1 **Assessing the environmental performance of plastic-based and felt-based**

2 **green wall systems in a life-cycle perspective**

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Abstract

8 With the remarkable growth of cities and the increase of built-up areas, mitigation of urban heat

9 island effects has become one of the most crucial challenges in social and environmental

10 sustainability with significant impacts on public health. This has led to an increasing development

11 of urban green infrastructure. Among those nature-based solutions, green wall systems have been

12 receiving a growing attention, being a passive technology with their ability to reduce greenhouse

13 gas emissions, adapt to climate change, improve air quality and reduce the heat island effect in

14 urban environments. Despite that growing interest in studying the functions and features of such

15 green systems, and the various types of living walls nowadays available, most studies evaluate

16 their energy efficiency and performance only during the use phase. This study aimed to assess the

17 overall environmental performances of two types of green walls in a life cycle perspective,

18 considering the embodied energy, greenhouse gas emissions, materials and energy consumption,

19 and embodied carbon. After collecting inventory data related to all components and processes of

20 each system, a life cycle assessment with cradle to gate approach has been performed by means of

21 the OpenLCA software to compare the performances of a felt-based system without organic

growth medium and a system based on plastic modules with organic growth medium. The main

impacts have been detected in the production stage and materials used in systems structure. By

comparing the results achieved in the 16 impact categories analyzed, the felt-based system showed

the highest overall impact, with the use of fertilizers and aluminum components playing a crucial

part. Polypropylene used to produce the panels, water used for plant irrigation and potting soil

composition are the main environmental impact contributors in the plastic-based system. The

results pointed out the importance of accurate choice of materials for the design and production of

green walls.

1. Introduction and goals

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

In recent years, the green walls system has been prevalent and used as a tool for urban space sustainability [8]. Green infrastructures can improve urban life quality and reduce the world's environmental impact caused by climate change [9, 10]. Building facades are an excellent option 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_2 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.
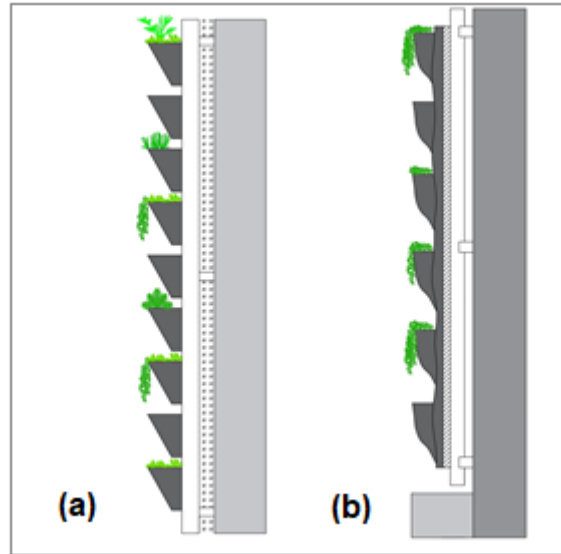
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136   *Fig. 1. a. Plastic-based green wall system. b. Felt-based green wall system.*

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^2 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_2 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.*

Components	Material	Weight (kg/m²)	Distances (km)	Service life (years)
Module	EPP recyclable	60	62	10
Module holder	Tempered steel	5.644	96.5	10
Upright	Aluminum (6060 T5)	3.51	55	10

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

184

185

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

Components	Material	Weight(kg/m²)	Distances(km)	Service life(years)
PVC panel	Expanded PVC	5	226	10
White fleece	Polypropylene	0.82	167	10
Wool fleece	Polyamide	0.93	167	10
PE fleece	Polyethylene	0.06	167	10
Bracket	Aluminum	0.2	131	10
Frame	Aluminum	1.578	131	10
Lateral shoulder	Aluminum (painted)	2.01	131	10
Water Tank	Aluminum (painted)	2.01	131	10
Watering system	PE	0.1	226	7.5
Water demand	Tap water	10950	-	10
Fertilizer	Nitrogen (N), diphosphorus	22.5	-	10

		pentoxide (P_2O_5), and potassium oxide K_2O			
Vegetation	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_2 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^+ eq.);

201   - Climate Change (kg CO_2 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^3 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^2 of green wall system will be

227 assessed based on the above mentioned categories separately.

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^2 of the plastic-based and felt-based systems.*

Impact category	Reference unit	Plastic-based	Felt-based
Acidification	molc H$^+$ eq	0.66414	0.81995
Climate change	kg CO$_2$ 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

13

|			
Photochemical ozone formation	kg NMVOC eq	1.070754	0.44234
Terrestrial eutrophication	molc N eq	1.16789	2.0404
Water resource depletion	m³ water eq	5.05124	2.18408

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

The impact of the plastic-based system on the climate change category is greater than the felt-based system (Fig. 2.a). This negative impact is due to the processes related to the production of polypropylene panels, which play the most important role. Polypropylene production processes alone account for 88% of the total negative effects. After that, water consumption with 5% has the most negative impact (Fig. 2.b). Vegetation due to CO_2 uptake can compensate for up to 74% of these negative effects. These effects are calculated for a period of 10 years. As the results show, if the process of CO_2 removal by vegetation continues, it will reach equilibrium after 14 years. Fertilizers used in the felt-based system have the greatest impact on the climate change category. In addition, the supporting system components are made of aluminum, which contributes significantly to increasing CO_2 production. The negative effects of inorganic nitrogen, inorganic potassium and inorganic phosphorus used in the production of nutrient solution are 32, 19 and 15% 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.
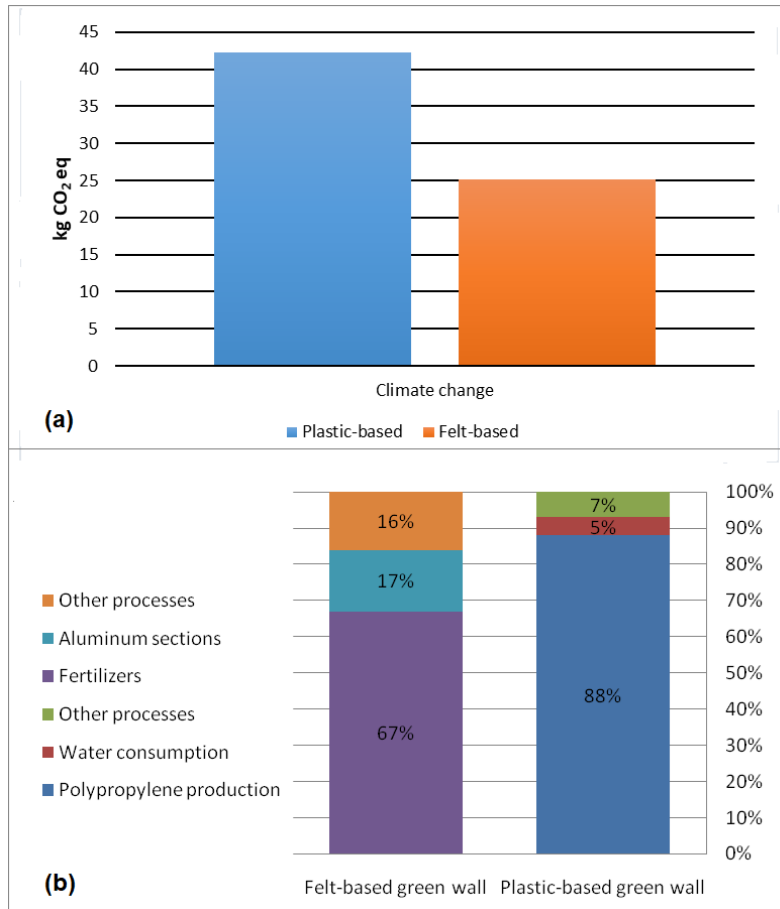
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255　*Fig. 2. (a) The climate change impact category; (b) Contributions of systems processes in the climate change impact*
256　*category*

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

15

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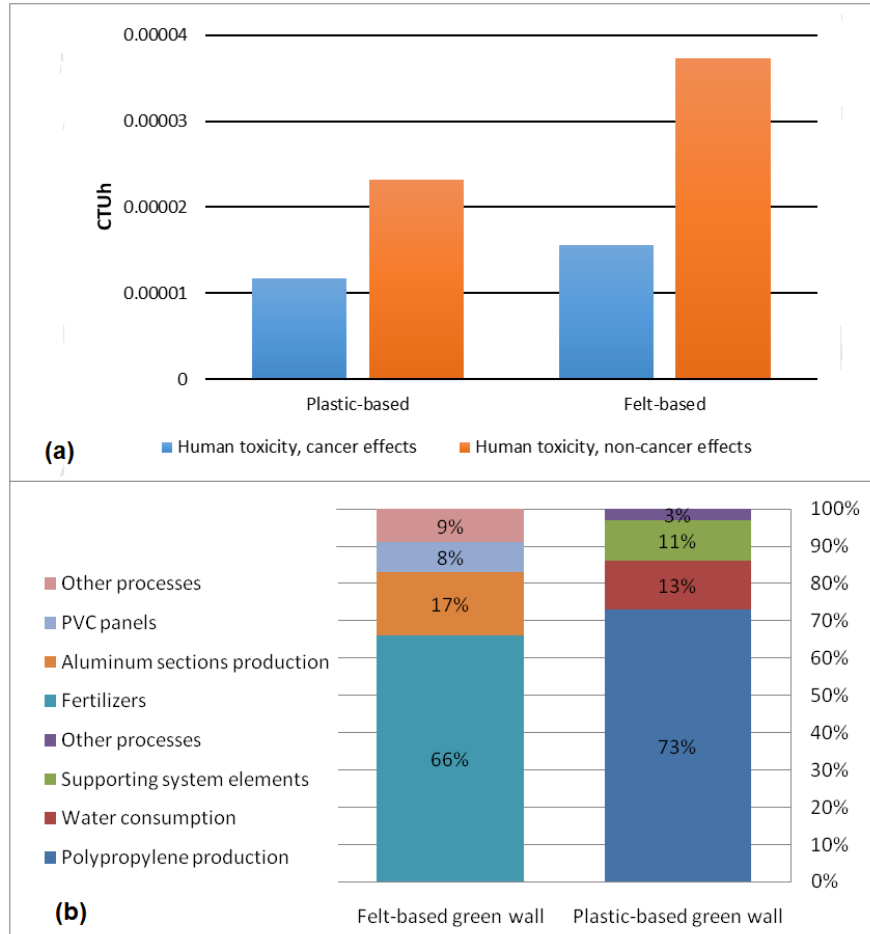
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267 *Fig. 3. (a) The human toxicity impact categories; (b) Contributions of systems processes in the human toxicity*
268 *impact categories.*

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

16

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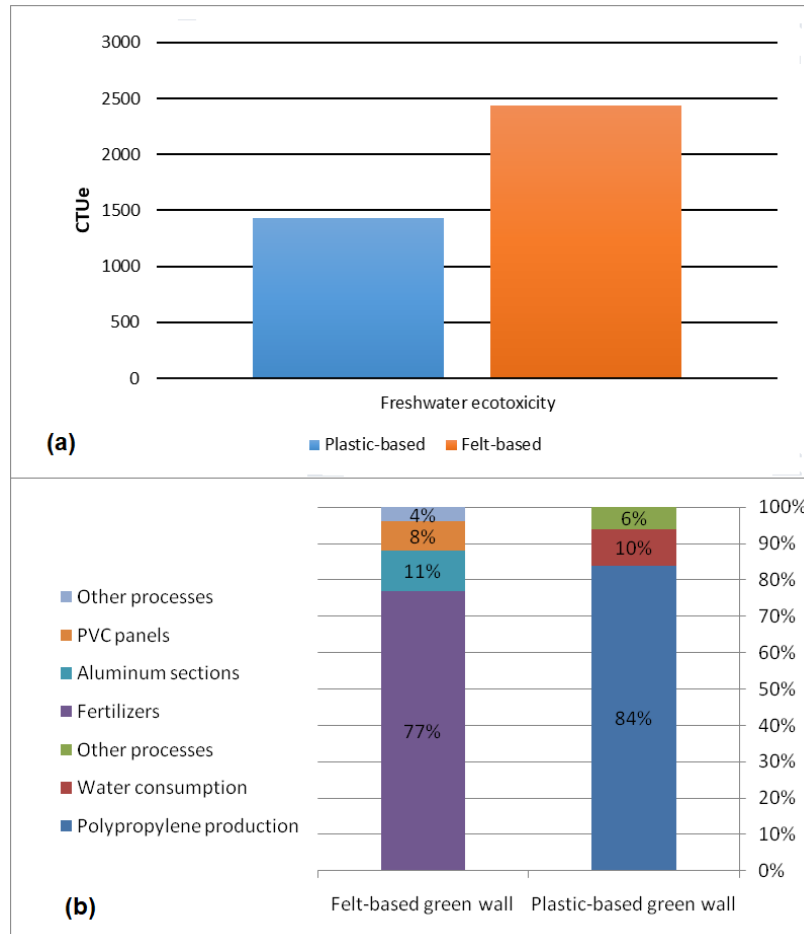
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277   *Fig. 4. (a) The freshwater ecotoxicity impact category; (b) Contributions of systems processes in the freshwater*
278   *ecotoxicity impact category.*

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

17

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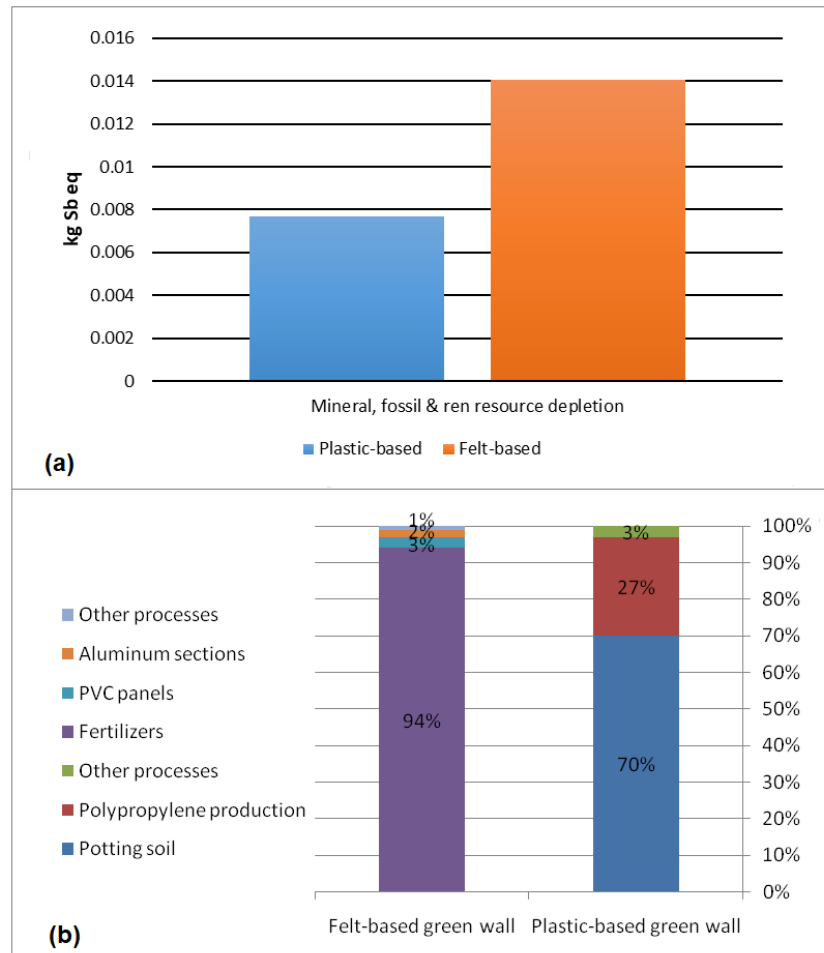
287 system.
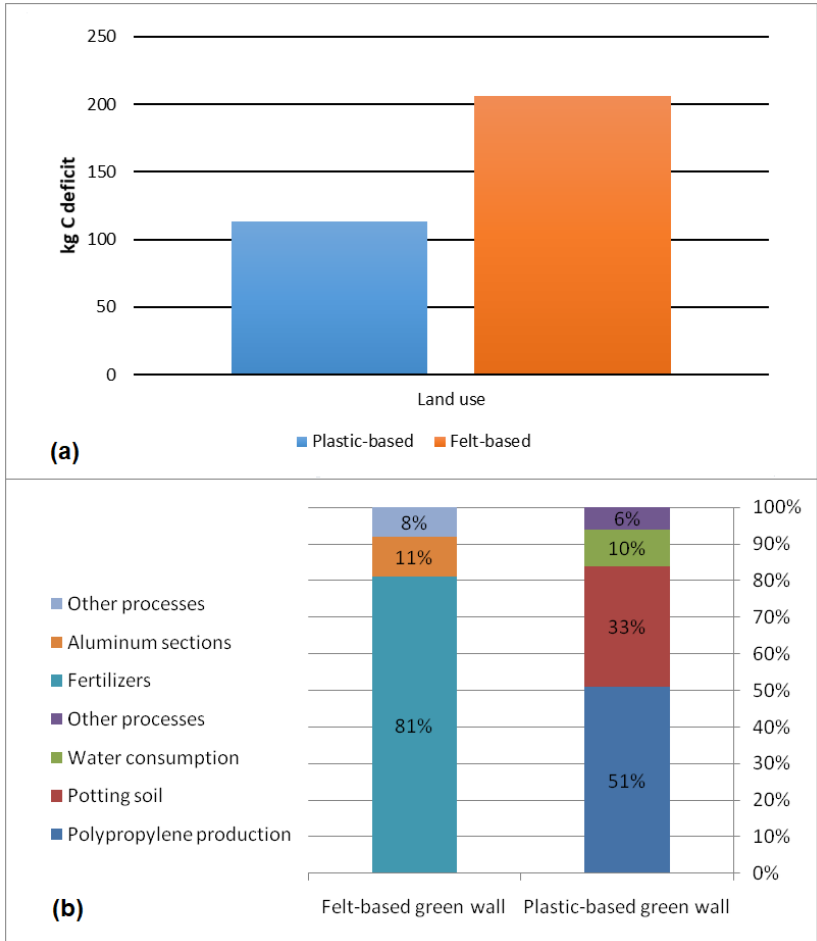
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289 *Fig. 5. (a) The land use impact category; (b) Contributions of systems processes in the land use impact category.*

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%

18

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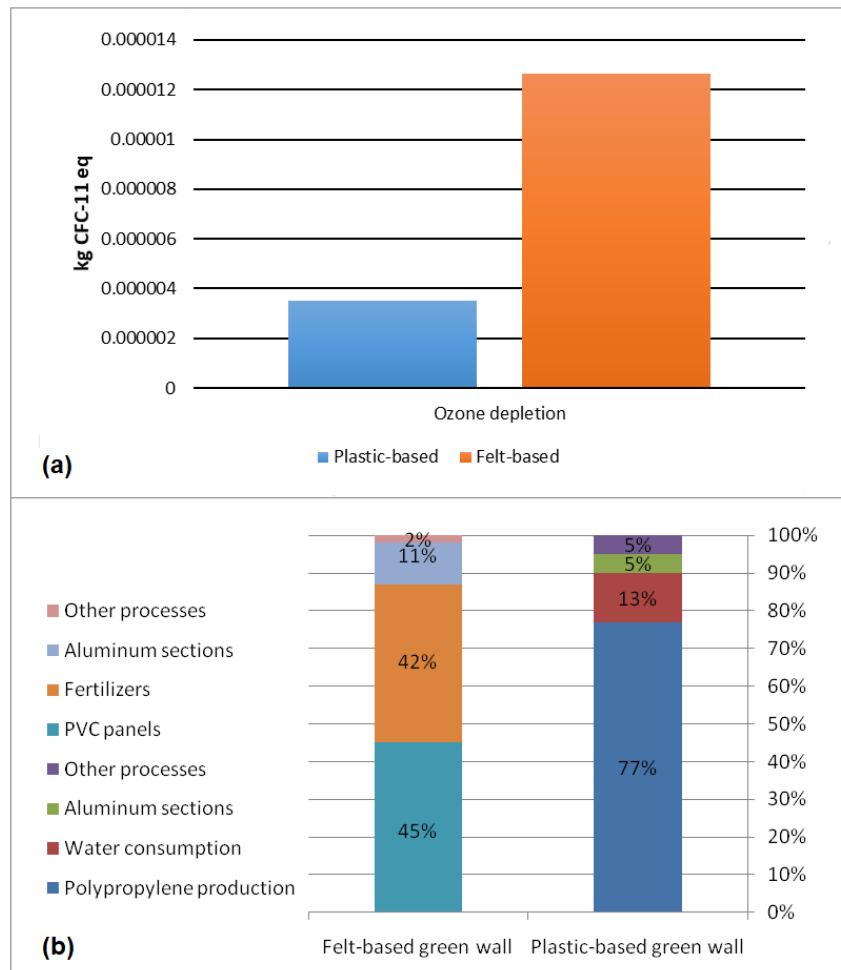
296   that of the plastic-based system.

297

(a)

(b)

298

299   *Fig. 6. (a) The mineral, fossil & ren 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).
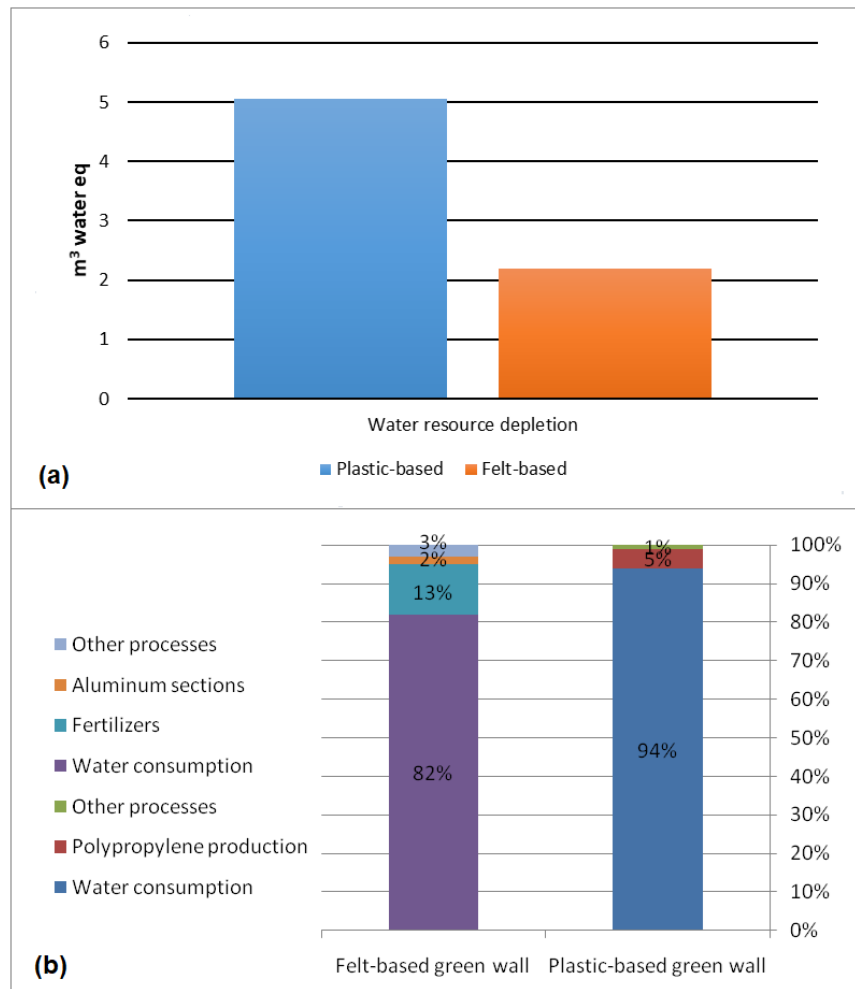
320 *Fig. 8. (a) The water resource depletion impact category; (b) Contributions of systems processes in the water*
321 *resource depletion impact category.*

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.

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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