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Assessing the environmental performance of plastic-based and felt-based green wall systems in a life-cycle perspective

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22 growth medium and a system based on plastic modules with organic growth medium. The main  
23 impacts have been detected in the production stage and materials used in systems structure. By  
24 comparing the results achieved in the 16 impact categories analyzed, the felt-based system showed  
25 the highest overall impact, with the use of fertilizers and aluminum components playing a crucial  
26 part. Polypropylene used to produce the panels, water used for plant irrigation and potting soil  
27 composition are the main environmental impact contributors in the plastic-based system. The  
28 results pointed out the importance of accurate choice of materials for the design and production of  
29 green walls.

30

31 **Keywords:** Life Cycle Assessment; Green walls; Green infrastructure; Environmental  
32 performance; Sustainability.

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## 42        **1. Introduction and goals**

43        The world's population is growing and is expected to reach 9.3 billion by 2050, most of whom will  
44        be living in cities [1]. This high tendency to urban life reminds us of the need to revise urban  
45        development. 87% of energy consumption from non-renewable sources worldwide is allocated to  
46        the construction sector, 40% of Europe [2]. According to statistics provided by the United States  
47        Green Building Council (USGBC), commercial and residential buildings are responsible for 30%  
48        of greenhouse gas emissions and 65% of US electricity consumption [3]. Given the increasing  
49        environmental problems such as global warming, deforestation, waste generation, applying the  
50        construction sector's sustainability concept is of paramount importance [3]. All active and passive  
51        technologies must be used to design an energy-efficient building and minimize its energy  
52        consumption. The embodied energy, the energy sequestered throughout the life-cycle of buildings  
53        and materials, constitutes the most significant energy input in a building [4]. Given the widespread  
54        environmental impacts of the construction sector, it is necessary to consider efficient strategies to  
55        reduce energy consumption and its consequences throughout the life cycle [5]. The development  
56        of environmental friendly construction processes to save energy, reduce greenhouse gas emissions,  
57        reuse, and recycle materials is a fundamental goal of green construction [6]. Some governments  
58        and municipalities, and researchers see integrating green systems in building design as a viable  
59        solution to change this situation [7].

60        In recent years, the green walls system has been prevalent and used as a tool for urban space  
61        sustainability [8]. Green infrastructures can improve urban life quality and reduce the world's  
62        environmental impact caused by climate change [9, 10]. Building facades are an excellent option  
63        to green the dense urban areas and create a bond between nature and buildings [11]. The direct

64 impact on temperature regulation, wind speed reduction, and increased biodiversity in dense urban  
65 environments are among the benefits of greening the building envelope to improve energy  
66 efficiency [12]. Wind can reduce a building's energy efficiency by up to 50%, while a plant layer  
67 acts as a buffer by preventing wind from moving along the building's surface [11]. Moreover, direct  
68 sunlight is filtered through the leaves, preventing direct contact with the building's body. Such a  
69 natural cover layer lowers the buildings' temperature during the summer while hindering internal  
70 heat escape in the winter. On the other hand, green roofs and facades cool the heated air by  
71 evaporating [11, 13]. Greening the facades of buildings using plants also has aesthetic and  
72 environmental benefits [11]. These systems can reduce air pollution and improve air quality by  
73 capturing fine dust in the air [14, 15]. By using green façades in the building, some economic,  
74 social, and environmental benefits will be achieved, such as reducing greenhouse gas emissions,  
75 adapting to climate change, reducing the impact of heat island on urban environments [13],  
76 increasing biodiversity, thermal insulation, social and psychological well-being of city dwellers  
77 [16]. It should be noted that by reducing the indoor air temperature by 0.5 ° C, it would save up to  
78 8% on electricity consumption for air conditioning [9]. Also, using this system can reduce the  
79 building's electricity usage by 16% in the hot summer months [17]. Vegetation can also be used to  
80 decrease sound transmission [18].

81 One of the most effective tools for quantifying environmental issues is the Life Cycle Assessment  
82 (LCA). *"A technique for assessing the environmental aspects and potential impacts associated*  
83 *with a product, by compiling an inventory of relevant inputs and outputs of a product system;*  
84 *evaluating the potential environmental impacts; and interpreting the results of the inventory*  
85 *analysis and impact assessment phases"* is a definition provided by ISO 14040 for LCA [19]. It  
86 has been widely acclaimed for collecting data on materials and their environmental impacts and

87 developing sustainable design and construction [20]. The LCA can be a powerful and systematic  
88 tool to improve design and optimization, and to determine the likely environmental burdens of a  
89 process or product. The life cycle assessment is an effective method to compare the building's  
90 environmental impacts during the production, construction, maintenance, and disposal phases [21].  
91 LCA studies have been conducted to establish guidelines to calculate some of the building  
92 materials' environmental impact and improve building performance. In Asif et al., different  
93 building materials were evaluated on CO<sub>2</sub> emission, and the results showed that concrete with 61%  
94 had the highest share of emission and energy incorporated [22]. Kosareo and Ries applied the life  
95 cycle assessment to evaluate green technologies, such as intensive and extensive green roofs, then,  
96 have been compared to conventional solutions. They were concluded that vegetation has more  
97 energy advantages due to its lower thermal conductivity in the substrate [23]. In another LCA study  
98 on green roofs, Saiz, Susana, et al. found out the environmental impacts can be reduced 1 to 5%  
99 on average with applying a green roof [24]. In Altan et al. 2015, five different types of green wall  
100 systems were evaluated for their environmental impacts and benefits over their cradle to grave life-  
101 cycle (cradle to grave). The results showed that the effects of unsupported systems were far lower  
102 due to the less need for maintenance and reuse of their components [25]. Based on LCA analysis  
103 to measure the effects of a living wall system include felt pockets, Natarajan et al. found that  
104 halving the irrigation volume could save 46% in energy usage and 37% in carbon emissions [26].  
105 In Hong Kong, a commercially vertical green system was analyzed to quantify its environmental  
106 burden and benefits during manufacturing, transportation, use, and disposal stages. Results showed  
107 that the production phase is characterized by the highest impacts (47-93%) in all environmental  
108 impact categories [17]. Based on Feng et al. that performed an LCA analysis on three living wall

109 system (LWS), the materials and plants used in these systems in combination with the weather  
110 conditions and the building type strongly influence these systems' performance [27].

111 The proven benefits of these technologies have contributed to their distribution in recent years and  
112 the development of numerous types of systems with different components and characteristics.  
113 Despite the growing interest in studying the various specific functions and features of such green  
114 systems, most studies evaluate their energy efficiency and performance only during the use phase,  
115 regardless of their emissions and energy incorporated from manufacturing to dismantling.  
116 Therefore, further research is needed to address their overall environmental performances and  
117 accounting and in a life cycle perspective, considering the embodied energy, greenhouse gas  
118 emissions, materials and energy consumption, and embodied carbon, thus providing a systemic  
119 evaluation contributing to sustainable design of living walls system (LWS).

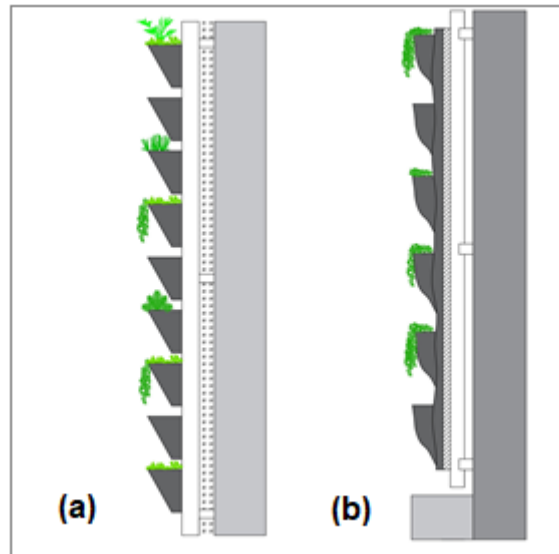
120 This work aims to evaluate two typologies of green wall systems with different characteristics and  
121 production processes, assessing their production, construction, and maintenance phases, in order  
122 to better understand their strengths and weaknesses, at the same time providing useful elements to  
123 improve the design and manufacturing of environmentally friendly systems. The green wall  
124 systems are compared to assess their environmental performances depending on their structure and  
125 composition. The study aims to evaluate materials and processes related to the final product and  
126 quantify the various environmental impacts, highlighting the contribution of each factor at each  
127 phase of the life cycle, determining the efficiency and sustainability of the system. The research  
128 will thus identify factors negatively affecting the environmental burdens of these systems, allowing  
129 to reduce their environmental effects.

## 130 **2. Materials and methods**



131        **2.1. Description of the studied systems**

132        This study was performed on two modular green wall systems, a plastic-based and a felt-based  
133        system, each one with a different structure. Figure 1 shows a schematic drawing of the studied  
134        systems.



135  
136

*Fig. 1. a. Plastic-based green wall system. b. Felt-based green wall system.*

- 137        - The first system is a vertical green system made of plastic modules. These panels provide  
138        the system rigidity and impermeability. These modules are made of recyclable EPP and  
139        weigh 60 kg per square meter. Vegetation can be placed before or after installation and can  
140        be easily replaced during the system's use. An irrigation system is required and can be  
141        automated. The main components of the supporting system are aluminum and soil is used  
142        as a growing medium.
- 143        - The second one is a type of modular system composed of the felt layers. 3-4 felt layers  
144        make the planting pockets, and a plant can be placed into each pocket. Plants that can be  
145        pre-grown and inserted into gaps. The supporting system is made of an aluminum frame

146 and an expanded PVC panel. Fertirrigation powered by an automated irrigation system is  
147 used to provide water and fertilizers required by plants. The system's daily water  
148 consumption is ½ liter per square meter.

## 149 2.2. Functional unit and system boundaries

150 The LCA's functional unit is defined by ISO 14040 as the reference unit for determining system  
151 performance [19]. This study considers 1 m<sup>2</sup> of the reference surface area of the green wall as a  
152 functional unit.

153 Steps and activities related to the production and assembly of various parts of a green wall create  
154 the system boundaries from the beginning to the end. In this study, the system boundaries consist  
155 of the production, construction, and maintenance phases.

- 156 • **Production stage**

157 At the production phase, the main focus is on analyzing the raw materials, resources, and energy  
158 used to produce all the components and pieces of each system. The parameters of greenhouse gas  
159 emissions, resource consumption, materials, and energy are measured at this stage [11].

- 160 • **Construction stage**

161 Assembly of the system and its components occurs during the construction phase. Aspects such as  
162 shipping distance, mode of transport, and CO<sub>2</sub> emission are crucial to obtain the entire materials  
163 environmental impacts over its life cycle.

- 164 • **Maintenance stage**

165 The most critical factor in the maintenance phase is the amount of water required by the irrigation  
166 system. The amount of impact due to resource consumption that depends on the number of times

167 the system is irrigated. Investigating the amount of water needed to maintain the systems gives us  
 168 an understanding of water consumption over each system's life cycle. Moreover, the used  
 169 fertilizers, pruning and plants substitution, and other system elements and materials replacement  
 170 must be considered during operation.

171 **2.3. Software, database and data inventory**

172 Since the various green wall systems usually differ in terms of the materials used in their  
 173 production and the method it is assembled, all components used in these systems must be examined  
 174 through the LCA framework. The environmental burden, caused by each system, is influenced by  
 175 the proportion of materials used in its components. They are evaluated and simulated by the  
 176 OpenLCA software and the Ecoinvent® v3.7 database. The results of this software will be used  
 177 for life cycle analysis.

178 All the components of both systems are given in Tables 1 and 2. Materials and processes related  
 179 to the final product will be evaluated to calculate the environmental impacts. Inventory analysis is  
 180 possible with access to information on production, construction, and maintenance. All stages of a  
 181 life cycle assessment are essential, but inventory analysis plays a key role. The processes in the  
 182 Ecoinvent® database can be used to perform the inventory analysis process [28].

183 *Table 1. The components of plastic-based system and some data for LCA analysis.*

<b>Components</b>	<b>Material</b>	<b>Weight (kg/m<sup>2</sup>)</b>	<b>Distances (km)</b>	<b>Service life (years)</b>
<b>Module</b>	EPP recyclable	60	62	10
<b>Module holder</b>	Tempered steel	5.644	96.5	10
<b>Upright</b>	Aluminum (6060 T5)	3.51	55	10

<b>Nuts and Bolts</b>	Stainless steel (AISI 304)	0.4	96.5	10
<b>Filter</b>	PP	0.288	62	10
<b>Potting soil</b>	Potting soil mix (40% peat moss, 20% sand, and 40% vermiculite)	12	-	10
<b>Watering system</b>	PE	0.1	62	7.5
<b>Water demand</b>	Tap water	29200	-	10
<b>Vegetation</b>	Hedera	1.5	-	10

184

185

*Table 2. The components of felt-based system and some data for LCA analysis.*

<b>Components</b>	<b>Material</b>	<b>Weight(kg/m<sup>2</sup>)</b>	<b>Distances(km)</b>	<b>Service life(years)</b>
<b>PVC panel</b>	Expanded PVC	5	226	10
<b>White fleece</b>	Polypropylene	0.82	167	10
<b>Wool fleece</b>	Polyamide	0.93	167	10
<b>PE fleece</b>	Polyethylene	0.06	167	10
<b>Bracket</b>	Aluminum	0.2	131	10
<b>Frame</b>	Aluminum	1.578	131	10
<b>Lateral shoulder</b>	Aluminum (painted)	2.01	131	10
<b>Water Tank</b>	Aluminum (painted)	2.01	131	10
<b>Watering system</b>	PE	0.1	226	7.5
<b>Water demand</b>	Tap water	10950	-	10
<b>Fertilizer</b>	Nitrogen (N), diphosphorus	22.5	-	10

	pentoxide (P <sub>2</sub> O <sub>5</sub> ), and potassium oxide K <sub>2</sub> O			
<b>Vegetation</b>	Pteropsida	7.5	-	3.5

186

187 Given that the lifespan of green walls is usually estimated to be ten years, factors potentially  
 188 affecting the environment during this period are evaluated. Input data used in the LCLA represent  
 189 the characteristics of these types of systems available on the market. Based on previous studies, to  
 190 balance the environmental burdens of the green walls system, the CO<sub>2</sub> uptake by plants is assumed  
 191 12kg/year for one square meter [7]. Only the felt-based green wall system needs a nutrient solution  
 192 for plant growth due to a lack of organic substrate. The LCA of the intelligent irrigation system  
 193 responsible for monitoring and injecting the nutrient solution required for the felt-based system,  
 194 as well as processes related to growing plants on the farm lie outside the system boundaries  
 195 therefore are not considered in this study. Pipes used for irrigation become clogged due to salt  
 196 crystallization and sediments and must be replaced every 7.5 years.

197 **2.4. Life Cycle impact Assessment**

198 According to the European Commission-endorsed LCIA method, the following categories should  
 199 be examined using the ILCD (International Reference Life Cycle Data System) method [37]:

- 200 - Acidification (molc H<sup>+</sup> eq.);
- 201 - Climate Change (kg CO<sub>2</sub> eq.);
- 202 - Freshwater Ecotoxicity (CTUe);
- 203 - Freshwater Eutrophication (kg P eq.);

- 204 - Human Toxicity-Cancer Effect (CTUh);
- 205 - Human Toxicity-Non-Cancer Effect (CTUh);
- 206 - Ionizing radiation E (interim) (CTUe);
- 207 - Ionizing radiation HH (kBq U235 eq.);
- 208 - Land Use (kg C deficit);
- 209 - Marine Eutrophication (kg N eq.);
- 210 - Mineral and Fossil Resource Depletion (kg Sb eq.);
- 211 - Ozone Depletion (kg CFC-11 eq.);
- 212 - Particulate Matter (kg PM2.5 eq.);
- 213 - Photochemical Ozone Formation (kg NMVOC eq.);
- 214 - Terrestrial Eutrophication (molc N eq.);
- 215 - Water resource depletion (m<sup>3</sup> water eq.);

216 Based on the literature, due to the very small impact of other categories, climate change, human  
 217 toxicity, and freshwater ecotoxicity are more important to show the study's results. [29]. In addition,  
 218 reviewing the results obtained in the categories of land use, Mineral, fossil and ren resource  
 219 depletion, ozone depletion, and water resource depletion can help to understand better the negative  
 220 effects of each system on the environment. The amount of greenhouse gas emissions during the  
 221 system life cycle directly affects the category of climate change. Many studies equal gas emissions  
 222 and climate change with the environmental impact of materials [30]. The potential effects of  
 223 releasing toxic compounds into the human environment are considered in the human toxicity

224 category. The freshwater ecotoxicity category focuses on releasing toxic substances into the air,  
 225 water, and soil and their effects on the freshwater ecosystem [13]. The main purpose of this section  
 226 is to weigh the results of the entire analysis. The impact of 1 m<sup>2</sup> of green wall system will be  
 227 assessed based on the above mentioned categories separately.

### 228 3. Results and discussion

229 As it is clear from the impact results obtained for the two systems under study shown in Table 3,  
 230 the felt-based system has higher negative effects than the plastic-based system in all the main  
 231 impact categories, with the exception of climate change and water resource depletion.

232 *Table 3. Environmental impacts for a 1 m<sup>2</sup> of the plastic-based and felt-based systems.*

Impact category	Reference unit	Plastic-based	Felt-based
Acidification	molc H <sup>+</sup> eq	0.66414	0.81995
Climate change	kg CO <sub>2</sub> eq	42.2056	25.15523
Freshwater ecotoxicity	CTUe	1428.6235	2435.9842
Freshwater eutrophication	kg P eq	0.0468	0.046612
Human toxicity, cancer effects	CTUh	1.1704E-05	1.5543E-05
Human toxicity, non-cancer effects	CTUh	2.3251E-05	3.7312E-05
Ionizing radiation E (interim)	CTUe	5.8794E-05	3.5006E-05
Ionizing radiation HH	kBq U235 eq	21.86134	10.91895
Land use	kg C deficit	113.5358	205.9807
Marine eutrophication	kg N eq	0.11503	0.1693
Mineral, fossil & ren resource depletion	kg Sb eq	0.00771	0.01409
Ozone depletion	kg CFC-11 eq	3.5156E-06	1.2647E-05
Particulate matter	kg PM2.5 eq	0.06751	0.090744

Photochemical ozone formation	kg NMVOC eq	1.070754	0.44234
Terrestrial eutrophication	molc N eq	1.16789	2.0404
Water resource depletion	m <sup>3</sup> water eq	5.05124	2.18408

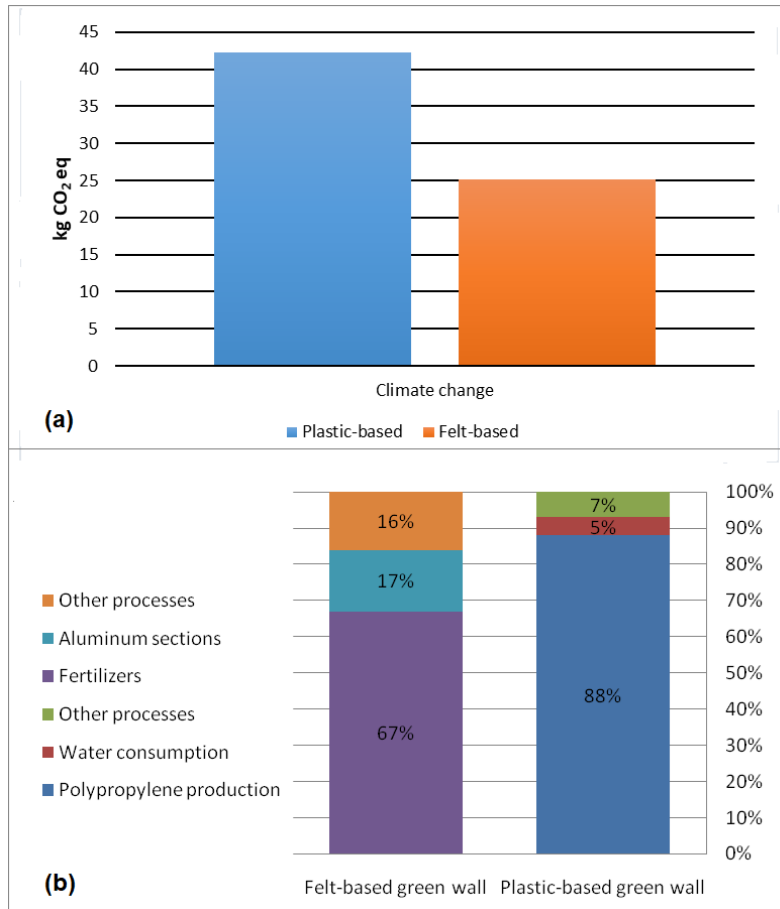
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234 As predicted and confirmed by the results of previous studies, the production phase has the largest  
 235 share of environmental impacts. This is mainly due to the type of materials and components used  
 236 in the production of these systems [31, 32]. Since the assembly process of these systems is done  
 237 manually and no special machines are used, the construction stage has the lowest impact [31]. The  
 238 water used to irrigate the plants and the fertilizer used in the felt-based system are the main  
 239 environmental impact factors in the maintenance phase [32].

240 The impact of the plastic-based system on the climate change category is greater than the felt-  
 241 based system (Fig. 2.a). This negative impact is due to the processes related to the production of  
 242 polypropylene panels, which play the most important role. Polypropylene production processes  
 243 alone account for 88% of the total negative effects. After that, water consumption with 5% has the  
 244 most negative impact (Fig. 2.b). Vegetation due to CO<sub>2</sub> uptake can compensate for up to 74% of  
 245 these negative effects. These effects are calculated for a period of 10 years. As the results show, if  
 246 the process of CO<sub>2</sub> removal by vegetation continues, it will reach equilibrium after 14 years.  
 247 Fertilizers used in the felt-based system have the greatest impact on the climate change category.  
 248 In addition, the supporting system components are made of aluminum, which contributes  
 249 significantly to increasing CO<sub>2</sub> production. The negative effects of inorganic nitrogen, inorganic  
 250 potassium and inorganic phosphorus used in the production of nutrient solution are 32, 19 and 15%  
 251 and 67% in total. Furthermore, the aluminum sections have a 17% negative effect (Fig. 2.b).



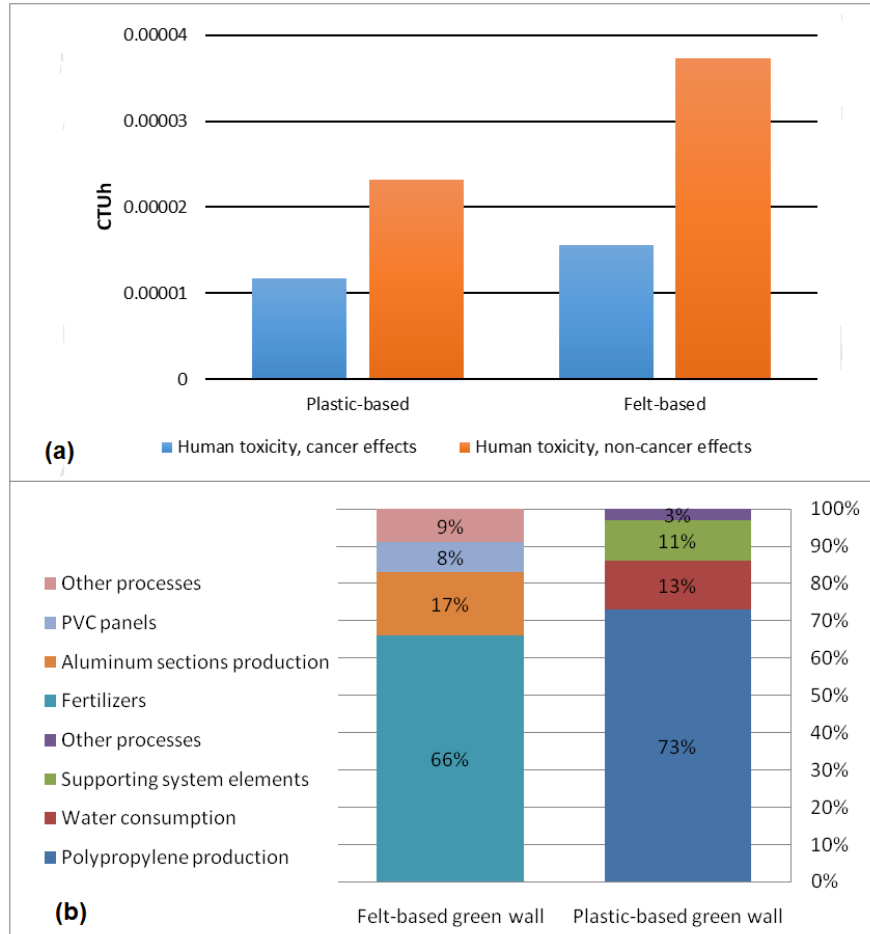
252 However, thanks to photosynthesis by plants, these negative effects are reduced up to 83% and can  
 253 be expected to reach equilibrium after about 12 years.



254 Fig. 2. (a) The climate change impact category; (b) Contributions of systems processes in the climate change impact  
 255 category  
 256

257 In the case of categories related to human health, for the plastic-based system, between 70 and  
 258 80% of the impact is related to the production of polypropylene panels. Then, water consumption  
 259 with 13% and production of supporting system elements with 11% have the most negative effect  
 260 (Fig. 3.b). On the other hand, 66% of the total negative effects are related to inorganic fertilizers  
 261 in the felt-based system. Of this amount, 31% is related to inorganic nitrogen, 19% is related to  
 262 inorganic potassium, and 16% is related to inorganic phosphorus. This has led to an increase in the  
 263 negative effects of this system compared to the plastic-based system. In addition, we can mention

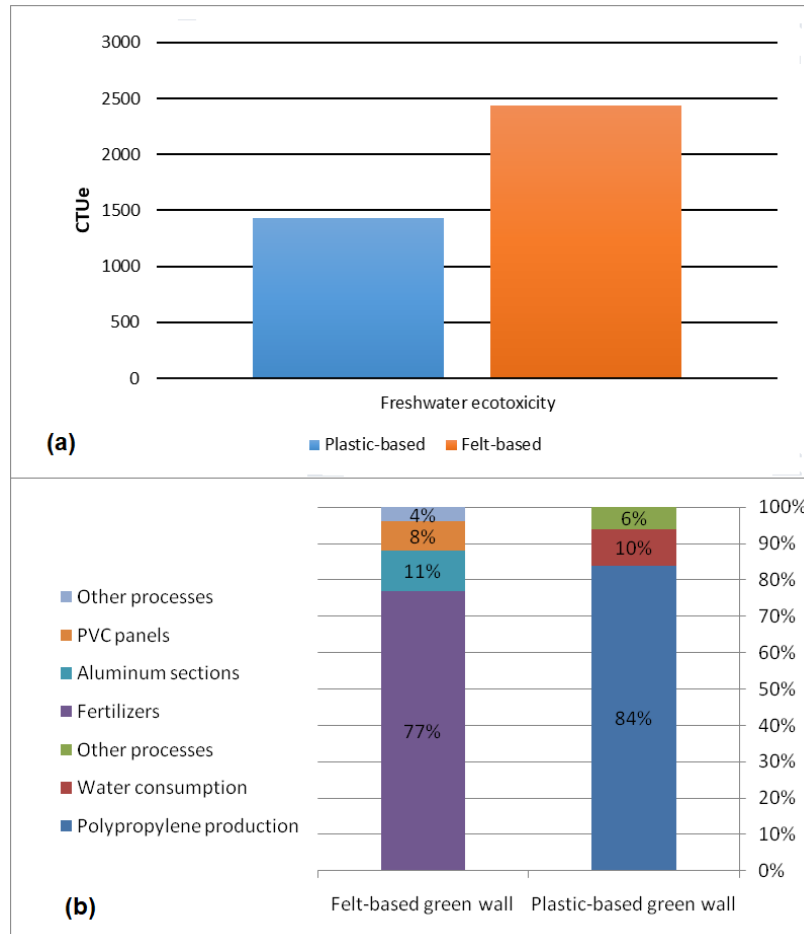
264 the impact of the aluminum sections production process with 17% and PVC panels used in the  
 265 supporting system with 8% (Fig. 3.b).



266  
 267 *Fig. 3. (a) The human toxicity impact categories; (b) Contributions of systems processes in the human toxicity*  
 268 *impact categories.*

269 As shown in figure 4, in the freshwater ecotoxicity category, the impact of the felt-based system  
 270 is greater than the plastic-based system. 77% is the nutrient solutions contribution in the felt-based  
 271 system, that inorganic nitrogen, potassium and phosphorus share are 37%, 20% and 20%,  
 272 respectively. Casting of aluminum parts in the supporting system and PVC panels are also effective  
 273 with 11 and 8% (Fig. 4.b). On the other hand, 84% is the share of the plastic panels production

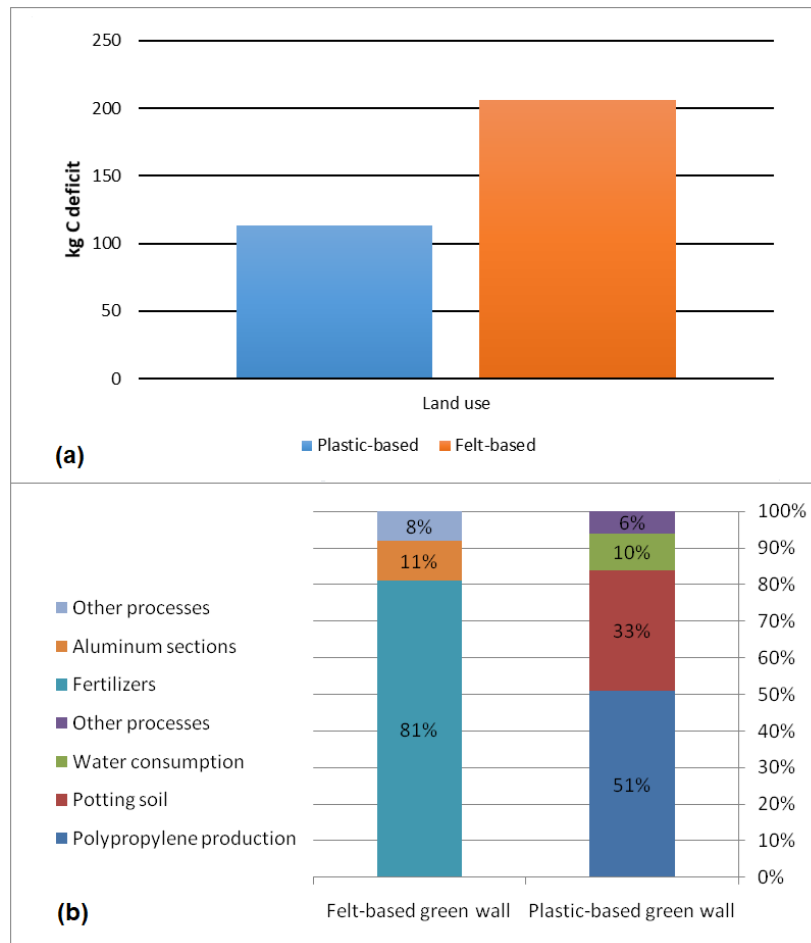
274 contribution in the plastic-based system. Water consumption is the next effective process in the  
 275 plastic-based system with a 10% impact (Fig. 4.b).



276  
 277 *Fig. 4. (a) The freshwater ecotoxicity impact category; (b) Contributions of systems processes in the freshwater*  
 278 *ecotoxicity impact category.*

279 Like most other categories, in the land use category, nutrient solutions and aluminum components  
 280 of the supporting system in the felt-based system have the greatest impact. 34% for inorganic  
 281 nitrogen, 26% for inorganic potassium, 21% for inorganic phosphorus and 11% for casting  
 282 aluminum parts (Fig. 5.b). In the plastic-based system, the processes related to polypropylene  
 283 production with a 51% share are the most effective. But the remarkable point in this category is  
 284 the significant share of potting soil with 33%, that 28% is the share of the peat moss production

285 process. The share of water consumption in this category is 10% (Fig. 5.b). Figure 5 shows the  
 286 overall impact of the felt-based system in this category is almost twice that of the plastic-based  
 287 system.



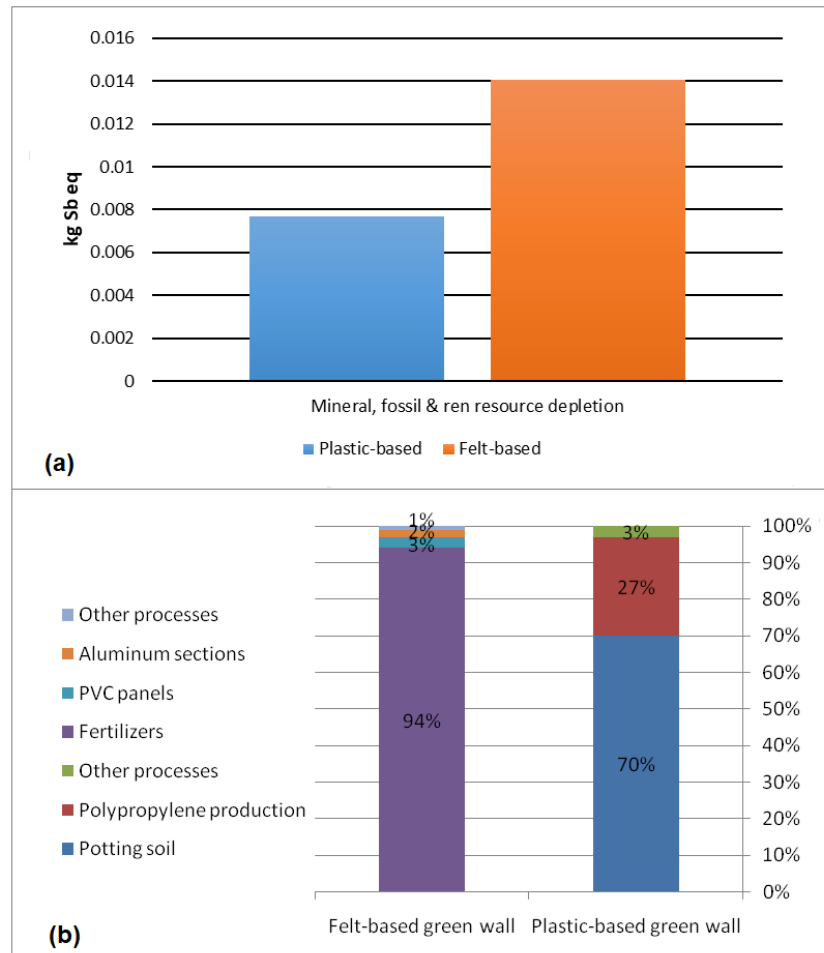
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289 *Fig. 5. (a) The land use impact category; (b) Contributions of systems processes in the land use impact category.*

290 The results related to the mineral, fossil & renewable resource depletion category show that the  
 291 potting soil used for the plastic-based system has a 70% share singly, which is related to the  
 292 vermiculite mining operation. Polypropylene panels have a 27% share too (Fig. 6.b). In the felt-  
 293 based system, the impact due to the inorganic nitrogen fertilizer production process is about 68%,  
 294 which is the highest. The share of inorganic phosphorus is 17% and inorganic potassium is 9%

295 (Fig. 6.b). Figure 6 shows that the felt-based system impact in this category is approximately twice  
 296 that of the plastic-based system.

297

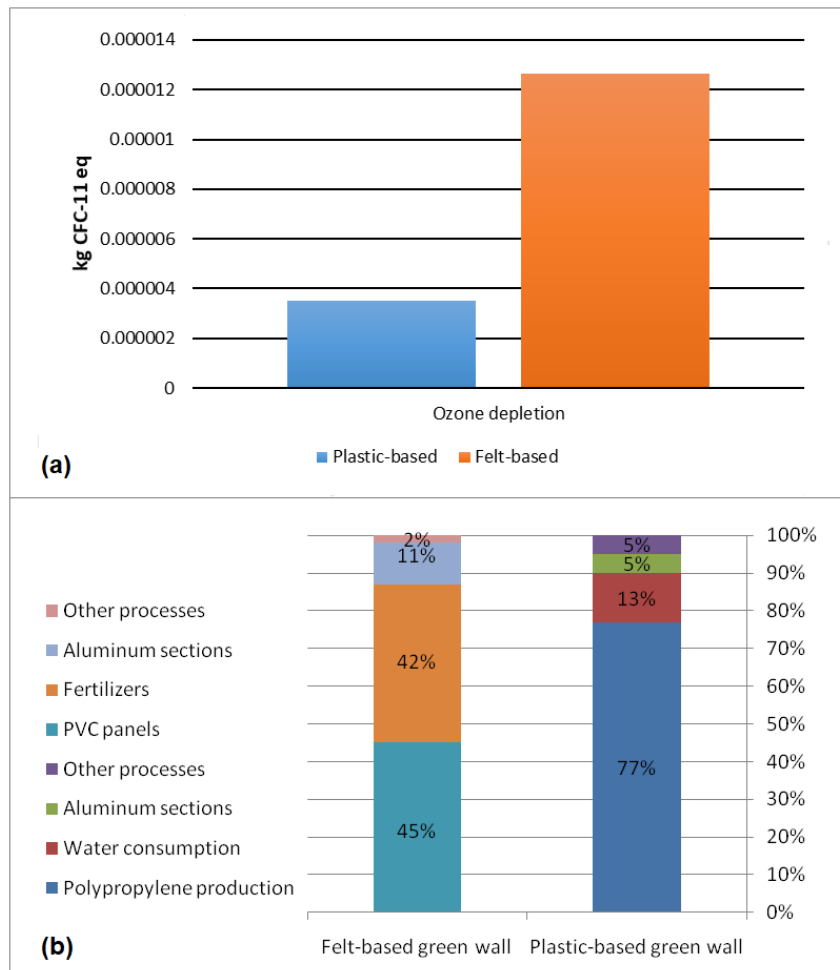


298

299 *Fig. 6. (a) The mineral, fossil & renewable resource depletion impact category; (b) Contributions of systems processes in*  
 300 *the mineral, fossil & renewable resource depletion impact category.*

301 Like other categories in the impact category of ozone depletion, for the plastic-based system, the  
 302 largest share is related to the plastic production process with 77%, and water consumption and  
 303 Aluminum sections are in the next ranks with 13 and 5% (Fig. 7.b). But for the felt-based system  
 304 in this impact category, the results are different. The PVC panel production process used in the

305 supporting system accounts for 45% of the impact. In addition, inorganic fertilizers with 42% (20%  
 306 for inorganic nitrogen, 12% for inorganic potassium and 10% for inorganic phosphorus) and the  
 307 use of aluminum components with 11% exacerbate this negative impact (Fig. 7.b) and make the  
 308 negative effects of the felt-based system in this category far greater than the plastic-based system  
 309 (Fig. 7).

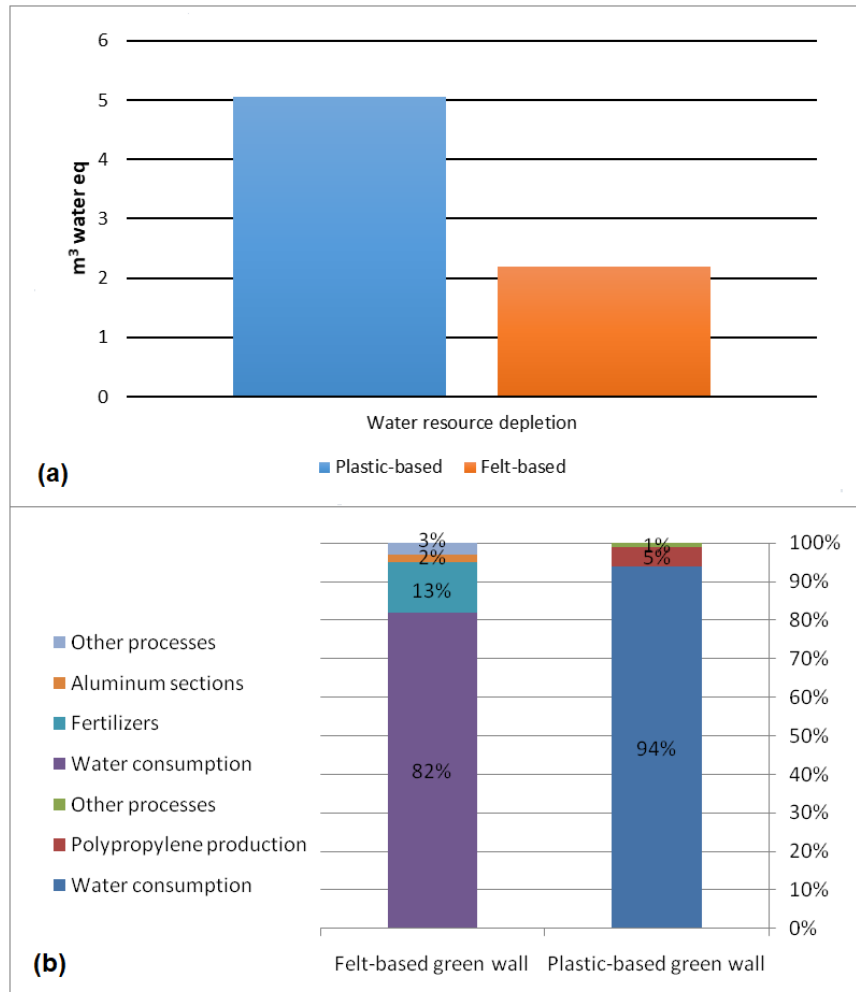


310

311 *Fig. 7. (a) The ozone depletion impact category; (b) Contributions of systems processes in the ozone depletion*  
 312 *impact category.*

313 As mentioned before, in the impact category of water resources depletion, the largest share is  
 314 related to the use phase. Water used to irrigate plants has a 94% share in a plastic-based system,

315 compared to 82% for a felt-based system (Fig. 8.b). In addition, the effect of nutrient solution used  
 316 is about 13%. However, the main reason for the difference in the results of the two systems is  
 317 related to the difference in vegetation, as the plant used in the plastic-based system needs more  
 318 water for irrigation (Fig. 8).



319

320 *Fig. 8. (a) The water resource depletion impact category; (b) Contributions of systems processes in the water*  
 321 *resource depletion impact category.*

322 We can understand that the felt-based system has the greatest environmental impact in almost all  
 323 categories due to aluminum components in the supporting system and inorganic chemical  
 324 fertilizers necessary since no growing medium is used for plants. These results are consistent with

325 the results reported in previous studies [11, 31]. Examining the results of the plastic-based system,  
326 it can be concluded that the high volume of polypropylene used to produce the panels and the water  
327 used for the plant irrigation and the potting soil composition have the greatest environmental  
328 impact. The role of materials used in the production of these systems should be highlighted. By  
329 making changes in the structure of both systems, a more stable design can be achieved. In addition,  
330 by replacing aluminum with other materials in the support system of both systems, environmental  
331 impacts can be reduced. Aluminum can have up to 10 times more environmental impact than any  
332 other material [29]. Using recycled plastics to produce the required panels in the plastic-based  
333 system can be expected to reduce environmental impacts. Also, the use of plants with the need for  
334 less irrigation, changing the growing medium composition, and fertilization can be led to a  
335 significant reduction.

#### 336 **4. Conclusions**

337 In this research, by evaluating the life cycle of two green walls system, all the advantages and  
338 disadvantages of the systems during their lifespan can be identified and expressed quantitatively.  
339 With the quantification of environmental impacts, the contribution of each factor at each phase of  
340 the life cycle can be understood, and the efficiency of the system can be determined according to  
341 all the effective phases and factors. In this way, critical points can be identified, and their  
342 environmental effects can be eliminated or reduced. Moreover, one of the factors affecting the  
343 environmental burden of these systems is the materials used in their production process that can  
344 be reduced by replacing them with suitable materials. By trusting the results of this study and  
345 increasing consumer confidence, the use of these systems can be increased.



346 We can achieve more sustainable structures and fewer environmental impacts by pursuing this  
347 study. It can help architects, ecologists, and engineers find new nature-based solutions to solve  
348 environmental problems. It is also expected to improve the ecological sustainability of systems  
349 throughout their lifecycle by comparing the results.

350 In general, we can conclude that the production stage has the most environmental effects compared  
351 to other stages. This shows the importance of the careful selection of materials for the system  
352 components production. By replacing more sustainable materials, we can reduce environmental  
353 impacts in both systems. Plants can recoup the carbon released in the production process after 12  
354 and 14 years, and since the lifespan of a building is often estimated at 50 years, they can help  
355 purify the air in later years. However, choosing plants suitable for climatic conditions, choosing  
356 the right growing medium, and not needing nutrient solutions, and excessive irrigation can  
357 minimize the negative effects of the use stage.

358 Since the green wall system is a new technology, there is still a need for further studies on them.  
359 Increasing the number of case studies with specific data and results will help improve the design  
360 and development of these systems. On the other hand, due to the expansion of these systems in  
361 recent years, there is still no accurate information about their fate and effects at the end of life.

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365

366

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