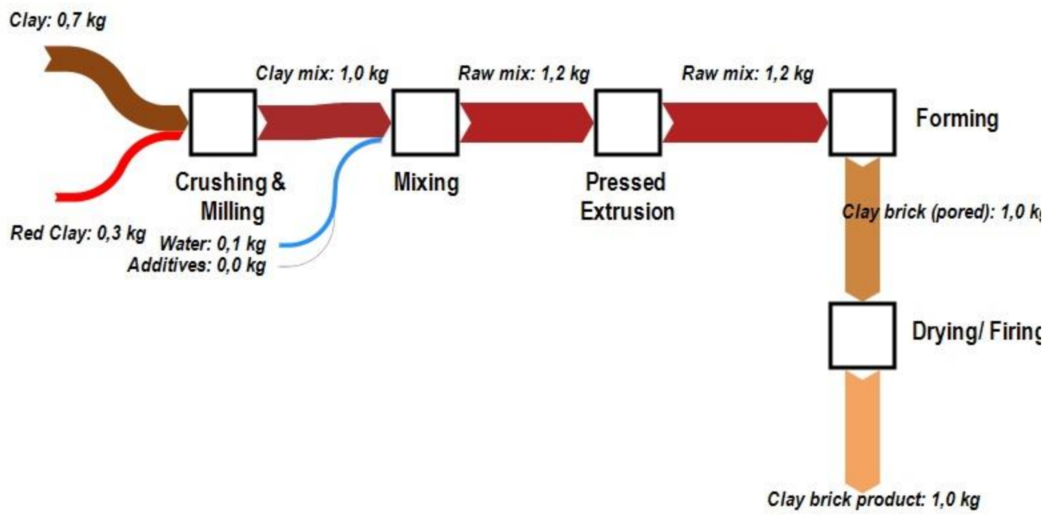
PVC



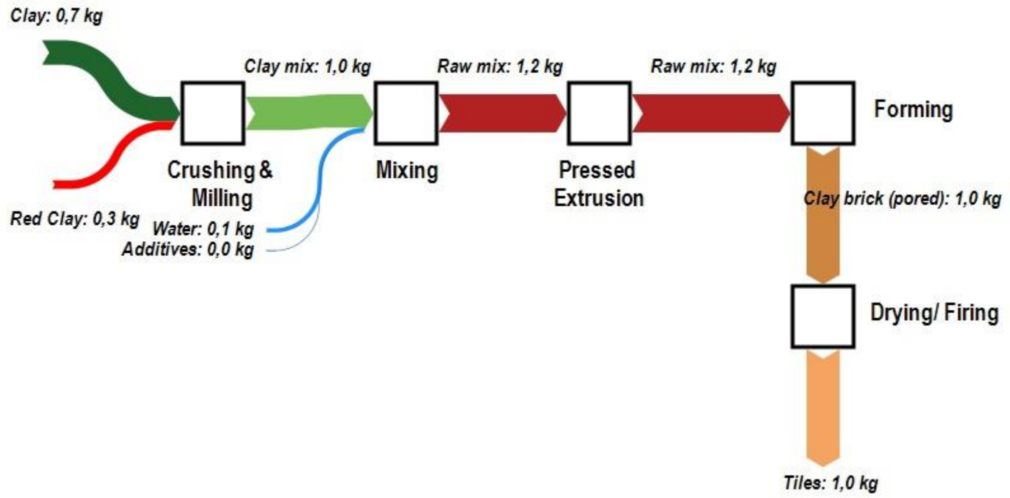
Float Flat Glass



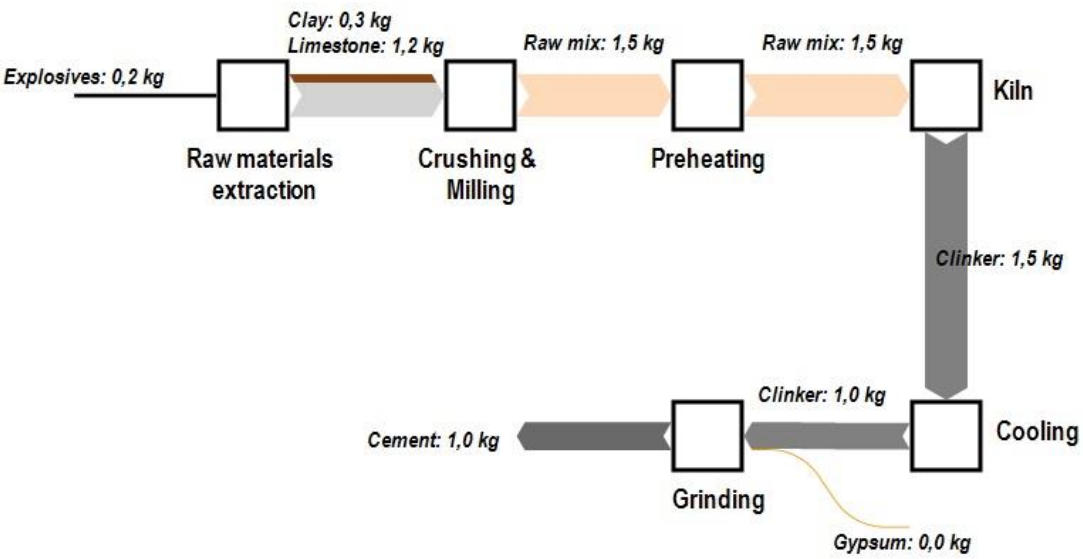
Brick



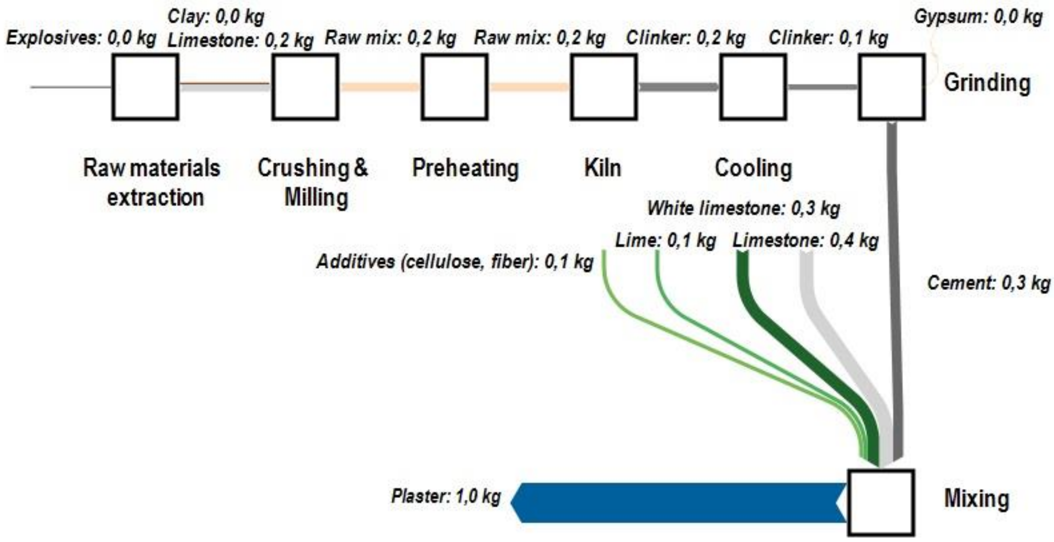
Tiles



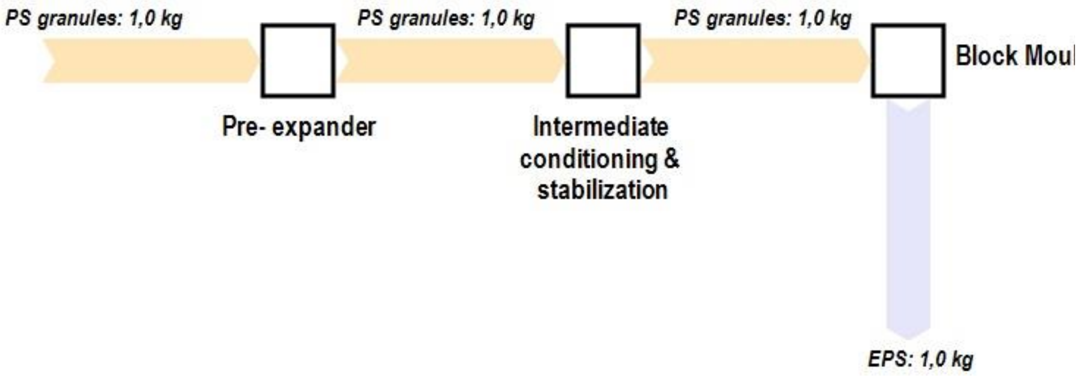
Cement



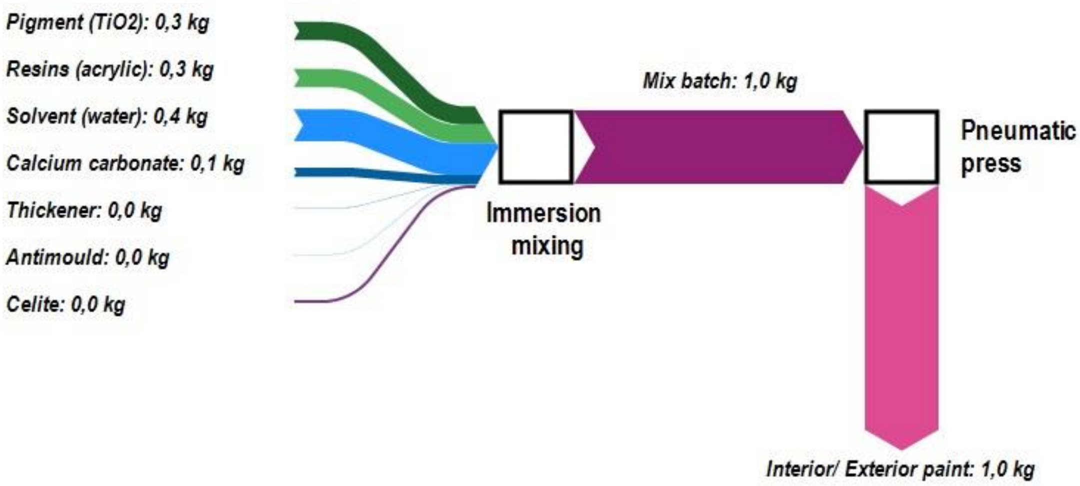
Plaster



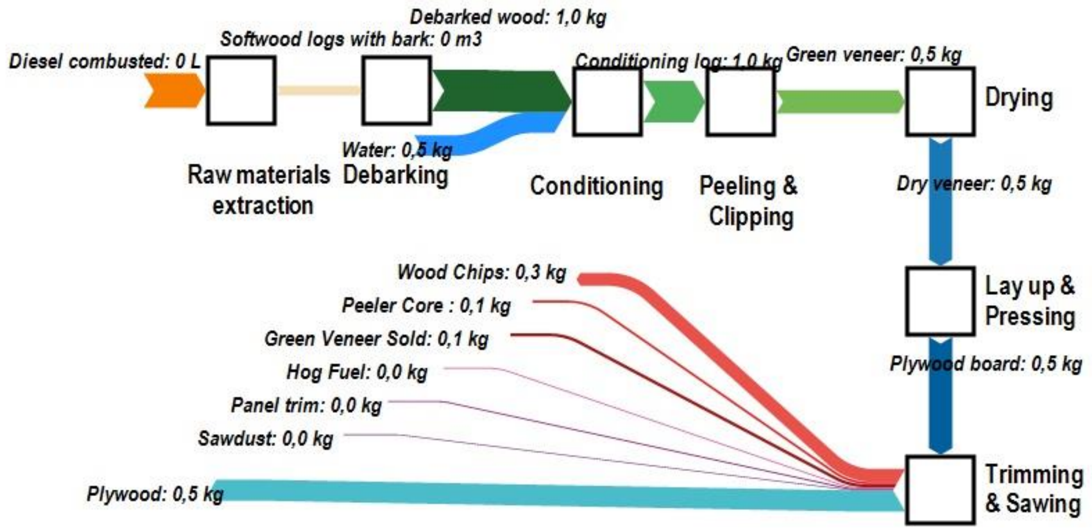
EPS



Paint



Plywood



Steel