International Journal on Advanced Science Engineering Information Technology

Vol.13 (2023) No. 1
ISSN: 2088-5334

Environmental Impact Assessment in the Synthesis of Antistatic Bionanocomposite Compared with the Synthesis of Polypropylene

Muhammad Syukur Sarfat [a], Dwi Setyaningsih [a,b,*], Farah Fahma [a], Nastiti Siswi Indrasti [a], Sudirman [c]

[a] *Department of Agroindustrial Engineering, IPB University, Bogor, 16680, Indonesia*
[b] *Surfactan and Bioenergy Reasearch Center, IPB University, Bogor, 16144, Indonesia*
[c] *National Nuclear Energy Agency of Indonesia, Puspitek, Serpong, 15314, Indonesia*

*Corresponding author: *dwisetyaningsih@apps.ipb.ac.id*

***Abstract*— This study aims to identify the environmental impact in the synthesis of antistatic bionanocomposites compared to polypropylene synthesis. It is done using the Life Cycle Assessment (LCA) method with SimaPro 9.1.1 software. The results showed that using 2% of M-DAG and 2.5% of CNC in the synthesis of antistatic bionanocomposites can reduce the environmental impact compared with the synthesis of PP. This is indicated by the decline in the impact value per impact categories, namely 4.46% of ADP, 3.70% of ADP-FF, 4.21% of GWP, 4.48% of ODP, 4.63% of HTP, 5.10% of FWAEP, 4.84% of MAEP, 2021% of TEP, 4.08% of POP, 4.41% of AP, and 4.85% of EP. After normalization of the impact category, the total environmental impact per function unit in antistatic bionancomposite synthesis is smaller than PP synthesis, with a percentage reduction of the environmental impact of 4.58%. The efficient use of energy and natural resources is considered necessary to reduce the environmental impact per kg of antistatic bionanocomposite pellets. The higher percentage of reduced by products, the lower total environmental impact per kg of antistatic bionanocomposite pellets. The application of reuse, reduce, and recycle methods on co-products from antistatic bio-nanocomposite synthesis needs to be done because it positively impacts the environment. Further research needs to be carried out to identify environmental impacts in synthesizing antistatic bionanocomposites in a wider scope of the study, namely cradle to grave, if possible.**

***Keywords*— Environmental impact assessment; synthesis of antistatic bionanocomposite; improvements analysis.**

Manuscript received 28 Nov. 2021; revised 20 Jan. 2022; accepted 4 May. 2022. Date of publication 28 Feb. 2023.

I. Introduction

Environmental Impact Assessment (EIA) is evaluating the environmental impact of manufacturing activities, taking into account the interrelated cultural, socio-economic, and human health impacts, both beneficial and detrimental. According to United Nations Environment Program (UNEP), EIA is a tool used to identify manufacturing activity's environmental, social, and economic impacts. It aims to calculate environmental impacts at every stage in the manufacturing activity. This is done to support the sustainable development goals proclaimed by UNEP where A healthy environment influences the 17 sustainable development goals. The world needs to make greater efforts and take steps towards finding better solutions to climate change and biodiversity loss to truly transform the societies' economies.

The antistatic bionanocomposites were synthesised using mono-diacylglycerols (M-DAG) as an antistatic agent [1], cellulose nanocrystals (CNC) as a reinforcement [2], [3], [4], [5], [6], [7], polypropylene (PP) as an thermoplastic matrix [5], [7], and supporting materials consist of maleic anhydride polypropylene (MAPP), antioxidant (AO), and mineral oil (MO) [5], [7]. Synthesis of antistatic bionanocomposites requires energy and costs, which can cause environmental impacts from the use of energy and the resulting waste [8]. Energy and environmental issues are the two main challenges in the present and future centuries. Innovative and sustainable choices are needed to address the energy crisis and climate change [9].

The Life Cycle Assessment (LCA) was used to calculate the environmental impact during the synthesis of antistatic bionanocomposite [10]. It is a method for evaluating the environmental impact of a product's life cycle. LCA takes into account all activities involved in product creation with a holistic approach, such as raw material handling, transportation, manufacturing, distribution, use and disposal [11]. The LCA study begins with determining the goals and scope, followed by quantifying all material and energy inputs used in the process of producing the product [10]. To calculate the environmental impact during synthesis of antistatic bionanocomposites used Life Cycle Assessment (LCA) [10]. LCA is the method to evaluates the environmental impact of a product life cycle. LCA takes into account all the activities involved in creating a product with a holistic approach, such as raw material handling, transportation, manufacturing, distribution, use, and disposal [11]. The LCA study begins with determining the goals and scope, followed by quantifying all energy and material inputs used in the process of producing the product [10].

The proposed hypothesis is that the synthesis of antistatic nanocomposites requires raw materials and energy use, the environmental impact of using raw materials, energy use, and waste generated. It is hoped that identification results can provide an overview of the environmental impact of antistatic nanocomposite synthesis. Therefore, this study aimed to identify the environmental impact during the synthesis of antistatic bionanocomposite compared to the synthesis of polypropylene (PP).

II. Materials and Method

The Life Cycle Assessment (LCA) method with SimaPro 9.1.1 software was used to identify environmental impacts during the synthesis of antistatic bionanocomposites [10], [12]. It is a comprehensive scientific approach used to determine the environmental impact of various processes [13]. All inputs, outputs, and related potential environmental impact of a product throughout its life cycle will be calculated using LCA [10]. The implementation of LCA is based on the guidelines of the ISO 14040:2006 standard, which states the principles and framework for LCA, and the ISO 14044:2006 standard, which states the requirements and guidelines for LCA. Based on the standards of ISO 14040:2006 and ISO 14044:2006, there are four recommended phases in an LCA study, namely the purpose and scope of the definition, Life Cycle Inventory Analysis (LCI), Life Cycle Impact Assessment (LCIA), and interpretation (Fig. 1).

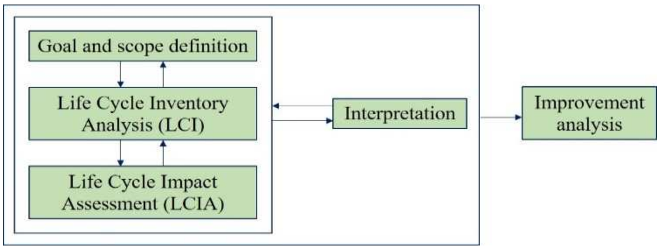

Fig. 1 Phases of LCA study

A. *Goal and Scope Definition*

During the synthesis of antistatic bionanocomposites, LCA studies were carried out according to ISO 14040:2006 and ISO 14044:2006 standards. The aim is to broaden the information from synthesizing antistatic bionanocomposites to producing products as antistatic bionanocomposite pellets. This analysis aims to compare the environmental impact of the synthesis of antistatic bionanocomposites and the synthesis of polypropylene (PP). This study discusses the synthesis of antistatic bionanocomposites and PP from the side of four sub-processes: the mixing, the extrusion, the air knife, and the pelletizing sub-process.

B. *Life Cycle Inventory Analysis (LCI)*

According to Marendra *et al.* [14], the inventory analysis follows the ISO 14040:2006 and ISO 14040:2006 standards, consisting of data collection of inputs and outputs of a product production system. In the inventory analysis, total energy and material inputs, products, by-products, and emissions generated in each sub-process are calculated per functional unit.

C. *Life Cycle Impact Assessment (LCIA)*

An impact assessment was carried out to evaluate environmental impacts based on inventory analysis results [10]. The integration of environmental impacts from the use of raw materials, energy use, and waste generated was analyzed using CML-IA baseline method in the SimaPro 9.1.1 software developed by the Center of Environmental Science (CML) of Leiden University in The Netherlands. Normalization is one of the optional stages in the LCIA, and is the last stage of impact assessment using the CML-IA baseline method. The purpose is to compare the impact categories in the same unit.

D. *Interpretation*

The results of the LCA study will be the basis that used as a reference for decision-making and policies for improvement [14]. Interpretation is a systematic technique to evaluate information from the life cycle inventory results and the life cycle impact assessment results. The evaluation results from LCI and LCIA are summarized in the interpretation stage, which is a series of conclusions and recommendations in research.

E. *Improvement Analysis*

Analysis of the improvement in the synthesis of the antistatic bionanocomposite system was carried out in several ways such as reducing energy use with efficient use of water and electricity, as well as minimizing waste. In this study, an analysis of improvements in the synthesis of anti-static nanocomposites was carried out in several scenarios using production methods (waste or by-product minimization).

III. Results and Discussion

A. *Flow Diagram*

The antistatic bionanocomposite and PP synthesis flow chart consists of four sub-processes: the mixing sub-process, the extrusion sub-process, the air knife sub-process and the pelletizing sub-process. Fig. 2 shows a flow diagram for the synthesis of antistatic bionanocomposite. The flow diagram of synthesis of PP is the same as the flow diagram for synthesis of antistatic bionanocomposites, but without the addition of material such as mono-diacylglycerol (M-DAG), cellulose nanocrystalline (CNC), and maleic anhydride polypropylene (MAPP).

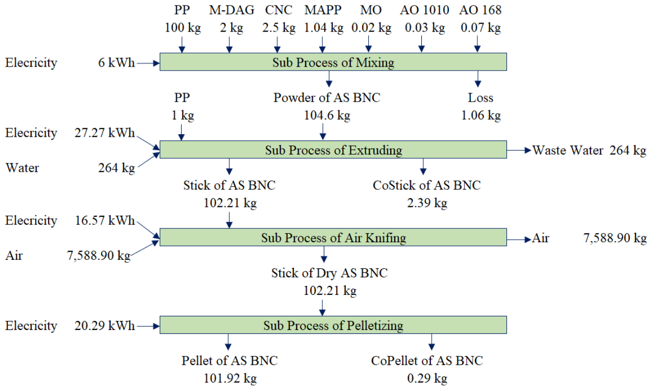

Fig. 2 Flow diagram of synthesis of antistatic bionanocomposites. AS BNC: antistatic bionanocomposites; PP: polypropylene; M-DAG: mono-diacylglycerol; CNC: cellulose nanocrystaline; MAPP: maleic anhydrite polypropylene; MO: mineral oil; AO: antioxidant

1) Sub process of mixing: In this stage, all the raw materials mixed until completely mixed using a ribbon mixer. The specifications of the ribbon mixer used are horizontal ribbon mixer, model: VRB-0.1 m³, capacity: 40-50 kg per hour and stir motor: 3 kWh. The output of this stage is an antistatic bionanocomposite powder used in the extrusion sub-process and material loss.

2) Sub proces of extruding: At this stage, the antistatic bionanocomposite powder is extruded to form antistatic bionanocomposite sticks using an extruder. It is a typical twin screw extruder with a 9-10 kg/hour capacity, a stirrer motor, and an electric power of 0.22 kWh and 0.038 kWh respectively. The output of this stage is an antistatic bionanocomposite stick used in the water knifing sub process and an antistatic bionanocomposite co-stick as a by-product. Before that, the sticks of antistatic bionanocomposite are passed to the masterbatch.

3) Sub process of air knifing: In this stage, the stick of antistatic bionanocomposites passed on the air knife. The specifications of the air knife used are AK-6 (6 cm) with electricity power: 1.49 kWh, flow rate of air: 683 kg per hour. Output from this stage is dry stick of antistatic bionanocomposites used in the sub process of pelletizing.

4) Sub process of pelletizing: At this stage, dry sticks of antistatic bionanocomposite were cut to form antistatic bionanocomposite pellets using pelletizer. It used a dolphin engineering pelletizer with a 9-10 kg/h and stirrer motor 1.83 kWh. The output of this stage is an antistatic bionanocomposite pellets as the main product and an antistatic bionanocomposite co-pellet as a by-product.

B. Life Cycle Assessment (LCA)

1) Goal and scoping definition: The purpose of this analysis was to compare the environmental impact of the synthesis of antistatic bionanocomposites from a mixture of 94.38% of PP, 2% of M-DAG, 2.5% of CNC, 1% of MAPP, 0.02% of MO, 0.03% of AO 1010, and 0.07% of AO 168 with synthesis of PP from pure PP powder (99.880%), MO (0.020%), AO 1010 (0.030%), and AO 168 (0.070%). The study focused on synthesis of antistatic bionancomposites that consists of four sub-processess, namely the mixing sub-process, the extrusion sub-process, the air knife sub-process, and the pelletizing sub-process, so that it fits the "gate-to-gate" life cycle with a special focus on life cycle inventory data in the synthesis of antistatic bionanocomposites. There are two functional units used on this study, 1 kg of antistatic bionancomposite pellet and 1 kg of PP pellets.

2) Life Cycle Inventory Analysis (LCI): LCIA is identified based on the input and output flows of each material and energy used. In this phase, a search for potential points that can have an environmental impact will be carried out. Table 1 shows the LCI for each antistatic biocomposite and PP synthesis sub-process. The functional units in the inventory analysis were 1 kg of antistatic bionanocomposite pellets and 1 kg of PP pellets. Based on the results of LCI, the potential points that can cause environmental impacts are the use of water, polypropylene (PP) and electricity. PP is a non-degradable polymer, but it must be reused [15]. The use of electricity that uses coal as its generator triggers a high potential for environmental impacts. It is due to coal is nonrenewable energy source and a prodigious generator of environmental pollution. It releases large quantities of particles as aerosols in the atmosphere and has hazardous substances such as coal micro-particles and nanoparticles. Its by-products constitutes an invisible risk to human health [16].

3) Life Cycle Impact Assessment (LCIA): LCIA was analyzed using the basic CML-IA method in SimaPro 9.1.1 software. There are 11 categories of impacts identified, namely abiotic depletion potential (ADP), abiotic depletion potential – fossil fuels (ADP-FF), global warming potential (GWP), ozone depletion potential (ODP), potential human toxicity (HTP), freshwater ecotoxicity potential (FWAEP), potential marine ecotoxicity (MAEP), potential terrestrial ecotoxicity (TEP), photochemical oxidation potential (POP), acidification potential (AP), and potential eutrophication (EP). Based on Table 2, the total environmental impact shows that the use of 2% M-DAG and 2,5% CNC in antistatic bionanocomposite synthesis can reduce the total environmental impact when compared to PP synthesis. There are several reduced impact categories, such as 4.46% of ADP, 3.70% of ADP-FF, 4.21% of GWP, 4.48% of ODP, 4.63% of HTP, 5.10% of FWAEP, 4.84% of MAEP, 2021% of TEP, 4.08% of POP, 4.41% of AP, and 4.85% of EP (Table 2). According to Hervy *et al.* [19], an environmental impact assessment of a 30% glass fiber reinforced polypropylene composite by weight showed that the climate change potential from start to finish was 18.9 kg CO2 eq and resource potential was 283.5 MJ. The same study showed that bacterial cellulose-reinforced epoxy composite and cellulose nanofiber had a climate change potential of 13.8 kg CO2 eq and 8.6 kg CO2 eq, respectively, with resource potentials of 271.6 MJ and 149.6 MJ, respectively. Based on Table 2, the high impact of each category comes from the mixing sub-process caused by the use of non-renewable materials, namely polypropylene (PP). PP comes from non-renewable petrochemicals and is known to cause environmental problems due to its non-biodegradability [15]. This is supported by Fig. 3, which shows the high impact of each category from the mixing sub-process. The same result was shown in PP synthesis, but the total impact value in PP synthesis was greater than the total impact value in antistatic bionanocomposite synthesis. This indicates that the synthesis of PP uses more non-renewable resources compared to the synthesis of antistatic bionanocomposites. The results of LCIA after normalization of impact categories show that the total environmental impact per function unit in the synthesis of antistatic bionanocomposite was smaller than the synthesis of PP with a percentage reduction in the environmental impact of 4.58% (Table 3 and Fig. 4).

TABLE I
LCI IN THE SYNTHESIS OF ANTISTATIC BIONANOCOMPOSITES AND SYNTHESIS OF PP

Sub process	**Synthesis of AS BNC**		**Synthesis of PP**	
	Materials and energy	**Value per f.u**	**Materials and energy**	**Value per f.u**
Sub process of mixing	***Input:***		***Input:***	
	Material input (kg):		Material input (kg):	
	- PP	0.981	- PP	1.037
	- CNC	0.025	- CNC	0.000
	- M-DAG	0.020	- M-DAG	0.000
	- MAPP	0.010	- MAPP	0.000
	- MO	0.000	- MO	0.000
	- AO-1010	0.000	- AO-1010	0.000
	- AO-168	0.001	- AO-168	0.001
	Energy input (kWh):		Energy input (kWh):	
	- Electricity	0.059	- Electricity	0.062
	Output:		***Output:***	
	Material output (kg):		Material output (kg):	
	- Powder of AS BNC	1.026	- Powder of PP	1.028
	- Loss	0.010	- Loss	0.010
	Energy output (kWh):		Energy output (kWh):	
	- Electricity potential	0.127	- Electricity potential	0.127
Sub process of extruding	***Input:***		***Input:***	
	Material input (kg):		Material input (kg):	
	- Powder of AS BNC	1.026	- Powder of PP	1.028
	- PP	0.010	- PP	0.010
	- Water	2.590	- Water	2.737
	Energy input (kWh):		Energy input (kWh):	
	- Electricity	0.268	- Electricity	0.283
	Output:		***Output:***	
	Material output (kg):		Material output (kg):	
	- Stick of AS BNC	1.003	- Stick of PP	1.003
	- CoStick of AS BNC	0.023	- CoStick of PP	0.025
	- Wastewater	2.590	- Wastewater	2.737
	Energy output (kWh):		Energy output (kWh):	
	- Electricity potential	0.288	- Electricity potential	0.304
Sub process of air knifing	***Input:***		***Input:***	
	Material input (kg):		Material input (kg):	
	- Stick of AS BNC	1.003	- Stick of PP	1.003
	- Air	74.456	- Air	78.688
	Energy input (kWh):		Energy input (kWh):	
	- Electricity	0.163	- Electricity	0.172
	Output:		***Output:***	
	Material output (kg):		Material output (kg):	
	- Stick of dry AS BNC	1.003	- Stick of dry PP	1.003
	- Air	74.456	- Air	78.688
	Energy output (kWh):		Energy output (kWh):	
	- Electricity potential	0.000	- Electricity potential	0.000
Sub process of pelletizing	***Input:***		***Input:***	
	Material input (kg):		Material input (kg):	
	- Stick of Dry AS BNC	1.003	- Stick of dry PP	1.003
	Energy input (kWh):		Energy Input (kWh):	
	- Electricity	0.199	- Electricity	0.210
	Output:		***Output:***	
	Material output (kg):		Material output (kg):	
	- Pellet of AS BNC	1.000	- Pellet of PP	1.000
	- CoPellet of AS BNC	0.003	- CoPellet of PP	0.003
	Energy output (kWh):		Energy output (kWh):	
	- Electricity potential	0.035	- Electricity Potential	0.036

Note: AS BNC = antistatic bionanocomposites; PP = polypropylene; f.u = functional unit

TABLE II
THE RESULT OF LCIA IN THE SYNTHESIS OF ANTISTATIC BIONANOCOMPOSITES AND PP PER IMPACT CATEGORIES

No	Impact categories		Sub process of mixing	Sub process of extruding	Sub process of air knifing	Sub process of pelletizing	Total	Impact reduction percentage
1	ADP	PP	2.36E-05	7.59E-07	3.24E-07	3.97E-07	2.51E-05	4.46%
	(kg Sb eq)	AS BNC	2.28E-05	6.26E-07	2.49E-07	3.06E-07	2.39E-05	
2	ADP-FF	PP	7.27E+01	3.81E+00	1.91E+00	2.34E+00	8.08E+01	3.70%
	(MJ)	AS BNC	7.03E+01	3.57E+00	1.79E+00	2.19E+00	7.78E+01	
3	GWP	PP	2.31E+00	3.18E-01	1.84E-01	2.25E-01	3.03E+00	4.21%
	(kg CO_2 eq)	AS BNC	2.23E+00	2.97E-01	1.71E-01	2.10E-01	2.91E+00	
4	ODP	PP	4.76E-08	9.70E-09	5.75E-09	7.04E-09	7.01E-08	4.48%
	(kg CFC-11 eq)	AS BNC	4.60E-08	9.05E-09	5.36E-09	6.56E-09	6.70E-08	
5	HTP	PP	3.27E-01	4.09E-02	2.35E-02	2.88E-02	4.20E-01	4.63%
	(kg 1,4-DB eq)	AS BNC	3.16E-01	3.75E-02	2.14E-02	2.63E-02	4.01E-01	
6	FWAEP	PP	1.22E-02	3.10E-03	1.87E-03	2.28E-03	1.95E-02	5.10%
	(kg 1,4-DB eq)	AS BNC	1.18E-02	2.87E-03	1.72E-03	2.11E-03	1.85E-02	
7	MAEP	PP	4.16E+02	1.27E+02	7.65E+01	9.36E+01	7.13E+02	4.84%
	(kg 1,4-DB eq)	AS BNC	4.01E+02	1.18E+02	7.13E+01	8.73E+01	6.78E+02	
8	TEP	PP	1.69E-03	5.42E-04	3.27E-04	4.01E-04	2.96E-03	20.21%
	(kg 1,4-DB eq)	AS BNC	1.59E-03	3.32E-04	1.97E-04	2.41E-04	2.36E-03	
9	POP	PP	4.68E-04	4.66E-05	2.61E-05	3.20E-05	5.73E-04	4.08%
	(kg C_2H_4 eq)	AS BNC	4.52E-04	4.34E-05	2.43E-05	2.97E-05	5.50E-04	
10	AP	PP	8.17E-03	1.35E-03	7.91E-04	9.68E-04	1.13E-02	4.41%
	(kg SO_2 eq)	AS BNC	7.88E-03	1.26E-03	7.35E-04	9.01E-04	1.08E-02	
11	EP	PP	8.26E-04	2.58E-04	1.56E-04	1.91E-04	1.43E-03	4.85%
	(kg PO_4 eq)	AS BNC	7.97E-04	2.41E-04	1.45E-04	1.78E-04	1.36E-03	

Note: AS BNC = antistatic bionanocomposites; PP = polypropylene

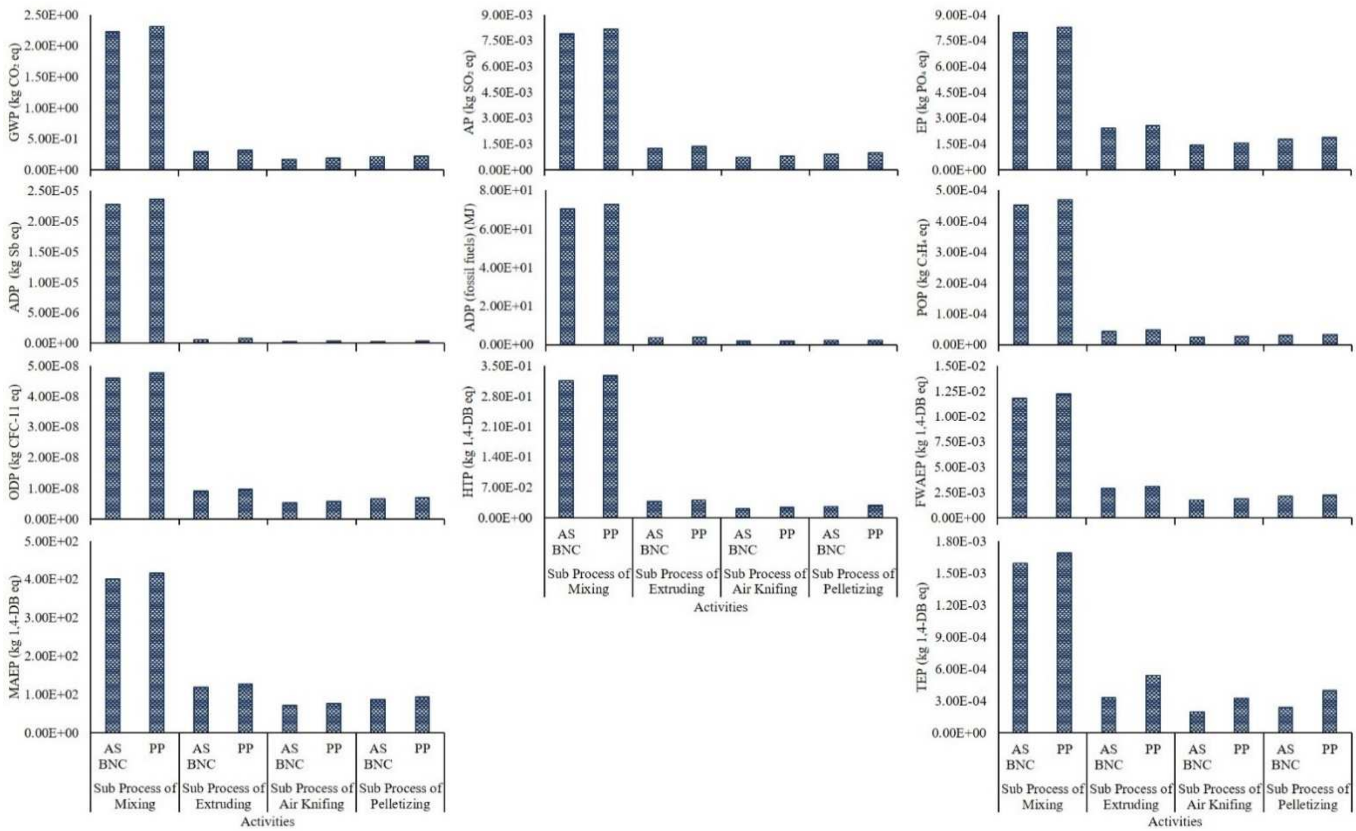

Fig. 3 Bar chart of LCIA of synthesis of antistatic bionanocomposites and PP per impact categories. AS BNC: antistatic bionanocomposites; PP: polypropylene

TABLE III
THE RESULT OF LCIA IN THE SYNTHESIS OF ANTISTATIC BIONANOCOMPOSITES AND PP PER FINCTIONAL UNIT AFTER NORMALIZATION

Treatments	Sub process of mixing	Sub process of extruding	Sub process of air knifing	Sub process of pelletizing	Total of environmental impact of all process
PP	7.12E-12	1.38E-12	8.13E-13	9.96E-13	1.03E-11
AS BNC	6.87E-12	1.28E-12	7.55E-13	9.25E-13	9.83E-12
Environmental impact reduced	3.48%	6.92%	7.12%	7.08%	4.58%

Note: AS BNC = antistatic bionanocomposites; PP = polypropylene

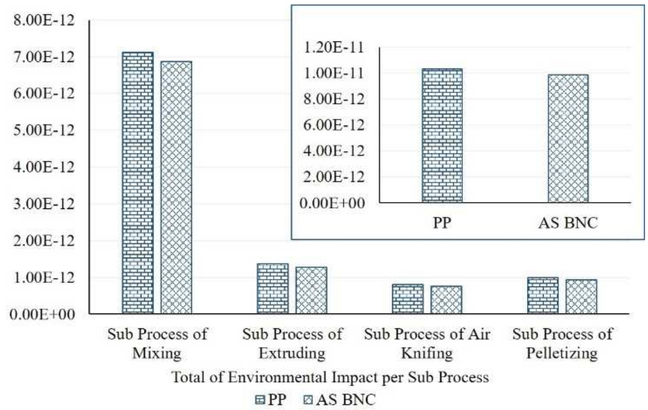

Fig. 4 Bar chart of LCIA of synthesis of antistatic bionanocomposites and PP per functional unit after normalization. AS BNC: antistatic bionanocomposites; PP: polypropylene

C. Improvement Analysis

The improvement in the synthesis of the antistatic bionanocomposite system was analyzed in several ways, namely reducing energy use with efficient use of water and electricity and minimizing waste. Energy reduction is presented to improve environmental and economic sustainability [17].

Water use efficiency is conducted by minimizing water use or reusing water that has been used. This can reduce the environmental impact of biocomposite synthesis [17]. The efficiency of electricity use is conducted by minimizing the use of electricity or using environmentally friendly electricity, such as the use of solar power, wind, hydroelectric power, marine or tidal energy, geothermal energy, and biomass [18]. Waste minimization is carried out by applying clean production [19] or green technology [20].

Analysis of improvements in the synthesis of antistatic bionanocomposites was carried out in several scenarios using a clean production method (waste or by-product minimization), namely by reducing by-products by 25%, as scenario 1, reducing by-products by 50% as scenario 2, and reducing by-products by 75% as scenario 3. Table 4 shows the LCIA results in the synthesis of antistatic bionanocomposites per impact category of each scenario.

TABLE IV
THE RESULT OF LCIA IN THE SYNTHESIS OF ANTISTATIC BIONANOCOMPOSITES PER IMPACT CATEGORIES OF EACH SCENARIO

Impact categories	**Total of environmental impact per kg of antistatic bionanocomposite pellets**			
	Existing	**Scenario 1**	**Scenario 2**	**Scenario 3**
Pellet of AS BNC (kg)	101.92*	102.59*	103.26*	103.93*
1. ADP (kg Sb eq)	2.39E-05	2.38E-05	2.36E-05	2.35E-05
2. ADP-FF (MJ)	7.78E+01	7.73E+01	7.68E+01	7.63E+01
3. GWP (kg CO_2 eq)	2.91E+00	2.89E+00	2.87E+00	2.85E+00
4. ODP (kg CFC-11 eq)	6.70E-08	6.65E-08	6.61E-08	6.57E-08
5. HTP (kg 1,4-DB eq)	4.01E-01	3.98E-01	3.96E-01	3.93E-01
6. FWAEP (kg 1,4-DB eq)	1.85E-02	1.84E-02	1.82E-02	1.81E-02
7. MAEP (kg 1,4-DB eq)	6.78E+02	6.74E+02	6.69E+02	6.65E+02
8. TEP (kg 1,4-DB eq)	2.36E-03	2.35E-03	2.33E-03	2.32E-03
9. POP (kg C_2H_4 eq)	5.50E-04	5.46E-04	5.43E-04	5.39E-04
10. AP (kg SO_2 eq)	1.08E-02	1.07E-02	1.06E-02	1.06E-02
11. EP (kg PO_4 eq)	1.36E-03	1.35E-03	1.34E-03	1.33E-03
Environmental impact reduced at each scenario	-	0.653%	1.298%	1.934%

Note: AS BNC = antistatic bionanocomposites; *Product of antistatic bionanocomposite pellets before and after improvements

Based on Table 5 and Fig. 5 after normalization of impact categories, the reduced by-products can reduce the total environmental impact per kg of antistatic bionanocomposite pellets. The higher percentage of reduced by-products, the lower total environmental impact per kg of antistatic bionanocomposite pellets. Waste or by-product minimization is a process to reduce the amount and activity of waste or by-products to the lowest level that is reasonably achievable. Implementing cleaner and renewable production systems is very important for achieving sustainable development. It is observed in processes that consume less resources and energy and releases lower amounts of waste and emissions. It has been widely applied in the process industry [21].

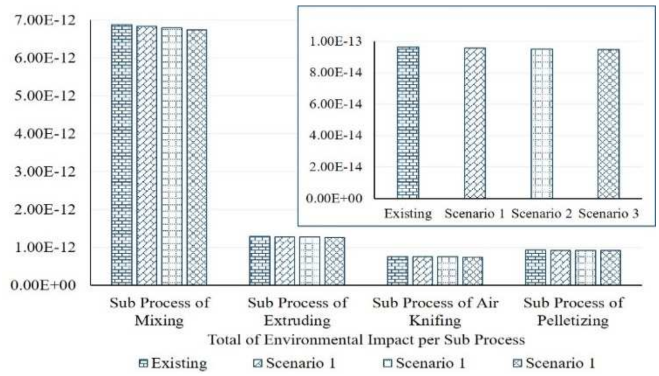

Fig. 5 Bar chart of the result of LCIA in the synthesis of antistatic bionanocomposites per functional unit of each scenario after normalization

TABLE V
RESULT OF LCIA IN THE SYNTHESIS OF ANTISTATIC BIONANOCOMPOSITES PER FUNCTIONAL UNIT OF EACH SCENARIO AFTER NORMALIZATION

Treatments	**Total of environmental impact per sub process**				**Total of environmental impact of all process**	**Percentage of environmental impact reduced**
	Sub process of mixing	**Sub process of extruding**	**Sub process of air knifing**	**Sub process of pelletizing**		
Existing	6.87E-12	1.28E-12	7.55E-13	9.25E-13	9.83E-12	-
Scenario 1	6.83E-12	1.27E-12	7.50E-13	9.19E-13	9.77E-12	0.6531%
Scenario 1	6.78E-12	1.26E-12	7.45E-13	9.13E-13	9.71E-12	1.2977%
Scenario 1	6.74E-12	1.26E-12	7.41E-13	9.07E-13	9.64E-12	1.9340%

Note: AS BNC = antistatic bionanocomposites; *Product of antistatic bionanocomposite pellets before and after improvements

The application of reuse, reduce, and recycle methods on co-products from antistatic bionanocomposite synthesis needs to be done because it has a positive impact on the environment and is beneficial [22], [23]. In addition, the legal system in the field of environmental assessment needs to be implemented properly by the government [24] and international cooperation between countries in the field of environmental protection [25].

IV. Conclusion

In conclusion, the total environmental impact shows that using 2% M-DAG and 2.5% CNC in the synthesis of antistatic bionanocomposites can reduce the total environmental impact compared to PP synthesis. This is indicated by the decline in the impact value per impact category. The total of environmental impacts after the normalization of the impact category shows that the total environmental impact per function unit in the synthesis of antistatic bionanocomposite is smaller than the PP synthesis with the percentage of environmental impact reduced by 4.58%. Efficiency in the use of energy and natural resources is considered necessary to minimize the environmental impact per kg of antistatic bionanocomposite pellets. The higher the percentage of reduced by-products, the lower the total environmental impact per kg of antistatic bionanocomposite pellets. The application of reuse, reduce, and recycle methods on co-products from antistatic bionanocomposite synthesis needs to be done because it positively impacts the environment. The further research needs to be carried out to identify environmental impacts in synthesizing antistatic bionanocomposites in a wider scope of study, namely cradle to grave, if possible.

Acknowledgment

The authors are grateful to Palm Oil Plantation Fund Management Agency (POPFMA) for supporting this research.

References

[1] S. Salsabila, D. Setyaningsih, Q. R. Jannah, and N. Muna, “Formulation of mono-diacylglycerol from palm fatty acid distillate and glycerol as antistatic agents on plastics,” 2021, doi: 10.1088/1755-1315/749/1/012069.

[2] F. N. N. M. Hussin, R. A. Wahab, and N. Attan, “Nanocellulose and nanoclay as reinforcement materials in polymer composites: A review,” *Malaysian J. Fundam. Appl. Sci.*, vol. 16, no. 2, pp. 145–153, 2020, doi: 10.11113/mjfas.v16n2.1430.

[3] G. da S. Maradini *et al.*, “Characterization of polyester nanocomposites reinforced with conifer fiber cellulose nanocrystals,” *Polymers (Basel).*, vol. 12, no. 12, p. 2838, 2020, doi: 10.3390/polym12122838.

[4] C. Miao and W. Y. Hamad, “Critical insights into the reinforcement potential of cellulose nanocrystals in polymer nanocomposites,” *Curr. Opin. Solid State Mater. Sci.*, vol. 23, no. 4, p. 100761, 2019, doi: 10.1016/j.cossms.2019.06.005.

[5] T. Sunny and K. L. Pickering, “Cellulose nanocrystal treatment of aligned short hemp fibre mats for reinforcement in polypropylene matrix composites,” *Cellulose*, vol. 28, pp. 8429–8444, 2021, doi: 10.1007/s10570-021-04091-3.

[6] J. Shojaeiarani, D. S. Bajwa, and S. Chanda, “Cellulose nanocrystal based composites: A review,” *Composites Part C: Open Access*. p. 100164, 2021, doi: 10.1016/j.jcomc.2021.100164.

[7] Y. Liu, S. Zhang, X. Wang, Y. Pan, F. Zhang, and J. Huang, “Mechanical and aging resistance properties of polypropylene (PP) reinforced with nanocellulose/attapulgite composites (NCC/AT),” *Compos. Interfaces*, vol. 27, no. 1, pp. 73–85, 2020, doi: 10.1080/09276440.2019.1600971.

[8] R. A. Jibhakate, N. W. Nirwan, and K. S. Rambhad, “Enhancing the effectiveness of green technology in manufacturing industry,” in *Materials Today: Proceedings*, 2021, pp. 4298–4305, doi: 10.1016/j.matpr.2021.04.592.

[9] P. S. Goh and A. F. Ismail, “Nanocomposites for environmental and energy applications,” *Nanomaterials*. p. 156, 2021, doi: 10.3390/nano11020345.

[10] J. Pryshlakivsky and C. Searcy, “Life Cycle Assessment as a decision-making tool: Practitioner and managerial considerations,” *Journal of Cleaner Production*. p. 127344, 2021, doi: 10.1016/j.jclepro.2021.127344.

[11] S. A. Abbasi, A. Busnaina, and J. A. Isaacs, “Cumulative energy demand for printing nanoscale electronics,” in *Procedia CIRP*, 2019, pp. 298–303, doi: 10.1016/j.procir.2018.12.018.

[12] E. H. Szafranko, “Selected problems of the environmental impact analysis of investment projects based on life cycle assessment procedure,” *J. Ecol. Eng.*, vol. 20, no. 9, pp. 87–94, 2019, doi: 10.12911/22998993/112504.

[13] B. Agarski, D. Vukelic, M. I. Micunovic, and I. Budak, “Evaluation of the environmental impact of plastic cap production, packaging, and disposal,” *J. Environ. Manage.*, vol. 245, pp. 55–65, 2019, doi: 10.1016/j.jenvman.2019.05.078.

[14] F. Marendra, A. Rahmada, A. Prasetya, R. B. Cahyono, and T. Ariyanto, “Kajian Dampak Lingkungan pada Sistem Produksi Listrik dari Limbah Buah Menggunakan Life Cycle Assessment,” *J. Rekayasa Proses*, vol. 12, no. 2, pp. 27–39, 2018, doi: 10.22146/jrekpros.36425.

[15] G. Atiwesh, A. Mikhael, C. C. Parrish, J. Banoub, and T.-A. T. Le, “Environmental impact of bioplastic use: A review,” *Heliyon*, vol. 7, no. 9, p. e07918, 2021, doi: 10.1016/j.heliyon.2021.e07918.

[16] J. Gasparotto and K. Da Boit Martinello, “Coal as an energy source and its impacts on human health,” *Energy Geosci.*, vol. 2, no. 2, pp. 113–120, 2021, doi: 10.1016/j.engeos.2020.07.003.

[17] G. Mert, B. S. Linke, and J. C. Aurich, “Analysing the Cumulative Energy Demand of Product-service Systems for wind Turbines,” in *Procedia CIRP*, 2017, pp. 214–219, doi: 10.1016/j.procir.2016.09.018.

[18] N. V. Rudenko, V. V. Ershov, and V. V. Evstafiev, “The Environment Friendly Power Source for Power Supply of Mobile Communication Base Stations,” in *IOP Conference Series: Earth and Environmental Science*, 2017, p. 012024, doi: 10.1088/1755-1315/66/1/012024.

[19] P. Purwanto, “Cleaner Production And Waste Minimization,” in *Global Classroom Solid and Scheduled Waste Management; Faculty of Civil Engineering Technology; Universiti Malaysia Pahang*, 2021, pp. 1–47, doi: 10.13140/RG.2.2.33609.16486.

[20] J. Zhang *et al.*, “Understanding the impact of environmental regulations on green technology innovation efficiency in the construction industry,” *Sustain. Cities Soc.*, vol. 65, p. 102647, 2021, doi: 10.1016/j.scs.2020.102647.

[21] A. Gonzalez-Garay and G. Guillen-Gosalbez, “Framework for the optimal design of sustainable processes incorporating data envelopment analysis,” in *Computer Aided Chemical Engineering*, 2018, pp. 1711–1716.

[22] B. Zegardło, “Comparative Assessment of Environmental Effects by LCA Method of Natural Aggregates Extraction Processes and Production of Their Substitutes from Waste in the City Mining System,” *J. Ecol. Eng.*, vol. 22, no. 8, pp. 251–257, 2021, doi: 10.12911/22998993/139119.

[23] L. F. C. Silva, M. E. Silva, I. Brás, I. Domingos, D. Wessel, and J. V. Ferreira, “A Cradle-to-Grave Life Cycle Assessment Study on a New Countertop Material,” *J. Ecol. Eng.*, vol. 22, no. 11, pp. 239–245, 2021, doi: 10.12911/22998993/142947.

[24] J. Harasymiuk, “Environmental impact assessments in investment process-legal and methodological aspects,” *J. Ecol. Eng.*, vol. 20, no. 10, pp. 79–87, 2019, doi: 10.12911/22998993/112857.

[25] A. Harat and A. Jaguś, “Procedure for the Transboundary Environmental Impact Assessment of Contemplated Investment Projects in the Polish Legal System,” *J. Ecol. Eng.*, vol. 21, no. 8, pp. 285–291, 2020, doi: 10.12911/22998993/126881.