Building refurbishment: comparison of bio-based materials, conventional materials and new construction scenarios

Methodological approach to the LCA calculation

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The LCA was developed in compilance with the ISO 14040 [1], 14044 [2] standard and the EN 15978 [3] (building LCA), and the EN 15804 [4] (construction product LCA). These standards organize the information related to the building life cycle into **Modules** (so called Information Modules). They are organized according to the following criteria (see Figure 1):

- **Module A,** includes the information (impacts) related to the product and building construction stage.
- **Module B**, includes the information (impacts) related to the building use stage.
- **Module C,** includes the information (impacts) related to the building end of life stage.
- **Module D,** includes the information (impacts) related to the benefits beyond the system (e.g., recycling and reuse of materials, production of energy tranfered to the grid).

When considering the LCA of refurbishment process several particuarities arise. One of them is the difficulty/complexity in obtaining information related to the existing building to conduct a complete LCA following the current standards (see Figure 1). Thus, the present study focused the LCA of the refurbishment process in calculating the impacts of the partial / total demolition, transport and final disposal of the existing building (**Module C** including C1, C2, C4), the impacts of the product and construction stages (**Module A** including A1, A2, A3, A4 and A5) and the impacts of the total demolition, transport and final disposal of the existing building (**Module C** including C1, C2, C4) of the Refurbished Building (excluding the remaining materials and elements of the original building).

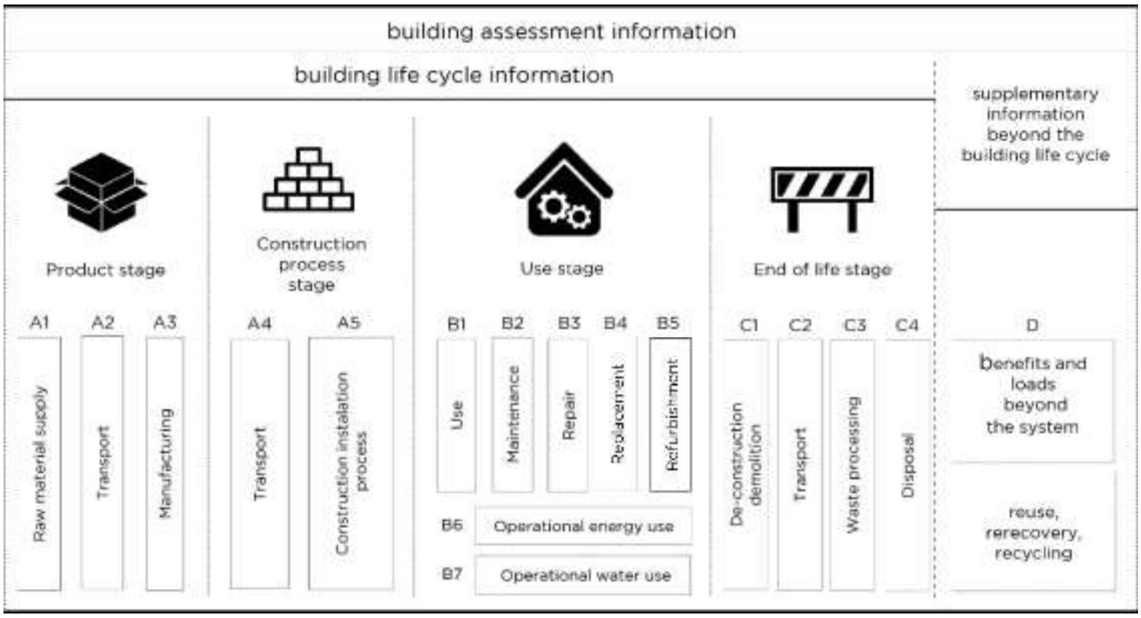


Figure 1. Life Cycle Assessment Information Modules. Source EN 15978 [3].

This LCA modularity organization of the refurbished building is based on the study conducted by Frey et al. [5], and collecetd by Hasik et al. [6] as a methodological approch to compare the benefit of renovation/ refurbishment vs new construction.

The present LCA compared three options: 1) a renovation scenario with bio-based materials, 2) a renovation scenario with conventional materials and 3) the new building construction and complete demolition of the existing. Figure 2 and 3 ilustrates the LCA Information **Modules** included in the LCA to each compared options.

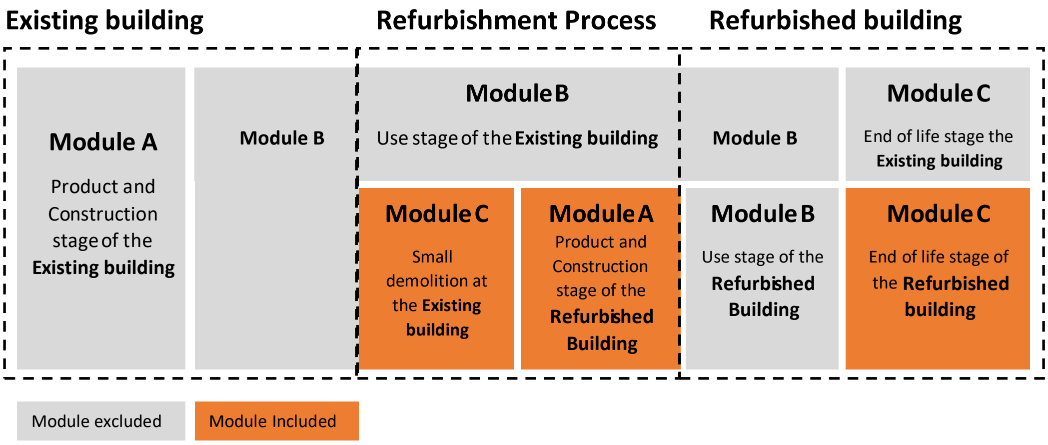


Figure 2. Life Cycle Assessment Information Modules included in the study Option 1 and 2. Source based on [5,6].

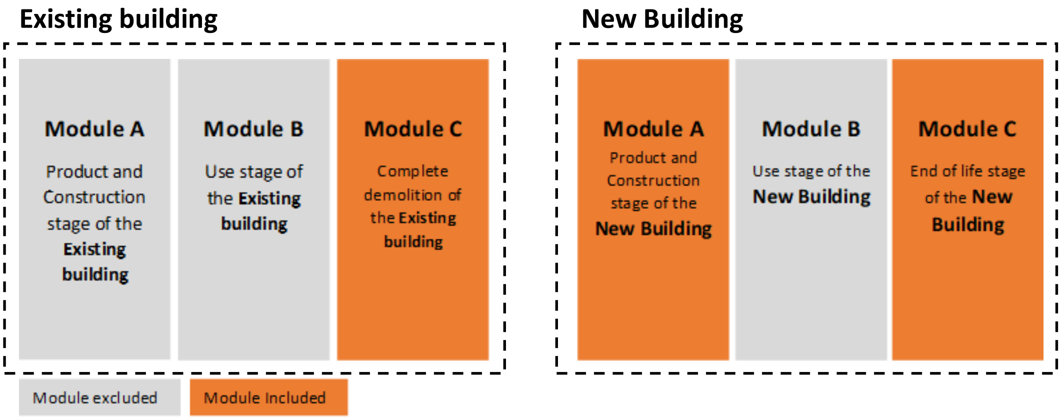


Figure 3. Life Cycle Assessment Information Modules included in the study Option 3. Source based on [5,6].

1. Goal and scope definition

Functional unit	complete building, it is recommended to transform the results to impact square meter (dividing the results by GFA of the building).
Building service life	50 years (according to CTE [7])
System Boundaries	Embodied Impacts produced by the building materials. A1-A3, A4, A5 and C1, C2 and C4.

2. Life Cycle inventory

LCA calculation Sofware	Excel
LCA database	Ecoinvent v 1.2

a. Assumptions

Transport to site / to end of life	
Process	unit process (Ecoinvent v1.2)
	transport, lorry 16t
Construction and deconstruction process	
Construction waste production	5% of building materials
Energy and fuel consumption	Calculation based on [8].

End of life scenario definition	
Bio-based materials	100% Incineration
Other materials	100% landfill
Distance to landfill / incineration	40 m

b. List of materials and inventory assumptions (refurbishment bio-based materials)

Listed material	Adapted materials to the ecoinvent v1.2
Stone	Basalt
FEL'X	Bitumen
Brick	Brick
Cement	Cement
Ceramic tile	Ceramic tile
Cork	Cork
Demolition (pre-construction)	Inert material
Glass	Glass
Gravel	Gravel
Gypsum	Gypsum
Limestone	Limestone
Cane	Log (cane)
EPDM	Polyethylene
Polystyrene	Polystyrene
Polystyrene	Sand
Metal	Steel
Straw	Straw
Wood	Wood
Rammed earth (composition based on [9], sand, 61.3%, Clay 34.4%,Straw 0.44%, Lime 3.7%)	Straw
	Lime
	Clay
	Sand (wall)

c. Materials and unit process inventory

Material (ecoinvent v1.2)	Input process (ecoinvent v1.2)	Output process (ecoinvent v1.2)
basalt	basalt, at mine	disposal, inert material, 0% water, to sanitary landfill
bitumen	bitumen, at refinery	disposal, bitumen, 1.4% water, to sanitary landfill
brick	brick, at plant	disposal, building, brick, to final disposal
cement	cement, unspecified, at plant	disposal, building, cement (in concrete) and mortar, to final disposal
Ceramic tile	ceramic tiles, at regional storage	disposal, building, brick, to final disposal
Clay (Rammed earth)	clay, at mine	disposal, inert material, 0% water, to sanitary landfill

cork	cork slab, at plant	disposal, building, waste wood, untreated, to final disposal
demolition (pre-construction)		disposal, inert material, 0% water, to sanitary landfill
glass	flat glass, coated, at plant	disposal, building, glass sheet, to final disposal
gravel	gravel, round, at mine	disposal, building, concrete gravel, to final disposal
gypsum	gypsum, mineral, at mine	disposal, gypsum, 19.4% water, to inert material landfill
lime (Rammed earth)	lime, hydrated, loose, at plant	disposal, inert material, 0% water, to sanitary landfill
limestone	limestone, at mine	disposal, limestone residue, 5% water, to inert material landfill
log (Cane)	logs, softwood, at forest	disposal, building, waste wood, chrome preserved, to final disposal
polyethylene	fleece, polyethylene, at plant	disposal, building, polyethylene/polypropylene products, to final disposal
polystyrene	polystyrene, expandable, at plant	disposal, polystyrene, 0.2% water, to sanitary landfill
sand	sand, at mine	disposal, building, cement (in concrete) and mortar, to final disposal
sand (Rammed earth)	silica sand, at plant	disposal, inert material, 0% water, to sanitary landfill
steel	steel, low-alloyed, at plant	disposal, steel, 0% water, to inert material landfill
straw (Rammed earth)	straw organic, at farm	disposal, building, waste wood, chrome preserved, to final disposal
straw	straw organic, at farm	disposal, inert material, 0% water, to sanitary landfill
wood	sawn timber, softwood, raw, kiln dried, u=20%, at plant	disposal, building wood, chrome preserved, 20% water, to municipal incineration

d. List of materials and inventory assumptions (refurbishment conventional materials and new building)

Listed material	**Adapted materials to the ecoinvent v1.2**
Aluminium	Aluminium
Brick	Brick
Cement	Cement
Ceramic Tile	Ceramic tile

Demolition (pre-construction)	Inert material
Glass	Glass
Gravel	Gravel
Gypsum	Gypsum
EPDM	Polyethylene
Polystyrene	Polystyrene
Polystyrene	Sand
Metal	Steel
Wood	Wood

3. Life Cycle Impact Assessment

Impact assessment	
Method	CML 2001 (Ecoinvent v 1.2)
Impact categories	acidification potential (kg SO2-Eq) climate change (kg CO2-Eq) eutrophication potential (kg PO4-Eq) freshwater aquatic ecotoxicity (kg 1,4-DCB-Eq) human toxicity (kg 1,4-DCB-Eq) stratospheric ozone depletion (kg CFC-11-Eq)
Biogenic carbon	Included (approach -1/+1 [10]) based on EN 16449 [11]

4. Life Cycle Assessment Results

4.1. Modules evaluated in Option 1 and Option 2

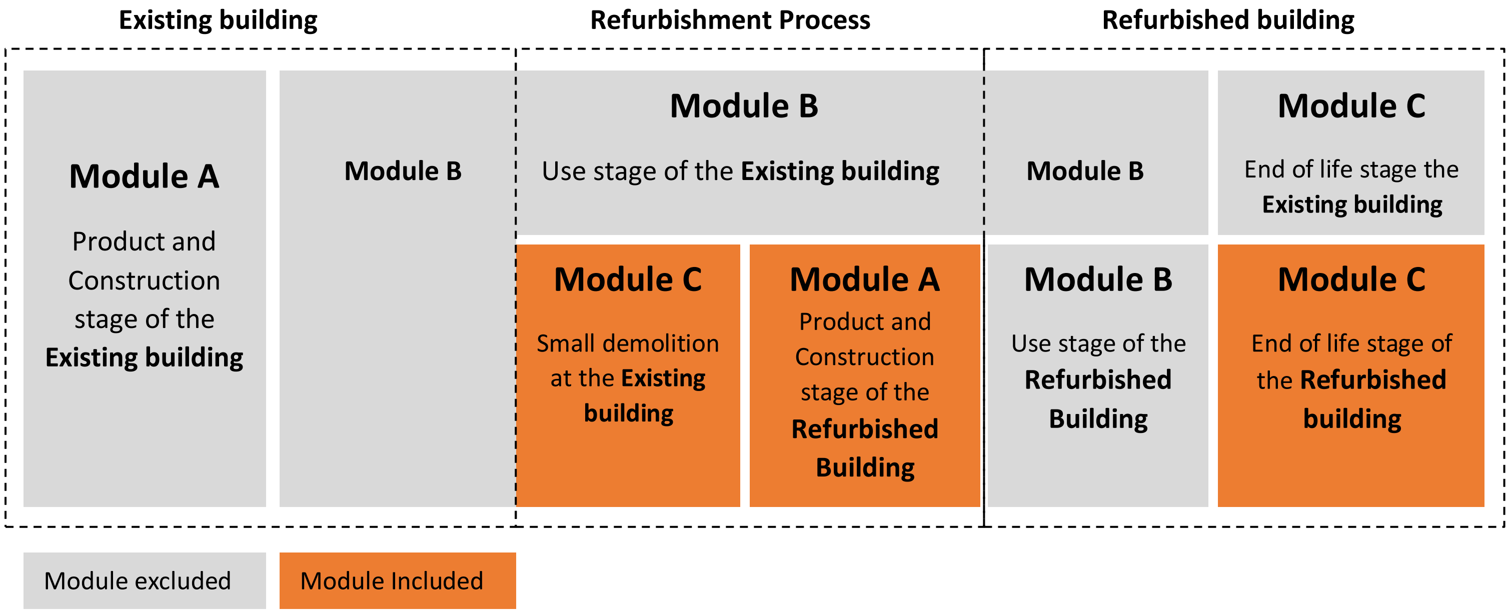


Table 1. Impacts on Option 1: Refurbishment with Bio-Based materials

Refurbishment with Bio-Based materials							
Information Module	LCA Stage	Acidification Potential	Climate Change	Eutrophication Potential	Freshwater aquatic ecotoxicity	Human Toxicity	Stratospheric ozone depletion
		kg SO2-Eq	kg CO2-Eq	kg PO4-Eq	kg 1,4-DCB-Eq	kg 1,4-DCB-Eq	kg CFC-11-Eq
Small Demolition at the existing building							

C	**C1**	**Small demolition**	34,055	1525,911	1,662	82,896	534,357	0,000113542
	C2	**Transport to final disposal**	3,927	592,304	0,644	33,242	121,920	0,000069618
	C4	**Final disposal**	2,274	298,596	0,369	13,593	100,292	0,000076752
Refurbished building								
A	**A1/A2/A3**	**Product**	23,404	2098,593	2,845	289,481	1084,192	0,000486415
A	**A4**	**Transport to Construction site**	17,126	2583,014	2,810	144,965	531,688	0,000303600
	A5	**Construction**	51,712	4731,662	6,929	950,762	1849,283	0,000388881
C	**C1**	**Demolition**	47,663	4211,605	4,587	228,797	1474,857	0,000313384
	C2	**Transport to final disposal**	8,056	1215,014	1,322	68,190	250,099	0,000142809
	C4	**Final disposal**	8,212	5324,190	1,386	842,691	402,066	0,000209986

Table 2. Impacts on Option 2: Refurbishment with conventional materials

Refurbishment with conventional materials								
Information Module		**LCA phase**	**acidification potential**	**climate change**	**eutrophication potential**	**freshwater aquatic ecotoxicity**	**human toxicity**	**stratospheric ozone depletion**
			kg SO2-Eq	kg CO2-Eq	kg PO4-Eq	kg 1,4-DCB-Eq	kg 1,4-DCB-Eq	kg CFC-11-Eq
Small demolition at the existing building								
C	**C1**	**Small demolition**	45,652	3814,777	4,155	207,239	1335,892	0,000283856
	C2	**Transport to final disposal**	9,818	1480,760	1,611	83,104	304,800	0,000174044
	C4	**Final disposal**	5,684	746,490	0,922	33,983	250,730	0,000191880
Refurbished building								
A	**A1/A2/A3**	**Product**	109,321	24343,018	9,827	2507,463	5454,036	0,001807663
	A4	**Transport to Construction site**	20,965	3161,975	3,439	177,458	650,862	0,000371649
	A5	**Construction**	55,964	5292,113	7,327	6701,470	1896,253	0,000401121
C	**C1**	**Demolition**	42,678	3824,543	4,399	195,700	1433,549	0,000299799
	C2	**Transport to final disposal**	8,273	1247,693	1,357	70,024	256,825	0,000146650
	C4	**Final disposal**	9,632	12579,247	1,619	6447,481	651,124	0,000229151

4.2. Modules evaluated in Option 3

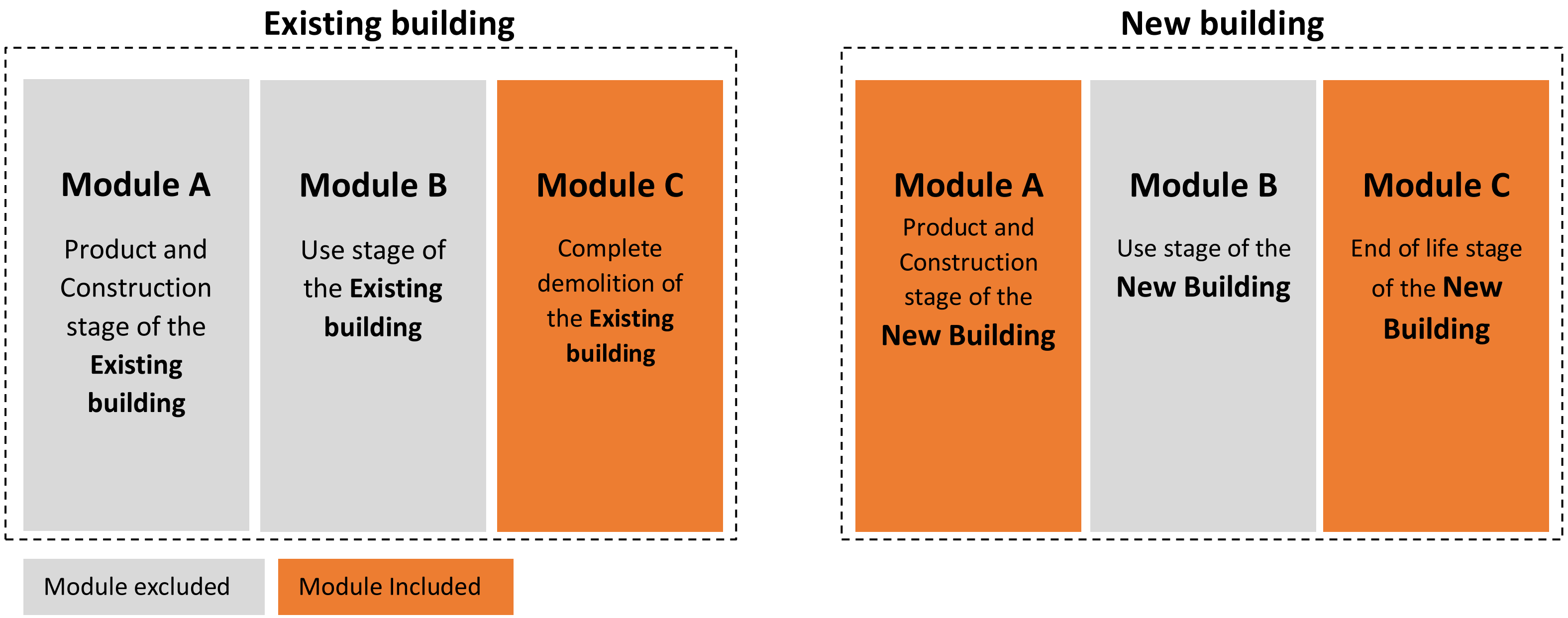


Table 3. Impacts on Option 3: Complete substitution of the existing building by a new construction

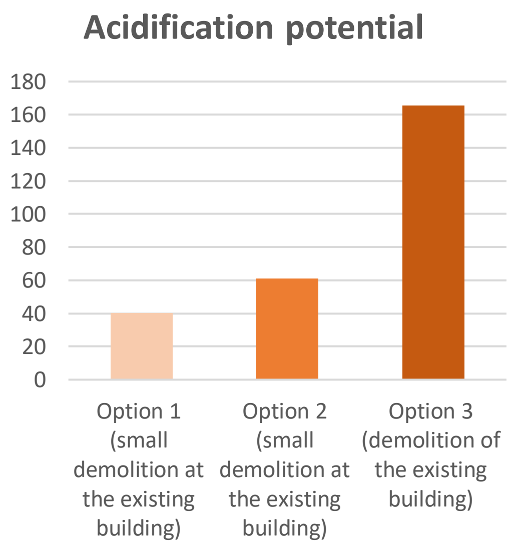
Complete substitution of the existing building by a new construction								
Information Module		**LCA phase**	**acidification potential**	**climate change**	**eutrophication potential**	**freshwater aquatic ecotoxicity**	**human toxicity**	**stratospheric ozone depletion**
			kg SO2-Eq	kg CO2-Eq	kg PO4-Eq	kg 1,4-DCB-Eq	kg 1,4-DCB-Eq	kg CFC-11-Eq
Total Demolition of the existing building								
	C1	**Demolition**	103,639	15259,108	16,618	828,957	5343,570	0,001135424
	C2	**Transport to final disposal**	39,272	5923,040	6,443	332,416	1219,200	0,000696176

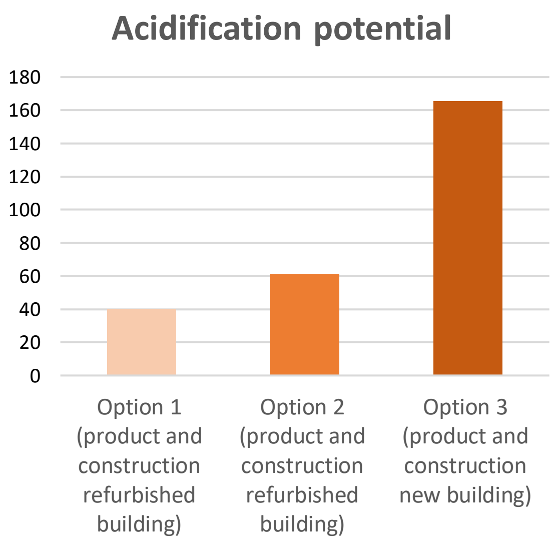
C	**C4**	**Final disposal**	22,737	2985,960	3,687	135,932	1002,920	0,000767520
New building								
A	**A1/A2/A3**	**Product**	146,450	39729,356	14,449	2771,280	6744,540	0,003098432
	A4	**Transport to Construction site**	48,424	7303,286	7,944	409,879	1503,310	0,000858406
	A5	**Construction**	**57,387**	5468,769	12,038	6854,150	1960,673	0,000435223
C	**C1**	**Demolition**	42,678	3824,543	4,399	195,700	1433,549	0,000299799
	C2	**Transport to final disposal**	31,939	4817,127	5,240	270,349	991,559	0,000566190
	C4	**Final disposal**	38,094	16112,370	6,330	6600,162	1939,521	0,000911183

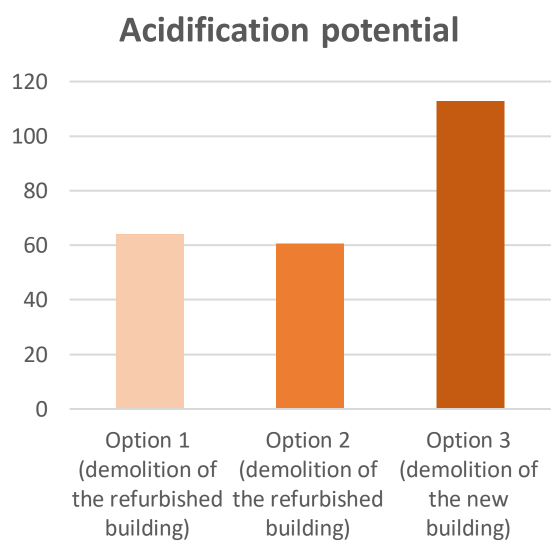
4.3. Comparison of the three options

Option 1	**Refurbishment with bio-based materials**
Option 2	**Refurbishment with conventional materials**
Option 3	**Substitution of the existing building by a new building**

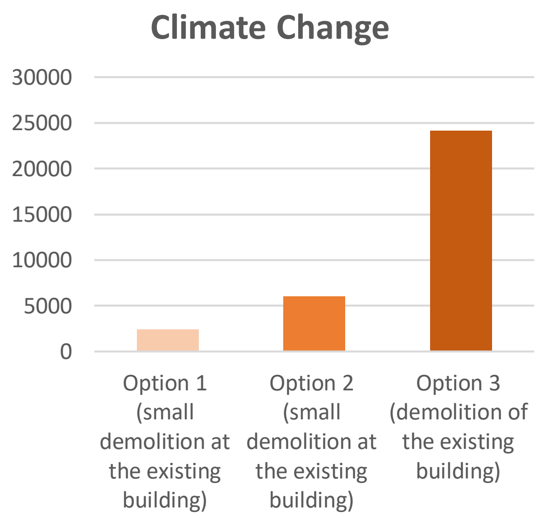
4.3.1. Acidification

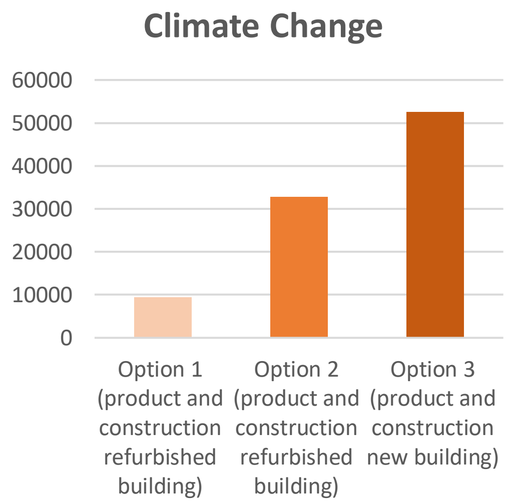


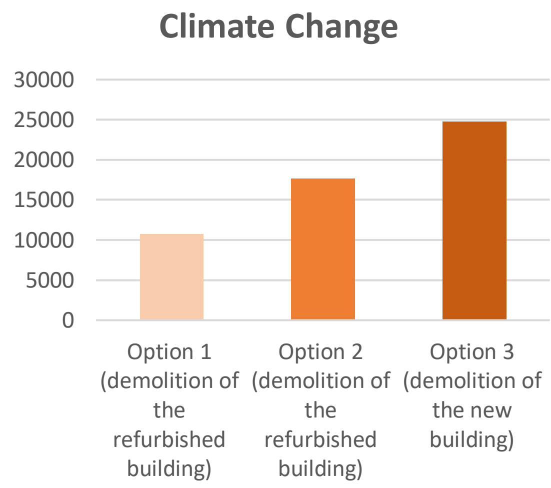




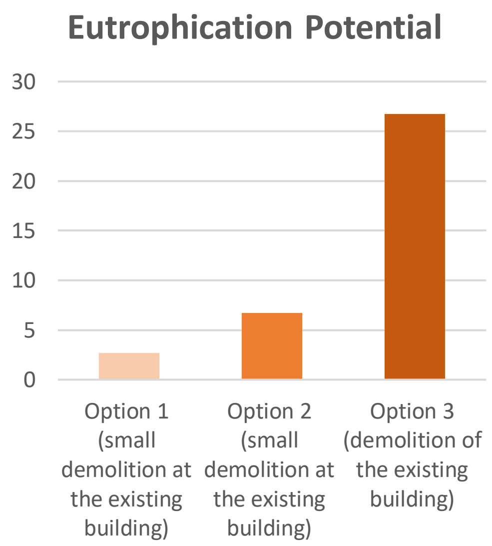
4.3.2. Climate change

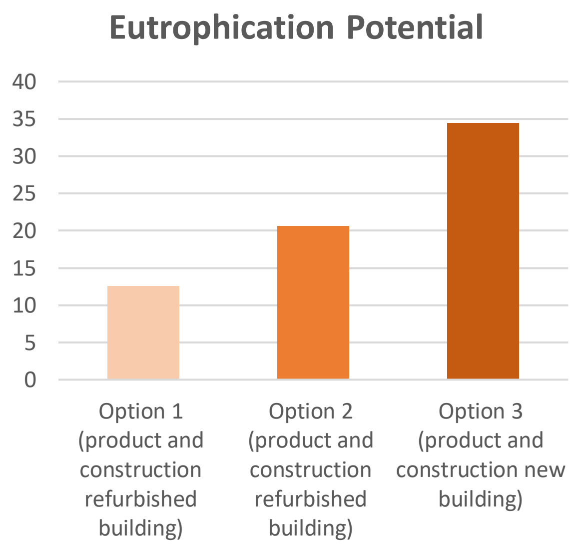


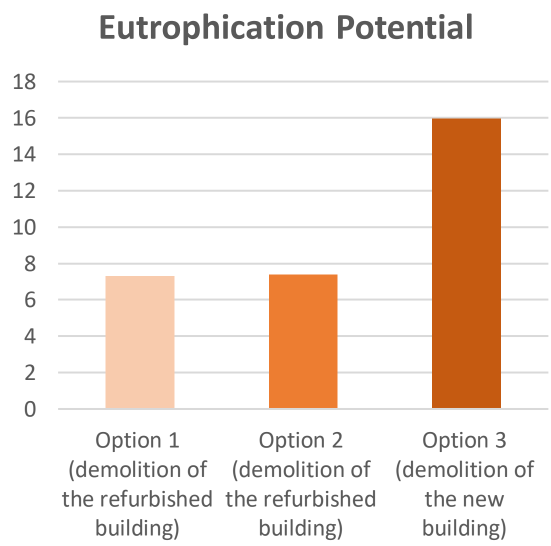




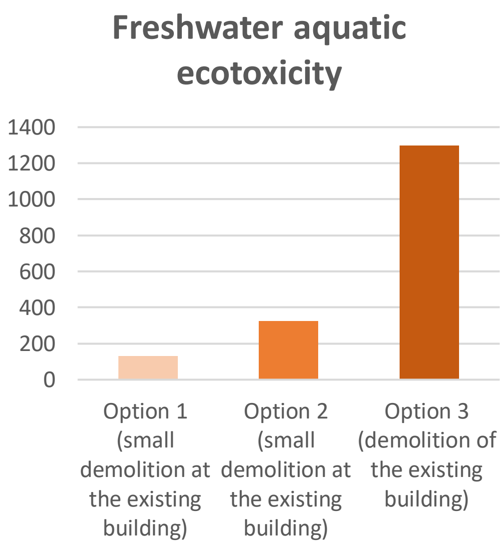
4.3.3. Eutrophication

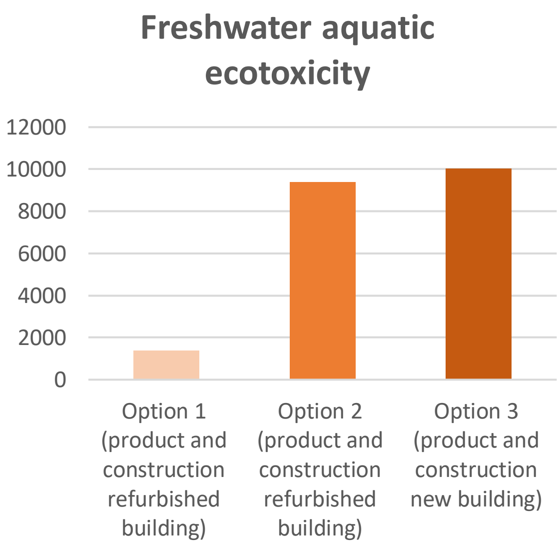


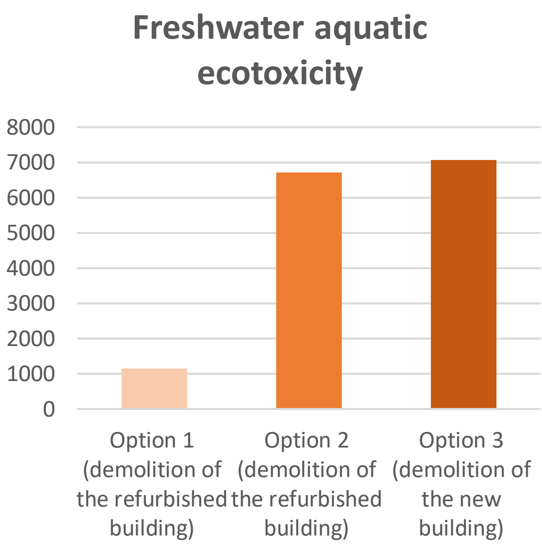




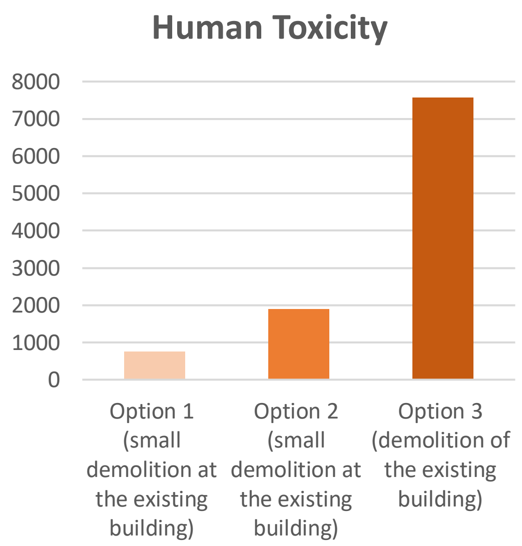
4.3.4. Freshwater aquatic ecotoxicity

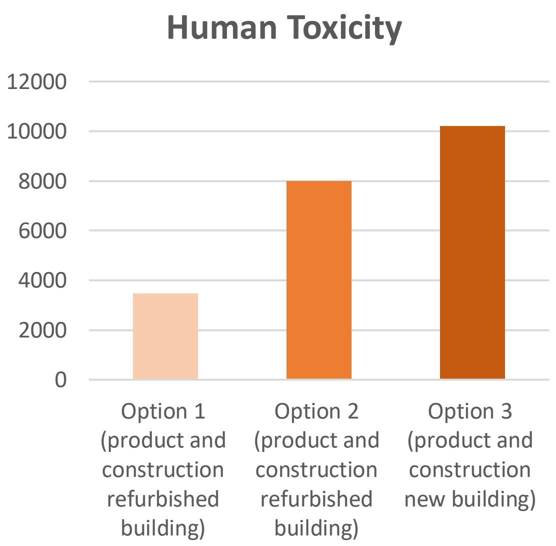


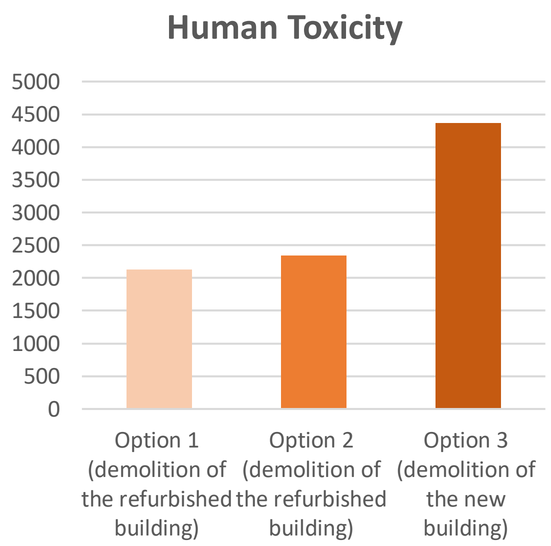




4.3.5. Human Toxicity







5. Conclusions

Three scenarios have been compared. Option 1 is the bio-based refurbishment project. Option 2 is a refurbishment project in which conventional materials would have been used, instead of the bio-based ones. Option 3 considers the demolition of the building and the construction of a new one.

The LCA has been carried out according to the ISO and EN standards and following the four phases (goals and scope definition, inventory, impact assessment and interpretation) and the modularity principles for building LCA. In addition, to provide a transparent analysis, we have attached the assumptions and data sources used in the analysis.

The results obtained provide evidence that the **Option 1:** renovation with bio-based materials produced the lowest impact in all the impact categories analysed and for all the information modules analysed (acidification, climate change, etc.). The only exception is the Acidification Potential at the demolition of the refurbished building. There, the Option 2 produces the lowest impacts, but with a minimum difference (6%) with Option 1. On the other hand, **Option 3:** Substitution of the existing building by a new building, is the one that caused the greatest impact in all the categories analysed and for all the information modules analysed.

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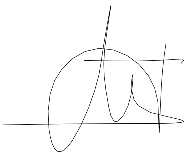

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