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ORIGINAL ARTICLE

Life cycle analysis of hybrid oil palm/glass fibre-reinforced polyurethane composites for automotive crash box

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ABSTRACT – Currently, the world is getting more poisonous due to the toxic contaminated and wastewater release from the industries activities. The designers should analyse the effect to the environmental and human health, prior starting any manufacturing and fabricating process. This technique able to optimize the company profit and reduced unnecessary cost by predict any consequences and do correction step before the problem emerge for every action taken. Therefore, this paper aim to provide the evidence that the selection of material and manufacturing process used to fabricate ACB has minimum impact on the environment and human health. A few methods can be used to calculate the environmental damage assessment such as network, compare and uncertainty analysis. In this study, analyse calculation method selected to predict the environmental impact. The results for the damage to human health analysis only contribute 0.0125 DALY, analysis results for the hazardous elements such as methane, trichlorofluoromethane and Chlorofluorocarbons produced during the fabrication process only 1.32 x 10^{-9} DALY. Besides, the major damage elements to ecosystem quality results only contribute 1.97 x 10^{-4} species.yr. Therefore, the remarkable results show that the process and material selection to fabricate ACB are very low which was below than 0.1 DALY. Moreover, damage assessment for the terrestrial ecotoxicity of pulforming process using oil palm natural/glass fibre reinforced polyurethane composite only contributed 1.13 × 10^{-10} (species.year). Consequently, the process could not damage the human health and indicates that the process is environmentally friendly and safe for the ecosystem.

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KEYWORDS
Life cycle analysis; automotive crash box; natural fibre composite; sustainability analysis

INTRODUCTION

Sustainability or environmental awareness rises cause the industries to evaluate the effect of their activities on the environment [1] . Peoples have become anxious about the issues of natural resource depletion and ecological footprint or environmental degradation [2, 3]. Many industries had responded to this awareness by producing greener products and using eco-friendly manufacturing processes [4–19]. Currently, seven major companies are actively using life cycle analysis (LCA) in the manufacturing process such as Credit Suisse, DSM N.V, Hoechst Group, Novo Nordisk, Procter and Gamble, The Body Shop, and Volvo [20]. The environmental performance of products and processes had become a serious issue. Therefore, most companies are exploring ways to minimise their activities which may have the possibilities to affect the environment [21–23]. Many companies had found that LCA is beneficial to discover ways of moving beyond compliance using pollution prevention strategies and sustainability management systems to improve their environmental performance. Sima Pro 8.5 was used as a tool to study the LCA on the pulforming process for oil palm/glass fibre-reinforced polyurethane composites to produce automotive crash box (ACB). Moreover, LCA was chosen to study the environmental impact of pulforming process by using oil palm/glass fibre-reinforced polyurethane composites due to the LCA method and software capability to predict the effect of manufacturing activities on the human health damage, measured by number of year life lost and the number of years lived disabled and were combined as disability adjusted life years, the unit used was DALY. Moreover, LCA also have a capability to predict the activities could damage the ecosystem, measure by annual species eliminating, the unit is species.year and it is written as (species.yr).

This concept considers the entire life cycle of a product, and it is known as a gate-to-gate approach for assessing industrial systems [24, 25]. A gate to gate approach, applied system boundary that commences with the collection and transportation of the palm kernel from the palm oil mills to the production of empty fruit bunch at the kernel crushing plants before sent to manufacturing to fabricate ACB using pulforming process. The inventory data which consists of inputs of raw materials and energy; outputs of solid, liquid and gaseous wastes presented in Table 1. The functional unit

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for this study is hybrid oil palm/glass fibre-reinforced polyurethane composites produced 1.76 x 10^{-3} m^3 of ACB using pulforming process. In addition, LCA is also a method to evaluate the environmental characteristics and potential effects related to a product, process, or services. It performs the analysis by compiling the inventory of relevant energy, material inputs, and environmental releases. Then, the evaluation process is performed to measure the potential environmental impacts associated with the identified inputs and output emission to the environment to achieve the objective of this study. Finally, the engineer must know how to interpret the results to assist the decision makers in decision making process [26]. Thus, from the numerous advantages and capabilities, it motivated the authors to performed LCA analysis to discover ACB fabricated by using pulforming process, which could damage the environmental or human health.

Figure 1 illustrates the life cycle stage used in LCA method to evaluate the environmental impact. The life cycle consisted of three main stages. The first stage is known as the input stage where the material used in the production and energy consumption involved in the manufacturing process such as electric energy, emission energy from the burning process, and transportation are listed as the input values. The second stage is called as the process, and the engineer must specify all related processes to fabricate the product. Outputs elements released are then specified during the manufacturing process in the third stage [27, 28]

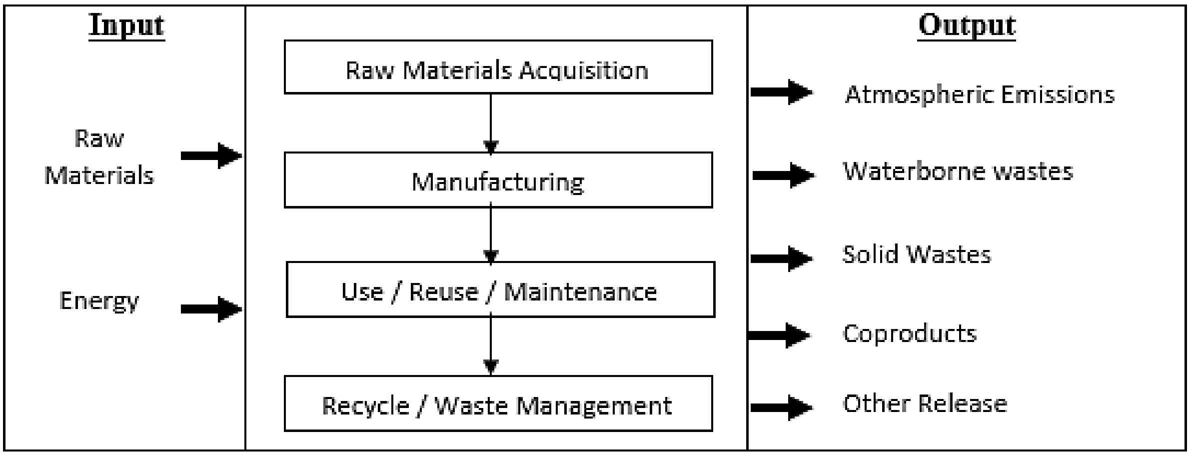


Figure 1. System boundary of hybrid oil palm/glass fibre-reinforced polyurethane composites for automotive crash box using manufacturing pulforming process [29]

METHODS AND MATERIALS

The LCA method as shown in Figure 2 is a systematic approach, it consists of four components: 1) goal definition and scoping, 2) inventory analysis, 3) impact assessment, and 4) interpretation results.

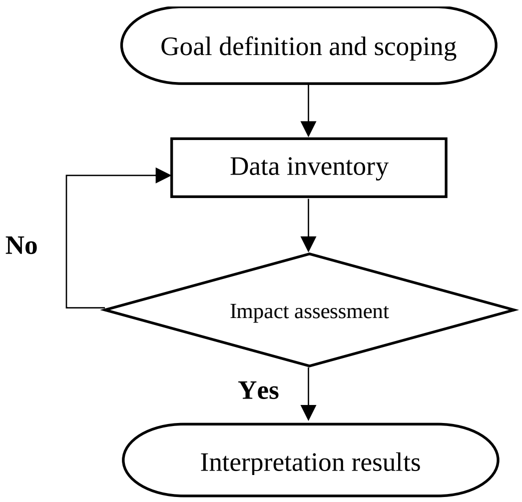


Figure 2. Components in LCA methods

The first component, which is the aim or goal of this research is to evaluate the environmental impact of the oil palm/glass fibre-reinforced composites pulforming process to fabricate ACB on human health and world ecosystem. Therefore, the values from three database libraries were chosen in the calculation. The first database library was Agri footprint (mass allocation), which includes the linked unit process inventories of crop cultivation, crop processing, animal production systems, and the processing of animal products for multi-impact life cycle assessments. The Agri-footprint also contains inventory data on transport, fertilisers production, and auxiliary materials [30]. The second database was the Eco invent three databases, this database contains life cycle inventory (LCI) data from various sectors such as energy production, transport, building materials, production of chemicals, metal production, and fruit and vegetables. The entire database consists of over 10,000 interlinked datasets, each of which describes a life cycle inventory on a process level [31]. The third database used in this calculation was the U.S. Life Cycle Inventory (USLCI), which is a publicly available database that allows users to objectively review and compare analysis results that are based on similar data collection and analysis methods [32]. The second component was the inventory analysis. This is the stage to classify and compute the energy, water, and materials usage as well as the environmental releases (e.g., air/gas emissions, solid waste disposal, and wastewater discharges) [33]. Table 1 shows the inventory data used in the evaluation of environmental impact and the references database where the values were taken from. In this study, the evaluation of oil palm/glass fibre-reinforced composites for ACB damage assessment under the biopolymer inventory, which material class was thermoset. The input value was divided into two categories: (1) the input from nature to fabricate ACB weight up to 2 kg such as land transformation from forest for oil palm empty fruit bunch of 159 m^2, occupational annual crop 1000 m^2.a (land occupation recorded as m^2 times a year) and land transformation from annual crop organic of 5.424 m^2. (2) The input from Technosphere material such as the total energy used for oil palm fibre production of 12.24 MJ and pulforming process of 3.1 MJ per kg of ACB production with oil palm/glass fibres of 13–32 kg per production by using pulforming process. In this case, the worst-case scenario was chosen, which is 32 kg. The output of the emission released to the environment from the process were dinitrogen monoxide (N_2O) direct emissions due to the use of 0.2051 kg manure, N_2O indirect emissions (leaching and volatilization) due to the use of 0.08718 kg manure, ammonia emission of 3.17 kg due to the use of manure, ammonia emission of 11.9 kg due to the use of fertiliser, carbon dioxide (CO_2), fossil of 244.3 kg direct emissions due to the use of fertiliser, CO_2, land transformation of 3756 kg, CO_2 fossil of 8653 kg due to the crop cultivation on drained organic soil, glyphosate of 0.2364 kg due to the use of herbicide,1.34 m^3 of affected wastewater, and 0.29 kg of pesticides emission into the soil. The third component of this study was the impact assessment. The evaluation of environment impact assessed the potential human and environmental effects of energy, water, material usage, and the ecological impact identified in the inventory analysis of software Sima Pro 8.5. The results are presented in the results and discussion section. The final component of this study was the interpretation of results. The evaluated results of the inventory analysis and impact assessment are discussed in the results and discussion section.

Table 1. Input, output, process details and data base used to analyse pulforming process of oil palm/glass fibre-reinforced polyurethane composite structure ACB [34–38]

Product	**Category**	**Comments**		**Process**
Oil Palm Natural/Glass Fibre Reinforced Polyurethane Hybrid Composite for ACB	Biopolymer Composite	Thermoset		Pulforming
(Input from Nature)				
Input from Nature	**Sub-component**	**Amount**	**Unit**	**Data Base/ Reference**
Transformation from forest for oil palm empty fruit bunch is	land	159	m^2	Calculated using the direct Land Use Change Assessment Tool 2016.1, Blonk Consultants, Gouda.
Transformation from annual crop organic	land	5.424	m^2	
Occupational annual crop	land	1000	m^2a	
Transformation from permanent crop	land	120.2	m^2	
Transformation to annual crop	land	204.6	m^2	
Input from nature / Technosphere: Materials / Fuels				
Input from Nature	**Sub-component**	**Amount**	**Unit**	**Data Base/ Reference**
Energy used for oil palm fibre production	nil	12.24	MJ	USLCI
Energy used for pulforming process	nil	3.1	MJ	Ecoinvent 3 - allocation at point of substitution - system
Energy used for glass fibre production	nil	13 - 32	MJ/kg	Ecoinvent 3 - allocation at point of substitution - system
Diesel consumption	nil	14.22	litre	Average value of diesel consumption
Distance	nil	75	km	

Output				
Output	Component	Amount	Unit	Data Base/ Reference
Mass of dinitrogen monoxide N_2O direct emissions, due to use of manure	air	0.2051	kg	Agri footprint Mass Allocation
Mass of dinitrogen monoxide N_2O indirect emissions (leaching and volatilization), due to use of manure	air	0.08718	kg	Agri footprint Mass Allocation
Mass of ammonia emission due to use of manure	air	3.17	kg	Agri footprint Mass Allocation
Mass of ammonia emission due to use of fertilizer	Air	11.9	kg	Agri footprint Mass Allocation
Mass of carbon dioxide CO_2, fossil direct emissions due to use of fertilizer,	Air	244.3	kg	Agri footprint Mass Allocation
Mass of carbon dioxide CO_2, land transformation,	Air	3756	kg	Agri footprint Mass Allocation
Mass of carbon dioxide CO_2 fossil due to crop cultivation on drained organic soil	Air	8653	kg	Agri footprint Mass Allocation
Mass of glyphosate due to use of herbicide	Air	0.2364	kg	Agri footprint Mass Allocation
Volume of wastewater	water	1.34	m^3	Agri footprint Mass Allocation
Mass of pesticides	water	0.29	kg	Agri footprint Mass Allocation
Mass of fertilizer	water	25.12	kg	Agri footprint Mass Allocation

RESULTS

Conventionally, ten or more different impact categories such as acidification, ozone layer depletion, ecotoxicity, and resource extraction used by LCA to express the emissions and resource extractions. It is very difficult to provide weightage factors for such many impact categories. Therefore, based on Simapro database manual methods library, a panel from Swiss LCA interest group requested to assess the damage impact based on three damage categories only [39]. Consequently, the impact categories were divided into three main damage assessment categories at the endpoint level as shown in Figure 3 which is 1) damage to human health (HH), 2) damage to ecosystem quality (ED), and 3) damage to resource availability (RA).

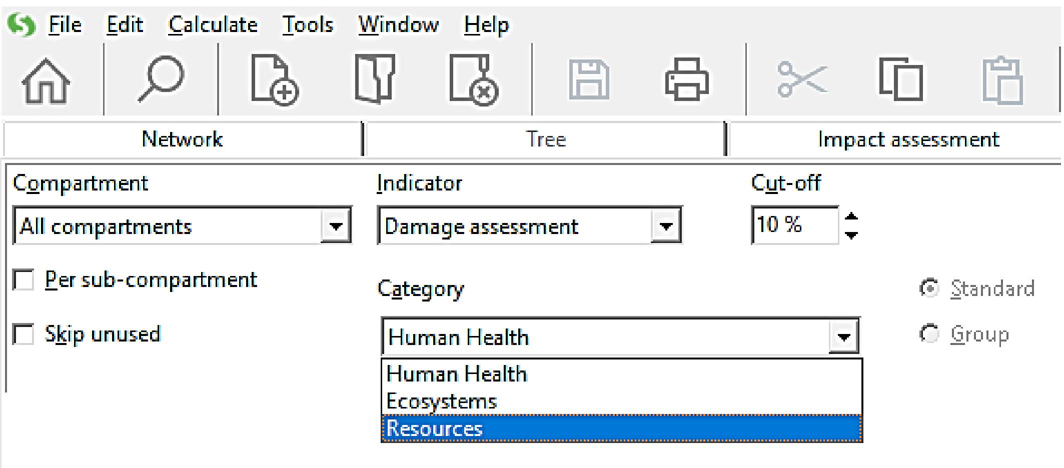


Figure 3. Categories of damage assessment available to analyse

The first category was the damage to human health. The category was expressed as the number of year life lost and the number of years lived disabled and were combined as disability adjusted life years (DALYs), an index that is also used by the world bank and world health organisation (WHO) as a measure of the global burden of disease. DALY combine information about morbidity and mortality in numbers of healthy years lost. The effect of human health (HH) covered: 1) climate change (disease + displacement), 2) ozone layer depletion (cancer + cataract), 3) radiation effects (cancer), 4) respiratory effects from the concentration of fine dust, and 5) cancer from the concentration of air, water, and food [23]. The second category was the damage to ecosystem quality (ED). The category was expressed as the loss of species over a certain area, during a certain time. It also included altered pH, nutrient availability, and concentration in soil. Exposure and effect analysis measured six categories which are 1) the decrease of natural areas, 2) regional effect on species numbers, 3) local effect on species numbers, 4) effect on, 5) target species, and 6) ecotoxicity: the toxic stress measured by potentially affected fraction (PAF). Where the formula to calculate the damage to ecosystems donated as [plant species (%) x affected area (m^2) x number of production years] known as eco system damage potential (EDP) [25]. The third category was the damage to resources (RA). The category was expressed as the surplus energy needed for the future extractions of minerals and fossil fuels. In these categories, damage effect for surplus cost energy at future extraction predicted from the concentration of ores and the availability of fossil fuels. The unit to measure RA is dollar ($), which represents the extra cost involved for future mineral and fossil resource extraction [40]. This research paper has no intention to analyse and studies about this category.

DISCUSSION

Damage to Human Health (HH)

Figure 4 shows the major element that contributes to the damage to human health. The results show air/ CO_2 contributed the biggest number, but the percentage of 0.0125 DALY was still very low, followed by land transformation of 0.0053 DALY, air/ammonia of 0.0013 DALY, and other elements known as the remaining substance of 0.00017 DALY. The unit of DALY launched by WHO was measured from the value of 0 for no effect or safe, the value of 0.67 and above for danger or critical, and the value of 1 for fatal damage or death [41].

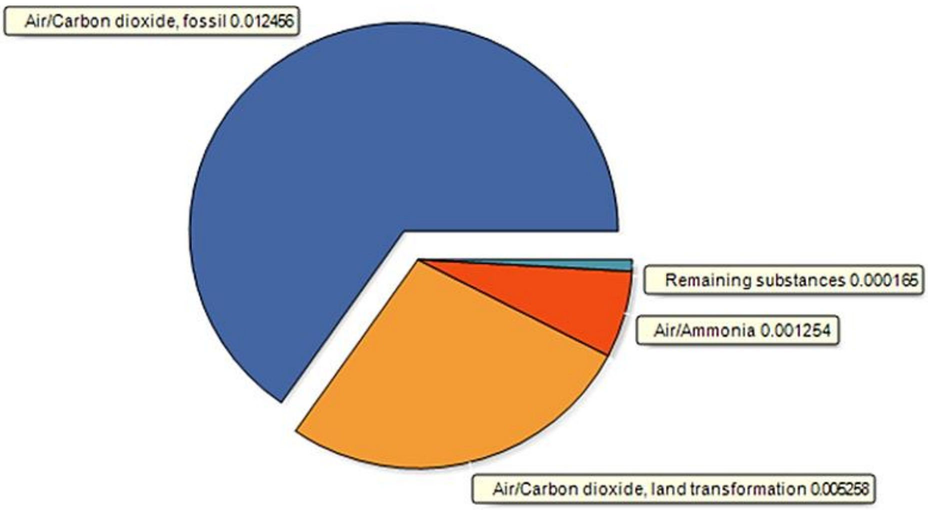


Figure 4. Human Health damage assessment of pulforming process for oil palm/glass fibre reinforce Polyurethane composite for ACB

Figure 5 shows the results of ozone depletion damage assessment of pulforming process for oil palm natural/glass fibre-reinforced composite. In this analysis, all the hazardous elements such as air/methane, trichlorofluoromethane, and CFC which can cause health diseases such as cancer and eczema [42–44] only produced 1.32×10^{-9} DALY where, air/ethane, dichlorofluoroethane can cause the health disease such as confusion, drowsiness, and unconsciousness [30] only contribute around 1.28×10^{-9} DALY to human health damage impact. Therefore, the results show the pulforming process using oil palm natural/glass fibre-reinforced composite for ACB are safe from ozone depletion and the impact was very low.

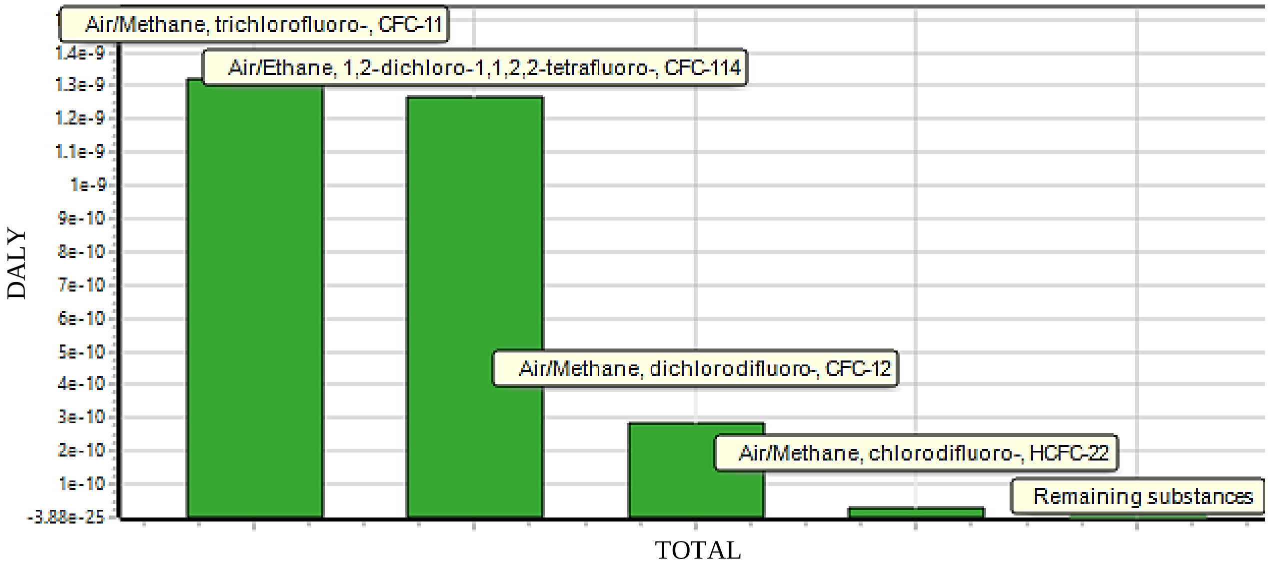
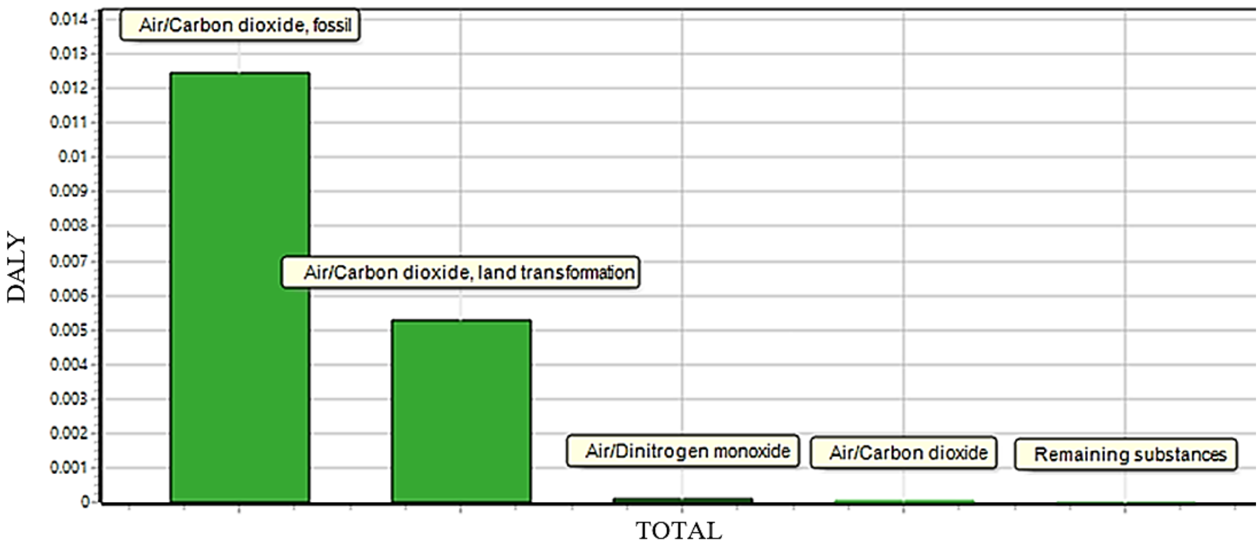


Figure 5. Ozone depletion damage assessment of pulforming process per impact categories results using oil palm/glass fibre-reinforced Polyurethane composite for ACB.

Figure 6 shows the results of climate change for human health damage assessment of the oil palm natural/glass fibre-reinforced polyurethane composite pulforming process to manufacture ACB. The major elements released to air, water, and soil which contributed to climate change human health in this process were from air/CO_2, fossil of 0.012 DALY, followed by air/ CO_2, land transformation of 0.0054 DALY, and other elements such as dinitrogen monoxide and remaining substances (other elements) which were below than 0.001 DALY. Thus, the results show the pulforming process using oil palm natural/glass fibre-reinforced polyurethane composite for ACB is a nonviolent manufacturing process for human health and environment. Furthermore, the impact to the climate change was too low.



Method: ReCiPe Endpoint (H) V1.13 / Europe ReciPe H/A / Damage assessment / Excluding long-term emissions. Analyzing 1 kg Oil Palm Natural/Gas Fiber Reinforced Polyurethane Hybrid Composite for ACB.

Figure 6. Climate Change Human Health of pulforming process per impact categories results using oil palm / glass fibre reinforce Polyurethane composite for ACB

Damage to Ecosystem Quality (ED)

In this category, the unit used to measure the ecosystem damage impact is species.year (species.yr.), which is approximately any species extinction estimated over time [45, 46]. From the results analysis shown in Figure 7, the raw material and annual crop contributed 1.97×10^{-4} species.yr, followed by air/ CO_2, fossil of 7.06×10^{-5}, and air/ CO^2, land transformation of 2.95×10^{-5}. The analysis shows that the selection of materials was the main contribution to the ecosystem damage.

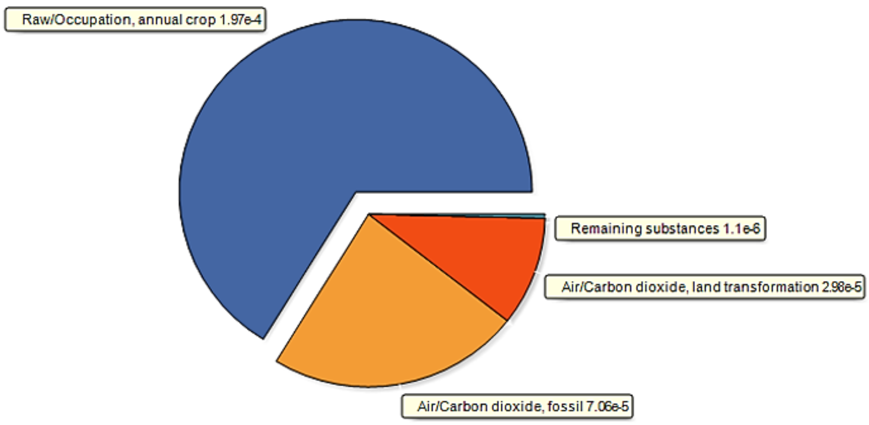


Figure 7. Ecosystem damage assessment analysis of pulforming process for oil palm/glass fibre-reinforced Polyurethane composite for ACB

Figure 8 shows the results of damage assessment for the terrestrial ecotoxicity of pulforming process per impact categories results using oil palm natural/glass fibre-reinforced polyurethane composite for ACB. The major damage in this process was produced by air/selenium of 1.13×10^{-10} species.yr, followed by air/ glyphosate of 5.8×10^{-11} species.yr, and air/ copper of 1.8×10^{-11} species.yr. The other elements were below 1.0×10^{-11} species.yr. The analysis results communicate that, the chemical reaction and the impact from the selected material and manufacturing process to fabricate ACB was very low and safe for the ecosystem.

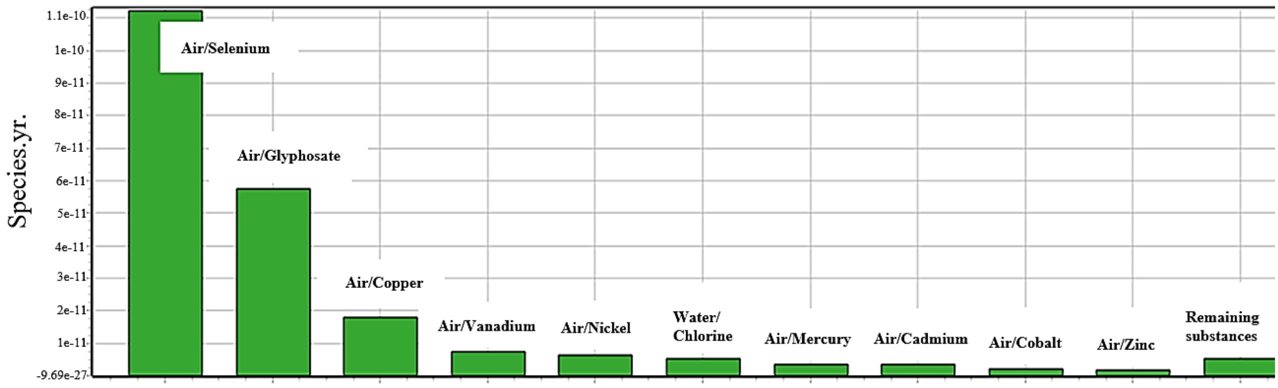


Figure 8. Terrestrial ecotoxicity of pulforming process per impact categories results using oil palm /glass fibre-reinforced Polyurethane composite for ACB

CONCLUSIONS

Based on the results, the pulforming process using oil palm natural/glass fibre-reinforced composite for ACB is safe and the emission was very minimal or under control. Thus, it could not cause any damage to human health. Furthermore, the terrestrial ecotoxicity of pulforming process under the ecosystem category was analysed. The results under eco system category have been communicated regarding decreased of production and biodiversity and decreased of wildlife for hunting or viewing. The results collected shows a small number of approximately any species extinction estimated over time expressed in species.years. Therefore, it also proves that the pulforming process of oil palm natural/glass fibre reinforced polyurethane composite for ACB is environment friendly and safe for human and ecosystem.

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