The Printing and Writing Paper Industry and Product in Indonesia: A Life Cycle Assessment Case Study

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The Printing and Writing Paper Industry and Product in Indonesia: A Life Cycle Assessment Case Study

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Abstract: This study utilized Life Cycle Assessment (LCA) to evaluate the environmental impacts of printing and writing papers as its heavy reliance on natural resources and forest products. The results were converted to ecopoints to identify the main contributors to impacts with a total impact of 6.23 mPt. The bleached kraft pulp stage was found to be crucial across most inventory parameters and impact assessment categories due to Eucalyptus sp. for pulp production. This process causes a major environmental impact in the form of heavy metal pollution of 2.44 mPt and acidification of 0.882 mPt. The greenhouse gas emissions impact of 0.435 mPt is also the main environmental impact resulting from energy use. Implementing a sustainable green industry through cleaner production and energy efficiency should be prioritized to achieve sustainable industrial development, which aims to minimize the environmental footprint while maintaining economic growth, social advancement, and quality of life. The findings of this study can be valuable for the printing and writing industries to plan future investments that enhance sustainability through reduce their carbon footprint, minimize waste and pollution, and conserve natural resources.

Keywords: Printing and Writing Paper Industry; Life Cycle Assessment; Cleaner Production; Ecopoints; Environmental Performance

1. Introduction

The Indonesian pulp and paper industry is highly competitive. The paper industry plays a crucial role in education and communication in Indonesia and globally. The Indonesian economy heavily relies on pulp and paper industries, which significantly contribute to the national economy. In 2021, Indonesia's export performance of the pulp and paper industry recorded a value of USD7.5 billion, or contributed 6.22% to non-oil and gas exports, which is also equivalent to contributing 3.84% to the GDP of the non-oil and gas processing industry. Meanwhile, exports have increased 12% in 2023 compared to the previous year.

When looking at the trend of pulp and paper production capacity in Indonesia over the last few years, the pulp and paper production capacity in Indonesia increased steadily until 2019, which suddenly fell during COVID period (2020-2022) due to travel restriction and close-down of businesses[1]. Then from 2023 onwards, the pulp and paper production capacity began to increase with the growth of businesses and economy worldwide (see Fig. 1).

Currently, Indonesia has a production capacity of 11.04 million tons of pulp and 16.6 million tons of paper per year. There are 71 active companies in this sector, including 63 paper industries, 6 integrated pulp and paper industries, and 2 pulp industries. Based on FAO data, Indonesia is the largest producer of pulp and paper in the ASEAN region, the 2nd largest in Asia for pulp products, and the 4th largest in Asia for paper products, while at the world level, Indonesia is the 7th largest producer of pulp and 6th largest for paper products[2]. It made this industry an important economic potential for the country.

Paper is available in different forms and grades. There are several categories that paper products can be classified into, including newsprint, tissue and towel, box board (which encompasses cereal and shoe boxes), printing and writing materials, and a range of specialized items. Paper grades used for books, periodicals, catalogs, brochures, calendars, business forms, commercial printing, and copy paper belong within the printing and writing category. In 2023, the printing and writing paper was the 3rd rank of the leading grades in Indonesia (see Fig. 2).

The manufacturing of printing and writing paper, like that of paper products in general, uses a lot of energy, water, and fiber, the bulk of which is derived from wood, along with inorganic fillers[3]. In 2022, fibers, pulps, and energy were the three largest costs in the pulp and paper industry in Indonesia (see Fig. 3)[4] . Despite economic growth and technological advancements, paper production activities can negatively affect the environment, including changes in water, soil, and air quality.

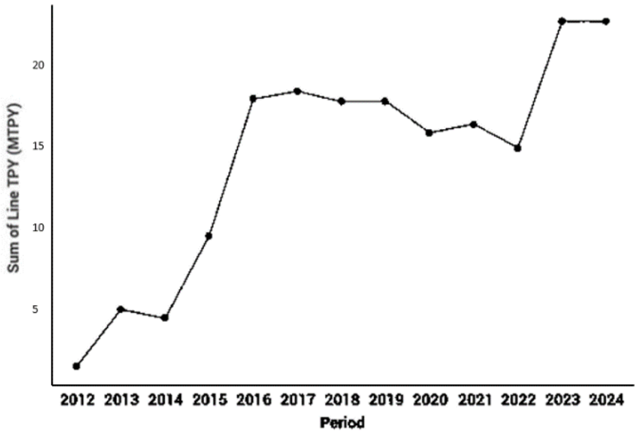

Fig. 1: Capacity of The Pulp and Paper Production in Indonesia.
Source: compiled by authors based on[2].

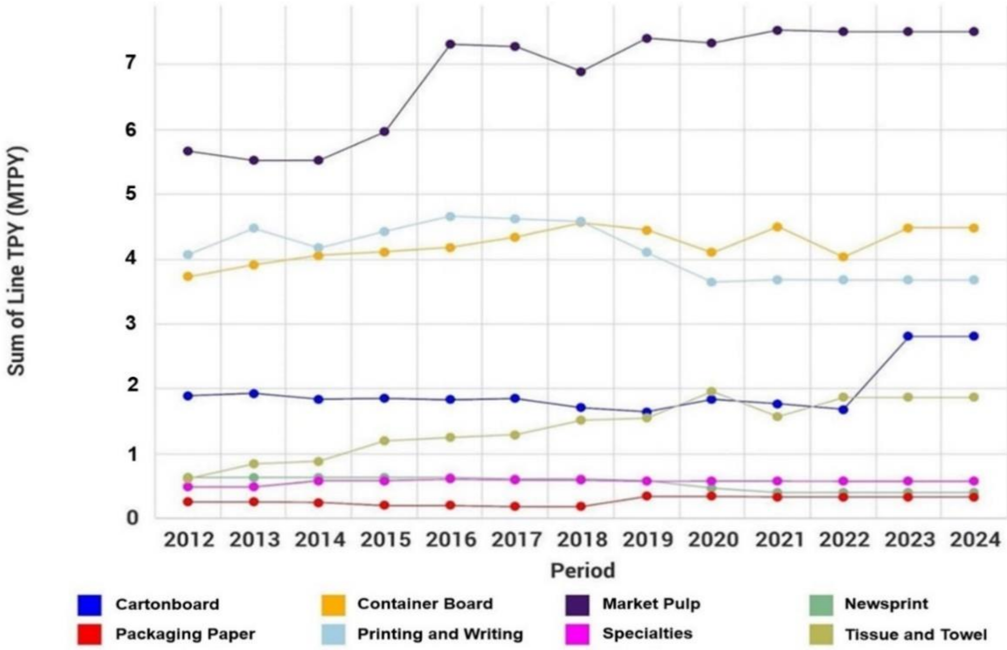

Fig. 2: Pulp & Paper Capacity in Indonesia by Major Grade (Actual and Announced 2012-2024)
Source: compiled by authors based on[2,4].

In Indonesia, the production of printing and writing paper involves the use of bleached kraft hardwood pulp derived from *Eucalyptus sp.* or *Acacia mangium*, along with softwood pulp[5]. The production processes result in wastewater, solid waste, and air emissions. Solid waste includes wood waste, sludge, ash, screening, and centric leaner rejects. Air emissions mainly come from digester inflatable tanks, chemical recovery boilers, and steam boilers[6].

Environmental sustainability is a priority in Indonesia's pulp and paper industry[7]. It is important to evaluate and identify factors impacting the environment in all production and industry activities to make improvements[8]. Implementing eco-efficient environmental management plans may be beneficial to address these issues[9]. Examining the life cycle of paper products is crucial to reducing environmental effects and improving production efficiency[10]. Assessing the effects of printing and writing paper can be done in part by applying the Life Cycle Assessment technique[11,12].

A systematic method for assessing a product's ecological impact across its whole life cycle is the Life Cycle Assessment (LCA) method[13]. This method, sometimes known as "cradle to grave," looks at every stage, from resource extraction to the product's ultimate disposal[14]. The method assesses adverse effects on the ecosystem, human health, and natural resources, and it covers the product life cycle in production, distribution, transportation, and disposal[15–17]. LCA can also be used to evaluate the influence of industry and its operations on resources and industrial situations, and it can be combined with economic considerations to guide development decisions[18–22].

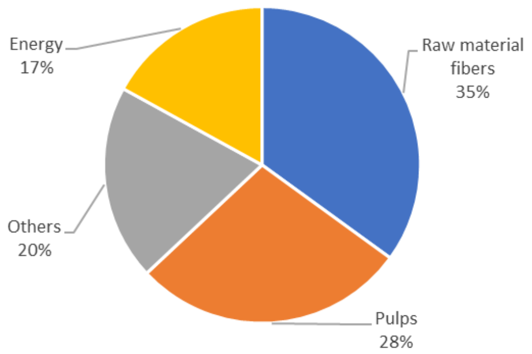

Fig. 3: Cost Breakdown of Pulp and Paper Industry in Indonesia.
Source: compiled by authors based on[4].

Although LCA is important for global marketing competition, there is a need for a comprehensive study of LCA for printing and writing paper products in Indonesia[23]. The lack of information in this area can lead to negative impacts related to these products[24]. Therefore, it is necessary to conduct a thorough study of LCA specifically for printing and writing papers in Indonesia. LCA has recently become a critical methodology for decision-making in policy contexts that can affect entire sectors or societies[5].

The LCA conducted in this study focused on various processes, such as paper production, energy production, chemical usage, and waste treatment. The primary goal of this research is to evaluate the possible environmental consequences of the complete life cycle of paper manufacturing. The aim of this study is to evaluate the potential environmental effects of printing and writing paper, to identify the processes that have the greatest impact on these effects, and to analyze the strategy to minimize the environmental load. Additionally, the study aims to provide comprehensive and understandable information to decision-makers, including a review of the importance of LCA in assessing environmental burdens. The LCA methodology is expected to decrease the environmental impact of the printing and writing paper industry, thus enhancing its environmental performance. The main body of the article will be presented below with suitable headings.

2. Description Process of Making the Printing and Writing Paper

The company studied uses *Eucalyptus sp.* as a source of bleached kraft hardwood pulp. Apart from that, *Eucalyptus sp.* has been considered as a raw material for bleached kraft hardwood pulp. As it is abundant in Indonesia's industrial plantation forest (Hutan Tanaman Industri).

Then, softwood pulp is added to the mix to increase the paper's strength. Cationic starch, Optical Brightening Agent (OBA), Alkenyl Succinic Anhydride (ASA) or AKD, and defoamer biocide are among the chemicals that are introduced and combined with the pulp during the stock preparation stage. To increase the strength and shade of the paper, fillers are also added to the pulp; varying ratios result in different grades. Figure 4 provides a thorough breakdown of the pulp and paper production process.

The pulp and paper industries are known for their high resource consumption and environmental pollution[25]. In addition to pulp, energy, water, and chemicals are the most critical inputs in the papermaking process. The whole process can be divided into three parts: pulp, paper, energy, and utilities[23].

Pulp mills include processes such as wood processing, cooking, washing and sorting of brown pulp, and bleaching of ECF (elemental non-chlorine) pulp with chlorine dioxide. Bark and black liquor generate energy for firewood cooking, while activated sludge plants and solid waste from landfills treat wastewater. Achieving the required ISO brightness is essential for printing and writing papers used in offices.

The paper mill carries out the final step in paper production, which encompasses various activities, from shaping the paper to creating the end-products. The bleached white pulp, acquired during the bleaching process, is then transported to the paper mill, where it is combined with additives and fillers as part of the stock preparation process. Subsequently, the mixture is sent to the headbox to form sheets. The consistency of the stock is regulated by diluting it with white water. Paper is produced by undergoing pressing, drying, and calendaring.

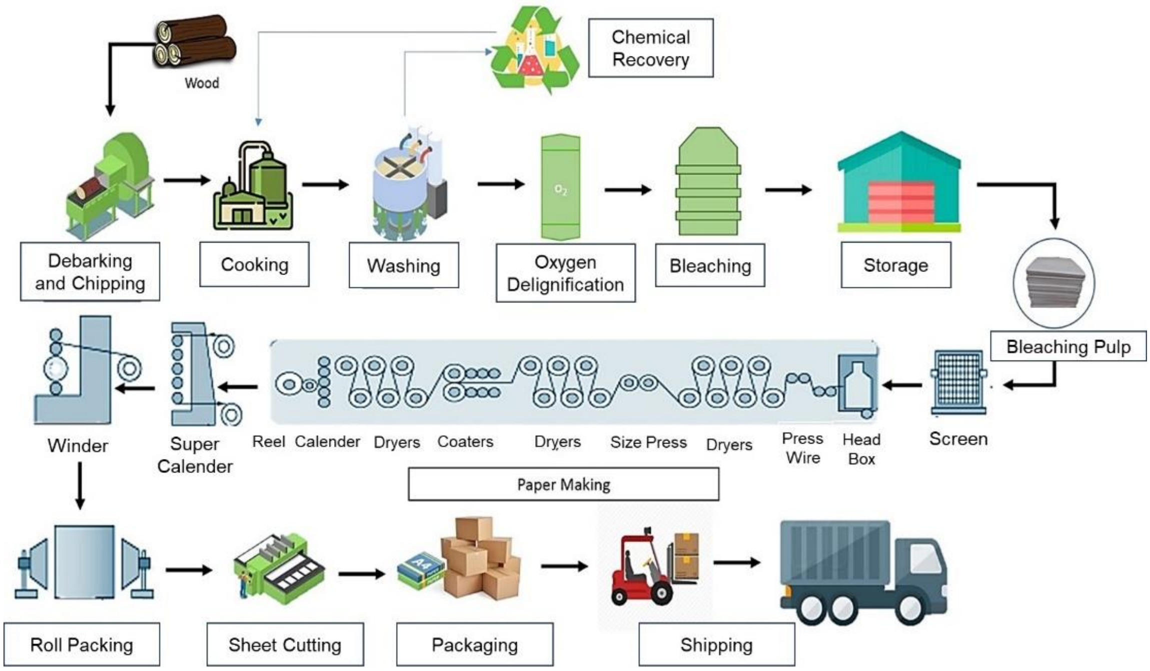

Fig. 4: Process description of pulp and paper making.

Water plays a critical role throughout the pulp and paper-making process. Water efficiency and sustainable management are prioritized[26]. Wastewater treatment involves primary and secondary treatment processes. Electricity and steam are necessary for most stages of the process. Under the ecolabel criteria outlined in the Indonesian National Standards for printing and writing paper (SNI 7188.1.3-2016), the average water consumption should not exceed 20 m^3 per ton of paper, electricity usage should be below 800 kWh per ton of paper, and steam usage should not exceed 3 tons per ton of printing and writing paper. Solid wastes generated during pulp and paper manufacturing include sludge, sediment and sand, lime sludge, sieving residue, and pin chips (wood). These wastes are usually disposed of in landfills, and the main components are boiler ash, sludge, sediment, and sand[27].

3. Methodology

This study utilized the Life Cycle Assessment (LCA) approach in factories to decrease the environmental impact of paper printing and writing activities. The stages of LCA used in this research adhere to ISO 14040-44, 2006. The system boundary is limited to processing raw materials (pulp production) and paper production itself, which corresponds to "gate-to-gate". The life cycle stages include stock preparation, paper making, energy production, transportation, and waste treatment. Each stage consists of inputs such as energy sourced from the national grid. The LCA considers the emissions released to air, water, and soil. The study did not consider the emissions from the capital goods such as buildings and machinery[28] (see at Fig. 5).

The functional unit serves as a benchmark for comparing inventory data. This study defined the functional unit as 1 ton of white printing and writing paper with a standard weight between 70 g/m^2 and 100 g/m^2. The study assumed that materials comprising less than 1% of the mass of the functional units were excluded.

Inventory stage data was obtained from the Indonesian printing and writing paper industries. The data collection process included collecting data in the field, using one year of data as a baseline. As part of the data collection and calculations, all inputs and outputs of the system were identified and measured. This includes resource consumption and emissions. The consumption consists of materials and energy. The emissions consist of air, water, and soil. The life cycle inventory is shown in Table 1.

The life cycle inventory data were then input into the LCA software SimaPro 9.1 to assess the environmental impact of the studied products[29]. In SimaPro 9.1 software, a product is defined by a flowchart that lists its components, materials, and production processes linked to use and disposal scenarios representing the entire product lifecycle. The use of SimaPro enables users to apply the LCA knowledge effectively, make informed decisions, optimize product lifecycles, and leave a positive impression on the company. In this phase, value characterization uses the Ecopoint 97 method to assess several environmental damage categories based on the previous life cycle inventory. Ecopoints 97 is good to use in LCA path calculations because it gives different results from others in the Ozone Layer Depletion category. It shows that Ecopoints 97 analysis can provide valuable and unique information on environmental impacts[30].

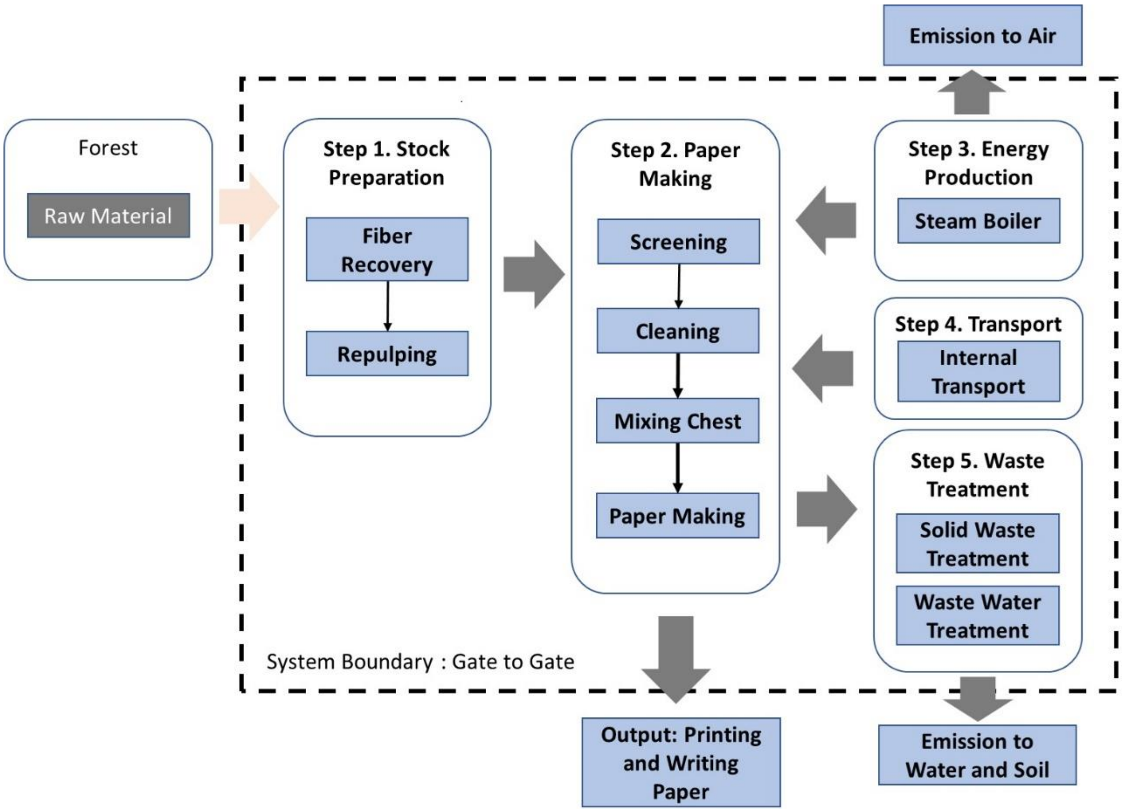

Fig. 5: System Boundary of Life Cycle Inventory.

The data is analyzed to determine an environmental impact value, revealing the part that contributes the most to the sustainability challenges. ReCiPe 2016 method was used in this study to categorize the Life Cycle Impact Assessment (LCIA), considering global warming, acidification, ozone layer depletion, eutrophication, heavy metals, carcinogens, energy sources, and solid waste. The chosen categories are based on the available parameters from the inventory analysis[31)]. The impacts calculated using the software have different units, so they cannot be combined to obtain a single environmental score. Therefore, several steps are followed to convert all impacts into a single score called 'Ecopoint'.

The first step is classification to determine the midpoint impact categories resulting from emissions throughout the life cycle of a paper product. Each emission is then converted into equivalent emissions representing each impact through characterization. The characterized impact value is normalized by dividing it by the country-specific normalization factor for each impact. Normalization aims to understand the magnitude of the contribution relative impact for each process indicator system results of each researched product[32)]. This normalization allows for easy comparison of the results from the impact category indicators. Ecoindicator 99 uses inventory parameters to standardize results. Normalization helps to interpret LCIA results and conveys information about the relative importance of indicators in impact categories. After normalization, all indicators have the same unit (year) to facilitate comparison, expressing the effect as a percentage. The normalized point effect represents a percentage of the annual cost of the given product and effect. Normalization can also be applied in the characterization phase. Finally, the normalized environmental impact values are multiplied by appropriate weights to determine ecopoints, ensuring that all impacts are in the same unit. This integration allows for a single environmental score. The acquired data will be additionally normalized and separated based on the weighting factor of the utilized methodology[32)]. Weighting is an optional step in LCIA and is crucial for aligning impact categories with learning objectives and stakeholder values. The final step is interpretation, where an analysis is conducted to identify the materials that have the most significant environmental impact in printing and writing paper manufacturing.

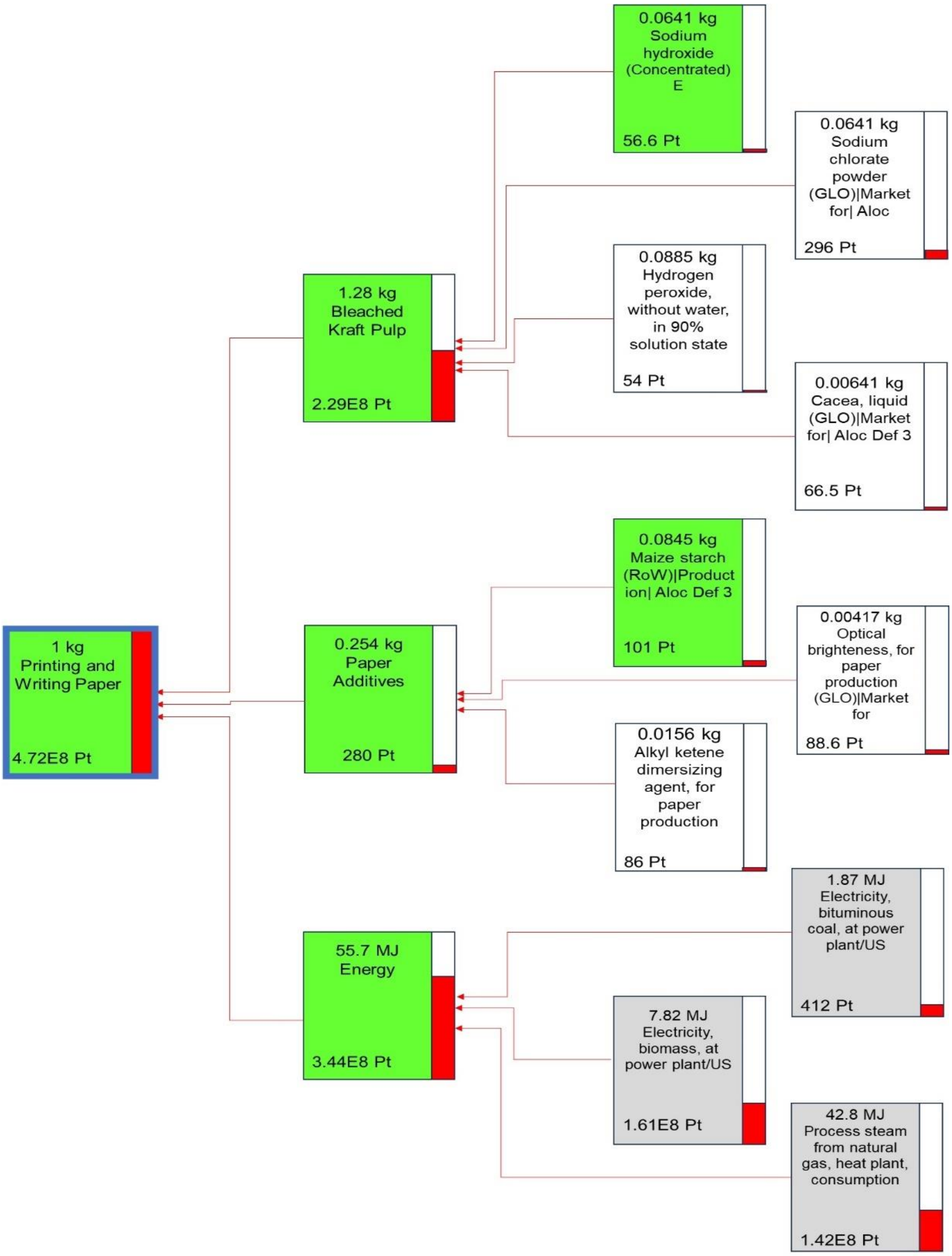

Fig. 6: The flowchart for printing and writing paper.

4. Result and Discussion

4.1 Flowchart of the Printing and Writing Paper Life Cycle

The life cycle flow chart shows the flow of the whole process, which consists of several processes that can affect the environment, especially the input of production data to the printing and writing paper process. A flow diagram or tree diagram describes the distribution of total environmental impacts and targets areas of most significant impact. The betting level can be estimated using the red bar chart. The relative significance and contribution of each stage to the overall life cycle of the system are denoted by the thickness of the line. Each processing unit involved in the product's life cycle is represented by a box in the table, and the box is colored differently based on its input for the process.

For the production process of printing and writing paper, the input weight for bleached kraft pulp is 1.28 kg, paper additives are 0.254 kg, and energy is 55.7 MJ. By referring to the flow chart in Fig. 6, it is evident that energy has the largest contribution to the total impact, accounting for

60%. It can be further explained by the significant energy input from electricity and biomass at power plants, as well as process steam from natural gas and heat plants. Figure 6 presents the flowchart illustrating the activities involved in the cycle of 1 kg of printing and writing paper, allowing us to observe the impact contribution of each manufacturing process for each component.

4.2 Inventory Analysis Results

The analysis of the inventory-level results is restricted to a small number of key factors, which include nitrogen oxides (NOx), Sulphur oxide (SOx), carbon dioxide (CO_2), chemical oxygen demand (COD), adsorbable organic halogens (AOX), non-methane volatile organic compounds (NMVOC), ammonia (NH_3), ozone layer, phosphorus (P), nitrogen (N), nitrate (in soil), and waste. These data are organized into different categories that contribute to the environmental impact. For instance, CO_2 is classified as global warming emissions, NOx and SOx as acidification impacts, and P and N as eutrophication impacts. Additionally, nitrate (in soil) and waste fall under solid waste, and AOX is categorized as a carcinogen. Table 1 displays the inventory data for printing and writing paper production per one ton of product.

The characterization stage results indicate that each inventory parameter displays a 100% result because they are still in their respective units, making comparison impossible. The inventory parameters reveal that bleached kraft pulp, energy, and additives in the paper production process contribute to NOx, SOx, NMVOC, NH_3, CO_2, and ozone emissions. The contribution of each life cycle stage on these inventory parameters can be seen in Fig. 7. The paper additives stage is responsible for the highest contribution, 99%, to nitrate emissions. The bleached kraft pulp stage emits approximately 73% of the COD, while paper production (printing and writing paper) accounts for 21% of the total emissions for this parameter.

On the other hand, P and N emissions are attributed to the bleached kraft pulp stage, paper additives, and paper production stage. Energy generation contributes to roughly 50% of the NOx emissions, with the bleached kraft pulp stage also making a significant contribution of 48% to these emissions. The trend is quite similar for CO_2 emissions.

The inventory parameters depicted in Fig. 8 demonstrate their contribution through normalizing for the entire life cycle of each process stage. By normalizing, the emissions of each parameter are attributed to different life cycle effects. Furthermore, the figures reveal the varied impacts within each damage category, with NH_3, ozone, P, N, and waste exhibiting a lesser life cycle compared to other parameters.

Table 1. Inventory data for printing and writing paper product.

Input from Nature		
Material	**Value**	**Unit**
Wood	5.18	ton
Water	39.85	m^3
Input from Technosphere		
Material	**Value**	**Unit**
Energy		
Electricity from fossil	1.82×10^3	MJ
Electricity from biomass	7.52×10^3	MJ
Steam	4.28×10^4	MJ
Chemical		
Sodium Hydroxide	64.1	kg
Sodium Chlorate	64.1	kg
Oxygen	32.1	kg
EDTA	5.13	kg
Sulphur Dioxide	12.8	kg
Hydrogen Peroxide	38.5	kg
Ozone	6.41	kg
Magnesium Sulphate	3.85	kg
Calcium Carbonate	195	kg
Starch	34.5	kg
OBA	4.17	kg
AKD	15.6	kg
Output to Technosphere		
Material	**Value**	**Unit**
Printing and writing paper	1	ton
Emission to air		
Nitrogen dioxide	0.006140023	kg
Sulphur dioxide	0.001886628	kg
Hydrogen sulphide	6.00E-05	kg
Sulphur oxide	0.002560132	kg
Sulphur	0.000895948	kg
Nitrogen oxides	0.93499911	kg
Emission to water		
Phosphorus	0.004000278	kg
BOD	0.680000348	kg
COD	28.10000017	kg
Suspended solid	1.040000174	kg
Nitrogen	0.072799994	kg
Phosphate	0.102399862	kg
Suspended solid	1.28	kg
AOX	0.384000099	kg
Cadmium	1.28	g
Lead	0.511999803	g
Copper	1.28	g
Chromium	0.895999901	g
Nickel	1.151999803	g
Zinc	19.2	g

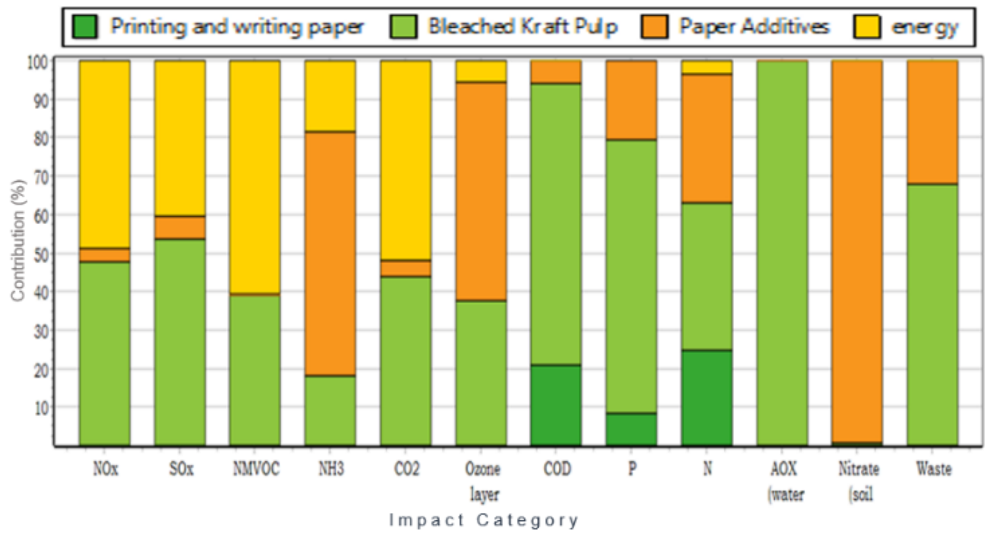

Fig. 7: Relative contribution of characterization of the stages considered in the life cycle of printing and writing paper to the inventory parameters.

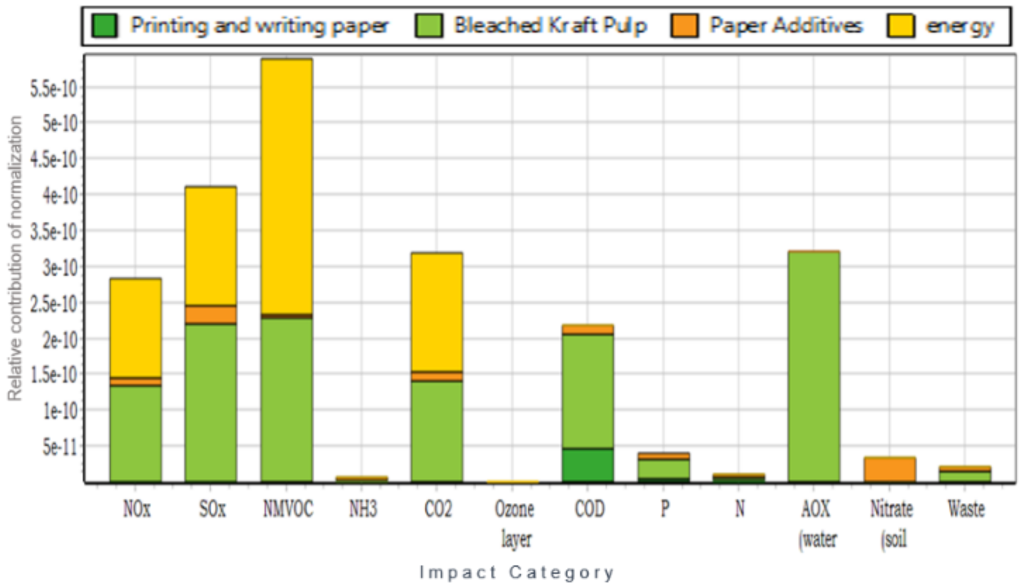

Fig. 8: Relative contribution of normalization of the stages considered in the life cycle of printing and writing paper to the inventory parameters.

4.3 Impact Assessment Results

The impact of each category on the life cycle, whether positive or negative, is shown in the characterization. The highest effect score on the y-axis bar graph represents the impact category for each process stage. According to the results from SimaPro software, all products have a positive value, which is harmful to the environment. Figure 9 displays the relative contribution of the different stages of the printing and writing paper life cycle to the impact assessment categories considered in this study. The bleached kraft pulp stage is responsible for 98% of the total solid waste, making it the most significant contributor. In the production of pulp, various types of solid waste are generated in the kraft process, such as inorganic sludge (which consists of dregs, green liquor sludge, and lime mud) from chemical recycling, bark & wood residues from wood processing, sludge from sewage treatment (including inorganic materials, fibers and biological sludge), dust from boilers & furnaces, and wood processing waste (mainly sand)[25]. Therefore, the most significant environmental concern of pulp and paper mills is the generation of sewage and solid waste, as this industry uses a significant amount of water in its production processes.

This stage also contributes significantly to the heavy metal category, accounting for 80% of its impact. It is also responsible for the eutrophication potential, ozone layer damage, carcinogen, and acidification, contributing 56%, 52%, 52%, and 50%, respectively. The bleached kraft pulp stage generates COD and phosphorus emissions, leading to eutrophication potential. Chemicals used in pulp bleaching result in ozone layer damage. SO_2 emissions contribute to the total acidification potential. Energy production is the main contributor to global warming, accounting for 51% of the total global warming potential, with NOx and CO_2 emissions being the primary culprits. Methane emissions from landfills also play a significant role in the final disposal stage.

Normalization, like weighting, is optional in LCIA. It was necessary to perform normalization, grouping, and weighting between categories to identify the hot spots throughout the life cycle. The normalization factors show the total impact of a reference area in a particular year, and they pertain to a particular impact category. The impact of each process on the environment is shown in Fig. 10. This figure illustrates that heavy metal, energy resources, greenhouse gases, and acidification have the most significant environmental impact compared to other factors, with values of $6.1e^{-4}$, $4.8e^{-4}$, $3.4e^{-4}$, and $1.9e^{-4}$, respectively. The highest impact category is heavy metal, which comes from bleached kraft pulp stages of $4.9e^{-4}$ and $1.0e^{-4}$ from paper additives. Conversely, the smallest contribution comes from energy by $1.0e^{-4}$. Overall, the bleached kraft pulp stages predominantly influence the impact categories.

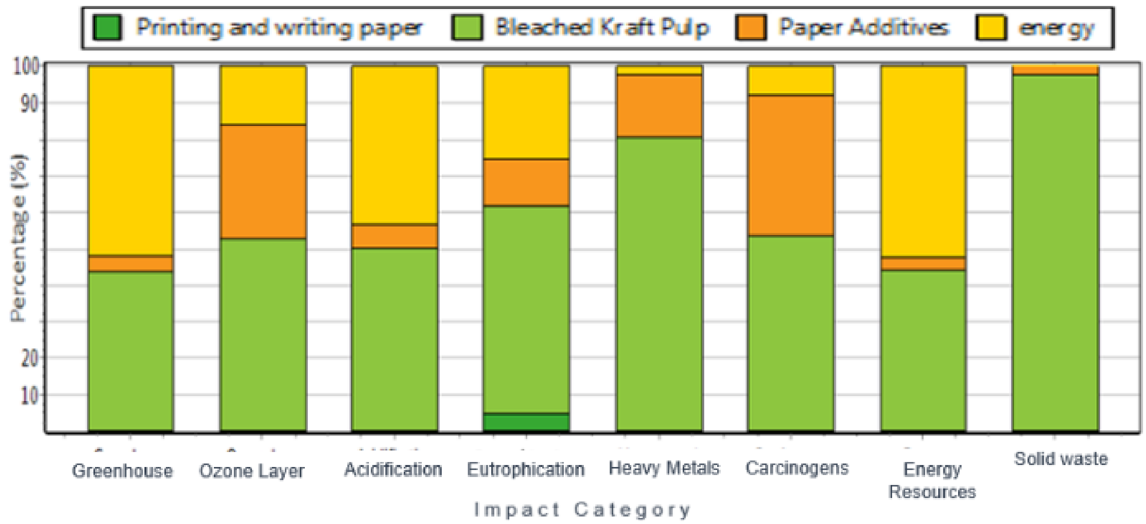

Fig. 9: Relative contribution of characterization of the stages in the life cycle to the impact categories.

Weighting is the fourth and final step in LCIA, following classification, characterization, and normalization. The weighted outcomes have a unified unit and can be combined to generate a solitary score representing the environmental impact of a product or scenario. This weighting is important because the impact category should reflect learning objectives and stakeholder values. The impact assessment was quantitatively conducted on six categories: heavy metals, acidification, eutrophication, greenhouse gases, carcinogens, and the ozone layer. The calculation results are presented in mPt units (points). The complete weighting results are provided in Table 2 which the biggest impact category for each process is shown in yellow highlight.

Table 2 shows the overall impact of printing and writing paper products at 6.23 mPt. The Pareto diagram (Fig. 11) illustrates that heavy metals, acidification, and greenhouse gases (global warming potential) have the most significant environmental impacts, with values of 3.03 mPt, 1.76 mPt, and 0.84 mPt, respectively. The energy stage is the primary factor contributing to global warming potential, primarily due to its release of NOx and CO_2 emissions. The bleached kraft pulp phase is the most important acidification potential, mainly due to SO_2 emission during energy production, 52% of the total volume.

Table 2. Weighting calculation value for each stage of the process (Unit: mPt).

Impact Category	Printing and Writing Paper	Bleached Kraft Pulp	Paper Additives	Energy	Total
Heavy Metals	X	2.440	0.524	0.0692	**3.0332**
Acidification	0.000549	0.882	0.109	0.765	**1.756549**
Greenhouse	X	0.369	0.034	0.435	**0.838**
Eutrophication	0.0233	0.284	0.0662	0.125	**0.4985**
Carcinogens	X	0.051	0.0363	0.00749	**0.09479**
Ozone Layer	X	0.00419	0.0025	0.0013	**0.00799**
Total	**0.02**	**4.03**	**0.77**	**1.40**	**6.23**

Bleached kraft pulp phases are responsible for 80,4% of the heavy metal emissions in the environment. This process decontaminates black liquor from the pulp and paper industry, where black liquor, a liquid with a solid content of 70-72%, is added to the digester during papermaking[33]. In addition, heavy metals can originate from solid waste, bioremediation, or landfills. The bleached kraft pulp phase represents the most significant eutrophication risk due to its COD and NOx emissions. COD and phosphorus emissions are the main factors behind this eutrophication potential, while ozone depletion at this stage is caused by chemicals used in pulp bleaching. In addition, bleached kraft pulp is the primary cause of cancer-causing substances and ozone depletion. Bleached pulp has clearly been shown to have the most significant environmental impact. To mitigate this effect, recycling the green liquid in the cauldron is recommended to reset the caustic process and turn it into a white liquid that can be added to the cauldron. Fig. 11 illustrates the environmental impact of each process.

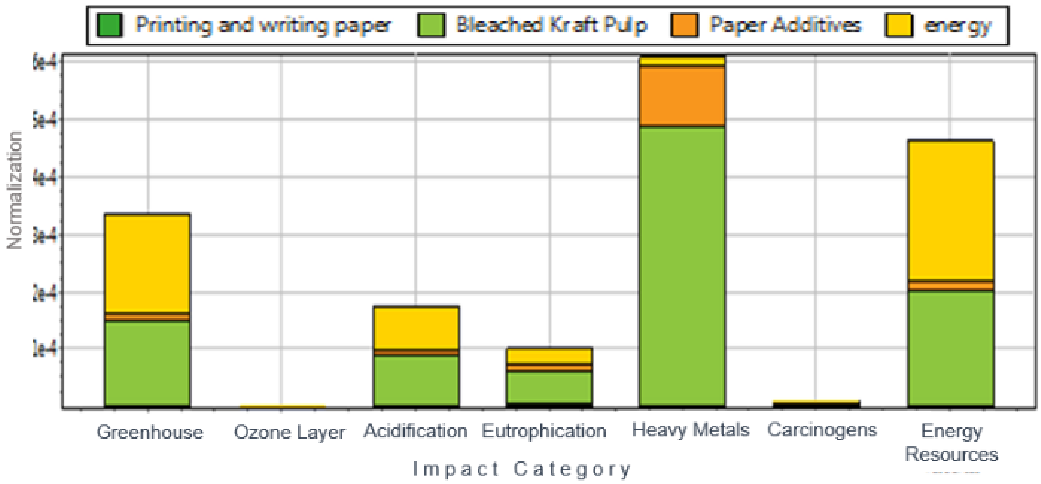

Fig. 10: Normalization to the impact category.

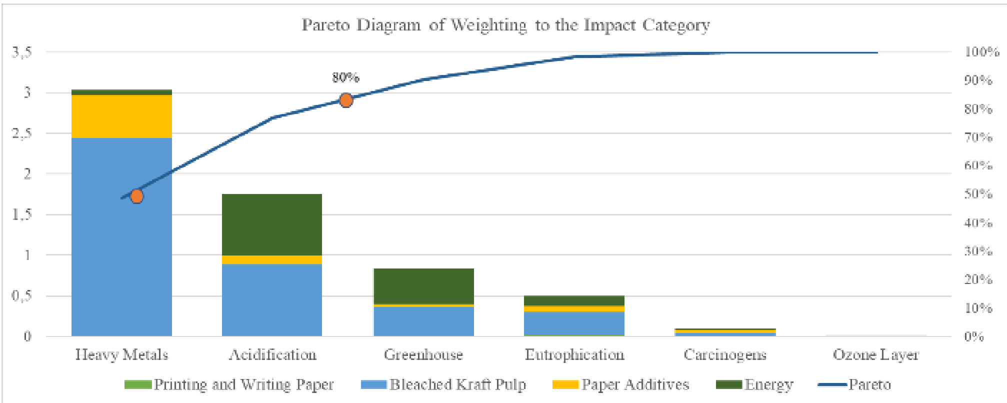

Fig. 11: Weighting to the impact category.

This study found that heavy metal pollution is the most significant environmental impact category. Different LCA results showed that acidification has a minimal effect on the printing and writing industry[11]. In Portugal, the various stages of paper production have a significant impact on inventory parameters and assessment categories. The primary potential impacts in Brazil are associated with pulp extraction, bleaching, and offset paper manufacturing, which is precisely due to electricity and thermal energy production.

Energy use is the primary cause of negative environmental effects[34]. However, this study found that the bleached kraft pulp stage is crucial in most inventory parameters and impact assessment categories. For instance, the environmental impact of Indonesia's printing and writing industry differs from that of similar companies.

4.4 Strategy to minimize the environmental impact

To address the environmental impact, the reduction strategy for Indonesian paper and writing companies should prioritize the implementation of a sustainable green industry that incorporates clean production and clean energy. Cleaner production encompasses the 5R principles: minimizing waste at its source, reusing waste, recycling waste, separating materials or energy from waste, and considering how a clean industry can reduce greenhouse gas emissions.

Waste from the sources can be depleted by using the efficiency of the kraft pulp bleaching process. Meanwhile, oxygen delignification could be an option for the efficiency of the kraft pulp bleaching process using *Eucalyptus sp.*[35,36]. Increasing the efficiency of the kraft pulp bleaching process can reduce water use, thereby reducing energy consumption and ultimately reducing the environmental impact.

Based on Sousa et al. (2023), oxygen delignification is used after cooking to oxidize and dissolve lignin before bleaching. The bleaching section follows the sequence O/O-D-E-D-D[36]. This scheme begins with two consecutive oxygen delignification (O/O) stages. Followed by stage D0 to remove organic compounds dissolved in the oxidation stage. Stage E is carried out to remove and clean dissolved organic compounds and NPE along the fiber lines. Two stages of ClO2 (D1 and D2) are useful to increase brightness stability, threaten the residual lignin, and condition the pulp for the paper production process.

In addition, recycling green liquid (condensate) in the boiler is a practical and effective way for industries to improve energy efficiency, reduce water consumption, and minimize environmental impact in their operations[37]. The green liquid, often referred to as condensate, is the water that has been condensed from steam after it has been used in various processes. By recycling this condensate back into the boiler, industries can save energy and water, as the condensate is already hot and can help preheat the incoming water, reducing the energy required to heat it to steam again. Additionally, recycling condensate can reduce the need for freshwater intake and minimize the discharge of wastewater, contributing to overall environmental sustainability in industrial operations. Proper treatment and recycling of condensate can also help prevent corrosion and scale build-up in the boiler system, extending its lifespan and reducing maintenance costs[38].

Recycling waste into bioproducts is also an encouraging alternative for the valorization of printing and writing industry waste. The concept of circular economy used to produce bioethanol, polyhydroxyalkanoates (PHAs), and biogas from the waste is a good possibility[39]. De-ashing process of primary sludge confirmed an extensive minimize in the enzyme dosage simultaneously improved ethanol production. The sources of PHA suggested from liquor and wastewater that will be processed by Mixed microbial Cultures (MMC). Anaerobic digestion (AD) has been proposed to produce biogas from wastewater treatment in the printing and writing industry.

The paper industry holds significant potential for carbon reduction because it relies on biomass and renewable plant fibers, which act as carbon sinks[21,40]. Adopting a clean energy strategy is crucial to reduce impacts, such as modifying coal fuel and utilizing alternative fuels like biomass, RDF pellets, or sludge while optimizing fuel and electricity consumption[15,41,42].

In addition, pulp-making could use paper repulping for recycling. Printing and writing paper containing 10-30 percent recycled material minimizes the environmental impact and still provides the best quality[43]. However, the industry should be encouraged the use of paper with high recycled content, but still pay attention to product quality and performance[37] .

While many companies focus on cost-effective measures that improve financial performance over time, implementing a sustainable green industry necessitates substantial resources, including financial, human, and temporal commitments[44,45]. For example, recycling paper can reduce environmental impact but may require additional activity and production time[43]. Therefore, company commitment becomes imperative in adopting a sustainable green industry, as it can yield benefits such as increased economic value, social employment opportunities, the production of green products, and improved environmental management[46–49]. Additionally, the company's reputation within society will likely be enhanced by implementing cleaner production practices[50,51].

5. Conclusion

The current research focuses on assessing the environmental effects of printing-writing paper products throughout their life cycle. These products have various impacts on the environment, including using raw materials like bleached Kraft pulp, the processes involved in printing and writing paper, adding paper additives, and energy consumption. Overall, the printing and writing paper products have a total impact of 6.23 mPt.

The stage of obtaining bleached kraft pulp plays a crucial role in inventory parameters and impact assessment categories. It significantly contributes to heavy metals, acidification, eutrophication, carcinogens, and the depletion of the ozone layer. Mainly, the categories with the most significant environmental impact are heavy metal pollution, acidification, and greenhouse gas emissions, with values of 3.0 mPt, 1.85 mPt, and 0.8 mPt, respectively.

The implementation of a sustainable green industry should be the prioritize to prevent the environmental damage, that incorporates clean production and clean energy. The findings of this study can be fateful for the printing and writing industry to plan forthcoming investments that enhance sustainability. The industry can identify the key processes responsible for each impact category by analyzing the inventory and impact assessment results. This knowledge can guide the industry in improving not only the production process itself but also the management of waste liquids and exhaust gases, thereby enhancing its environmental performance. Furthermore, discussions on sustainability can extend beyond waste treatment, pollution prevention, and encompass energy usage.

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