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Implementation of Greenhouse Gas Reduction in the Unmanned Vehicles Industry Using LCA Method

Implementasi Pengurangan Gas Rumah Kaca pada Industri Kendaraan Nir Awak Menggunakan Metode LCA

Handoko Subawi[1*] & Arini Sedawati[1]
[1]Indonesian Aerospace Ltd, Jl. Pajajaran 154 Bandung 40174, Indonesia
[*]E-mail: subawihandoko@gmail.com

Abstract. The study purposes to assess the environmental aspect of the process technology of medium-altitude long-endurance unmanned vehicles using LCA method. The LCA scope in this study uses the limitation of the cradle-to-gate category. The potential impact is estimated using the impact characterization value parameter which is calculated using SimaPro trial software. Further, the normalization value is obtained using the normalization factor referring to the international reference life-cycle data system (ILCD). Based on the study, the parameters of climate change and freshwater ecotoxicity are the two dominant parameters among the categories of environmental impacts studied. The source of this impact comes from the use of diesel fuel to operate the boiler and the use of chemicals for the surface treatment process of components made of aluminum metal. The production capacity of the unmanned vehicle under study is six vehicles per year, with an airframe weight of 428 kg per vehicle, excluding the propeller system and avionics. When compared with the design of similar vehicles made of metal, the potential for reducing climate change pollution that can be achieved is 302,152 kg CO_2 eq./kg of product, while the potential for reducing freshwater ecotoxicity is 157,836 kg 1,4-dichlorobenzene eq./kg of product.

Keywords: characterization value, climate change, ecotoxicity, life cycle assessment, normalization factor, unmanned vehicle.

Abstrak. *Studi life cycle assessment dilakukan terhadap proses produk kendaraan nir awak jenis medium-altitude long-endurance. Potensi dampak diperkirakan menggunakan parameter nilai karakterisasi dampak yang dihitung menggunakan metoda SimaPro. Sedangkan nilai normalisasi diperoleh menggunakan factor normalisasi mengacu pada metoda international reference life-cycle data system (ILCD). Berdasarkan kajian, parameter climate change dan freshwater ecotoxicity merupakan dua parameter dominan diantara sepuluh kategori dampak lingkungan yang dikaji. Sumber dampak ini berasal dari penggunaan bahan bakar solar untuk mengoperasikan boiler dan juga penggunaan bahan kimia untuk proses surface treatment komponen yang terbuat dari logam aluminium. Kapasitas produksi kendaraan nir awak yang dikaji adalah enam kendaraan per tahun, dengan berat airframe 428 kg per kendaraan, tidak termasuk system propeller dan avionik. Jika dibandingkan dengan perancangan kendaraan sejenis dari bahan logam, maka potensi pengurangan pencemaran climate change yang dapat dicapai sebesar 302.153 kg* CO_2 *eq./kg produk, sedangkan potensi pengurangan pencemaran freshwater ecotoxicity sebesar 157.836 kg 1,4-dichloro benzene eq./kg produk.*

Kata kunci: *nilai karakterisasi, perubahan iklim, ekotoksisitas, penilaian siklus lingkungan, faktor normalisasi, pesawat nir-awak.*

INTRODUCTION

Life Cycle Assessment (LCA) studies in Indonesia have shown improvement in recent years with the variety of product systems studied. Among the LCA studies in Indonesia that have been published are related to renewable energy, plantations, water and wastewater treatment, and other manufactured products. Chaerul and Allia observed several critical issues for improving the quality of LCA studies in Indonesia (Chaerul and Allia, 2020). Life cycle assessment studies have been used to evaluate the impact categories of several food products, such as cassava chips by Ulya, et al. (2020), tofu by Rosyidah, et al. (2019), by Sukmana, et al. (2019), and milk by Allia, et al. (2018).

The issue of global warming is caused by greenhouse gas emissions from human activities. Along with the increase in the needs of daily life, human activities in food production also increase. Previous researchers have conducted research to determine the impact of global warming, for example from the activities of the food industry. The method used in analyzing the data uses the LCA method with SimaPro 8.4 trial software.

The application of LCA studies is also used to evaluate potential impacts on industry, such as plastic bags by Hanun, et al. (2019), electronics by Clemma, et al. (2019), as well as studies on energy generation by Permatasari, et al. (2019). The study of global coal-fired energy generation is important, where this technology covers 38% of the global electricity market. This is influenced by the competitive price of coal which is widely available. However, the emissions generated by coal-fired power plants are more significant compared to other power plants. All countries in the world are trying to reduce the potential for global warming by reducing CO_2 emissions. One solution is to save on the use of fossil energy so that CO_2 decreases, for example using renewable energy.

Currently, biomass has become a renewable energy source and is widely used for power generation. Biomass resources can be used entirely to produce so-called biomass power plants. In practice coal-fired power plants can use a certain percentage of coal mixture. Some researchers use the LCA method to evaluate emissions from coal-fired power plants compared to biomass. In general, electricity will have an important impact when it is obtained from the grid from coal-fired power plants. The results show that biomass power plants produce lower emissions than coal power plants.

The application of LCA studies is also applied to evaluate the potential environmental impacts of plantations by Stichnothe and Bessoub (2017), and by Soraya, et al. (2014). The increasing demand for palm oil is driven by the increase in human population, income growth and the biodiesel stimulation program. Subawi and Ahmad (2012) reported that oil palm plantations cover an area at about eight million hectares and other seventeen million hectares have not been planted in Indonesia . Palm oil production also releases large amounts of wastewater. Cultivation and processing of these plants is considered a source of emissions with a large potential for environmental impact. The loss of nitrogen (N) in the palm oil production system is a major cause of environmental and economic problems.

The life cycle assessment method is also used to evaluate the potential environmental impact of biodiesel production from palm oil in Indonesia. The basis of the biodiesel calculation uses the tonnage unit. The main contributor to the potential for global warming is the use of fertilizers and herbicides during the planting stage. Co-products from the processing of palm oil can be used for energy resources in factories. The biodiesel production process is a major contributor to the impact of photochemical oxidation. Transportation activities also have a significant contribution to environmental impact.

This study evaluates the environmental impact of the activities of the unmanned vehicle industry. Based on the environmental aspect, efforts to reduce potential emissions are carried out by the application of non-metallic materials for the manufacture of vehicles. Technical studies related to flight performance and aerodynamic aspects are not discussed in this paper. It is important in this study to also conduct a comparative study between the use of metallic materials against non-metallic materials for the production of superior unmanned vehicles in this decade with an airframe weighing less than 450 kg per unit.

RESEARCH METHOD

The steps of the life cycle assessment (LCA) process applied in this study are described starting from the raw material preparation step to the assembly step of the unmanned vehicles as the final product. The LCA method uses the mass and energy balances data for a production process (see Table 1). The production process consumes raw materials, results medium-altitude long-endurance unmanned vehicles and releases wastes. The mass balance is prepared to describe the production capacity on an annual basis to facilitate the study. The LCA scope in this study uses the limitation of the cradle-to-gate category. Based on the production process, several work centers that use significant resources are identified, including fuel, water, chemicals, electricity, and others.

The LCA method begins with a detailed data analysis by considering the characterization factors of all the raw materials used and the waste produced. Then, the categorical indicators were analyzed based on the ten types of impact categories selected (see Table 2). Furthermore, the data base is analyzed in more detail with respect to the characterization factor of all raw materials used and the waste released. to obtain a characterization value. The calculation of all input data used the concept of the SimaPro trial software. Furthermore, the normalization factor is determined to obtain the normalization value according to the international reference life-cycle data system (ILCD) method by Aymard and Genoulaz (2018). The impact on manufacturing can be obtained from the characterization value divided by the number of products produced. Based on the characterization value, it will be seen the category of environmental impacts that contribute significantly to environmental issues. The results of the calculation to get the emission value from the production process of unmanned vehicles using metal materials will be compared with the potential emissions of making unmanned vehicles from non-metallic materials.

RESULT AND DISCUSSION

Medium-altitude long-endurance unmanned vehicles are types of vehicles without passengers to fulfill various missions such as reconnaissance, monitoring and surveillance over a land or sea area, as well as for other non-military purposes. The operation of this type of vehicle does not have the risk of an accident like commercial or military aircraft in general. The design and manufacture of this type of vehicle in addition to considering aspects of aerodynamics and flight control, also considers aspects of environmental conservation. Environmental aspects of concern include fuel efficiency, and the application of the vehicle's airframe structure, which is applied during the design, production, and service life stages.

The stages of the process within the scope of the cradle to gate study discussed include the procurement of raw materials, manufacture of detailed parts, sub-assembly, and final assembly. The environmental impact categories examined in this study include: climate change, ozone depletion, human health cancer, human health non-cancer, respiratory inorganic, acidification, eutrophication, fresh water ecotoxicity, abiotic resource depletion, and land use.

Inventory Data

Inventory data includes details of raw materials and energy used to produce medium-altitude long-endurance unmanned vehicles. Data analysis is done by detailing the list of incoming materials and energy compared to those that go out. In addition to the products produced, the amount of waste (solid, liquid, gas) produced is also listed. In general, the unit used is kg/kg product. The calculation assumes vehicle production capacity per year. Table 1 shows material used in production of medium-altitude long-endurance unmanned vehicles.

Table 1. Material used in production

No	Work center	Raw materials, kg	Vendor part, kg	Nett product, kg	Material waste, kg	Nett product/ raw mat'l	Nett product, kg/unit
I	Detail parts						
1	Machining	591		104	487	18%	17
2	Sheet metal	138		98	40	71%	16
3	Composite	3.239		2.364	874	73%	394
4	Metal bond	-		-	-		-
	Sub total	3.968		2.566	1.402	65%	428
II	Sub assembly						
5	Vendor item	173	0,5	172	1		0
	Sub total	4.141	0,5	2.738	1.402	66%	428
III	Final assembly						
6	Vendor item		133				133
	Total	4.141	133	2.738	1.402	66%	561
IV	Others						
7	Mould	219	-	131	88	60%	

Detail parts manufacturing

Details of parts for medium-altitude long-endurance vehicles mostly use non-metallic materials. In addition to having a lighter density, non-metallic materials provide a greener environmental effect than metal materials. The use of non-metallic materials will make the vehicle's weight lighter than vehicles made of metal materials. The type of overhead used is similar although in different amounts, namely chemicals, electricity, fuel and water. While the metal material used in general is aluminum metal. Figure 1 shows the energy mass balance of the detailed manufacture of parts for a medium-altitude long-endurance vehicle.

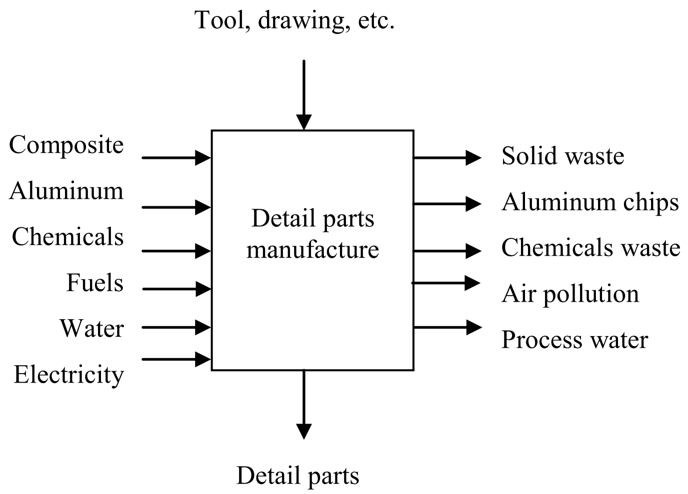

Figure 1. Detail parts manufacturing diagram for medium-altitude long-endurance vehicles.

The process water used will be recycled and processed in the process water treatment center, while the liquid waste is channeled in the liquid waste treatment center. Solid waste in the form of plastic scraps is collected for further processing. Scrap metal material from metal machining is collected and pressed to be utilized by the industrial sector.

Sub assembly

The sub-assembly center for medium-altitude long-endurance vehicles is the center for the assembly of vehicle component parts. Vehicle components include wings, fuselage, tail, empennage (horizontal, vertical, tail), and also landing gear. Assembly is carried out following the design drawings using tools and jigs. The assembly of non-metallic parts is carried out using the secondary bonding method, while the joining of metal parts uses the nut-bolt, rivet and welding techniques. Figure 2 shows the mass and energy balances for the sub-assembly activities of medium-altitude long-endurance vehicle components.

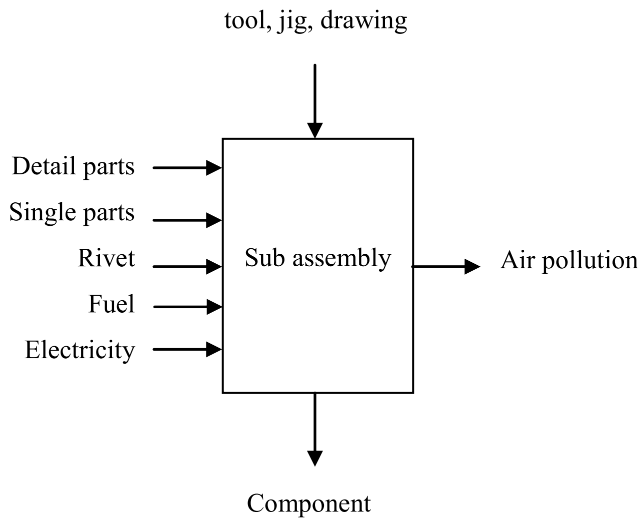

Figure 2. Sub-assembly diagram of medium-altitude long-endurance vehicles.

Energy sources for production operations use electricity and fuel. Assembly equipment can use a power source or use compressed air from a compressed air center. The work equipment is driven by 4-5 bar compressed air. Controlled compressed air does not contain moisture and oil contaminants.

Final assembly

The final assembly center for medium-altitude long-endurance vehicles manages the final assembly activities for vehicle components. Vehicle components installed at this stage include navigation systems, avionics systems, electrical systems, instrumentation, hydraulic systems, propellers, and vehicle engines. Figure 3 shows the mass and energy balances for the final assembly activities for the manufacture of medium-altitude long-endurance vehicles.

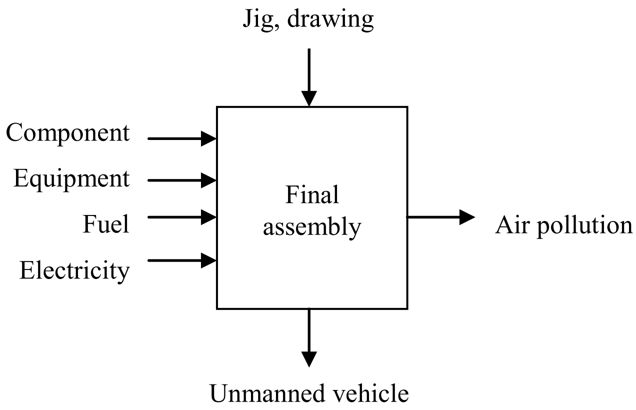

Figure 3. Final assembly diagram of medium-altitude long-endurance vehicles.

Characterization value

The characterization stage is the evaluation stage for each category of medium-altitude long-endurance vehicle production activity against environmental impact aspects. This stage is a tool for calculating the contribution of activities to impact indicator. At this stage, the life cycle inventory results from all categories can be analyzed directly. This characterization uses various methods that can be selected, such as ILCD 2011. Acero et al. identified other types of characterization approaches that can be used, such as CML 2001, CED, Ecoindicator 99, ReCiPe, TRACI 2.1, USEtox, and others (Acero, et al., 2017). The characterization values are presented in Table 2.

Based on the calculation of the characterization values in the table above, it can be shown that the impact categories of climate change and fresh water eco-toxicity are significant contributors because of the manufacture of medium-altitude long-endurance vehicles. The potential impact as an impact to manufacturing is obtained from the characterization value divided by the total product weight. In addition, the resource weight is obtained from the resource weight multiplied by the characterization factor. The by-product in the form of waste (residue) is used as the basis for calculating the contribution. The contribution value is obtained from the percentage of the residual weight value multiplied by the characterization factor.

Table 2. Characterization value of the unmanned vehicle industry.

No	Environmental impact category	Unit	Non-metallic vehicles		Metal vehicle	
			Characterization value	Contribution, %	Characterization value	Contribution, %
1	Climate change	kg CO_2 eq./kg	261.137	83,43%	563.290	93,81%
2	Ozone depletion	kg CFC-11 eq./kg	183.966	0%	343.396	0%
3	Human health cancer	kg 1,4-dichloro benzene eq./kg	183.966	0%	343.396	0%
4	Human health non-cancer	DALY/kg	184.112	0,16%	343.526	0,06%
5	Respiratory inorganic	DALY/kg	183.966	0,00%	343.396	0,00%
6	Acidification	kg SO_2 eq./kg	184.300	0,36%	345.198	0,41%
7	Eutrophication	kg $PO4^{3-}$ eq./kg	184.053	0,10%	343.646	0,11%
8	Fresh water eco-toxicity	kg 1,4-dichloro benzene eq./kg	198.726	15,96%	356.563	5,62%
9	Abiotic resource depletion	kg antimony eq./kg	183.966	0%	343.396	0%
10	Land use	m^2*yr/kg	183.966	0%	343.396	0%

If the medium-altitude long-endurance vehicle is made predominantly of aluminum metal, it will produce the same pollution impact category, namely by climate change and fresh water eco-toxicity. However, the characterization value of metal vehicles is greater than that of non-metallic vehicles. This shows that medium-altitude long-endurance vehicles made of non-metallic materials are relatively more environmentally friendly than vehicles made of metal.

Normalization stage

In the normalization stage, the environmental impact indicator data is evaluated for its correlation to the environmental impact category. The normalization value is obtained from the multiplication between the normalization factor and the characterization value. The normalization factor used in this calculation is obtained from the international reference life-cycle data system. The normalization factor for the production activities of the medium-altitude long-endurance unmanned vehicles is presented in Table 3 below.

Table 3. Normalization factors of the unmanned vehicle industry.

No	Protection Area	Impact Category	Normalization Factor
1	Human health	Global warming	2.39.E-11
2		Ozone Depletion	8.91.E-13
3		Human toxicity	0.00.E+00

No	Protection Area	Impact Category	Normalization Factor
4		Carcinogenic effects on humans	4.84.E-11
5		Respiratory Inorganic	2.58.E-11
6	Natural Environment	Acidification	1.89.E-11
7		Eutrophication	1.71.E-11
8	Resources	Fresh Water Ecotoxicity	4.14.E-11
9		Abiotic Resource Depletion	3.54.E-11
10		Land Use	3.54.E-11

The normalization value obtained from the simaPro trial software is presented in Table 4. The value is obtained because of multiplying the characterization value against the normalization factor. The normalization factor is obtained from ILCD or the normalization EU27 2010. The results of the calculation of the normalization value show that the production activities of unmanned vehicles do not show any significant normalization values among the list of impact categories studied. Human health is determined by clean air, free of contaminants. Contaminants are generally the result of burning fuel or releasing chemicals. The normalized value of the human health impact obtained is 8.91×10^{-6}. The cause of air contaminants is the burning of diesel fuel in the production environment. The results of this study indicate that global warming causes greenhouse gases, such as CO_2, to be present in the combustion of diesel fuel.

Table 4. Normalized values of the unmanned vehicle industry

No	Environmental impact category	Unit	Characterization value	Normalization Factor	Normalization value
1	Climate change	kg CO_2 eq./kg	261.137	2.39.E-11	6.24.E-06
2	Ozone depletion	kg CFC-11 eq./kg	183.966	8.91.E-13	1.64.E-07
3	Human health cancer	kg 1.4-dichloro benzene eq./kg	183.966	0.00.E+00	0.00.E+00
4	Human health non-cancer	DALY/kg	184.112	4.84.E-11	8.91.E-06
5	Respiratory inorganic	DALY/kg	183.966	2.58.E-11	4.75.E-06
6	Acidification	kg SO_2 eq./kg	184.300	1.89.E-11	3.48.E-06
7	Eutrophication	kg $PO4^{3-}$ eq./kg	184.053	1.71.E-11	3.15.E-06
8	Fresh water ecotoxicity	kg 1.4-dichloro benzene eq./kg	198.726	4.14.E-11	8.23.E-06
9	Abiotic resource depletion	kg antimony eq./kg	183.966	3.54.E-11	6.51.E-06
10	Land use	m^2*yr /kg	183.966	3.54.E-11	6.51.E-06

Acidification parameter is defined as an increase in acidity in the environment caused by the entry of acid into the environment. Meanwhile, emissions from diesel fuel produce acid when it reacts with water. This event often occurs when rainwater reacts with SO_x and NO_x contaminants during rain, producing acid rain. The main result of fuel combustion, CO_2, can also cause acidification. Increased CO_2 release will lead to further ocean acidification. This can happen, where CO_2 react with water, causing an increase in the concentration of bicarbonate (HCO_3^-) and carbonic acid (H_2CO_3), when the concentration of CO_2 in the atmosphere increases. The impact category of acidification has a normalized value of 1.89×10^{-11}.

Eutrophication parameters are used to describe the type of pollution in the environment where aquatic plants (e.g.: water hyacinth) grows very quickly in water bodies. Eutrophication is caused by the entry of excessive substances into water bodies. Eutrophication has low normalization value of 1.71×10^{-11}. Whereas ecotoxicity showed a slightly higher normalization value of 4.14×10^{-11}. However, this value is relatively low, so it is easy to control.

The characterization values can be used as the basis for calculating emission reduction. Emission reduction was selected based on the difference between the characterization values of metallic UAVs and actual UAVs using composite materials. The emission reduction unit used is the same as the characterization value unit. Table 5 shows the results of the calculation of the characterization values for metallic UAVs and composite UAVs. The difference between the two is used as the emission reduction number by the UAV industry.

Table 5 Emission reduction of the unmanned vehicle industry.

No	Important Impact Categories	Unit	Metallic UAV Characterization value	Actual UAV Characterization value	Emission reduction
1	Climate change	kg CO_2 eq. /year	563,289.7	261,137.3	302,152.4
2	Fresh Water Ecotoxicity	kg 1,4-dichloro benzene eq. /year	356,562.6	198.726.5	157,836.1

Impact to manufacturing

Based on the characterization values obtained, for example, the category of climate change, the value of the impact on manufacturing can then be calculated. The unit of characterization value uses kg CO_2 equivalent released by the medium-altitude long-endurance unmanned vehicles industry activities. The value of climate change impact to manufacturing is obtained from the characterization value divided by the total weight of the product produced, in a certain time unit. Table 6 shows an example of calculating the climate change impact to manufacturing the medium-altitude long-endurance unmanned vehicles compared to other products for which data is available.

Table 6. Comparison of climate change impact to manufacturing.

Aircraft program	Climate change impact, kg CO_2 eq. product	Product base, kg	Climate change impact, kg CO_2 eq. / kg	Reference(s)
MALE	3,E+05	3,E+03	79	
CN235	8,E+06	6,E+04	130	Permatasari et al. (2019)
A320	2,E+07	4,E+04	564	Lewis (2013)
A330	5,E+07	1,E+05	464	Lewis (2013)
A380	8,E+07	3,E+05	299	Lewis (2013)

CONCLUSION

Based on LCA analysis on the manufacture of medium-altitude long-endurance unmanned vehicles, the process stage that has significant impact on the environment is the heating process in the autoclave and boiler. The autoclave process is the main stage of working on non-metallic materials, while the boiler is used for surface treatment for a small number of metal components. Meanwhile, the significant environmental impact compared to others in the production of medium-altitude long-endurance unmanned vehicles is the impact of climate change and ecotoxicity. In this case, the environmental program to reduce the environmental impact on the manufacture of medium-altitude long-endurance vehicles with a capacity of six vehicles per year is the use of non-metallic materials. Based on an annual production base of six vehicles at about 428 kg weight /unit, when compared to similar vehicle designs made of metal, the potential for reducing climate change pollution that can be achieved is 302,152 kg CO_2 eq./kg of product, while reduction opportunity of freshwater ecotoxicity parameter is 157,836 kg 1,4-dichlorobenzene eq./kg of product.

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