ADDIS ABABA UNIVERSITY

COLLEGE OF NATURAL AND COMPUTATIONAL SCIENCE

CENTER OF ENVIRONMENTAL SCIENCE

LIFECYCLE ASSESSMENT OF PAPER PRODUCTION FROM RAW WOOD PULP AND RECYCLED WASTE PAPER IN ETHIOPIA

M.SC. THESIS

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A THESIS SUBMITTED TO DEPARTMENT OF ENVIRONMENTAL SCIENCE PRESENTED IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTERS OF SCIENCE IN ENVIRONMENTAL SCIENCE.

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Declaration

I declare that this research work entitled ‘life cycle assessment of paper production from raw wood pulp and recycled waste paper in Ethiopia is conducted by myself, and has not been presented somewhere else for assessment. Where material used from other sources for the thesis has been properly acknowledged.

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Abstract

In this study, evaluated the environmental impacts associated with paper making recesses at Ethiopia Pulp and Paper Share Company and Anmol products Ethiopia industry, Ethiopia, by employing the life cycle assessment techniques. The International Standard Organization 14040 framework and guidelines guided this assessment, focusing on manufacturing one unit of white and yellow Manila paper. Data was gathered through site observations, lab experiment, documents, measurement record and database. The functional unit examined was based on the Cumulative Energy Demand, the ReCiPe2016 v1.03: Midpoint and Intergovernmental Panel on climate change 2021 method. The assessment considered both renewable and non-renewable energy consumption across six impact categories. The results indicate that the production of white Manila paper exhibited the primary energy demand of 5.095 MJ-Eq with highest primary biomass consumption, primarily due to the Kraft pulp production processes from both hard and softwood, which cumulatively contributed 88%, Conversely, yellow Manila paper production showed the total energy demand of 2.778 MJ-Eq with highest primary biomass consumption, attributed to the significant use of renewable energy for hard and soft wood pulp making. From the impact analysis, Terrestrial eco toxicity (0.924 and 0.112 kg 1, 4 –DCB- Eq), Human Toxicity –carcinogenic (0.00243 and 4.39E-04kg 1, 4 –DCB- Eq), Human toxicity-non-carcinogenic (0.175 and 4.94E-02 kg 1, 4 –DCB- Eq), Global warming - GWP20a (0.0587 and 1.02E-02 kg CO2-Eq), ozone depletion (1.474E-07 and 3.63E-08 kg CO2-Eq) and Freshwater Eutrophication (1.37E-05 kg PO-4Eq) for white and yellow Manila paper respectively. The result revealed that the environmental burdens vary with the variations of input and output types. The pulp production was major contributors to the environmental burdens for both white and yellow Manila paper. Therefore, the company owners and management should evaluate environmental performance which helps for strategic decision and planning.

Key words: Life cycle Assessment, Paper product, recipe mid-point 2016, cumulative energy demand, open LCA software, production process, unit process.

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List of Abbreviations and Acronyms

LCIA	Life Cycle Impact Assessment
LCI	Life Cycle Inventory
EPPSC	Ethiopian Pulp and Paper Share Company
APEPLC	Anmol Products Ethiopia Private License Company
IPCC	*Intergovernmental Panel on climate change*
CED	Cumulative Energy Demand
ISO	International Organization for Standardization
CFC- EQ	Chlorofluorocarbons Equivalent
CO2-Eq	Carbon Dioxide Equivalent
GWP 20	Global Warming Potential -20 year
Kg	Kilogram
MJ-EQ	Mega joule Equivalent
G	Gram
Kwh	Kilo Watt Hour
Mg/m ^{3}	Milligram per cubic Meter
µg/m ^{3}	Micrograms per cubic Meter
COD	Chemical oxygen demand
ET	Ethiopia
VOC	Volatile Organic Compound
CO2	Carbon Dioxide
PM2.5	Particulate Matter2.5
PM10	Particulate Matter 10
DCB-EQ	Dichlorobenzene Equivalent
ILCD	International Life Cycle Data system.
CSV	Comma Separated Value
HHV	Higher heating value
EURO	European Emission Standard

1. Introduction

1.1 Background

The pulp and paper industry is one of the largest global industries, significantly contributing to the world's economy (Chauhan & Meena, 2021). Pulp and paper production involves processing raw materials such as wood, straw, or other plant fibers through various processes like crushing, soaking, grinding, fiber separation, and coagulation (Liang et al., 2023). Typically, this production relies on fibrous raw materials, which may include primary fibers sourced directly from plants and secondary fibers obtained from recycled paper. In developed countries like the United States of America and Canada, about 90% of the conventional raw material for pulp and paper production comes from wood. Cellulose is primarily obtained from hardwood or softwood, which is in higher demand compared to non-wood materials (HAILU, 2020).

Paper products are primarily used for office paper, cardboard, packaging material, and newspapers (Megra et al., 2022). The demand and use of pulp and paper have historically marked the levels of civilization and development of many societies (Haile,et al., 2021). Modern life's daily consumption of paper and paper products is driving demand, which is increasing with population growth and modernization (Gebeyehu, 2022). According to Fast markets, global paper consumption is expected to increase by 40% by 2028, with recycled paper consumption projected to rise by 64%. Paper production has risen from 404 million tons in 2014 to 409 million tons in 2018, with most waste paper being recycled to produce paper products (Simamora1 et al., 2024).

Life cycle assessment (LCA) is a method or tool used to analyze the environmental impacts that occur as a result of the manufacturing process of a product (Passarini and Ciacci, 2020). LCA is a valuable technique for policymakers to promote waste management strategies and select high-priority environmental options that positively impact sustainability (Moosavi et al., 2021).LCA analyzes environmental impacts through several stages, offering a comprehensive view of the resources used (inputs) and materials produced (outputs) in a process. Environmental burdens assessed using LCA include global warming, acidification, eutrophication, ozone layer depletion,

depletion of a biotic resources, human toxicity, and other factors (M Yani et al 2022). Life Cycle Assessment (LCA) has emerged as a critical tool for evaluating the environmental impacts of products and services. Research on LCA has grown over the last 20 years, with more than 25,000 related articles in scientific databases like Scopus. However, the concept is relatively new to Africa, where the number of related networks is low compared to other regions (Karkour et al., 2021).

Nevertheless, no LCA studies have been conducted on paper manufacturing in Ethiopia paper industry. Therefore, this LCA study aims to analyze the environmental impact of paper production in paper mill under investigation.

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1.2. Statement of problem

Environmental pollution is a great concern nowadays. The production and demand of paper and related products is increasing considerably around the world. This is leading to a raise in energy consumption and CO2 emissions in the pulp and paper industry for higher production. The pulp and paper industry consumes large quantities of fresh water and discharges significant amounts of wastewater (Sharma et al., 2020). Paper mills typically use a mix of toxic chemicals to reduce wood to pulp and bleaching paper. Potential byproducts include mercury, water effluents like absorbable organic halides and total suspended solids, and solid waste such as boiler ash and effluent sludge can harm the environment when released into water and land (Suraj & Khan, 2015).Solid wastes in the pulp and paper industry constitutes around 45% wastewater sludge , 25% ash (Riquelme et al., 2023).The pulp and paper mill generates a large volume of wastes with an estimate of around 100 tons per 550 tons of pulp production. Though the toxicity of pulp and paper wastes is minimal appropriate disposal technique is required for appropriate management of the land, environment, and allied issues (Haile et al., 2021).

The papermaking process is complex and has extensive environmental impacts beyond the actual production process. It is toxic, resource-intensive, and pollutants that cause significant health issues and environmental degradation. Additionally, deforestation to obtain paper pulp the primary material used for papermaking and the disposal of paper waste products are major contributors to greenhouse gas emissions (Smith, 2011). With the growing clamor of consumers for greener products and the increasing awareness of issues related to sustainable development, environmental considerations are becoming a source of competitive advantage for industries. In view of these developments, there is a growing need for tools that can be used to assess environmental impacts of products and manufacturing processes. One systematic approach for the identification and management of environmental impacts in industry is life-cycle assessment (LCA) (Pineda-Henson et al., 2002).The paper industry needs practical methodologies to integrate LCA with decision-making tools (Moosavi et al., 2021).However, there is no information in the literature on the investigation of environmental impact of paper manufacturing by applied LCA technique in Ethiopia paper industry. Hence, this research aims to fill this gap by evaluate the environmental impacts associated with the paper production process using a comprehensive life cycle assessment (LCA) tool.

1.3. Research question

1. What are the major unit processes in the production of Manila paper?

2. How does the Manila paper product manufacturing impact environment?

3. What are the environmental impacts of Manila paper production?

4. Which unit processes the most contributors to the environmental impact of Manila paper making?

1.4. Objective

1.4.1. General objective

The main objective of this study was to analyze the environmental impacts of Manila paper production by applying life cycle assessment technique.

1.4.2. Specific objectives

The specific objectives are:

1. Distinguish the unit processes of Manila paper production to draw the system boundary;
2. Perform inventory analysis of a Manila paper production;
3. Evaluate the potential environmental impacts of a Manila paper production;
4. Identify the most contributor unit processes to the Manila paper production environmental effects.

2. Literature review

2.1. Overview of pulp and paper industry

The milestones in the pulp and paper industry was stem from the invention of the cylinder paper machine by John Dickinson in 1809, leading to a rise in the Fourdriniermachine's usage for making thin paper. Seventeen years later, a steam cylinder was introduced for drying the papers. The United States of America began to use the Fourdrinier engine only in 1927. Friedrich Gottlob Keller discovered the mechanical process of making pulp from wood of low quality in 1814, whereas the soda process was just introduced in 1854 by Charles Watt and Hugh Burgess. Benjamin Chew Tilgh, an American chemist, through his British Patent, founded the sulfite process three years later. This process was able to produce a good and ready-bleached pulp. Finally, Kraft or sulphate process was discovered from a basic experiment of Carl Dahl in Danzig in 1884 which is a dominant method used today. Those milestones provided the basis for the modern pulp and paper industry (Series, 2020).

2.2. Pulp and Paper Technologies

Pulp and paper manufacturing process consists of five steps, which are plantation, raw material preparation, pulping, stock preparation and papermaking, and finally, post use treatment. Usually forest products removal from the oldest stand counterbalances the growth of another stands. Hence there is no change in biomass yearly. The forest will continue to be a reservoir once established, but will not be either a carbon sink or carbon source. A net carbon sink will be formed from normal forest establishment that contains little carbon in the vegetation. Before the first harvest, this phase will make one rotation with the greatest sequestration. It is a common growth habit of trees to persist for a long period in the mature form, but with very little volume growth. The criteria of natural normal forest would contain many stands with a low proportion of stands and a high standing volume in the vast growth phase. To replace it with a managed forest, clearing a natural forest will make a large capacity reservoir with a smaller one. Hence a well-managed plantation is important (Sembiring et al., 2020).

2.2.1. Pulp production

During the pulping process, wood chips are separated into individual cellulose fibers by removing the lignin (the intercellular material that cements the cellulose fibers together) from the wood. There are five main types of pulping processes: (1) chemical; (2) mechanical; (3) semi chemical; (4) recycle; and (5) other (e.g., dissolving, non-wood). Chemical pulping is the most common pulping process. Chemical (i.e., Kraft, soda, and sulfite) pulping involves "cooking" of raw materials (e.g. Wood chips) using aqueous chemical solutions and elevated temperature and pressure to extract pulp fibers. Kraft pulping is by far the most common pulping process used by plants in the United State of America for virgin fiber, accounting for more than 80 percent of total U.S.A pulp production. The Kraft pulping process uses an alkaline cooking liquor of sodium hydroxide (NaOH) and sodium sulfide (Na_2S) to digest the wood, while the similar soda process uses only NaOH. This cooking liquor is mixed with the wood chips in a reaction vessel (digester). After the wood chips have been "cooked," the contents of the digester are discharged under pressure into a blow tank. As the mass of softened, cooked chips impacts on the tangential entry of the blow tank, the chips disintegrate into fibers or "pulp." The pulp and spent cooking liquor are subsequently separated in a series of brown stock washers (Engineering et al., 2015).

2.2.2. Paper production

Modern paper making evolved from an ancient art in Egyptian civilization which used papyrus as writing media at around 3000 BC. The characteristics of the papers in this era are not the same as the papers used today. A more skillful papermaking later was reported from a Chinese named T'saiLun in 100 AD, utilizing a wide variety of materials such as bamboo or mulberry fibers. This method of papermaking was then spread throughout Middle East and Rome in the Mediterranean Sea after several centuries until it reached Europe, England, and America at the beginning of 15th century. In 1799, the first continuous papermaking machine called Fourdrinier machines was patented by a Nicholas Louis Robert from France (Series, 2020).The pulp is spread on a moving wire mesh or plastic mesh at the "wet" end of the machine, where the operator monitors the web speed and the water content of the pulp. Water and filtrate flow through the fabric, leaving only a network of fibers. The dough passes between different pressure rollers which express water and air until the fiber density reaches between 40% and 45%. The paste admitted into the inlet box usually contains more than 97% water. It is projected on a moving canvas. The filtering action of the latter, combined with that of a suction system, makes it possible to extract the major part of the water contained in the paste and to form a sheet. The pressing of the latter between rollers makes it possible to remove an additional quantity of water. The sheet then passes to the section of the dryer where, in contact with immense cylinders generally steamed, much of the residual water is evaporated. The sheet then undergoes several drying steps to obtain a consistency of 90% to 95%. Finally, it is cut and baled. Once compressed, these bales are wrapped for storage and transport (Ismaili et al., 2017).

2.3. Global Overview of pulp and paper production and consumption

The paper-making industry is developing continually in a drastic manner. In 2020, approximately 490 million metric tons of paper was produced worldwide. Approximately, 53.5 million tons of recycled waste paper is used for the production of paper. While in 2020, an estimated 399 million metric tons of paper and board consumed globally (Kumar et al., 2025).High energy costs and raw material prices impacted much of the region. Apparent consumption of paper and paperboard remained unchanged in 2022 at 89.9 million tons. During the second half of 2022, numerous paper-machine closures were driven by a decline in consumption. The latter was the result of higher raw material prices and lower advertising budgets for print products. Closures continued into 2023. The production of graphic grades fell by 9.6% to 24.2 million tons in 2022, with uncoated wood free paper down by 5.9% to 7.4 million tons, and coated paper down 10.6% to 8.3 million tons. Newsprint production was decreased by 10.0% to 4.1 million tons. The production of sanitary and household papers rose by 1.1% to 8.1 million tons. The production of packaging materials fell by 2.8% to 55.8 million tons, mainly because of high energy prices. Case material production fell by 3.5% in 2022 to 34.0 million tons, while carton board decreased by 2.0% to 11.7 million tons. Apparent consumption of graphic grades was decreased by 0.7% to 22.2 million tons in 2022. Uncoated wood free paper increased by 0.1% to 7.0 million tons, while coated papers decreased by 5.0% to 6.8 million tons. Apparent consumption of newsprint rose by 3.2% to 4.2 million tons. Apparent consumption of sanitary and household papers increased by 0.4% in 2022 to 8.1 million tons. Apparent consumption of packaging materials rose by 1.0% to 52.2 million tons in 2022. This positive trend was driven by increased carton board consumption that was up by 6.7% to 9.4 million tons. Case materials, in contrast, experienced a decline of 1.2% to 33.7 million tons, explained in part by lower levels of online shopping as consumers emerged from COVID19. Exports of packaging papers fell by 3.8% to 36.1 million tons, while imports rose by 2.7% to 32.5 million tons(America et al., 2023)

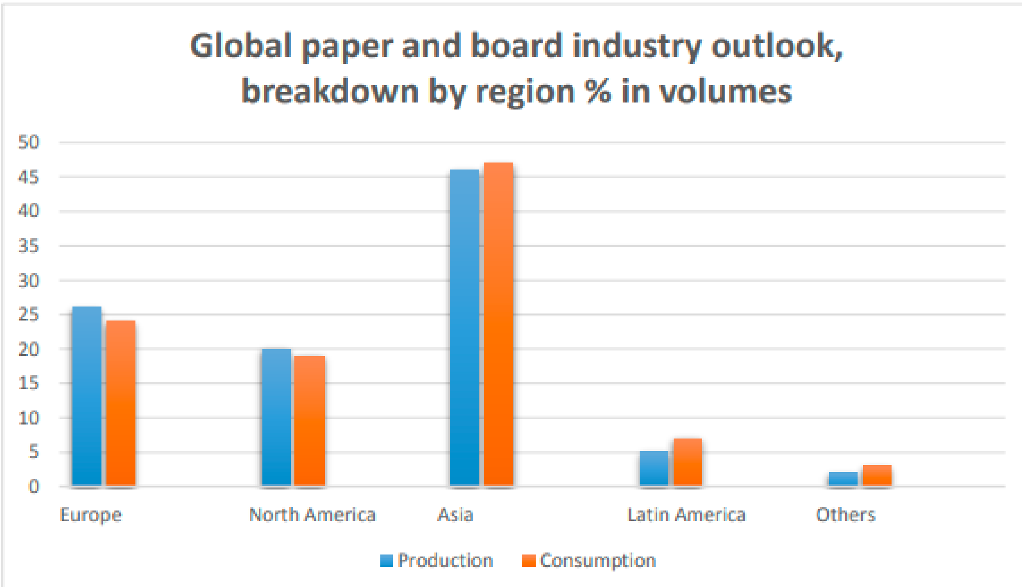

Figure 1: Global paper and board industry production and consumption. Source (The Global Paper Market – Current Review***).***

2.4. Pulp and paper industry states in Ethiopia

According to Ethiopia chemical construction input industry development institutes 2018, until recent year Ethiopia has no pulp mill. The paper mills of the country have been using pulp from recovered paper. In year 2019 Adal integrated pulp and paper mill was established in Oromia region, Gelan town with a capacity of producing 3,000 tons of pulp per year. In addition to this, two integrated pulp and paper mill projects (Tana Pulp and Paper S.C and Green Diamond Pulp and Paper PLC) based on bamboo and eucalyptus tree raw materials are under implementation.

In contrary to the extremely rising global demand and production of paper and paper products, paper production in Ethiopia is at its infant stage where there are only very few paper mills producing a maximum annual output of 35 thousand tons in aggregate which is less than 0.01% of global production. The huge capital investment and absence of pulp mill processing the raw material in the country are considered as the major reasons for these limited number of paper mills. These make the local production of paper inefficient and less competitive when compared to other sectors in the industry, which significantly affects the overall economic growth of the country (Lemma, 2018). As the Ethiopian economy expanded significantly over the last fifteen years, the demand for paper and paper products increased. In 2016/17, the demand for paper was 219,840 tons, with the country importing 126,389 tons. However, Ethiopia managed to satisfy only 18% of this demand, relying heavily on imports and spending millions of scarce hard currency on paper products (HAILU, 2020).

Data from the Chemicals and Construction Inputs Industry Development Institute (CCIIDI) reveals that Ethiopia's 2016/17 demand for paper was increasing. Local companies, operating at 62% capacity, produced only 40,000 tons, with the rest fulfilled through imports (CCIIDI, 2019). Almost a third of Ethiopia's population, about 30 million people, is enrolled in various levels of education and depends entirely on paper products. Consequently, Ethiopia's paper consumption has sharply increased with the rise in student numbers. For instance, the country imported 213,134 tons of exercise books in 2017 (CCIIDI, 2019). The demand for paper in Ethiopia is expected to continue rising (Hailu, 2020).

Table 1: Pulp and paper industry in Ethiopia (Haile, et al., 2021)

Company name	Planed production	Product type
Ethiopia pulp and paper s.c	6000	Printing and writing paper, Stationery paper , paper board , corrugated box, wood free and manila paper ,Kraft liner ,test liners ,fluting papers ,
Anmole products Ethiopia	12,000 -14,000	Printing writing paper, wood free and manila paper, Kraft liner, test liners, fluting papers.
Yekatit Paper Converting	1400	Different paper products
DA Packaging	2000	Kraft liner, test liners, fluting papers , corrugated carton
Barguba Trading	8000	Different paper products
Mamco paper products	200	Paper and tissue products
Burayu Development	10,000-11,500	Carton boxes ,trays, packets
Minaye	3500	Carton
Balaje Packaging	1800	Carton
Unlimited Packaging	20,000	Carton
Seven Hills Packaging	7000	Carton
AK less Paper product	350	Different paper products

2.5. Pulp and Paper manufacturing and demand in Ethiopia

In Ethiopia, paper demand is growing by 10 percent every year (ERCA, 2015). For instance, in 2003, average annual domestic production of paper was 7,266 tons, while in the same year, 127,132 tons of paper was imported which means the average total supply of paper during the period under consideration was 134,398 tons per annum (Abara & Bekele, 2021).The results indicated that between the years 1997 and 2016, Ethiopia imported on average 23700 tons of paper and paper products per year. To import such a quantity of paper and paper products the country spent on average US$ 29.85 million/year. Out of this, yearly average expenditure about 8.7% for Folding cartons, boxes, and cases of non-corrugated paper and paperboard, 8.5% for Paper for writing and coated with kaolin, 6.5% for printed paper or paperboard labels of all kinds, 6.4% for Fluting paper, 6.2 for Sack Kraft paper, about 6% for Cartons, Boxes, and cases of corrugated paper and paperboard, 5.6% for Copying or transfer papers, 5.5% for photographic paper and paperboards, and about 46% for other paper and paper products types (Tamiru & Abirham, 2022).

Chemicals and Construction Inputs Industry Development Institute (CCIIDI, 2018)

Table 1: The last five years imported virgin pulp and scrap papers*

	Imported virgin pulp			Imported scrap paper		
Year	Gross Wt. (Kg)	CIF Value (ETB)	CIF Value (USD)	Gross Wt. (Kg)	CIF Value (ETB)	CIF Value (USD)
2015	7,323,832.40	125,226,097.22	6,025,699.99	1,707,395.00	10,319,275.30	496,548.71
2016	7,949,797.12	138,462,101.92	6,310,023.24	1,732,512.00	10,767,221.70	490,686.03
2017	3,836,176.73	70,305,115.30	2,980,015.23	1,022,314.44	6,700,780.59	284,025.25
2018	6,465,125.01	146,093,521.65	5,410,871.17	1,474,061.30	24,455,395.30	845,512.79
2019	9,094,073.40	221,881,928.00	7,396,064.27	1,925,808.16	42,210,010.00	140,7000.33
Average	**6,933,800.93**	**140,393,752.82**	**5,624,534.78**	**1,572,418.18**	**18,890,536.58**	**704,754.62**

*Source: Ethiopian Revenue and Customs Authority.

2.6. Environmental impact of the pulp and paper industry

The most important indicator of human life and all plant and animal groups is the environment. Industrial plants are one of the largest sources of pollution worldwide (Moosavi et al., 2021).Industrial pollution of environmental segments is not a new phenomenon, where the air is polluted by exhausts coming out from the chimney, water bodies are polluted by the effluent coming from the industry and the soil is contaminated by the solid waste discharged and dumped in the vicinity of the industry. Among industries, Paper and Pulp industry plays a significant role in contaminating the fresh water bodies. The untreated effluents from pulp and paper mills that are discharged into water bodies, damages the water quality (Tripathy et al., 2022).

Pulp and paper mill effluent is an important source of environmental pollution due to the high content of chlorinated compounds chlorolignins, and chlorinated hydrocarbons along with resin acid, tannin acid, phenolics, lignosulphonic acids, various surfactants, plasticizers , biocides, waxes, fatty acids, heavy metals and other complex organic, inorganic compounds (P. Sharma et al., 2020).

Currently, the pulp and paper industry is one of the largest consumers of wood. Based on the demand, due to global economic growth, an increasing number of trees are harvested each year, also leading to increased amounts of wastes and pollutants, which represent a serious hazard for the environment. Chemical agents, such as sodium hydroxide, hydrogen peroxide, sodium carbonate, diethylenetriaminepentacetic acid, sodium silicate and surfactants, are used in large quantities by paper industries as part of the conventional methods of deinking waste paper, leading to the need to apply expensive wastewater treatments in order to meet environmental regulations (Yakubu & Vyas, 2023).

The pulp and paper industry is a major consumer of water in industry, and generates wastewater with high concentration of COD (chemical oxygen demand) and suspended solids, providing high pollutant loads. Water resources management requires planning the efficient use of water in paper manufacturing, involving washer filters, bleaching, liquors clarification, cooling towers and boilers(Francisco et al., 2014).

The global demand for wood products, such as paper, furniture, and construction materials, has severely damaged tropical forests, with paper production being the highest in demand. This demand is projected to increase over the next half-century, with wood consumption in 2060 expected to surpass all paper consumption types and rise by more than 100% from 2010 levels (Weis, 2020).

Besides the direct emissions derived from the energy and heat demand, the Paper and Pulp industry presents other direct and indirect emissions across the value chain; several studies have identified the environmental impact of upstream processes and manufacturing unit operations in the industry by performing Environmental Life Cycle Analysis (LCA) (Tello, 2023).In a general analysis of the industry's carbon and energy flow, Zhao et al., (2013) also identify material transport as an important energy consumer and carbon emitter by diesel combustion (Tello, 2023).

2.7. Environmental Impact categories and definition

Cumulative energy demand according to Frischknechtet al. (2007b) describes the consumption of fossil, nuclear and renewable energy sources along the life cycle of a good or a service. This includes direct use as well as indirect or grey energy consumption due to the use of, e.g. plastic or wood as construction or raw materials. This method was developed in the early seventies after the first oil crisis and has a long tradition (Boustead and Hancock, 1979; Pimentel, 1973). A CED assessment can be a good starting point in an assessment due to its simplicity in concept and its comparability with CED results in other studies (Jungbluth, 2024).

Chemicals emitted through anthropogenic activities contribute to Eco toxicity (EC) if they affect the function of ecosystems negatively by exerting toxic effects on the organisms that live in them (Oliveira et al., 2015).

Global Warming Potential (GWP) is the contribution of a substance to the greenhouse effect. GWPs are based on the heat-absorbing ability of each gas relative to that of carbon dioxide (CO_2), as well as the decay rate of each gas (the amount removed from the atmosphere over a given number of years)(Global Warming Potential Brief, 2008).

Emissions of organic materials can lead to oxygen consumption by bacteria degrading this organic matter and thus contributing to oxygen depletion similarly to what is observed as a result of the nutrient enrichment of lakes and coastal waters (Ralph et al., 2018)

.The main ozone depleting substances are resilient chemicals that contain chlorine or bromine atoms. Because of their long lifetime they are able to reach the upper stratosphere and can degrade the ozone layer through a chemical process of heterogeneous catalysis. The ozone depletion potential of a substance is a synthesis of a relative measure for the potency to form equivalent effective stratospheric chlorine and the predicted residency time(Ozone Depletion Potential Brief, 2015).

Table2: Impact categories unit (Acero et al., 2015)

Impact categories	**Reference unit**
Cumulative energy demand	MJ Equivalent
Eutrophication	Depend on the model : Kg PO43- Kg N and equivalent
Climate change	KgCO2 Equivalent
Eco toxicity	Depend on the model : Kg1,4-DB Equivalent
ozone depletion	Kg CFC-11 equivalent

2.8. LCA for the evaluation of environmental impacts of products, process and service

2.8.1. Historical overview of LCA

The development of Life-Cycle approaches has been driven by concerns related to the environmental pollution and the depletion of materials and energy. Ever since the first methodology was proposed in the 1960s, LCA has undergone robust evolution in both methodology and applications. So, it is now a well-known and widely used tool across the industry, academia, and policy. From its start in the 1960s to the broad-spread in just over 60 years, LCA has passed through different stages of development and adoption; a) the early years period (1960- 1970), b) Conception period (1970-1990), c) Standardization period (1990-2000), d) Elaborations' period (2000-2010), e) Concept broadening period (2010-till now) (Aliaa Amahmoud et al 2022).

The first studies to look at life cycle aspects of products and materials date from the late sixties and early seventies, and focused on issues such as energy efficiency, the consumption of raw materials and, to some extent, waste disposal. In 1969, for example, the Coca Cola Company funded a study to compare resource consumption and environmental releases associated with beverage containers (Hoffman & Schmidt, 1997).

2.8.2. Application of LCA

Recent decades have witnessed numerous applications of LCA to support decisions in an environmental sustainability context. Much effort has been made to facilitate the application of LCA and life cycle thinking in society ranging from the regulatory and governmental level, through industry and production to the level of citizens and consumers. The dissemination of LCA has been aided by a number of initiatives for supporting and harmonizing the application of the tool. In 1997 the first version of the ISO 14040 standard (later updated as ISO 2006a) was published in an attempt to harmonize the framework and principles of LCA and to increase transparency and comparability of LCA studies. In 2001, The United Nations Environment Programme (UNEP) and the Society for Environmental Toxicology and Chemistry (SETAC) joined forces in the launch of a global partnership to strengthen the dissemination and use of LCA worldwide, known as the Life Cycle Initiative (LCI). The purpose of the initiative was to "enable users around the world to put life cycle thinking into effective practice". Another initiative supporting a more widespread application of LCA was The European Commission's project, The European Platform of Life Cycle Assessment, launched in 2005. Its objective was to "promote life cycle thinking in business and in policy making" in the European Union by focusing on underlying data and methodological need (Rosenbaum, 2018).

LCA is used for identification of product improvement hotspots, to support sound decision making and to market products. Companies use it as an internal decision making tool to incorporate environmental improvements into the design and development of its products and packaging. Due to legislative pressure and public interest, companies are using EIA and LCA to make environmentally sound business choices. Government has used LCA to compare the impacts of alternative products for legislative decision-making and the development of strategic policies (John & Und, 2007).

LCA is widely recognized as a scientifically reliable tool to evaluate environmental impact; modeling techniques based on mathematical programming have been also widely used to integrate environmental issues for Green supply chain management. In fact, many studies have identified the integration of multi-objective optimization and LCA as a suitable practice to support sound decision making in supply chain design (Daya & Nourelfath, 2018).

2.8.3. Stage of LCA

LCA has four stages (ISO 14040:2006; ISO 14044:2006). The first stage is Goal and scope definition. The second stage, called the life cycle inventory (LCI), the third stage, is called the life cycle impact assessment (LCIA). The final stage of LCA is interpretation of the results. In some cases, the goal of the study can be fulfilled with just the LCI calculation and the interpretation, and the LCIA phase can be omitted. These studies should be called LCI studies and not LCA studies (ISO 14040:2006; ISO 14044:2006) (Pajula et al., 2017).

2.8.3.1. Goal and scope definition

The first phase of an LCA study consists of defining the goal and the scope of the study. This is a very important part in the LCA, as it determines and guides the choices to be made in the other phases of the study. Therefore it is recommended to spend sufficient time in this phase to clearly define what is the purpose of the study, the intended use of the results and what should be included. In the end, this will save time in the other phases of the work. It should also be noted that during the course of the study it may be necessary to come back and redefine the goal and scope when more knowledge has been acquired about the product system. Issues and information that were not known or could not have been foreseen in the beginning of the work may require that the goal needs to be reformulated. The scope should describe the detail and depth of the study, and show that the goal can be met with the actual extent of the limitations. When defining the scope of the study the following aspects should be considered and described: the product system, the functions of the product system, the functional unit, system boundary, allocation procedures, environmental impact assessment methodology and types of impacts, data requirements, assumptions and limitations and data quality requirement. LCA is an iterative technique, and as data and information are collected, various aspects of the scope may require modification in order to meet the goal of the study (Pålsson & Riise, 2011).

The system boundary section identifies the unit process considered in the LCA study. Generally, LCA is a “cradle-to-grave” approach and covers the whole product life cycle from the raw material extraction, the manufacturing and use stage to disposal. However, it can be equally applied to the selected stages of a product’s or process’s life cycle (Masternak-janus et al., 2015).

Product system boundary categorized into:

Cradle-to-grave: This approach indicates that the study will be complete in terms of its product's life cycle stages as the system will take into account elementary processes that will represent all the steps.

Cradle-to-gate: It is equivalent to the term "from the cradle to the factory gate" as it considers elementary processes from the stages of extraction and processing of natural resources to the manufacture of intermediate products and/or the final product.

Gate-to-gate: It means "from the gate to the factory gate" as it considers only the stage of the product's manufacture in the LCA study.

Gate-to-grave: It takes the "from the factory gate to the grave" approach as it only assumes elementary processes that will represent the stages of distribution, use and the product's end of life (disposal in landfill, incineration, recycling, remanufacturing, etc.). In this case, the inclusion of the background system occurs only for the steps downstream of the factory gate (Puglieri, 2021).

2.8.3.2. Inventory analysis

This stage involves collecting data on the inputs and outputs associated with each stage of the product's life cycle. This includes information on raw materials, energy and water use, emissions, and waste generation (Kulkarni, 2023).

2.8.3.3. Life cycle impact assessment

The LCIA methods are required to apply in the LCIA phrase, by which the aggregation of the inventory data showing emissions and resources consumptions are converted into impact categories. The impact categories are also known as indicators, and these indicators link different types of LCI results and cover different impact categories and characterization models. Common impact categories are climate change, human and eco toxicity, acidification, eutrophication and resource depletion. The indicators of the specific impact categories can be classified to midpoint or endpoint. A midpoint impact for the impact category climate change is for example kg CO_2-equivalents/kg gas; a referring endpoint impact could be impact on nature (such as a rise in sea level or global average temperature). While endpoint indicators allow users to clarify concrete environmental impacts, their calculation is associated with higher uncertainties than midpoint indicators. Any system process or unit activity gives negative value to each category of impact results which means benefit to the environment (Poopak & Agamuthu, 2011).To go from midpoint to endpoint indicator scores, additional midpoint-to-endpoint characterization factors (sometimes also referred to as severity or damage characterization factors) are needed, expressing the ability of a change in the midpoint indicator to affect the endpoint indicator. In contrast to the midpoint characterization factors which reflect the properties of the elementary flow and hence are elementary flow-specific, the midpoint-to-endpoint characterization factors reflect the properties of the midpoint indicator and there is hence only one per midpoint impact category. Some LCIA methods only support endpoint characterization and here the midpoint and midpoint-to-endpoint characterization is combined in one characterization factor (Ralph et al., 2018).Based on the deep comparison, LCIA methods can be categorized into two groups: resource based methods and emission based methods. The resource based methods focus on resources (inputs) taken from the nature with resource indicators (e.g. Cumulated Energy Demand); emission based methods focus on outputs to the nature, assessing one or multiple emissions (outputs) with the help of extended assessment models (e.g. CML 2002, ReCiPe) (Su, 2020) .There are several Life Cycle Impact Assessment (LCIA) methods that can be used when conducting an LCA and these methods consider different impact categories to assess the environmental impacts which can have distinct names and can be expressed using different units (Santos & Barbosa-póvoa, 2018) .

Recipe 2016 v1.03, Midpoint the models should refer to the global scale, the models should reflect the current state of the art in science, In case of multiple suitable global models, we prefer models that can be run in-house by the ReCiPe consortium The models should maintain consistency between the modelling of different impact categories, particularly relevant for toxicity, and Recipe provides a harmonized implementation of cause applied to model midpoint-to-endpoint factor (Huijbregts et al., 2017).

The IPCC-2021 provides 20-year, 100-year and 500-year GWP values for every major greenhouse gas. In every application of the GWP this choice of time horizon is necessary. With black carbon this choice can appear difficult since the time horizon produces large variation in

GWP values. This variation is explained by the differences between the time-dependent impacts of short and long-lived forcing agents. With black carbon, for example, a short time horizon like 20 years will capture all of its radiative forcing, but only a fraction of the forcing of carbon dioxide, a longer-lived agent. A longer time horizon like 100 years will still capture all of the forcing of black carbon, but it will also capture a greater fraction of carbon dioxide forcing, so the differences between their total forcing grows smaller over longer time horizons. This explains why the 100- year GWP for black carbon is much lower than the 20- year GWP(Walsh & Nichols, 2009).

Table 3: Environmental impact categories of major LCIA methods *Source: (Su, 2020).

Method	Descriptions	Midpoint impacts categories		Endpoint impacts categories
USEtox 2.01	It is a scientific consensus model for assessing human and Eco toxicological impact of chemical emission in life cycle assessment.	Fresh water Eco toxicity	Carcinogenic Non-carcinogenic	Ecosystem quality Human toxicity
EDIP20003	It is a follow -up of the EDIP97methodology, and it covers only emission categories and considerers midpoint impacts.	Global warming Ozone depletion Acidification Terrestrial eutrophication Aquatic eutrophication Ozone formation (human, vegetation)	Human toxicity (exposure rote via air ,water ,soil) Eco toxicity (water acute, water chronic, soil chronic Waste (hazard ,slag, ashes ,bulk waste ,radioactive waste)	N/A
IMPACT World+	It is developed as a joint major update to impact 2002+, EDIP, and LUCAS methodology, and it assesses local and regional impact categories.	Human toxicity Photochemical ozone formation Ozone layer depletion Global warming	Eco toxicity Acidification Eutrophication Water Land use Resource used	Human health Ecosystem quality Resource and ecosystem service Human health
ReCiPe	It is a follow up of Eco	Climate change	Fresh water Eco toxicity	Human health

	indicator 99 and CML 2002 methods that integrate and harmonies midpoint and endpoint approach.	Ozone depletion Terrestrial acidification Fresh water eutrophication Marine eutrophication Human toxicity Photochemical oxidant formation Particulate matter formation Terrestrial Eco toxicity	Marine Eco toxicity Ionizing radiation Agricultural land occupation Urban land occupation Natural land transformation Depletion of fossil fuel resource Depletion of mineral	Ecosystem quality Resource

2.8.3.3.1. Elements of life cycle impact assessment

The impact assessment consists of five elements of which the first three are mandatory according to the ISO 14040 standard:

Selection of impact categories: representative of the assessment parameters that were chosen as part of the scope definition.

Classification: elementary flows from the inventory by assigning them to impact categories according to their ability to contribute by impacting the chosen indicator.

Characterization: using environmental models for the impact category to quantify the ability of each of the assigned elementary flows to impact the indicator of the category.

Normalization : is used to inform about the relative magnitude of each of the characterized scores for the different impact categories by expressing them relative to a common set of reference impacts—one reference impact per impact category.

Grouping or weighting supports comparison across the impact categories by grouping and possibly ranking them according to their perceived severity, or by weighting them using weighting factors that for each impact category gives a quantitative expression of how severe it is relative to the other impact categories(Rosenbaum, 2018).

2.8.3.4. Life cycle interpretation

The last phase of LCA is the life cycle interpretation. Interpretation is the part of the study where results of the LCIA step are discussed and interpreted. The base of the study is the interpretation phase and the definition of the goal and scope phase, whereas LCI and LCIA create information on the product system. The results of the LCI or LCIA phases shall be interpreted according to the goal and scope of the study. The life cycle interpretation of an LCA comprises three main elements: identification of the significant issues based on the results of the LCI and LCIA phases of the LCA study, evaluation of results, including completeness, sensitivity, and consistency checks. Results from uncertainty analysis and data quality analysis are considered as well. Finally, the interpretation concludes and gives recommendations mentioning the limitations of the study (Contributing, 2021).

2.9. Software programs and data base analysis of LCA

2.9.1. Software programs

There are many types of software that can be used for impact analysis, for example, SimaPro, Open LCA, Gabi, Umberto, etc. Open LCA is a freeware package (open source) and a widely known software tool that is easy to handle and it allows the user to calculate all the stages associated to LCA. Another advantage of this tool is that it offers users the possibility of working with different databases, such as those used by GaBi, and others. Initially Open LCA was designed for calculating the environmental impact of products and processes, but it can now add economic aspects. In addition, it has a feature-rich, technically up-to-date introduction to the software. It also has the broadest selection of relevant, consistent LCI and sustainability databases available worldwide. OpenLCA has been developed by Green Delta since 2006 with the support of PE International (makers of GaBi), PRé Consultants (creators of SimaPro) and UNEP (United Nations Environ mentProgramme). Open LCA are available on different levels, such as process, product system, project, and impact method database. One of the advantageous features of Open LCA is that the process networks and graphical modeling can be created automatically and manually (Science, 2020).Open LCA supports the following formats for import and export: EcoSpold 1, EcoSpold 2, ILCD, SimaPro CSV (only import) and Excel (specific template).

SimaPro: one (of two) leading LCA Soft wares in the world, for decades, developed by PRé consultants. SimaPro supports two exchange formats: A proprietary CSV format and a slightly modified version of EcoSpold 1. Umberto LCA and material flow software developed by ifu, Germany Users in Germany and in some Latin American countries, No own reference data, data import requires collaboration with ifu, export to EcoSpold 1, and one process data set at a time (Ciroth, 2015).

GaBi software is product sustainability software that includes several tools for determining the potential environmental impact of a product. It is a leading modeling and analytic application for global Life Cycle Assessment (LCA) and reporting software, content databases with accessible data collection and reporting tools (Senusi et al., 2022).

2.9.2. Data base analysis of LCA

LCA studies require a high volume of data and their quality has a direct influence on the quality of the Life Cycle Inventory (LCI) and Life Cycle Assessment (LCA) study overall. The use of LCA databases enables users to (i) reduce time, efforts, and resources for data collection and (ii) reflect supply chains they have no direct control over. On the other side, it creates the need to align own modeling of the foreground LCA study with the modeling in the database. In recent years, countries worldwide have been more and more motivated in supporting LCA studies by providing national databases that reflect their economy, energy mix, and disposal technologies (Ciroth et al., 2019)

There are different types of database. The ecoinvent database helps companies manufacture products that are less impactful on the natural environment, policy makers implement new policies, and consumers adopt more environmentally friendly behavior (Eco invent Centre 2023).The latest version 3.9.1 of the ecoinvent database was released by the ecoinvent Association the 15th of December 2022 and includes major updates of 1099 new processes (datasets), 1876 updated datasets and 271 new products. Unique and interesting properties of the

Eco invent database separate documentation is available for each data set, and the link to this information can be found in openLCA software, every process dataset is available as a unit process and as a system process (with very few exceptions) in each of the system models and costs/revenues provided by Eco invent are included in the database (Spindler & Ciroth, 2022).

The Environmental Footprint (EF) database (ELCD 2020) is designed to support the use of product environmental footprint (PEF) category rules (PEFCR) and organization environmental footprint (OEF) sector rules (OEFSR). It is also applied for the Product Environmental Profile (PEP).

The Gabi Databases are the result of over 500 person years of direct data collection and analysis and over 2,000 person years of accumulated project work by the Sphera domain experts. For the past 30 years, Sphera has constantly developed and advanced the Gabi Databases to better meet tomorrow's data needs today (Dr. Thilo Kupfer, 2021).

2.10. Identification of the most contributions processes

The hotspots might serve the purpose of "warning" an organization about the area where they should focus their attention in order to improve the environmental performance of a product (PEF) or an organization (OEF). Whilst traditionally LCA practitioners are expected to provide primary/site-specific data for processes taking place in the foreground and secondary data for processes taking place in the background, in PEF/OEF the implementation of the materiality principle leads to a different approach. The processes most contributing to the final results (in terms of environmental impacts or savings) are those for which the best quality of data should be provided. For the processes less relevant it is possible to use data of lower quality. When identifying the percentage contribution from any process or flow it is important that absolute values are used (i.e. the minus sign is ignored) in calculating percentage contributions. This allows identifying the relevance of any credits (Zampori et al., 2016).

Table 4:Summary of requirements to define most relevant contributions (Zampori et al., 2016).

Item	**At what level dose relevance need to be identified**	**Threshold**
Most relevant impact categories	In the final results ,starting from normalized and weighted results but divisions possible if justified	No Threshold. Discussion left to TS but subject to stakeholder consultation and ATB opinion
Most relevant life cycle stage	For each impact categories, before normalization and weighting. not relevant for data needs identification	All life cycle stage contributing cumulatively more than 80 % of to any impact categories
Hotspots	For each impact categories, before normalization and weighting	Either (i) life cycle stages ,processes ,and elementary flow cumulatively contributing at least 50 % to any impact categories, or (ii) At list the two most relevant impact categories, life cycle stage, process and at least two elementary flows (minimum 6). Additional Hotspots may be identified by the TS
Most relevant process	For each impact categories, before normalization and weighting. Essential relevant for data needs identification	All processes contributing cumulatively more than 80 % of to any impact categories
Most relevant elementary flows	For each impact categories, before normalization and weighting. Essential relevant for data needs identification	All elementary flows contributing cumulatively more than 80 % of to any impact categories and in any cause all those contributing more than 5 % individually

3. Materials and Method

3.1. Description of study area

3.1.1. Anmole products Ethiopia PLC

The study area is located in Ginchi Oromia regional national state, Ethiopia (Figure 2). The Geo referenced location is ranges from 35 0‟ 00‟ 37 0‟ 00‟ up to 41 0‟ 00‟ 43 0‟ 00‟ E and 5 0‟ 00‟ up to 10 0‟ 00‟ N. Ginchi is the second district, a rural area in the Oromia region located about 80 kilometers from the capital city Addis Abeba. Ginchi district has a rather high population density(Original Research Article, 2020).

Information obtained from representative, APEPLC is the first foreign investment in the manufacturing of paper in Ethiopia, established in Aug15, 2003 produced several types of paper, such as newspaper, corrugated box, and Manila paper, utilizing an 80 percent combination of white and book brock waste paper and 20% imported raw wood pulp with water. The current monthly installed and attainable capacities were 27,000.0 and 12,000.00 tons, respectively.

3.1.2. Ethiopian Pulp and Paper share company

The Ethiopian Pulp and Paper share company (EPPSC) is established in August 05, 1963G.C as an independent legal entity. The shareholders of the company were government and internal fund corporation (IFC) who account 70% and 30%, respectively. During its establishment the company produce paper product of 25 tons daily and 8,500 tons annually. The company has two manufacturing plants of which one is paper production plant with design capacity of 15,982 tons/year which produce clusters of paper products and the other one is corrugated box production plant with design capacity of 11,470 tons/year. This capacity is designed after second upgrading study was completed by Sand Well Inc. in 2015 (TILAHUN, 2017).

EPPSC is located at WonjiShoa, Oromia Regional National State, Ethiopia (Figure 2). According to company respondents and corrugated boxes and Manila paper in various colors were created at the time using 80 percent recycled paper and 20 percent imported hard and soft virgin wood with water. The current monthly installed and attainable capacities were 15, 982.7 and 12,785.0 tons, respectively. WonjiShoa is a low-density area.

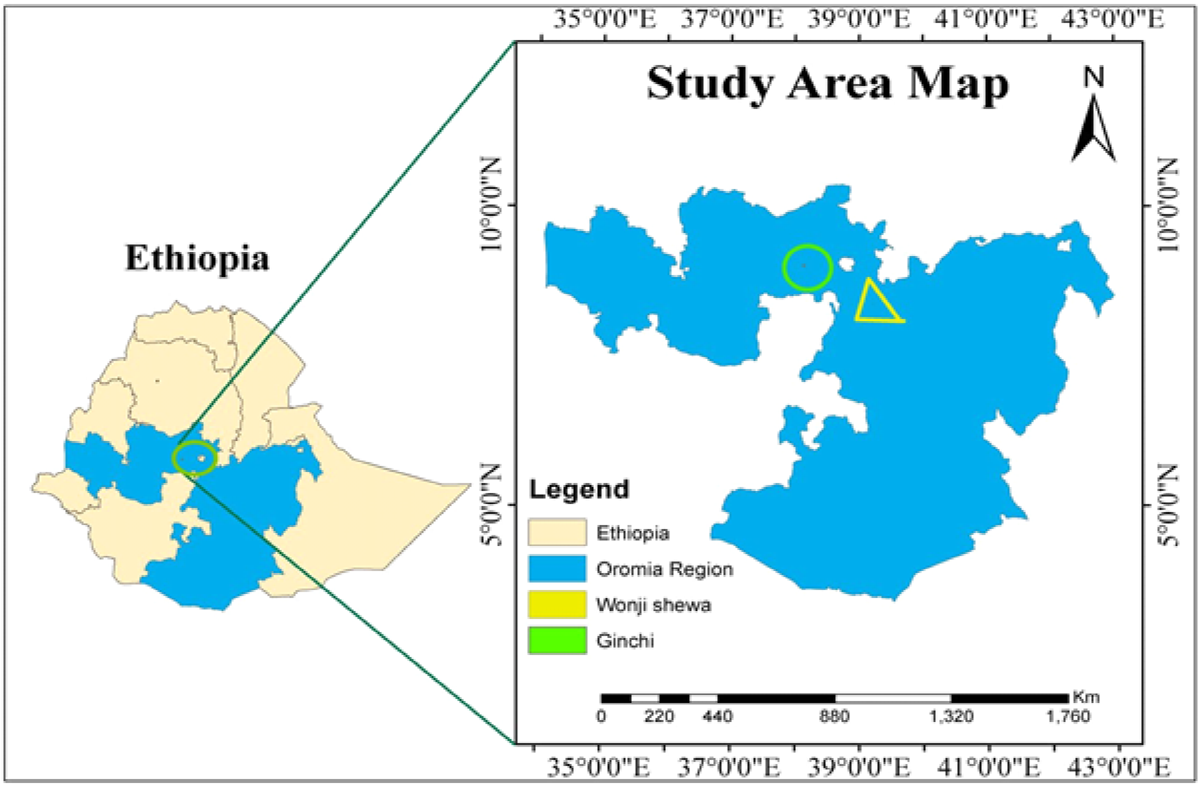

Figure 2: Map of study area

3.2. Sample site Selection

The Ethiopian Pulp and Paper Share Company and Anmole Products Ethiopia PLC were intentionally selected as the focus of a study within the context of twelveEthiopian paper manufacturing industries. The selection was based on several justifications, including their status as relatively beginner entrants to the paper production sector, their potential for growth and development, production capacity, their successful collection and organization of resource and emission data, as well as their willingness to provide input-output data for software analysis without any hindrances.

Furthermore, these factories were chosen due to the accessibility of their locations, their adoption of modern continuous production methods compared to other paper mills, and their specialization in producing similar types of paper that are widely distributed within the Ethiopian paper converting and packing industry.

The study specifically centered on Manila paper products because both companies predominantly manufactured this type. Manila paper is produced using a high proportion of recycled waste paper with a minimal amount of pulp added. Conversely, products such as corrugated boxes or newspapers require larger quantities of pulp than what is available through these factories' raw materials. It was also noted that customers mostly ordered Manila paper products based on descriptions provided by relevant bodies involved in the study.

3.3. Data collection and analysis

The LCA of the manila papers was conducted based on the principles and structure of the ISO 14040 standard to evaluate environmental effect comes from production processes.ISO 14040 standard is standard thatembracing all stages of LCA.

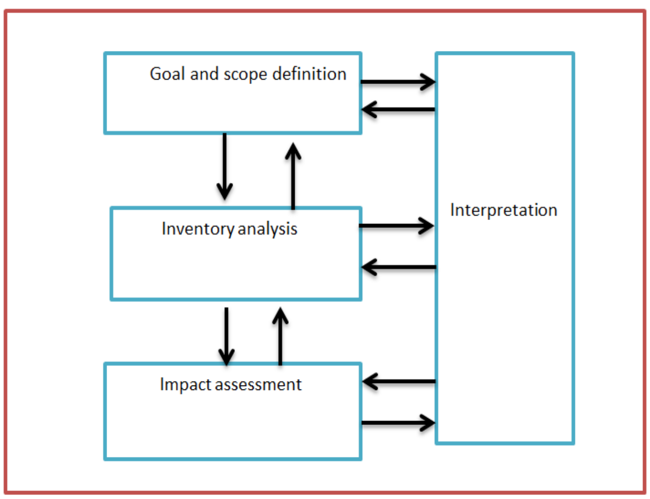

Figure 3: Framework of LCA adopted from the ISO 14040 standard

3.3.1. Goal and scope definition

In this stage clearly define the reason for conducting the LCA, aclear definition of the product and its lifecycle and a description of the system boundaries.

3.3.1.1. **Goal**

In this study, a life cycle assessment (LCA) is initiated by clearly defining the study's goals in a deliberate and conscious manner. This includes stating the rationale for conducting the study, specifying the application areas of LCA results, and identifying the intended audience. The primary goals of this research are to identify and evaluate environmental impacts associated with the paper manufacturing process (environmental analysis) using an LCA tool within Ethiopia's paper manufacturing industry. Specifically, it aims to assess the environmental performance of the paper making process by determining how different processes contribute to the life cycle of white and yellow Manila paper. Additionally, it provides an assessment of the overall environmental impact of paper production.

The target audience for this study includes industry, producers, and decision-makers within the industry or outside the company. The intended application is for companies to use it as a reference tool in evaluating their environmental impact during paper production in order to give priority in order to reduce negative impact. This can help increase their awareness about environmentally sustainable practices, conserve resources, save costs in obtaining sustainable products,for strategic planning, achieve competitive advantage, increase environmental awareness, manage supply chin riskand inform internal decision-making processes among producers seeking environmentally friendly business choices.

Furthermore, this research serves as a foundational assessment that can be applied to evaluate future paper-based products. It also serves as a waste management tool that can assist policymakers in implementing effective waste management strategies.

3.3.1.2. Scope

According to the ISO 14041 standard, when defining the scope of an LCA, a list of elements must be considered and clearly described. Based on the required data such as product description, function of the product system, product system description and system boundary, functional unit, assumptions, data quality requirements and allocation discussed.

Product description

In this investigation, the products under consideration were white and yellow Manila paper. The raw materials utilized to manufacture these paper products for both industries were virgin wood pulp, used (waste) paper, and fresh water.

The function of the product system

According to the explanation provided by the production department of the factory in the case study, Manila paper was produced with the specific purpose of manufacturing corrugated boxes. These boxes were supplied to the Ethiopian packing industry for producing packaging materials. Additionally, they were used as file folders in hospitals, schools, and other organizations.

The product system description and Boundaries

The system under study produces white and yellow Manila paper using currently available machine with unspecified technology in the companies.

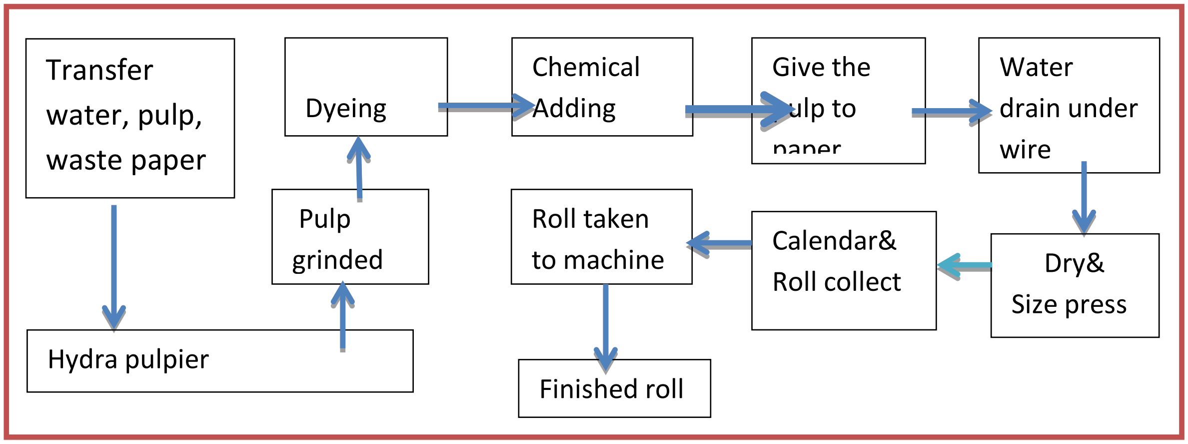

Figure 4: Process flow of white Manila paper production on paper machine

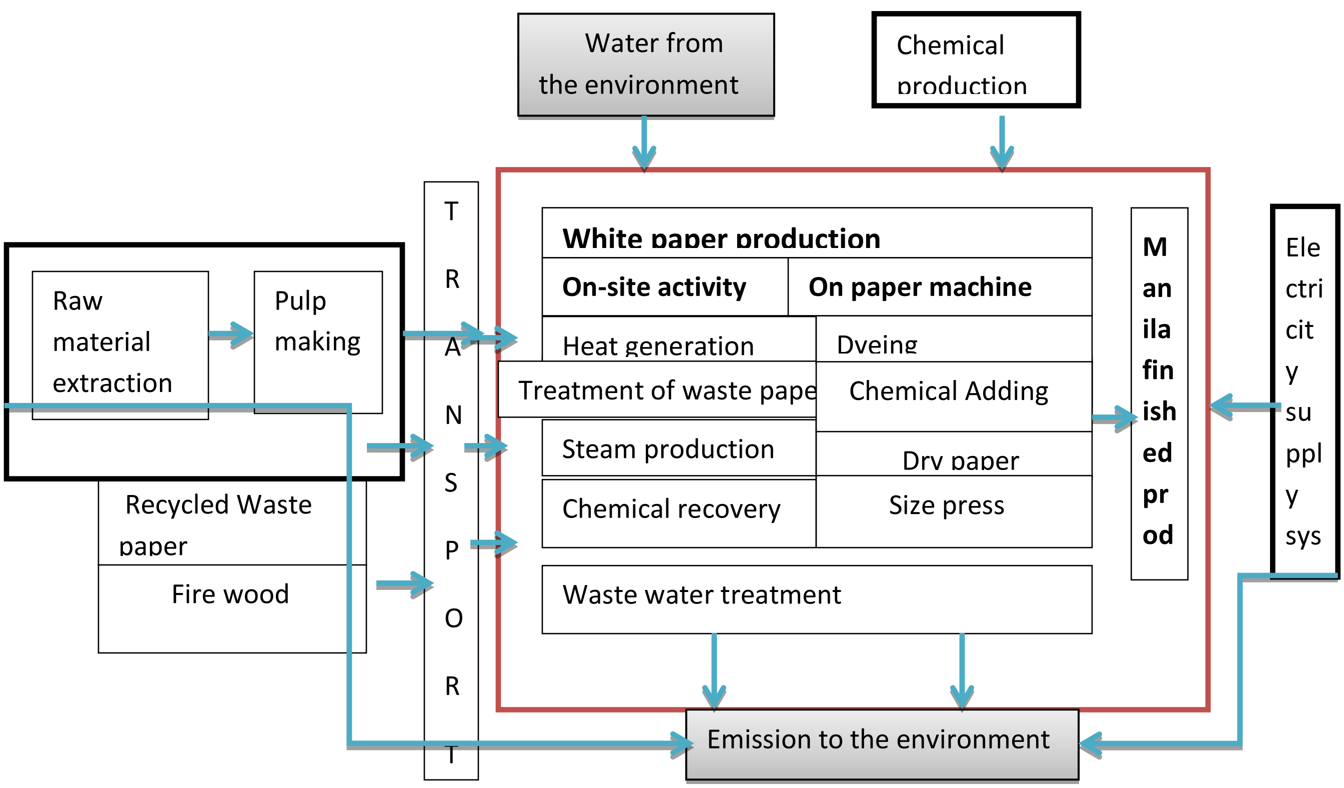

Figure 5: Simplified system boundary of white Manila paper

The system boundaries, as depicted in figures 4 and 5, encompass specific unit processes that are either included or excluded. The included unit processes are as follows: Pulp production, Electricity generation, Chemical production, Raw material transports, Treatment of recycled wastepaper, yellow Manila paper making, Dry paper and Size press process, dyeing, chemical adding and Waste water treatment. On the other hand, the excluded unit processes consist of paper distribution to customers, customer usage of the paper, end-of-life options such as reuse or land filling.

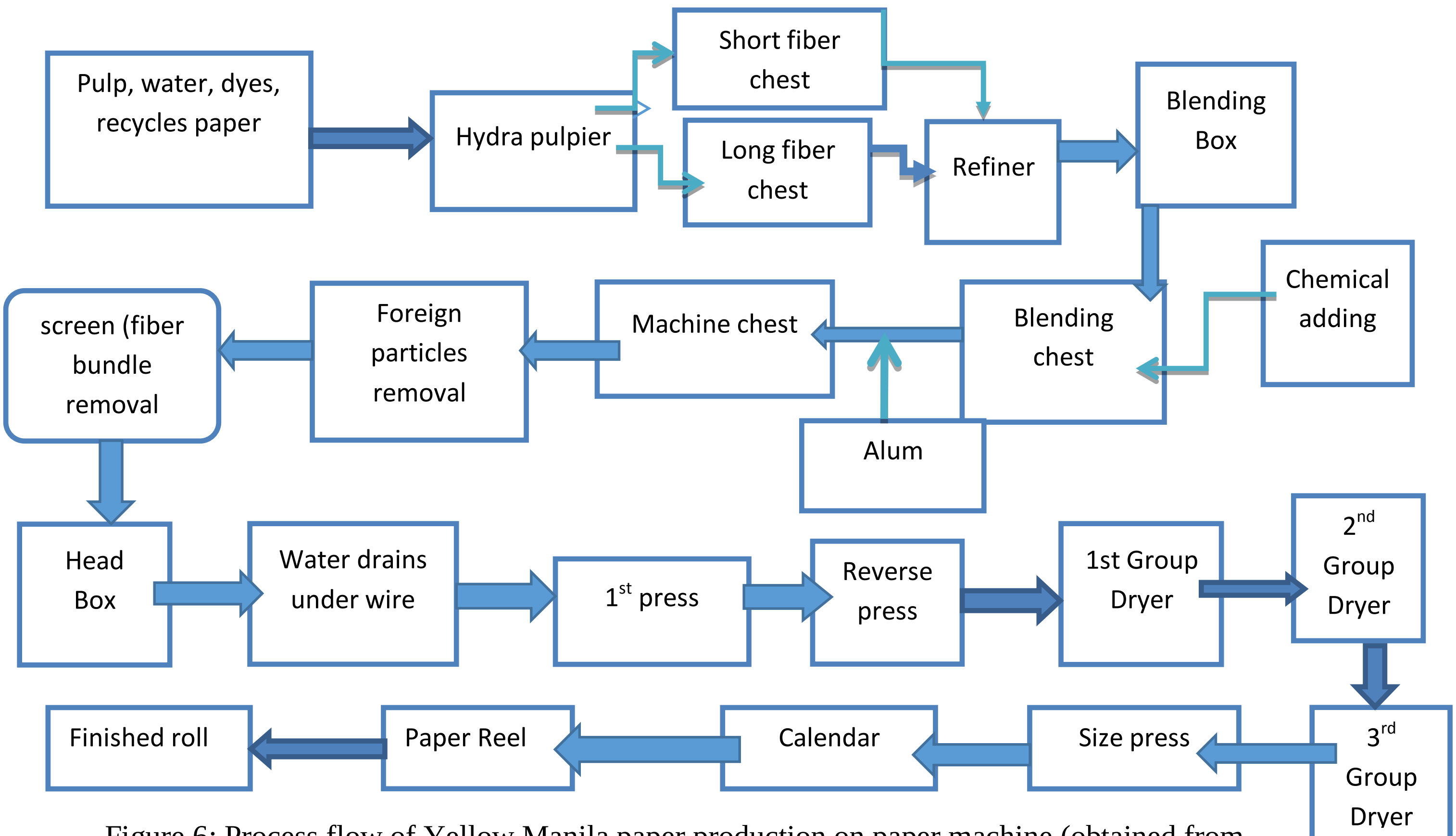

Figure 6: Process flow of Yellow Manila paper production on paper machine (obtained from factory)

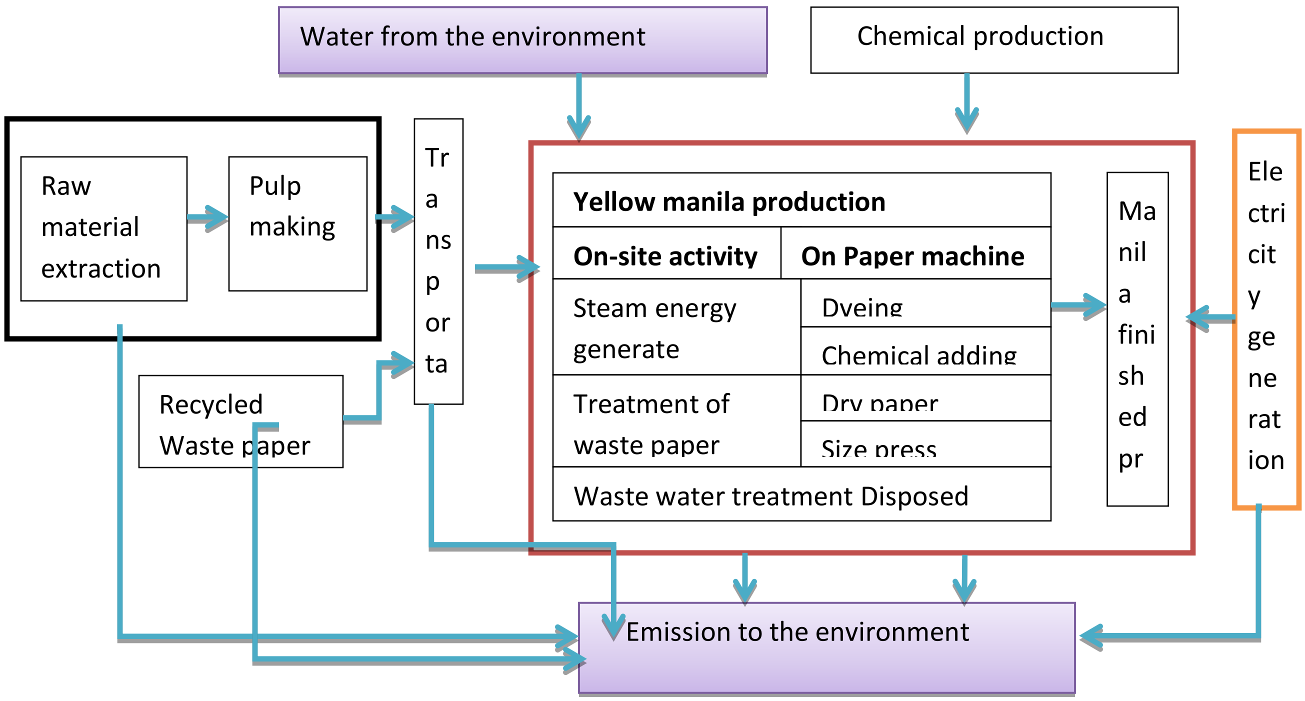

Figure 7: Simplified system boundary of yellow Manila paper

The system boundaries, briefly outlined in figures 5 and 6, encompass specific unit processes that are either included or excluded. Pulp production, Electricity generation, Chemical production, Raw material transports, Treatment of wastepaper, yellow Manila paper making, Dry paper & Size press process, dyeing, chemical adding , Waste water treatment and waste water disposal. While excluded unit processes Paper Distribution to customer, Paper used by customer, End of life (Ruse, land filling).Excluded from these boundaries are the following: distribution of paper to customers; usage of paper by customers; end-of-life options such as reuse or landfilling.

Production system

The production system under examination is divided into two subsystems. A raw material transportation unit process (outside industrial activity) and industrial subsystem process it included main product production, unit process on paper machine and others related work.

Raw material transportation

The raw material transportation unit operation in the industry under study including pulp, recycled waste paper and fire wood transport. **The Anmol products industry:** transportation upstream activity to produce the main products includes sulfate unbleached soft wood and sulfate bleached hard wood pulp shipped from Indonesia to Djibouti with sea container ship. The distance traveled by sea container ship from Indonesia to Djibouti was 7,991 kilometers. Pulp transported from Djibouti to Ginchi industrial plant using old low bed truck EURO2, 16-32 metric ton. The distance traveled by road from Djibouti to manufacturing plant was 1020 kilometers. The waste paper used for paper making was collected by suppliers. Waste paper for the production of white Manila paper goods was purchased from several Ethiopian source countries, although in this study, the majority of suppliers were chosen from the Mercato. The conveyance employed truck/lorry EURO4, 16- metric ton, with a road distance of 80 kilometers. Fire wood log mostly obtained from Ambo. The Used transportation was old entire EURO1 truck / lorry 16 metric tons. Travelled the distance from Ambo to the industrial plant was 38 kilometers. The raw material Fire wood used as fuel onsite heat energy generated to burn steam boiler to boiling water in the production process of steam energy for the purpose of drying paper product.

Figure 8: Raw material of Anmol products Ethiopia industry

Figure 9: Firewood log energy source (from factory)

The Ethiopian pulp and paper share company: raw material transportation to produce the yellow Manila paper consisted sulfate, soft and hard wood pulp imported from Sweden. The distance traveled by sea container ship from Sweden to Djibouti is 9,142.5 kilometers. The distance traveled by road from Djibouti to the WonjiShoa production plant is 862 kilometers with Old low bed truck EURO2, Load 16-32 metric ton. This industry utilized high amount of waste paper collected by suppliers for production. High amount is obtained from Berhanena Selam printing enterprise, Addis Ababa. Transportation employed a truck/lorry EURO3, 16 metric ton with a road distance of 110 kilometers. The interested bodies submitted the travelled distances and loaded amount, and the emissions were computed using the ecoenvent data base and impact assessment methodology.

Figure 10 : Raw material of EPPSC (from factory onsite observation

The industrial production subsystem process

Onsite heat energy generation this subsystem technique associated with energy created by the composition of mix logs in an open wood heater. The generated heat energy is used to power the burning steam boiler to produced steam energy.

Figure 11: Wood burned at open wood heater: APEPLC

Treatment of recycled waste paper (Rejected plastic wastes)

In these plants under investigation to produce Manila paper, wastes were removed before grinding the recycled waste paper. The waste that was removed was plastic rubbish. Wastes were treated by the firms by open dumping on industrial and agricultural soil.

Figure 12: rejected plastic wastes (from onsite observation)

Manila paper production: Manila paper manufactured on both factories includes different onsite industrial and on a paper machine unit process. It is the stage of obtained finished product.

Size press: It is unit operation on a paper machines in order to increase paper strength, resists deformation (stiffness), and printing quality of the products by applying a material, known as an adhesive to paper such as a polymer starch.

Drying paper process: Is industrial upstream unit process on a paper machine mass transfer performed where removal of water by evaporation from a paper still obtained the desired level.

Dyeing process: The industrial unit process on a paper machine involving transfer of dyes from the aqueous solution onto the fiber and dyes diffused into the fiber. There are different types of dyeing method the factory under investigation applying batch dyeing technique that involve the step – by –step transfer of dye from a dye bath to the paper material in the same piece of instrument.

Chemicals recovering: It is industrial axillary process that involve concentrating cooking liquor, combusting organic compounds, reducing inorganic compound for the purpose of recover cooking liquor chemical from exhausted.

Chemicals adding: The process in paper machine to give the paper certain desirable end use qualities or outside paper machine waste water treatment industrial process.

Figure 13: Paper machine section of APEPLC and f EPPSC

Waste water treatment: According to the quality department, this factory's waste water treatment used aerated lagoons.

Figure 14: Wastewater treatment of EPPSC

Sludge treatment on EPPSC: In this company, sludge from waste water treatment is used to farm agricultural soil. **Sludge from APEPLC** like Ethiopian pulp and paper Share Company in this industry, sludge from waste water treatment is used to land farming industrial soil.

Figure 15: Sludge out from waste water treatment

Figure 16: Sludge out land farming

Wastewater disposal: EPPSC: This factory wastewater was disposed of in agricultural soil and rivers. However, the treated waste water is reused (recycled) at the Anmole Products factory and is not disposed of.

Figure 17: Wastewater discharge of EPPSC

Functional unit

In this work, the functional unit was set at a standard weight of 140 g/m^2 white and 150 g/m^2 yellow Manila paper, producing one item. The functional unit in LCA provides a reference which inputs outputs related. This is a measure that allows quantification of the function defined.

Assumptions

The following assumptions were established in this work: without any technological specifications, machines were employed for the Manila paper production process, heat energy generation, and waste treatment.

Data quality requirement

In this study, chosen industries under study possible and feasible inventory data of inputs and out puts for one year from 2014 to 2015 were provided. Inputs material and energy production, raw material transportation, and waste treatment unit process of elementary flow, as well as the rest data, were obtained from the open LCA Eco invent database and literature review. Data analysis in open LCA has chosen auto link processes which start raw material extraction of input manufacturing unit operation. Perform a mass and energy balance using the received inputs outputs data transformed to per functional unit.

Allocation

This study avoided allocation because the product under study has liner production. No intermediate product production directly produced the main product. There is no portioning the input or output flow process or a product system between the product systems.

Strength and Limitation

The strength of this work was Show the resource used (input) and output of Manila paper production process. Assess the environmental impact of the paper product manufacturing process over its life cycle with its magnitude. Investigate contribution of different unit process to the overall impact and Identified the most relevant process contributed high environmental impacts. Provide useful information that can assist the pulp and paper industry in the planning of future investments leading to an increase in its sustainability and the environmental assessment of any paper product process coming from future developments. Besides those that concern pollution prevention, other issues with relevance to the context of sustainability, such as the energy consumption, can also be deal with. Collection of data starts raw material gain to product gain, which excludes downstream (paper distribution, used by customer and end of life activities) data collection. This is due to why the study was conducted and a lack of primary data availability. The raw material extraction stage of Manila paper production data gathering exclude because Ethiopia did not produce pulp; it used imported pulp and waste paper, which were collected and organized by the supplier for the production of paper products.

3.3.2. Inventory analysis

In this stage of LCA the collection of data for analysis processes has to be planned and carried out. The inputs and outputs of each unit process in the product systems different type of data can be collected which are On-site data, measurements recorded data, company documented, lap experiment and database. The LCI results are the compilation of flows over all the processes that are part of the LCA model. There are two types of data in life cycle assessment analysis. Data obtained from literatures, database, published and unpublished article are background data and data from primary source such as interview, recorded, and sit observation etc. is foreground data.

3.3.2.1. Inventory Data collection

In this inventory analysis, tools used for data gathering and calculation included a pen, calculator, writing paper, Microsoft Word, table, and Microsoft Excel. Primary data sources included both qualitative and quantitative information.

Individual face to-face and telephone interviews were conducted using a checklist and Structured questions to collect data on both qualitative and quantitative parameters. The sampling technique was chosen by the corporate department office as one respondent for each department to collect information which needed to created inputs outputs in open LCA software program.
The interview was focused on inventory data of area population density (low, high),raw material, resource and energy (pulp import country, type of processed pulp), the most suppliers of waste paper, used sizing agent, chemical and additives, source of energy, type of onsite generation energy, raw material used to heat and steam energy generated ,source of used water and type of used dye and dying process), waste treatment method (raw material pretreatment like reject of plastic waste from recycled waste paper during manila paper manufacturing ,the rejected plastic waste treated (open dump in to industrial and agricultural soil),waste water treated method used(aerobic ,used chemical for treated), sludge treatment out from waste water treated (land farming on industrial and agricultural soil) waste water discharge site for EPPSC factory(river and agricultural soil), raw material transportation (road, water /sea, ship, truck/lorry, EURO type with load metric ton ,traveled distance). Yearly data from 2014/2015 all material ,resource and emission quantity (water ,energy ,chemical ,virgin pulp, recycled waste paper, dye and sizing agent utilization and sludge ,plastic waste , carbon dioxide, volatile organic compound, heat, PM2.5 andPM10 (out from onsite heat generated and paper dry industrial activity),phosphate , nitrate, COD (EPPSC) emission data were collected standard weight of 140 g/m^2 white manila paper for APEPLC and 150 g/m^2 yellow manila paper for EPPPSC one items manufactured. On-site observation During filed visit see and gather

information were waste water treatment plant and waste water, solid waste (sludge, plastic) discharged area, onsite heat generated and paper production process in the paper machines.

Qualitative data was gathered through structured and individual interviews, such as source of energy, as well as on-site observation. For quantitative data, collect records from various departments in the manufacturing office, such as plastic garbage dumped and sludge amounts, conduct interviews with company truck drivers to determine distance, and obtain laboratory results. Secondary data was collected from the ecoenvent database, the internet, published and unpublished materials, and a book.

3.3.2.1. 1. Water, Soil and air pollutants

In this study most raw material, chemical and energy resource inputs and outputs quantity and process used data were obtained from selected study industry and related to inventory emission of input production, raw material transportation waste plastic and sludge treatment process used from open LCA Eco invent data base, while waste water characterization, heat production and dry paper manufacturing activity output parameter measurement was performed.

Waste water characterization

Experimental site

The laboratory operation of the waste water parameters Chemical oxygen demand, Phosphate, and Nitrate determination was carried out at Addis Ababa University's College of Natural and Computational Sciences, Department of Environmental Science laboratory. The recording measurements were made using ultraviolet visible spectrophotometer, model HACH DR 6000.

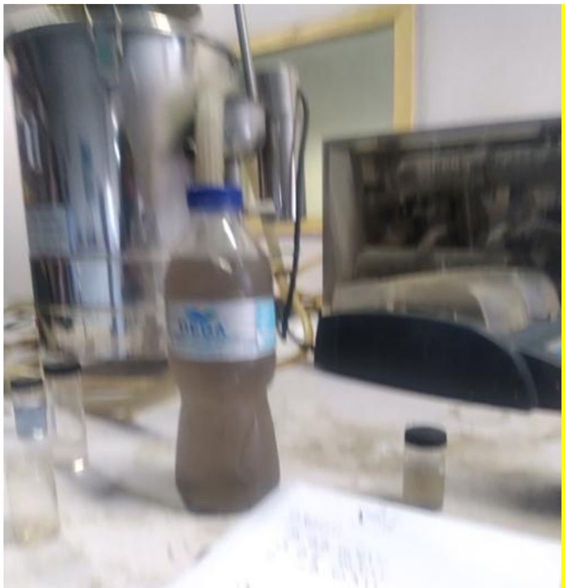

Figure 18: parameter determination Figure19: Spectrophotometer

Sampling technique

The waste water samples used in this experiment were taken from yellow Manila paper six ton produced in Ethiopian pulp and paper share company factory. Waste water Samples were taken in a plastic bottle and placed in lab refrigerator in order to prevent any possible reduction by microorganisms.

Chemical oxygen demand (COD) determination

Reagents and Chemical

All of the chemical used were of analytical grades and were obtained from sigma Aldrich such as potassium dichromate (99% purity), Sulfuric acid (99% purity), and Silver sulfate (99% purity). The used method was block digestion.

Apparatus

Digestion tube**,** Burette, conical flak, pipette, measuring cylinder were used.

Procedure

Three COD vials with stopper were taken, 2.5 ml of the sample to each of the two COD vials was added, 1.5 ml of potassium dichromate, and 3.5 ml of sulphuric acid were added. The COD vials were hooted, and the cap tubes tightly. Switched on the COD Digester and fixed the temperature 150 ºC and set the time at 2 hours. Placed the COD vials in to a block Digester at 150 ºC and heated for two hours. The Digester automatically switched of, removed the vials and allowed it to cool to the room temperature. Filled the burette with the ferrous ammonium sulfate solution, and adjusted to zero and fixed the burette to the stand. Transferred the contents of the sample vial to conical flask, and added few drops of ferroin indicator. The solution becomes bluish green in color. The endpoint of the titration is the appearance of the reddish brown color.

Phosphate and Nitrate determination

Reagents and Chemical

All the chemicals used were of high grade purity and were obtained from sigma Aldrich. Reagent water, sodium hydroxide (99%, purity), potassium per sulfate (99%, purity), Potassium nitrate (99%, purity) and Sulfuric acid (99%, purity) and used alkaline per sulfate digestion technique .

Apparatus

Autoclave, glass Digestion tubes, pipette, magnetic stirrer and Erlenmeyer flask

Procedure

About 10.0 ml of sample to a clean glass test tube or vial was added. Pipette 10.0 ml of each calibration standard, method blank, digestion check standard. Reagent water Added to 3 test tubes as method blanks. Pipette 5.0 ml of the per sulfate oxidizing reagent to each tube. Autoclaved the analytical batch at 100-120ºC for at least 30 minutes on the liquid automatic cycle, removed tubes from Autoclave and cool to room temperature .1.0 ml of buffer solution added to each tube and mix.

3.3.2.1.2. Ambient air Emission measurements

Ambient Air emission out from fired wood log combustion and dry paper unit process continuous three day recordings were performed. The measurements were conducted by talked device from Ethiopia environmental protection Authority (EPA) with Aeroqual series-500 gas sensor (Detects volatile organic compounds /VOCS/, Carbon dioxide/CO2. In this unit process during measured air emission no detected parameter were Carbon monoxide /CO, Nitrogen Dioxide /NO2/ and Sulfur Dioxide /SO2/. Hold PeaK 5800d multi detector (Detects PM2.5 &PM10 Particulate matter .VICTOR sound meter (Detects noise L) and clock humidity and temperature HTC-1 (detects heat). For inventory analysis used data are the average of three day recorded results.

Figure 19: Air emission recording of wood log combustion

3.3.2.2. Prepared a life cycle inventory table of a product system

The activities of inventory data collection finished calculation of environmental load per unit process and per functional unit was performed and prepared inventory database of a product system.

Table 5: Inputs for each unit process during the production of 1 item yellow Manila paper

Unit process	**Input**	**Amount**	**Unit**
Water transport	Pulp * Distance	34.10	kg.km
Road transport Djibouti to plant	Pulp *Distance	3.215	kg.km
Road transport A.A to plant	Waste paper* Distance	2.34	kg.km
	Kraft hard wood pulp bleached	1.55	G

Yellow Manila paper making	Kraft soft wood pulp bleached	2.175	G
	Waste paper	21.275	G
	Water for paper making	2.85	L
	Water for steam generation	0.0945	L
	Electricity for all unit process	6.37	Kwh
	Steam for dry paper	2.686	Kwh
Dyeing	Direct yellow	0.0188	G
Size press	Maize starch	1.875	G
Chemical adding	Alum	0.375	G
	Polyacrylamide	0.05	G

Table 6: The emissions from each unit process during 1 item yellow Manila paper making

Selected unit process	Output	Amount	Unit
	Water pollutants		
Waste water reject	COD	0.0051	Mg/L
	Phosphate	0.0000575	Mg/L
	Nitrate	0.000171	Mg/L
	Air pollutants		
Dry Paper	CO_2	0.0176	Mg /m 3
	PM2.5	0.003	Mg /m 3
	PM10	0.00588	Mg /m 3
	VOC	0.0217	Mg /m 3
	Heat	0.000785	J
	Soil contaminates		
Treatment of recycled paper	Waste Plastic	6.5	G
Treatment of Waste water	Sludge	45	G

Table 7: Inputs for each unit process during the production of 1 item white Manila paper.

Unit process	**Input**	**Amount**	**Unit**
Water transport	Pulp * Distance	2645.021	kg.km
Road transport Djibouti to plant	Pulp *Distance	337.62	kg.km
Road Transport A.A to plant	Waste paper* Distance	17.92	kg.km
Road Transport Ambo to plant	Wood log*Distance	10.64	kg.km
White Manila paper making	Kraft hard wood pulp bleached	210	G
	Kraft soft wood pulp unbleached	21	G
	Waste paper	224	G
	Water for paper making	8.4	L
	Water for steam generation	0.42	L
	Electricity for all unit process	0.0847	Kwh
	Steam for dry paper	0.00084	Kwh
	Heat fuel for steam boiler	0.000672	Kwh
Dyeing	Dye	4.62	G
Heat generation	Fire wood log	280	G
Size press	Maize starch	3.5	G
Chemical adding	Alkyl ketene dimer	1.68	G
Waste water treatment	Aluminum Sulfate	100.8	G
	Lime	20.362	G

Table 8: The Emissions from each unit process during 1 item white Manila paper making

Selected unit process	Output	Amount	Unit
	Air pollutants		
Dry Paper	CO2	0.00255	Mg /m 3
	PM2.5	0.0023	Mg /m 3
	PM10	0.00292	Mg /m 3

	VOC	0.0407	Mg /m 3
	Heat	0.000079	J
Heat generation	CO2	0.00189	Mg /m 3
	PM2.5	0.000325	Mg /m 3
	PM10	0.00067	Mg /m 3
	VOC	0.0532	Mg /m 3
	Heat	0.000148	J
	Soil contaminates		
Treatment of recycled paper	Waste Plastic	16.8	G
Treatment of Waste water	Sludge	42	G

3.3.3. Life cycle Impact assessment (LCIA)

In this part, a quantitative impact assessment was fulfilled. The Impact assessment is the third phase of LCA it consists five elements out of this in this study performed the three mandatory items: selection of impact cataloguers, classification and characterization .normalization and weighing not included because it is not mandatory and shortage of available data ,used method ,time and need scientific basis, social ,ethical and political values consideration. The impact categories selection phase executed based on the expected type of impact on the environment from inventory emission and resource consumption data, considering geographical location where the product produced ,which impact are significant for that geographical area ,from study area site observation were the waste is disposed etc.

Open LCA 2.0 V software program (released in May 2023) was used in this study, together with Eco invent 3.9.1 consequential - regionalized data set for low and middle-income countries. The cumulative energy demand, Recipe 2016 v1.03, Midpoint and IPCC 2021 methodologies are used to examine the potential environmental consequences of the paper producing process per functional unit under consideration.

Narrated and Produced by Dr. Mahinsasa Rathnayake Life cycle modeling in open LCA five levels which are flow, process, product systems and projects. However in this modeling LCA impact assessment of product systems was enough because the objective of the work is not compared the impact of two products. The project level performed in the comparative LCA study. Basically two different options through modeling in open LCA alternative one is take all unit process and then crate new production input them in have one process to the production of one products. The second alternative breaks down the production chain in to different process then connect with another. In this analysis used option one by considered simple to ran and minimizes time. **Source: Green Delta 2014 www. Green Delta .com**

Table 9 :- The Impact categories and related parameters.

Impact Category	**Parameter**
Global Warming,20 Year	CO_2,Heat,methane
Freshwater Eutrophication	COD,PO_4,NO_3
Terrestrial Eco toxicity	Heavy metal ,NO_X
Human toxicity: non Carcinogenic	PM,VOC, Heavy metal
Human toxicity- carcinogenic	VOC, PM, Heavy metal
Ozone layer depletion	Hydrocarbon, Methane,
Primary energy demand	Renewable and Non-renewable Energy
Solid waste	Plastic ,Sludge

4. Results and discussions

Interpretation is the fourth stage of life cycle assessment. The result of inventory analysis, resource and emission impact categories of a one items yellow and white Manila paper products analyzed and discussed in this part.

4.1. Inventory analysis

Based on individual parameters, preliminary interpretation can be made at the inventory analysis level. However, due to the extensive list of parameters provided by the inventory results, it becomes challenging to comprehensively interpret all elementary flows. Therefore, this paper focuses specifically on analyzing parameters obtained from foreground data (primary data), which include carbon dioxide (CO_2), volatile organic compounds (VOCs), particulate matter (PM2.5 and PM10), heat, resources used and output, plastic mixture, and sludge waste. In addition, the analysis also encompasses wastewater effluent emissions, such as phosphate, nitrate, and chemical oxygen demand (COD) for the EPPSC.

4.1.1. Resource used (Inputs) for production

As illustrated in figure 21 and 22 The raw materials, energy, and chemicals necessary to produce standard weight 140 g/m2 white and 150 g/m2 yellow Manila paper are one item in the Anmol products Ethiopia and Ethiopian pulp and paper sharing company industries. The most important resource consumed was firewood energy for heat generation, followed by recycled waste paper as raw material, hardwood pulp consumption for paper making, and the waste water treatment process Aluminum Sulfate usage for white manila paper, while yellow the use of electricity for all unit process operations, water, recycled waste paper as raw material and soft wood pulp for paper manufacturing were the largest contributors in terms of inputs use. The other process required fewer inputs in both factories. The amount of raw material utilized in a single unit of manufacturing in grams, while electricity energy is measured in kilowatt hours.

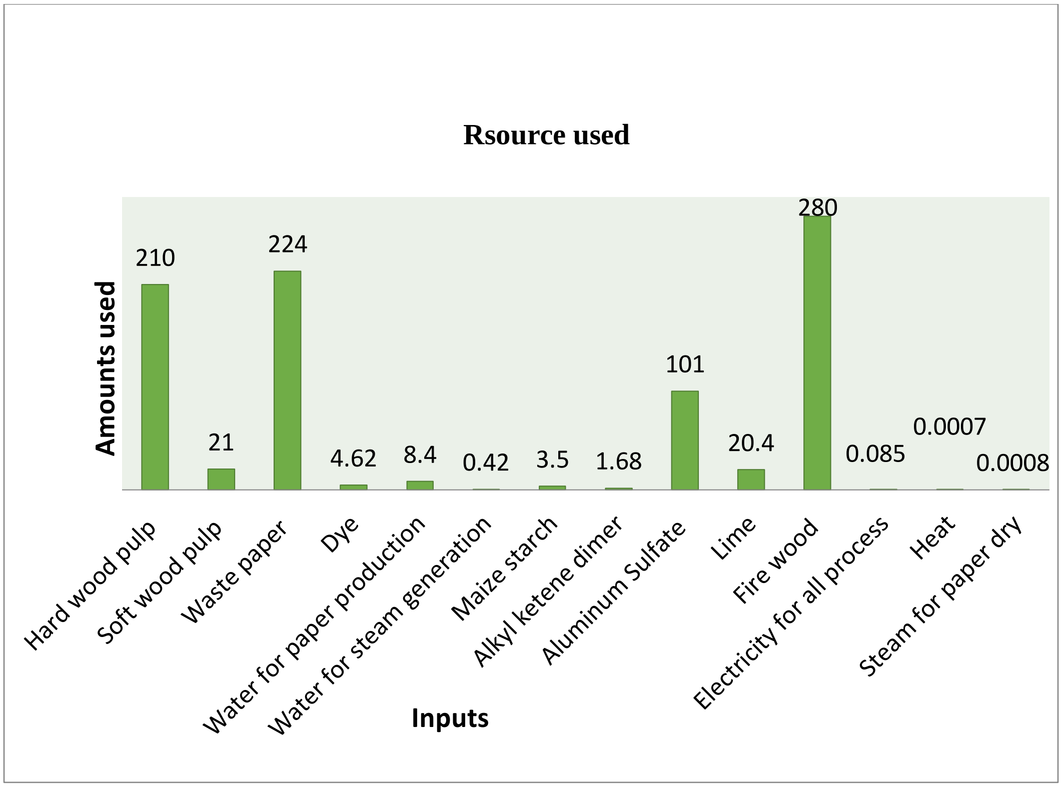

Figure 20: The quantity of the items (inputs) used for a one item white Manila paper production

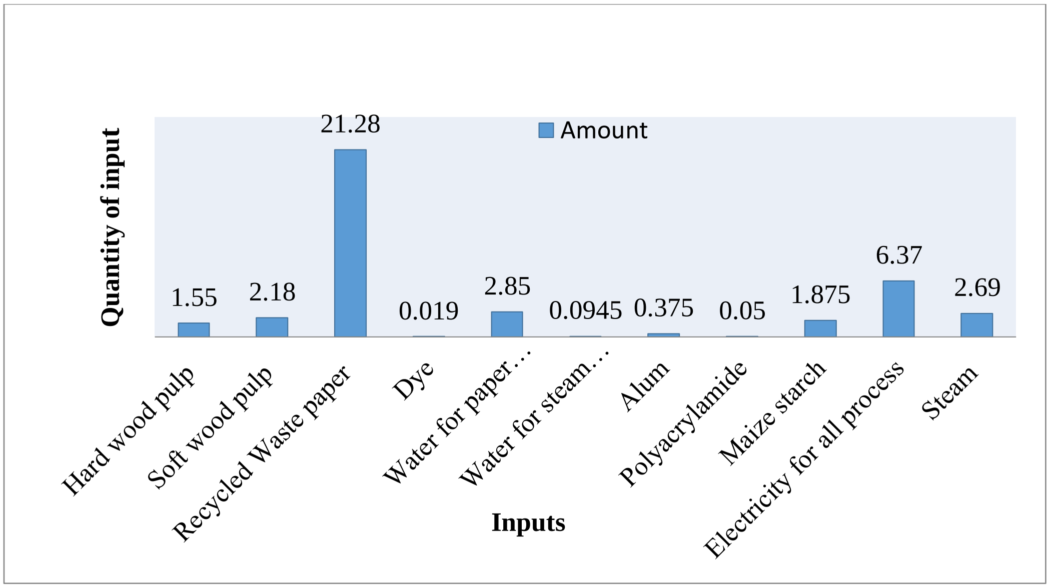

Figure 22: Quantity of items (input) for a one unit yellow Manila paper production

4.1.2. Quantity of pollutant emission

Figures 23 and 24 show the levels of pollutants emitted into the air, water, and soil. Volatile organic compounds (VOCs), particulate matter (PM2.5 and PM10), and waste heat were the most common air pollutants throughout the manufacturing of one item Manila paper. The generation of renewable carbon dioxide through the combustion of dried firewood in an outdoor wood heater process significantly contributes to air emissions during Manila paper production per functional unit, impacting the entire supply chain. The wood burned to generate heat energy is used as fuel for a steam boiler, producing steam energy. Additionally, the dry paper processes, which consume electricity, further contribute to ambient air emissions of carbon dioxide. Drying of the paper (printing paper, board, and tissue) is a major step on the paper producing machine requiring large amounts of energy and setting high demands on the quality for the produced paper grades (HAILU, 2020).

The main pollutants during Manila paper production were waste plastic and sludge. A one items paper manufacturing process at the factory is the contributors for industrial soil emission of plastic mixture and sludge waste. The most upstream include direct contributors were pretreatment of recycled waste paper raw materials and waste water treatment process. The yellow Manila paper production process also emitted Nitrate, phosphate, and chemical oxygen demand (COD) pollutants in to agricultural soil and river water. In the present inventory analysis consider waste water discharged from EPPSC but not include APEPLC because the factory dose not disposed waste water recycled for other purpose. This comprehensive analysis highlights the significant environmental impact of these activities like air, water and soil pollutant emissions within the Manila paper production supply chain. The amount of plastic and sludge waste in terms of gram, COD, NO_3 and PO_4 with mg/L, CO_2, VOC and PM in terms of mg/m^3

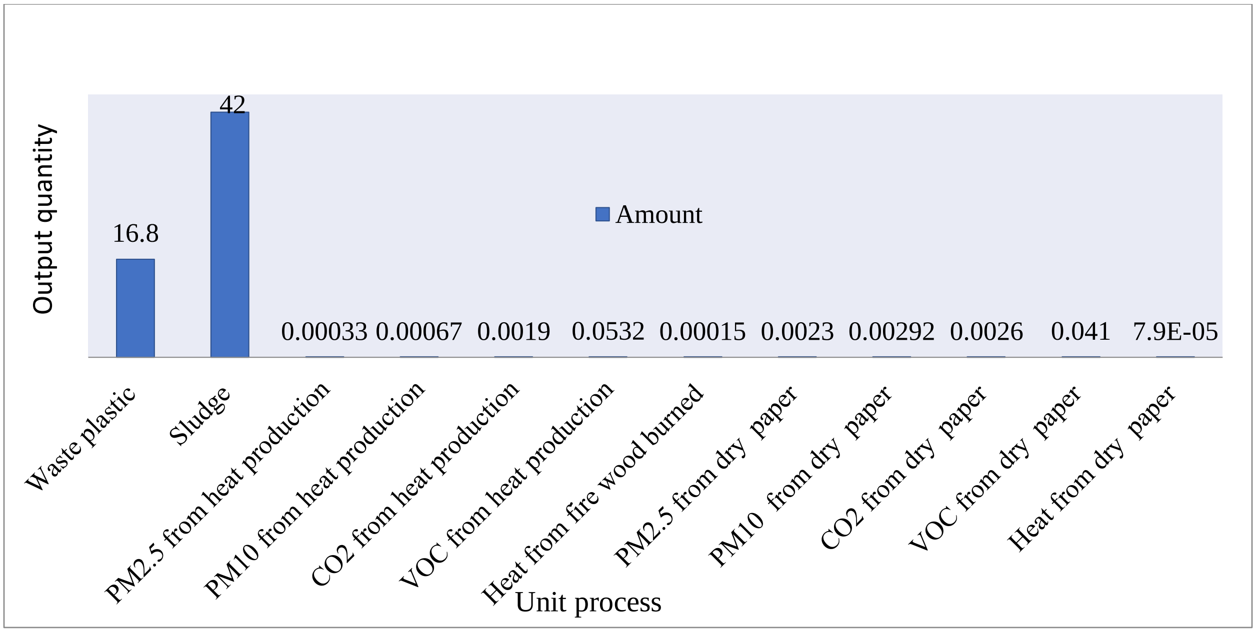

Figure 23: Types and quantity of emission from unit production of white Manila paper

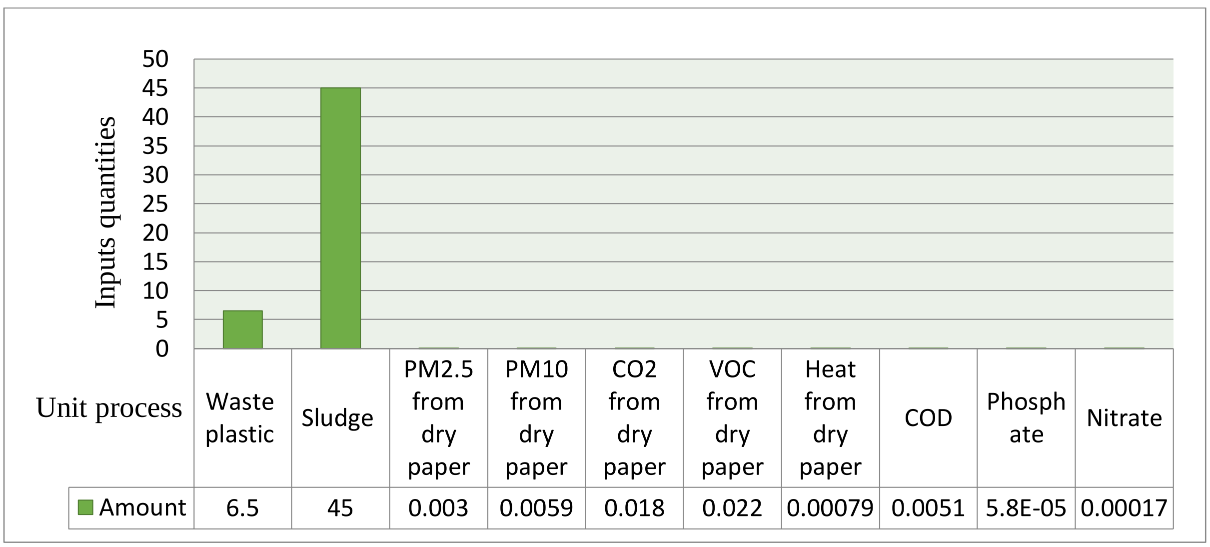

Figure 24: Types and quantity of emission from unit production of Yellow Manila paper

1.2. Life Cycle impact

The impact assessment results and discussions were divided in to two parts. Part one analyzes the consumption of primary energy demand and the product system under study. Part two describes the findings on the potential environmental impact caused by the selected emission based impact categories.

4.2.1 Primary energy demand (Resource based impact assessments)

Renewable energy derives from renewable resources such as biomass and water. Non-renewable energy refers to like fossil fuels and non- renewable biomass sources consumed during the Manila paper product making process.Table11 shows the energy demand for manufacturing one unit of white and yellow Manila paper products, taking into account both renewable and non-renewable sources and The energy use of a one ton offset paper production in Brazil is presented in table 12.

The cumulative energy demand for white Manila paper was 5.095 MJ-Eq, while for yellow Manila paper; it was 2.778 MJ-Eq. The current work total energy demand results different from the literature the primary energy use finding in Brazil (8.66E+03) this is because of the selected product, functional unit, renewable and non-renewable energy parameters ,chosen Software program with data base , the used production technology and the geographical location were the product is produced are different.

Renewable energy contributes significantly to the total energy demand, accounting for 86 % for white Manila paper and 93% for yellow Manila paper. Among the renewable sources, biomass contributes 80 %, while water contributes 7 % for white Manila paper and 76 % and 17 % for yellow Manila paper. The total renewable energy utilization of both white and yellow Manila paper higher than the previously, holding to 65.0 % of this total value due to, the inputs production usage each unit process different and in the present study not used wind, solar, geothermal and renewable fossil fuel energy elementary flow but the literature on is used. On the other hand, non-renewable energy makes up a smaller portion of the total energy demand, with 14% for white Manila paper and 5 % for yellow Manila paper. Notably, primary fossil fuel is the main source of non-renewable energy, accounting for 13 % and 5 % for white Manila paper and yellow Manila paper, respectively. However, the total non-renewable energy consumed of one unit Manila paper manufacturing lower than that of the literature one ton offset paper making corresponded to 35.0% of this total value. The factor for this variation like the used transports EURO type, selected parameter in this paper, excluded nuclear energy, and the input of non-renewable energy resource different in amount and type for each unit process. In conclusion, demonstrated paper manufacturing processes have resource based environmental impacts.

Table 10: Primary energy demands for the production of a one-item Manila paper

Primary energy demand	Unit	White manila	Yellow manila
		Amount	Amount
Total energy demands	MJ-Eq	5.095	2.778
Non-renewable energy (fossil)	MJ-Eq	0.645	0.131
Non-renewable energy (biomass)	MJ-Eq	0.0057	0.02
Non - renewable energy (total)	MJ-Eq	0.697	0.153
Renewable energy (biomass)	MJ-Eq	4.088	2.14
Renewable energy (water)	MJ-Eq	0.305	0.48
Renewable energy (total)	MJ-Eq	4.399	2.625

Table 11: The findings (energy use) of preview study conducted in Brazil

Primary energy demand	Unit	Value	System boundary ,FU ,assessment method ,Impact indicator, product & Reference
Total energy demands	MJeq	8.66E+03	Software and data base: simapro
Non-renewable energy (fossil)	MJeq	2.37E+03	System boundary: Cradle- to- gate
Non-renewable energy (nuclear)	MJeq	6.87E+02	Functional unit: 1 ton
Non - renewable energy (total)	MJeq	3.06E+03	Product : offset paper
Renewable energy (biomass, renewable fossil fuel)	MJeq	3.40E+01	Impact assessment method: CED
Renewable energy (water)	MJeq	5.04E+03	Impact indicator: Midpoint
Renewable energy (wind, solar, geothermal)	MJeq	5.24E+02	Reference: Oliveira et al., 2015
Renewable energy (total)	MJeq	5.60E+03	

4.2.2. Emission based impact assessments (potential environmental impacts)

The overall potential environmental impacts come from one item production of Manila paper are presented in table 13 and 14 , and table 7 data imply the potential environmental impacts of one ton paper making results obtained from Iran. According to (Poopak & Agamuthu, 2011), the total amount of terrestrial eco toxicity in the production of one ton A4 size paper in Iran is 7.34 kg 1, 4 –DCB-Eq, one unit white and yellow manila paper production in Ethiopia the overall significance of terrestrial eco toxicity is 0.924 and 0.112 kg 1, 4 –DCB-Eq respectively. This indicated that obtained result lower than from literature one because of the product system, the produced amount and the impact assessment method different and etc.1, 4 –DCB is a dichlorobenzene chemical compound carrying chlorine groups at positions 1 and 4 and toxicity impact expressed using the reference unit, kg 1, 4 –DCB equivalent.

In previous research conducted, the impact of Global warming for A4 size paper with a functional unit of one ton production is -729.81 kg CO2-Eq this Show the making process has environmental benefit, The Global warming impact of white and yellow Manila paper was 0.0587 and 1.02E-02 0.0584 kg CO2-Eq respectively in the present investigation, impact results show that positive sign have potentials environmental burden. The difference occurred as a result of the chosen software program with database, the used transport EURO type emission, the selected impact category 20 year in this context but the prior work 100 years.

A single piece of white and yellow Manila paper making industrial subsystem process the overall significance of human toxicity: carcinogen, human toxicity: Non-carcinogen and fresh water eutrophication effect were 0.00243, 0.1751 ,4.39E-04, 4.94E-02 kg 1, 4 –DCB-Eq and 1.37E-05 kg PO-4Eq respectively. The impact results show that Manila paper has the lower environmental impact than A4 size paper across the analyzed impact categories due to the impact category Eutrophication and human toxicity, was analyzed in general, not specifically, but in this work, studied independently, the functional unit and product different, the inputs –outputs variable. Also for Eutrophication waste water disposal technique.

An overall environmental impacts rise from the white and yellow Manila paper making process at mill per functional unit for the Ozone depletion impact categories were 1.474E-7 and 3.63E-08 Kg CFC-11-Eq respectively. In Iran, the Ozone depletion impact of A4 size paper products is 0.00015 this has the higher environmental impact than the present work. The difference comes from waste treatment method like effluent sludge, each unit process emission with different amount and type, and the used impact assessment tool and database characterization factor. In this paper, analysis notice that terrestrial eco toxicity account more quantity than other impact categories but does not concluded this impact the major impact categories' because need additional investigation such as severity or damage at end point level. Current and scholarly researches show that the paper products manufacturing processes have possible potential environmental impact implications.

Table 12: Types and magnitude of impacts result from the one item of white Manila paper production.

Impact category	Unit	Amount
Terrestrial eco toxicity	kg 1, 4-DCB-Eq	0.924
Human toxicity: carcinogenic	kg 1, 4-DCB-Eq	0.00243
Human toxicity-non-carcinogenic	kg 1, 4-DCB-Eq	0.175
Global warming - GWP20a	kg CO2-Eq	0.0587
ozone depletion	Kg CFC-11-Eq	1.474E-7

Table 13: Types and magnitude of impacts result from the a one item of yellow Manila paper production

Impact category	Unit	Amount
Terrestrial eco toxicity	kg 1, 4-DCB-Eq	0.112
Human toxicity:carcinogenic	kg 1, 4-DCB-Eq	4.39E-04
Human toxicity-non-carcinogenic	kg 1, 4-DCB-Eq	4.94E-02
Global warming - GWP20a	kg CO2-Eq	1.02E-02
ozone depletion	Kg CFC-11-Eq	3.63E-08
Freshwater Eutrophication	kg PO-4Eq	1.37E-05

Table 14: The results (potential environmental impacts) of preview study conducted in Iran

Impact category	Unit	Amount	Used element
Terrestrial eco toxicity	kg 1, 4-DCB-Eq	7.34	System boundary: cradle-to-gate, the literature one use input variable only product: A4 size paper
Global warming	kg CO2-Eq	-729.81	Functional unit : one ton of paper for 1 year
Human toxicity	kg 1, 4-DCB-Eq	242.14	assessment method: CML2 baseline2000
Eutrophication	kg PO-4Eq	0.71	Software and data base: simapro7.0,2006
Ozone depletion	Kg CFC-11-Eq	0.00015	Reference: (Poopak & Agamuthu, 2011).

4.2.3. The contributions of each unit processes to the Manila paper making environmental impacts

4.2.3.1. White Manila paper

The contribution results of different unit process to the white Manila paper life cycle environmental impacts are presented as follow.

4.2.3.1.1. Non-renewable energy demand

Fig. 23 shows the present contributions of each unit process for total **Non-renewable energy demand** for white Manila paper production per functional unit. The impact share of bleached Kraft pulp production from hard wood [0.222 MJ-Eq] industrial unit process is regarding 32 % on overall average resource used impact categories. This is mainly a result of natural gas, crude oil, hard and brawn coal that is resources in ground consumed different amount and type during raw material extraction and produced the final product of bleached pulp. The upstream unit operation pulp land transportation with lorry EURO2 [0.181 MJ-Eq] accounts for 26 % to this impact. This is as a result of consumption of natural gas, crude oil and hard coal resources in ground. Pulp transport sea container ship [0.098 MJ-Eq] the third in contribution at about 14 %. The production of maize starch in the paper mill [0.055 MJ-Eq] and recycled waste paper road transport with lorry EURO4 [0.052 MJ-Eq] also considerable contributor to the resource based impact is 8 % and 7 %. Other [0.089 MJ-Eq] axillaries activity has about 13 % due to utilization of resources in ground crude oil and natural gas. The shared burdens of each unit process occurred based on consumption of fossil fuel and non- biomass energy resource. Also the used transport type, Input amount produced, amount of waste plastic, sludge, selected process in open LCA, and characterization factor. The impact assessment result notified that the industrial unit operation of Land farming sludge waste treatment show negative percentage share which means environmental benefit in terms of non-renewable energy utilizations. Refer Appendixes. The cumulative percentages of the most five unit process above are 87% so the activities selected as'' most relevant''.

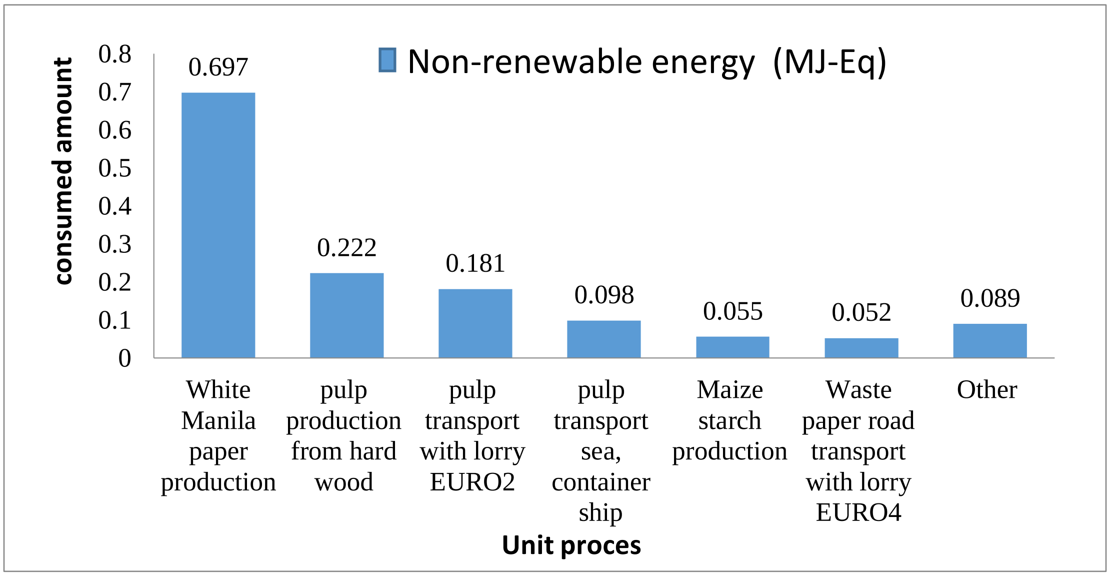

Figure 21: Non-renewable energy consumption for a unit of white Manila paper making

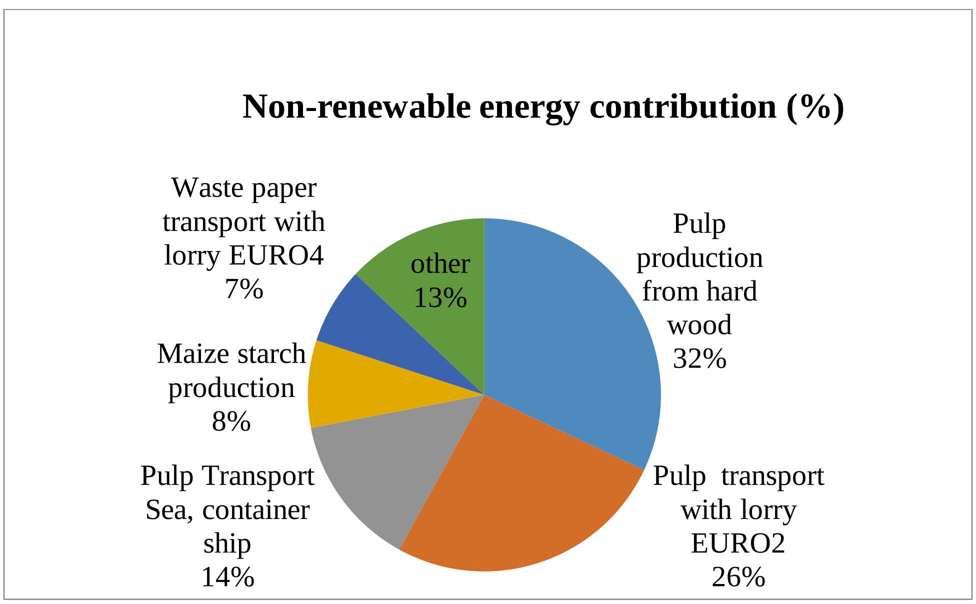

Figure 22: The proportion of impact result of each unit process

4.2.3.1.2. Renewable energy demand

As shown in figure 25 the present contributions of each unit process for total **renewable** energy used for **white Manila paper** production per functional unit. The process of making unbleached Kraft pulp from hard wood [3.032] is responsible for the highest contribution to **renewable** energy demands accounting for 69 % of the total. The production of bleached Kraft pulp from soft wood [0.857] contributes close to 19% to this impact category. The generation of electricity from hydropower [0.292] contributes approximately 7 %. Alkyl ketene dimer manufacturing [0.136] contributes around 3%. The production of maize starch [0.066] and other unit processes [0.016] have a very low contribution to this impact category at approximately 1 %. The percentages of impact for each unit process are mostly related to the high consumption of biotic resources such as biomass, and water resources such as hydropower reserves. Soft wood pulp is a type of wood derived from coniferous trees such as pine, spruce, cedar, and fir that has long fibers that enable tensile strength and durability in paper manufacturing. It is long and thin, and contains fewer impurities, whereas hard wood pulp is derived from deciduous trees such as birch, maple, and eucalyptus, which is short and thick and contains more impurities.

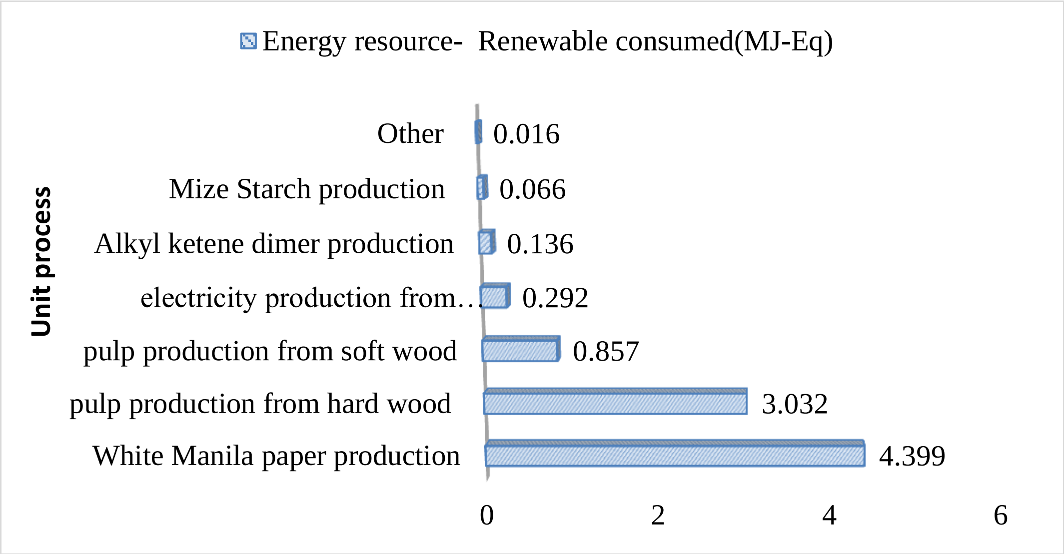

Figure 23: Quantity of renewable energy consumption in a unit of white Manila paper making

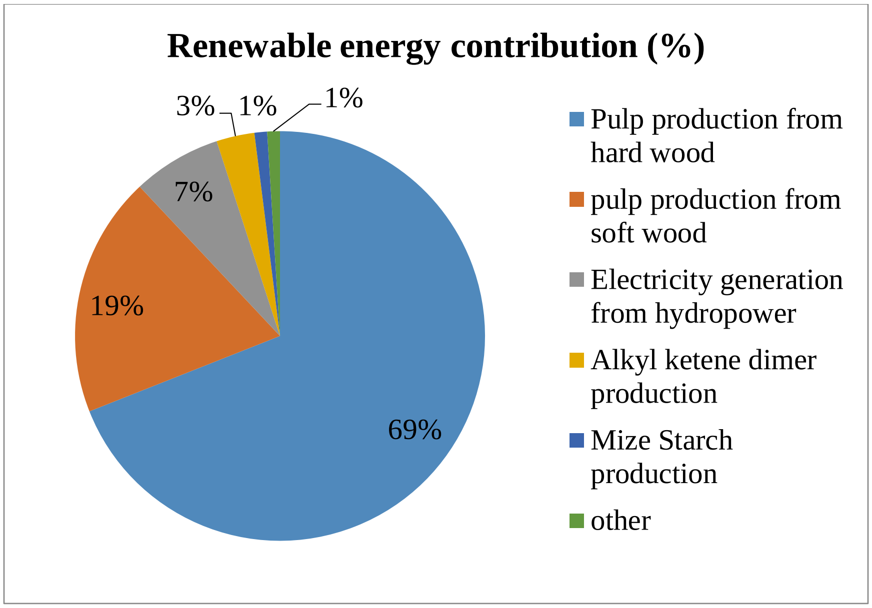

Figure 24: contributions (%) of each unit process –to overall impact result of white Manila paper

4.2.3.1.3. Terrestrial eco-toxicity

Figure 27 indicated that the industrial white Manila paper production life cycle stage contributed 100 % of TETP. The largest contributions to the overall terrestrial eco toxicity potential bleached Kraft pulp production form hardwood (54 % of impacts) and pulp transport by lorry EURO2 (25 % of impacts), the third, fourth, fifth are recycled waste paper transport by truck EURO4 (07 %), unbleached Kraft pulp production form softwood (03 %of impacts) and fire wood transport, by EURO1 (03 %of impacts).This is due to different amounts and types of chemical elements air emission for instance copper ion, Nickel II and Antimony ion. The relative contributor of treatment of sludge (-01 % of impact) Negative value indicated that the potential environmental impact is environmental benefit. Refer Appendix. Bleaching of pulp can be achieved by the removal of lignin in pulp or changing the structure of chromospheres group. Prior to the late 1980s, elemental chlorine was commonly used in the first stage of bleaching. Environmental concerns, however, have led to increasing use of alternative chemicals such as ozone, hydrogen peroxide, enzymes, and chlorine dioxide .the bleaching is accomplished by a series of alternating oxidation and extraction treatments ultimately leading to an almost lignin-free fiber (Martin et al., 2000).

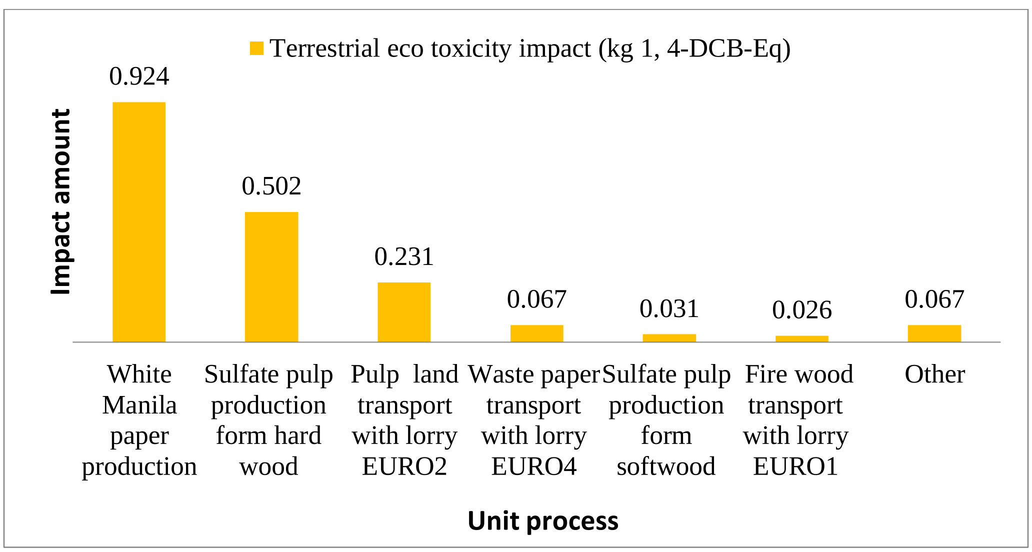

Figure 25: Amount of total terrestrial eco-toxicity from a unit white Manila paper

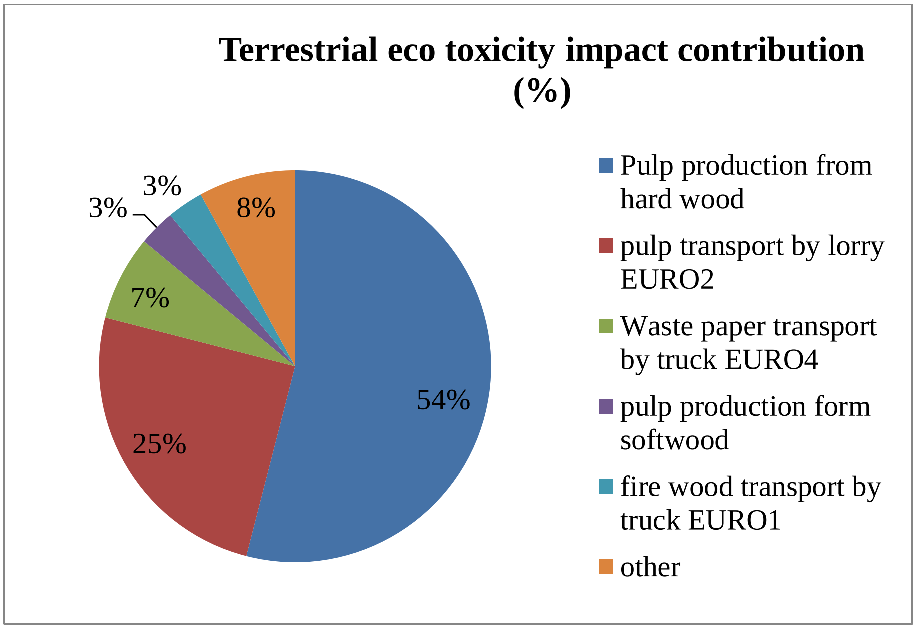

Figure 26: contribution (%) of unit process to terrestrial Eco toxicity impact of whit Manila paper

4.2.3.1.4. Human toxicity: carcinogenic

Table 29 shows that the relative environmental impact contribution of a single roll of white Manila paper is 100 % on HTPC. The dominant subsystem processes that contribute to this impact include bleached Kraft pulp making, aluminum sulfate production, pulp road transport by EURO2, alkyl ketene dimer manufacturing and pulp transport by ship, with impact shares of approximately 50%,22 %,5 % ,04 % and 4%, respectively. The sludge treatment unit process has a significant positive impact on the environment (-3.0%). This is impact is caused by the ground water and air emissions of metal ion such as chromium VI, nickel and arsenic at various levels.

Aluminum sulfate is a water-soluble salt that is primarily employed as a coagulant in the purification of drinking water and waste water treatment plants, as well as in paper manufacture. **Alkyl ketene dimer (AKD)** is a paper sizing agent that can theoretically esterify wood components and cause surface alteration (Hundhausen et al., 2009).

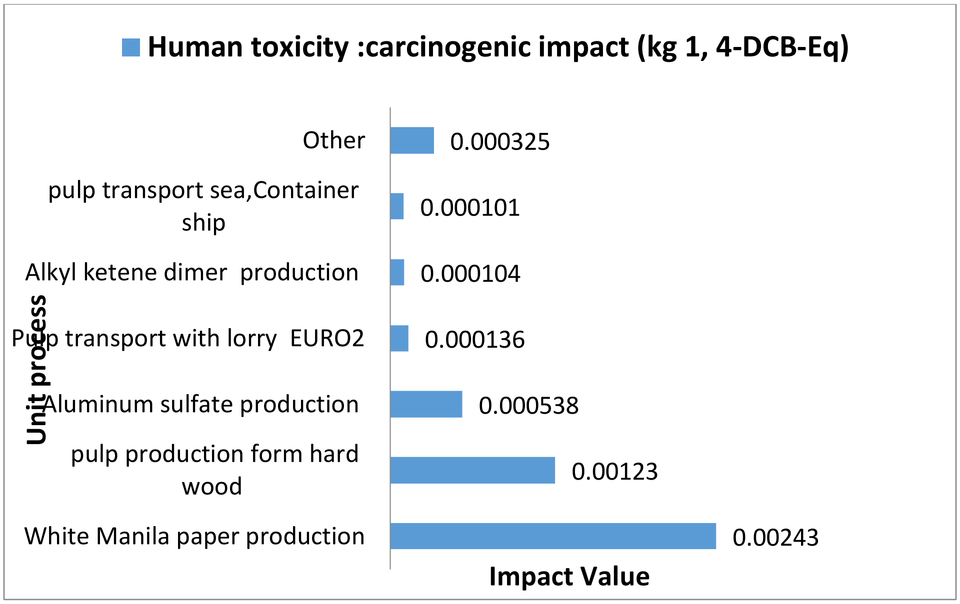

Figure 27: Level of total Human toxicity: carcinogenic result from a unit of white Manila paper

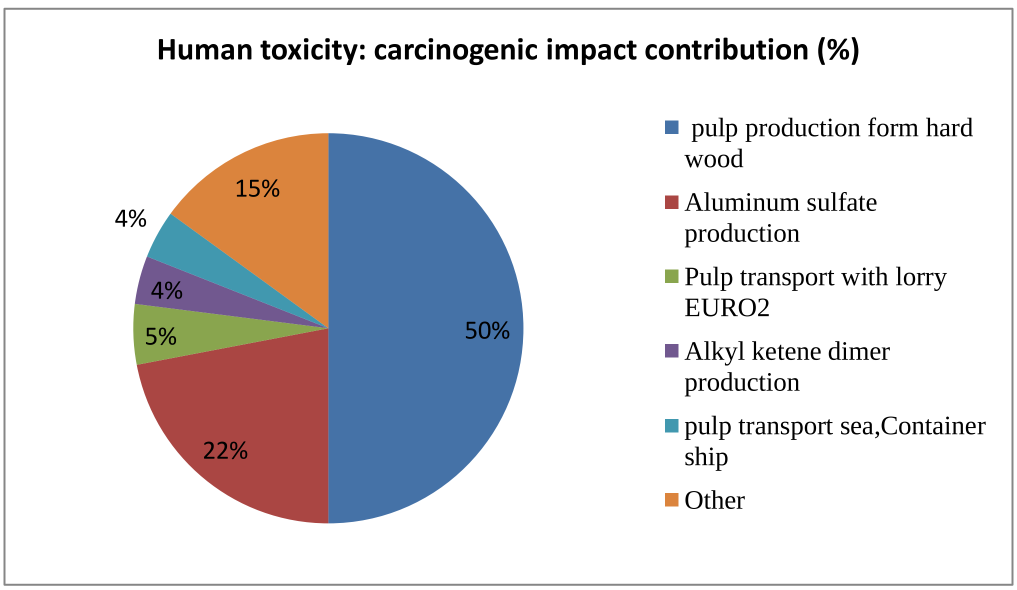

Figure 28: Relative contribution of production process to HTc impact categories

4.2.3.1.5. Human toxicity: non-carcinogenic

Figure 31 depicts the amount of top contributions from various unit processes to the non-carcinogenic human toxicity in terms of DCB-EQ. Figure 34presents the production of the main product per functional unit, with a contribution of 100 on the HTPnc impact categories. The leading contributors to the potential impact were open dump treatment of waste plastic (47%), land farming treatment of sludge (22%),bleached sulfate pulp production (18%), pulp transport by EURO2(5%) and maize starch production(2 %) These activities result in the emission of metals such as zinc II, lead and arsenic which have varying amounts and types in to water, soil and air. Additionally, the process of unbleached sulfate pulp production from soft wood has a negative impacts (-0.1 %) on environmental welfare.

EU emissions limits have been reduced in regular steps since the introduction of ‘Euro1’ in 1992 (May et al., 2013).The Euro emission standards were put in place in order to address ongoing concerns for public health and the environment related to air pollution caused by road transport and to also address risk of fragmentation of the European Single Market by the adoption of national standards and restrictions introduced by Member States. Vehicle emission standards for light-duty vehicles (i.e. cars and vans) and heavy-duty vehicles (i.e. lorries and buses) were implemented since 1992 through a series of Euro emission standards reflecting technical progress while addressing the emerging air quality issues (Staff et al., 2022).

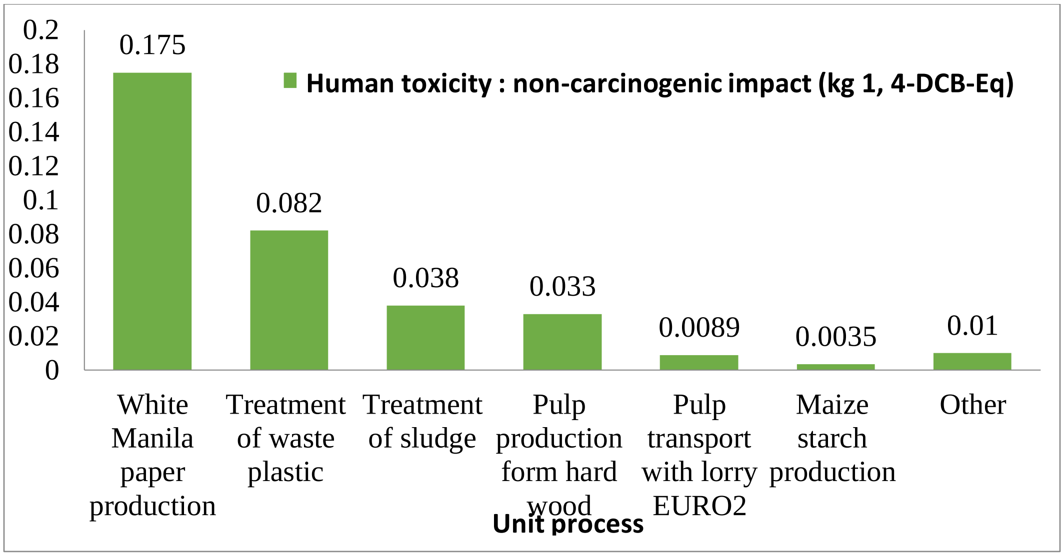

Figure 29: Total Human toxicity: non-carcinogenic impact with unit process contributions

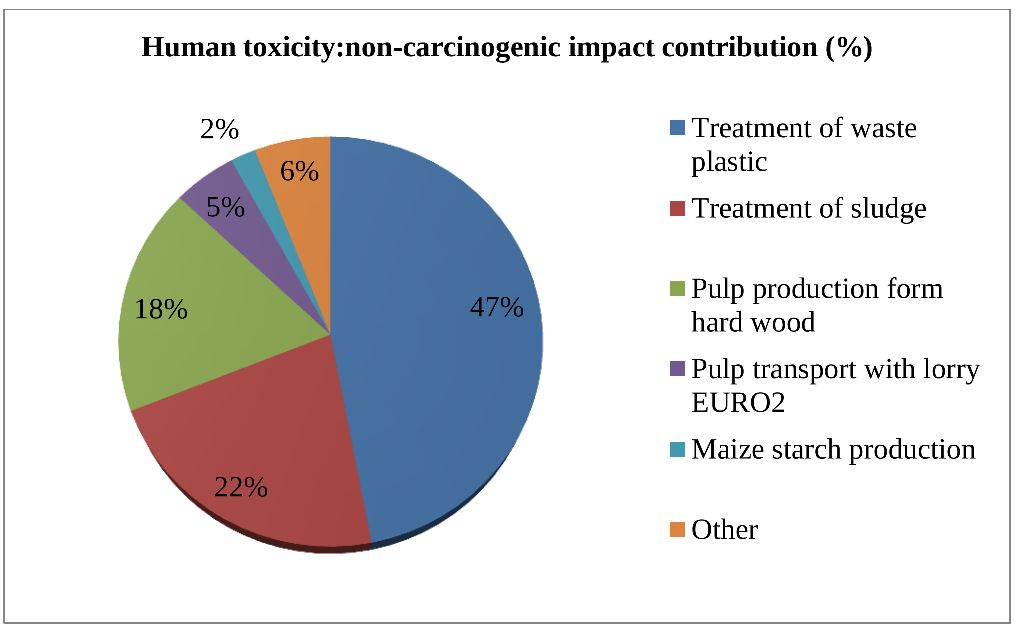

Figure 30: Contribution (%) of unit process to HTPnc impact of white Manila paper

4.2.3.1.6. Ozone depletion

The results shown in Figure 32 indicate that the total impact amounts of ozone depletion in terms of CFC-11-Eq. The results shown in table 33 indicate that the production of White Manila paper

per functional unit accounts for100 % of the ozone depletion impact. The land farming of sludge unit process was contributes 48% to the ozone depletion impact category, while Maize starch production accounts for an additional 21% .The manufacture of bleached pulp, alkyl ketene dimer, and pulp transport via container ship are responsible for 16%, 11% and 2%, respectively. This is due to the emission of dinitrogen monoxide in to air with both high and low population density. The production of sulfate pulp production from soft wood has environmental benefit (-0.2%).Maize starch is starch derived from corn grain that the factory under study used as sizing agent.

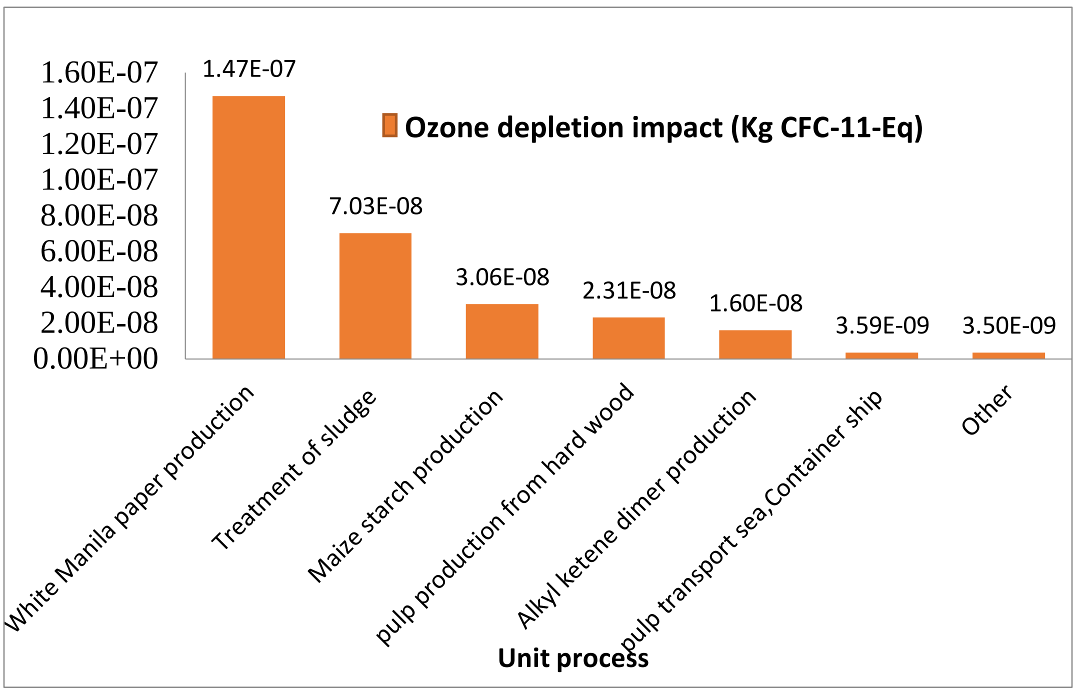

Figure 31: Total Ozone depletion impact of white Manila paper with unit process contributions

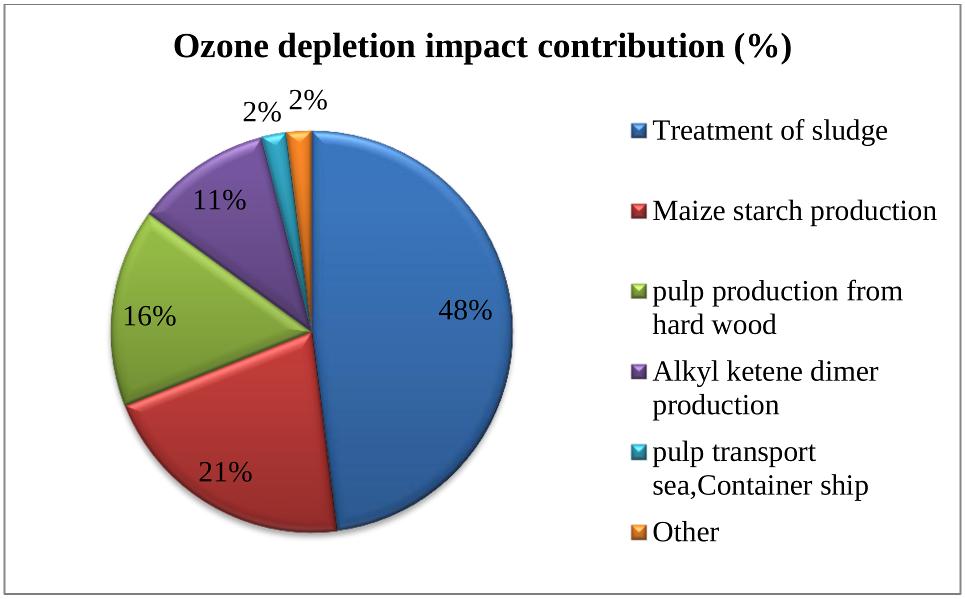

Figure 32: contribution (%) of unit process to the ozone depletion white Manila paper impact

4.2.3.1.7. Global warming - GWP20a

Figure 34 shows the top contributors to global warming, including other unit processes, in terms of CO2-Eq. Table 35 shows that the production of a single white Manila paper item has a 100 % relative contribution to global warming over a 20year period. The primary contributors to this impact are pulp production from hard wood (24 %), followed by pulp transport via lorry EURO2 (22 %), and pulp transport via sea container ship (14 %) . less than 10 % impacts share of the process are : Other processes such as maize starch production (8 %), pulp transport by lorry EURO4 (6 %), treatment of waste plastic (6 %) and production of sulfate pulp from soft wood (4 %), each have a share of less than 10% impact. The remaining unit processes contribute 15% to the overall impact, primarily due to air emissions of gases like carbon dioxide and methane from fossil fuels. The used transport standard also the factors for impact contribution difference because the EURO2 emission standard limits higher than EURO4 (Refer Appendix).

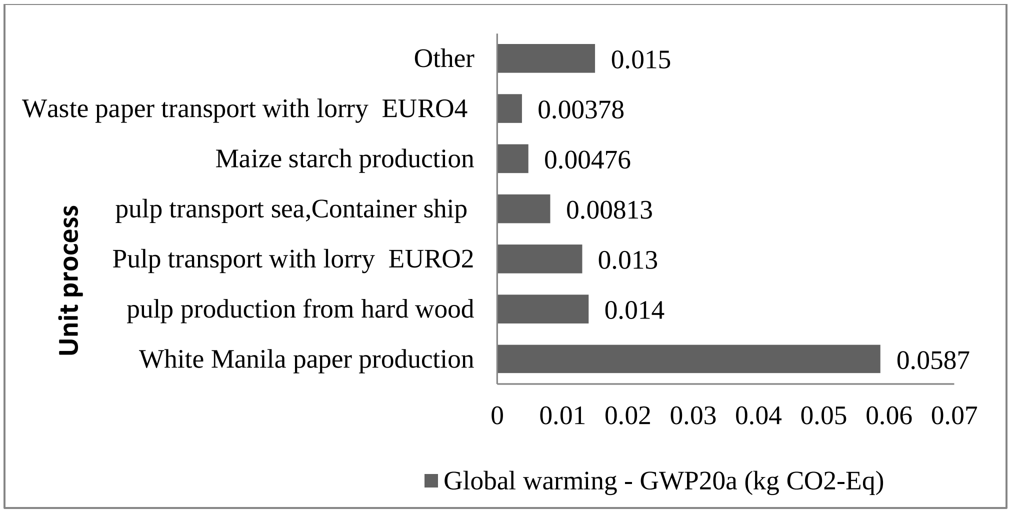

Figure 33: Total global warming impact of white Manila paper with unit process contributions

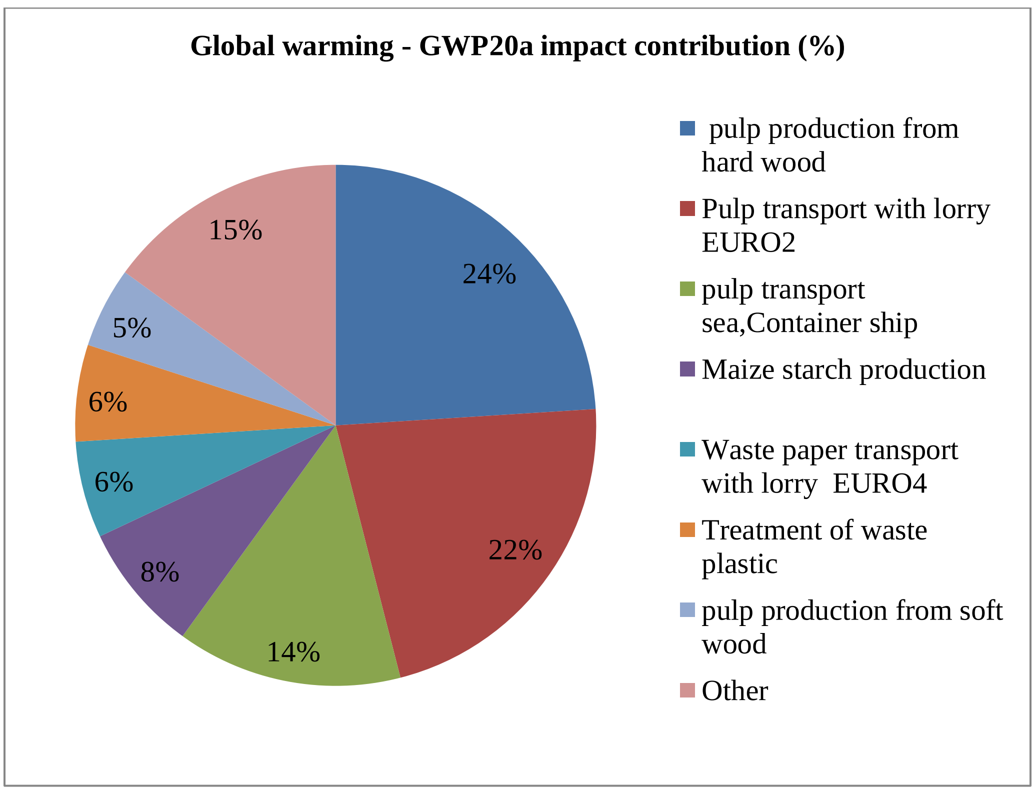

Figure 34: contribution (%) of unit process to GWP 20a white Manila paper impact

4.2.3.2. Yellow Manila paper

4.2.3.2.1. Non-renewable energy demand

As shown in Figure 37, “yellow Manila paper" is responsible for 100% of then on-renewable energy used in the factory's production process. Among the subsystem processes, the largest energy demand comes from pulp production from hard wood, accounting for 62 %, followed by pulp making from soft wood at 23 %. Maize starch production contributes 19 %, Raw material waste paper transport with lorry EURO3 4% shard, Land farming of sludge treatment -24 % accounted, while all other unit processes contributes 16 %. This distribution is primarily due to the heavy reliance on fossil fuels used, such as natural gas, crude oil, and hard ,brown coal. The amount of input production, open dump plastic ,land firming sludge waste treatment and the transportation method used also have significant impacts. Additionally, the results are influenced by the characterization factor of the impact assessment method. The negative sign in land farming sludge treatment was environmental benefited in terms of Non-renewable energy resource utilization.

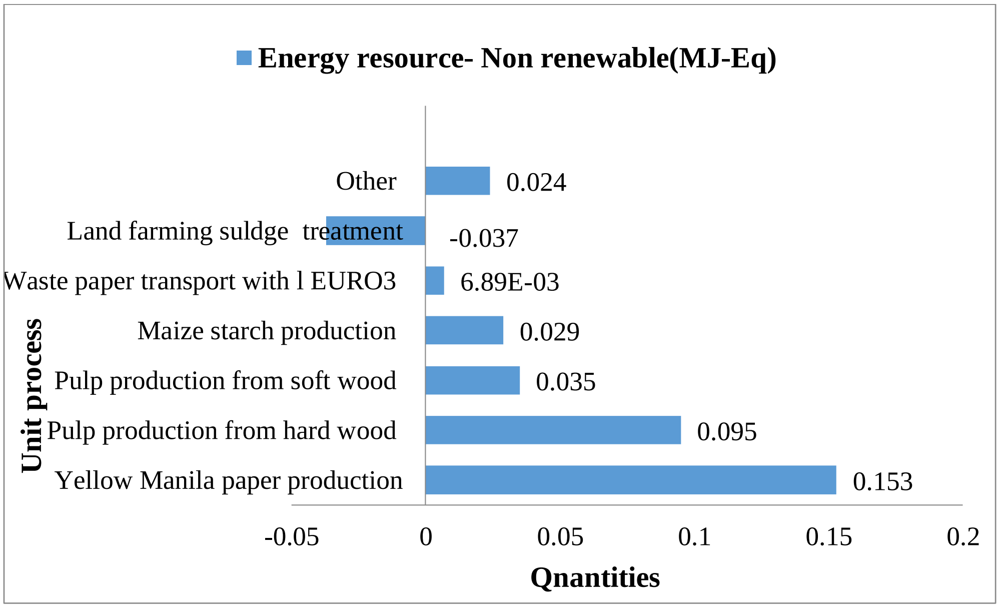

Figure 35: Non-renewable energy consumption of yellow Manila paper with unit process contributions.

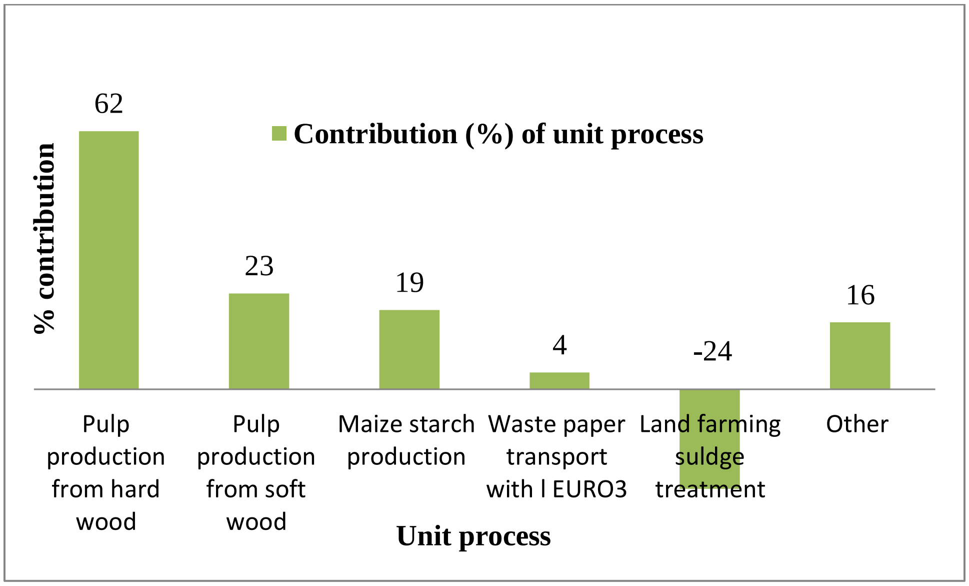

Figure 36: Contribution (%) of unit process -non-renewable energy depletion of yellow Manila paper

4.2.3.2.2. Renewable energy demand

Figure 38 illustrates that the total renewable energy required to produce a single item of yellow Manila paper is 2.625 MJ-Eq. Figure 39 shows that the industrial process of manufacturing the main product fully relies on renewable energy, with a relative contribution of 100 %. Among the unit processes, pulp making from hard wood holds the highest relative contribution to renewable energy consumption, at approximately 49 %, due to its significant use of biomass following this, Kraft pulp production from soft wood account for 31 %,Electricity generation share for 18 %, Maize starch production 1 % of impact, Land farming of sludge treatment -1 % of impact and other holds 2 %. It is worth noting that the negative value for the industrial activitysludge treatment indicates an environmental benefit. These contributions are primarily stem from the manipulation of unit processes, which make use of renewable energy sources like water and biomass.

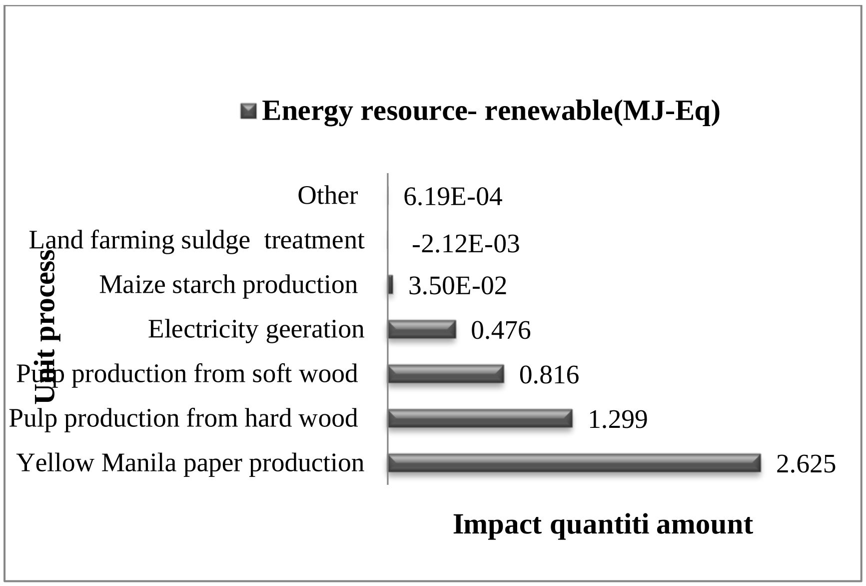

Figure 37: Renewable energy consumption of yellow Manila paper with unit process contributions

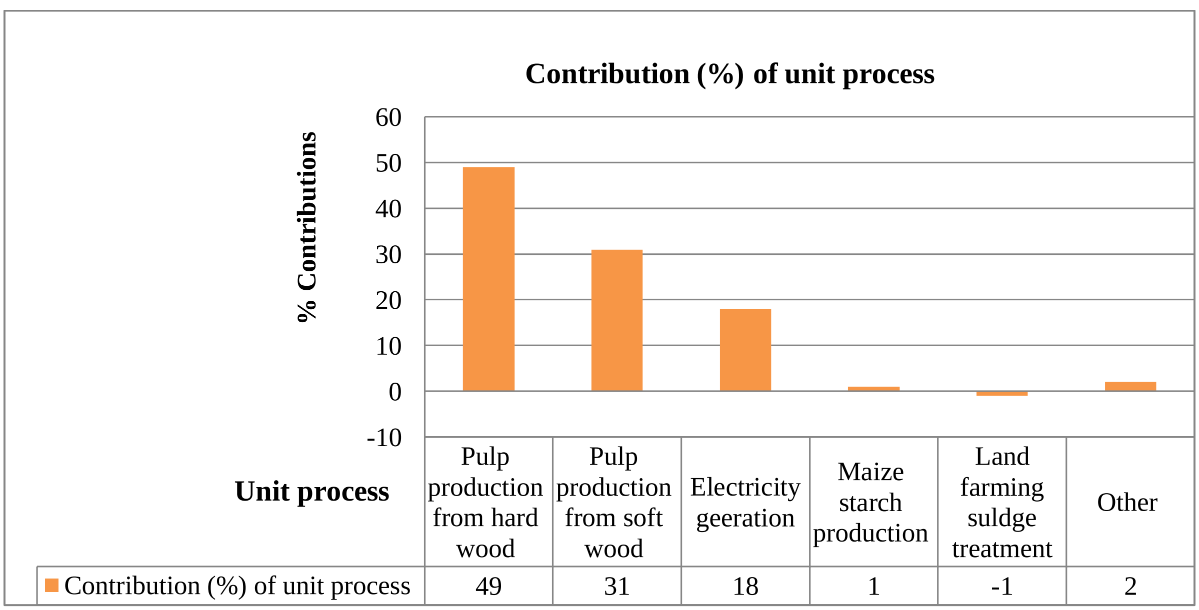

Figure 38: contribution (%) of unit process -renewable energy consumption of yellow Manila paper

4.2.3.2.3. Terrestrial eco toxicity

Figure 40 show the terrestrial eco toxicity (kg 1, 4-DCB-Eq) contribution of different unit processes. Figure 39 indicated the production of the main product per functional unit at mill relative contribution on TETP is 100 %.The manufacturing of hard wood pulp accounts for more than 50 % contribution to this impact category. The process of Maize starch production at 12 % is also an important contributor. Waste paper transport with lorry EURO3 8 % of impact, pulp transport with EURO2 share 7 % and the production of soft wood pulp 7 % of impact. All the other process account 2%. The reason for such share release of chemical element in to air, like copper ion and zinc II.

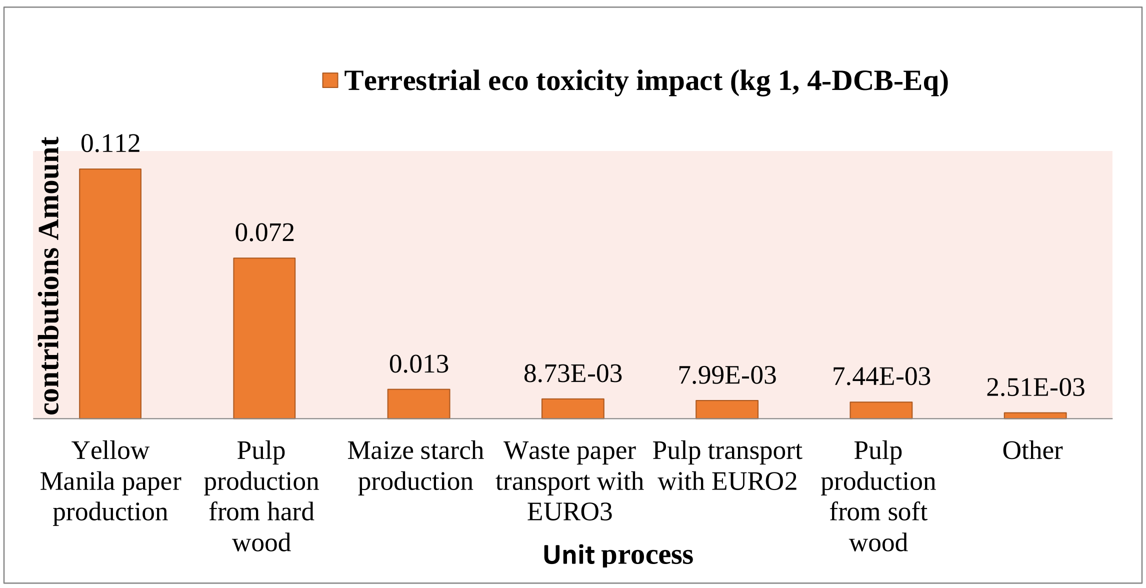

Figure 40: Total Terrestrial Eco toxicity result of yellow Manila paper with unit process contributions

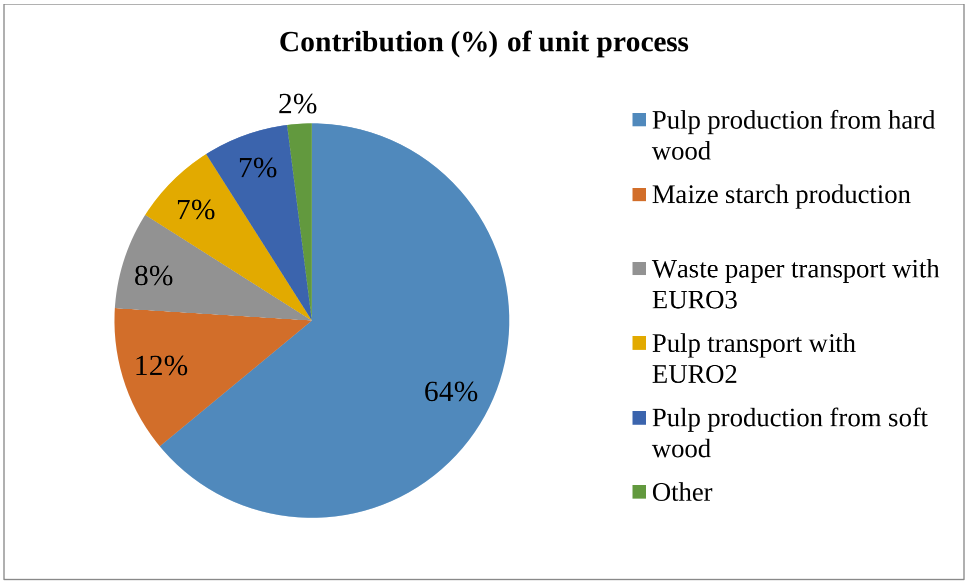

Figure 41: contributions (%) of unit process to TETP Impact of yellow Manila paper

4.2.3.2.4. Human toxicity: carcinogenic

Figure 42 shows impact amount contributions of each unit process with kg 1, 4 –DCB-Eq. From figure 43 notices that a one-item standard weight of 150 g/m^2 yellow Manila paper product relative contribution on HTPC is 100 %. The biggest contributor to this impact category is hard wood pulp making account40%. The Second contributor 27 % of impact is Aluminum sulfate production. The third contributor Maize starch manufacturing hold 11 %, the fourth one raw material waste paper transport with EURO3 shared10% and pulp making from soft wood 5% of impact and Other unit process shared 7 % as result of water and air emission of metal for example chromium VI and nickel.

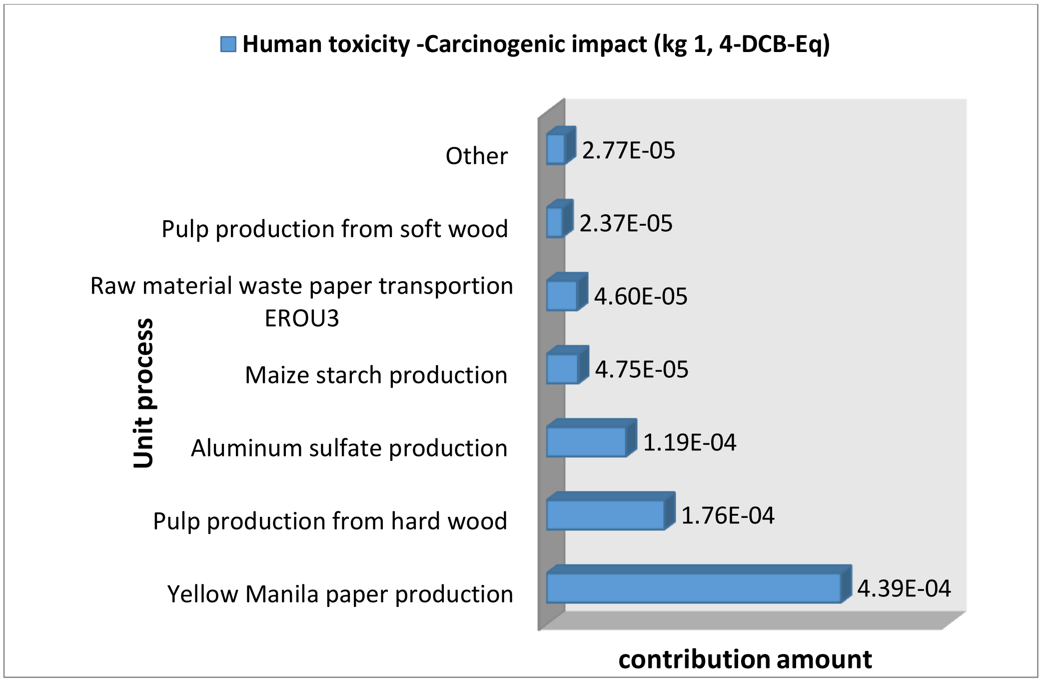

Figure 42: Total Human toxicity -carcinogenic impact of yellow Manila paper with unit processes contributions

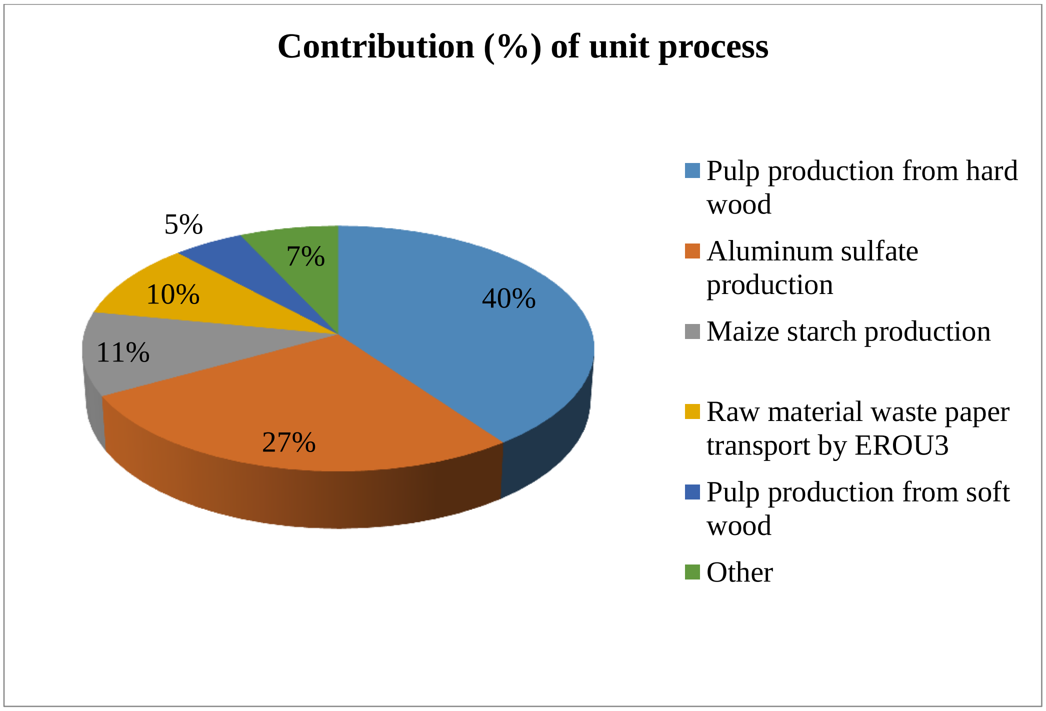

Figure 43: contributions (%) of unit process to yellow manila HTPC Impact

4.2.3.2.5. Human toxicity: Non-carcinogenic

Be seen in figure 44 the amount of top contributions and other unit processes to Human toxicity: non-carcinogenic in terms of DCB-Eq. fig 45 shows the production of the paper at the industry per functional unit account is a 100% relative contribution to this impact category. The impact share of the open dump treatment of waste plastic process is about 65 % of the impact category of HTPN. The Land farming treatment of sludge process accounts for 18 %. The process of pulp making from hard wood share 9 %, the production of Maize starch holed 4 % and pulp transport with truck EURO2 2 %. All the reaming process Burden shares have almost equal contributions of about less than 5 % each to the impact category. This occurred depend upon types and amounts of chemical element emission to water, soil and air such as Zink II, lead, Arsenic and sulphur dioxide.

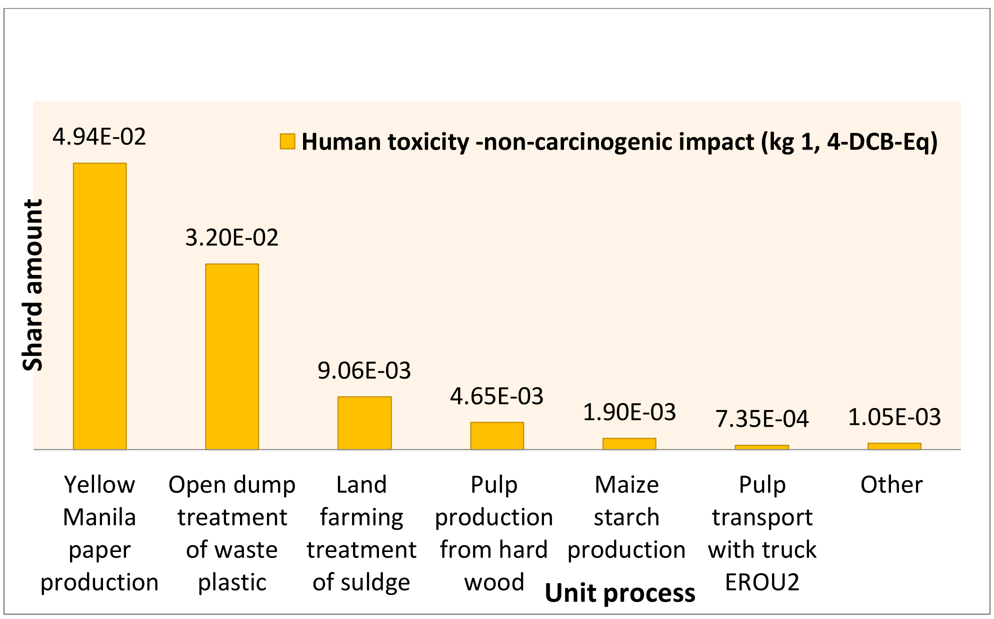

Figure 44 Total Human toxicity potential: Non-carcinogenic result of yellow Manila paper with unit process contribution

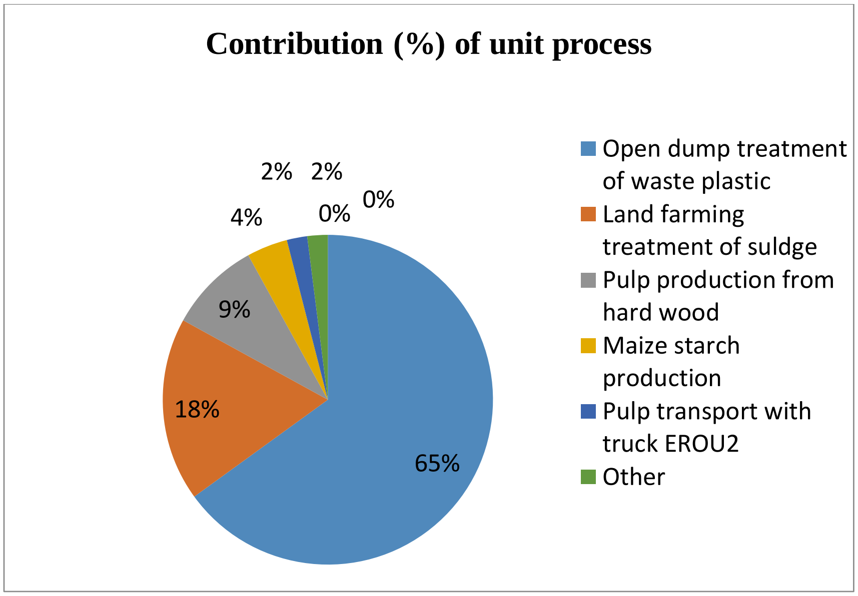

Figure 45: contributions (%) of unit process to the yellow manila HTPNC Impact

4.2.3.2.6. Global warming - GWP20a

The greenhouse emission contributions of the unit processes quantities are shown in Figure 46. The primary cause of the Global warming impact category was the yellow Manila paper making process in the factory, accounting for 100 %.The production of hard wood pulp unit process contributes 28 % to the global warming potentials for 20 years. The maize starch making process was the second largest contributor, responsible for approximately22% of the impact. The third contributor open dump treatment of waste plastic 18 % of impact, the generation of electricity share 6 % ,the fifth contributor raw material waste paper transport with EURO3 5% and other unit process covered 21% .This information is clearly shown in the graph for % contribution assessment in Figure 50, which shows the percentage contributions. This is due to the different type and amount of gases released into the air, such as Carbon dioxide, Dinitrogen monoxide and Methane from fossil fuel.

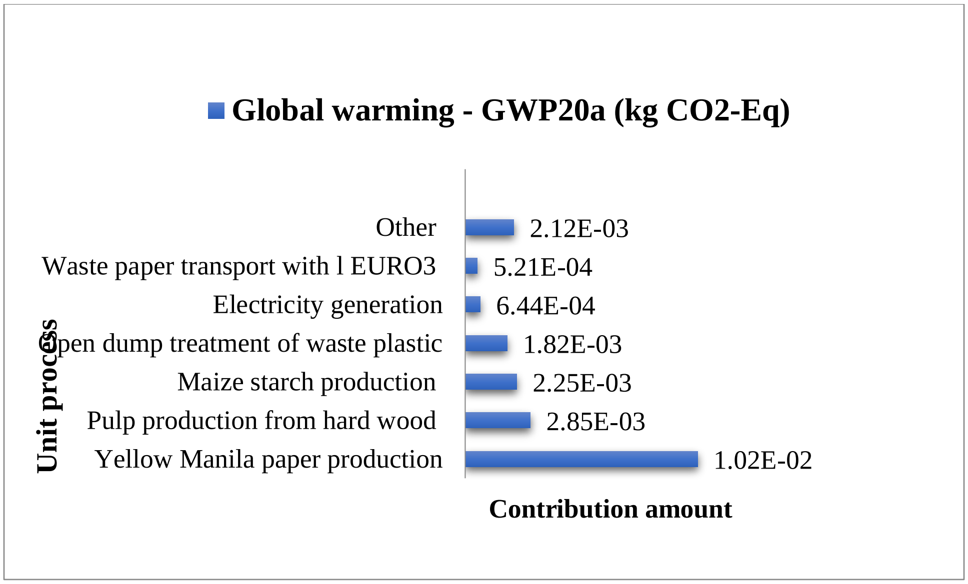

Figure 46: Total Global warming - GWP20a impact of yellow Manila paper with unit process contributions

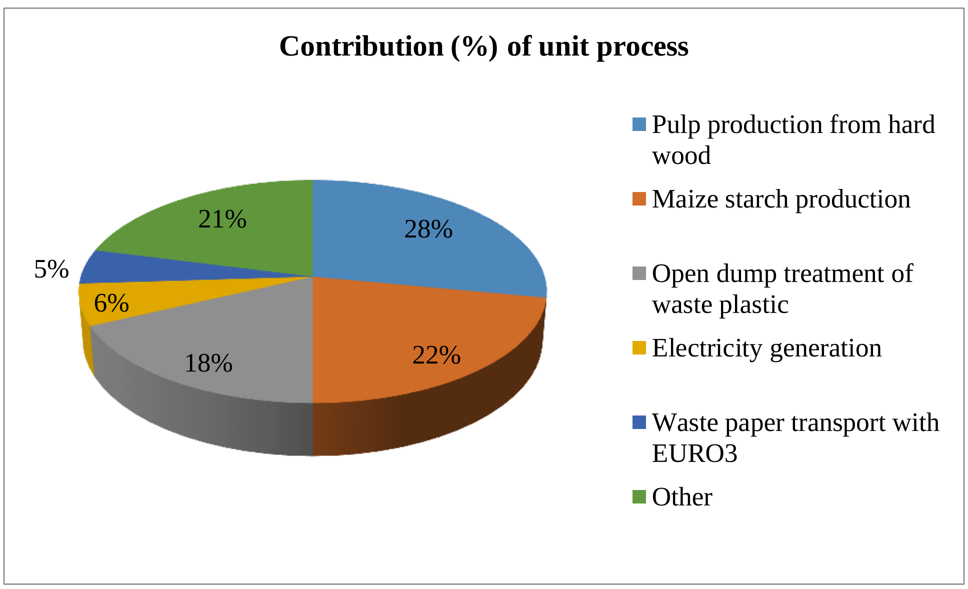

Figure 47: contributions (%) of unit process to global warming-20ayellow manila impact

4.2.3.2.6. Global warming - GWP20a

The impact assessment results in Figure 48 show the contributions amount of various processes to the ozone depletion substances measured in terms of CFC-11-Eq.The unit process Land farming treatment of sludge (46% of impact), maize starch production (45 % of impact) , pulp production from hard wood (9 % of impact) .pulp transport by container ship (1 % of impact) and soft wood making (-2 % of impact) is identified as principle causes for high impact in ozone depletion on average overall impact. The other process contributions less than 5 % .The upstream industrial unit activity this impact contribution accounts due to air emission of gases like Dinitrogen monoxide and methane.

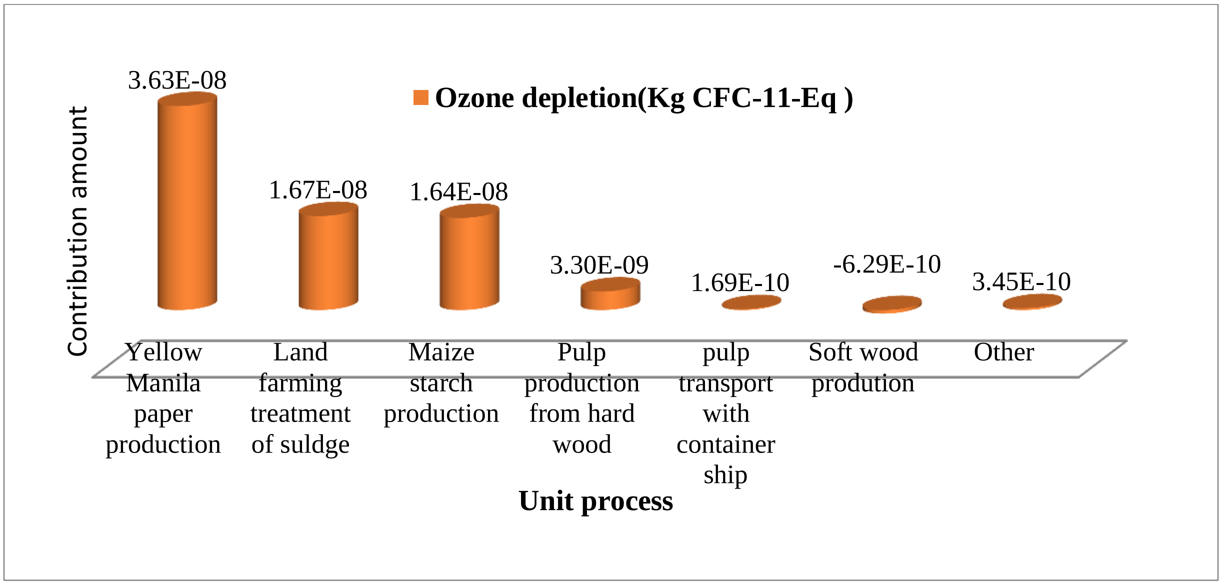

Figure 48: Total Ozone depletion result of yellow Manila paper with unit process contributions

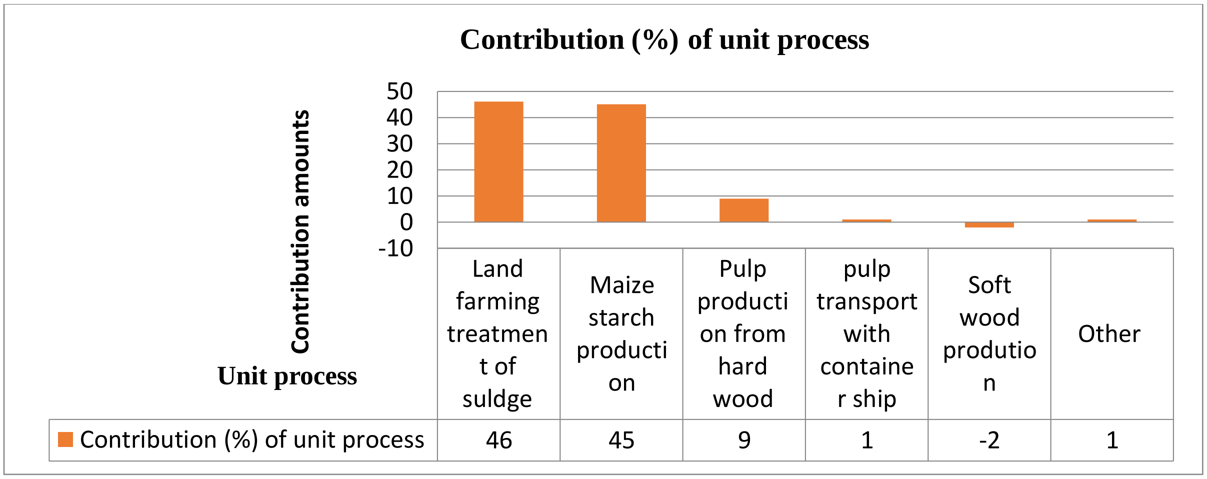

Figure 49: Contributions (%) of unit process to ozone depletion yellow Manila paper Impact

4.2.3.2.8. Freshwater eutrophication

Figure 50 show the amount of top contributions and other unit processes to Freshwater eco toxicity in terms of DCB-Eq. The results presented in Figure 51 show that the batch dyeing unit process contribute37% to freshwater eutrophication because waste water out from dyeing of paper activity on paper machine during yellow manila paper making discharge directly enter into awash river near to EPPSC factory . The maize starch production industrial process accounts for 27%, aluminum sulfate manufacturing 18 % of impact, polyacrylamide production 17 % of impact. This is due to elementary flow emission to water such as different types and amount of element like phosphate and phosphorus. Polyacrylamide is an organic nitrogen source polymer based material used to pulping additives and their improvement of dry strength, thereby enhancing the flexibility of paper. Open dump waste plastic 3 % of impact due to the plastic rubbish out from waste paper raw material pretreatment industrial unit process discharge agricultural and industrial soil near to the water body this inters in to the river by run of, while all remaining processes have a very low contribution, -2 %.

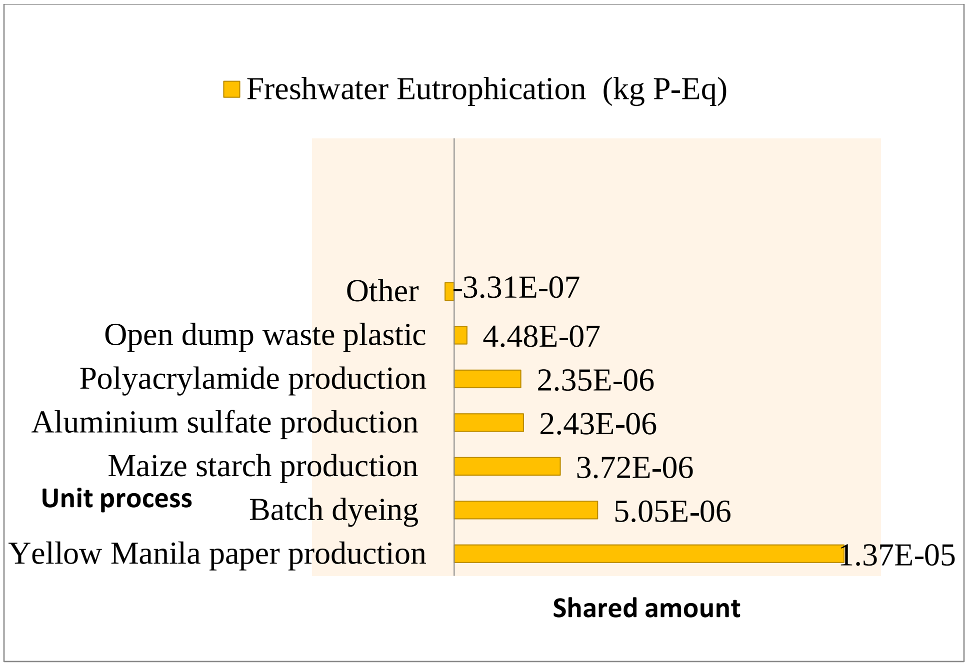

Figure 50: Total Freshwater Eutrophication impact of yellow Manila paper with unit process contributions.

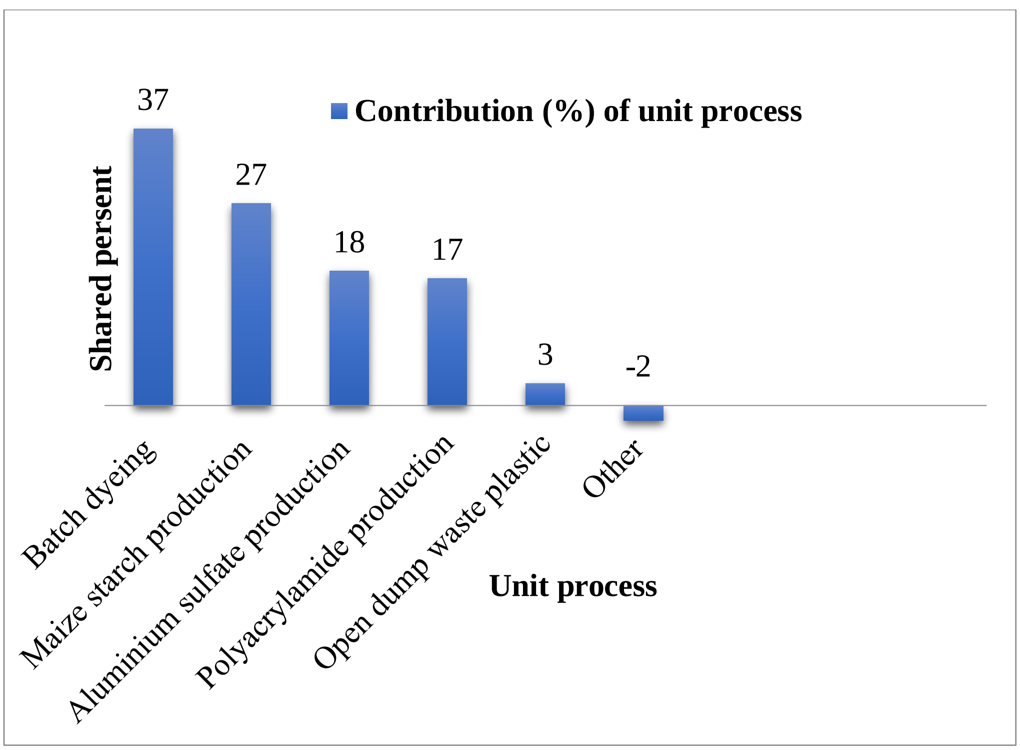

Figure 51: Contributions (%) of unit process to yellow Manila paper FEP Impact

5. Conclusion and recommendation

5.1 conclusion

This paper presented a Cradle-to-gate LCA study of Manila paper production in APEPLC and EPPSC industries, Ethiopia. The life cycle impact assessment was performed based on two approaches: primary energy demand and environmental impact potential. All the processes were than assessed using with open LCA 2.0.4 software with eco invent 3.9.1database. Based on the inventory analysis and impact assessment results, the following conclusions can be taken about the contribution of several processes to the Manila paper life cycle environmental impact.

The Manila paper production is the most important contributor ambient air pollutant of carbon dioxide, VOC, PM10 & PM2.5 and Heat due to onsite heat energy generated on APEPLC and dry paper process of both factory and soil pollutants emitted of sludge and plastic as result of waste water and recycled waste paper treatment. Yellow Manila paper making also contributed river water pollutant parameter of COD, Phosphate and nitrate. The most important raw material used was waste paper, soft and hard wood pulp both industry under study. The major utilized energy were fire wood for white Manila paper, while yellow Manila paper electricity.Hard wood pulp production (32 % of Non-renewable energy impact ,69 % of Renewable energy impact, 54 % of TETP impact , 50 % of HTPC impact, 24% of GWP20 impact) , (represented most of potential impacts contributors for white manila paper , while yellow manila paper hard wood (62 % of Non-renewable energy impact,49 % of Renewable energy impact,64 % of TETP impact,40 % of HTPC impact,28 % of GWP20 impact. Land farming Sludge treatment showed potential environmental benefits to renewable and non- renewable energy consumption impact categories, suggesting targeted interventions could mitigate the industry's footprint. The recycled waste paper was large quantity used raw material for both white and yellow manila paper production but more environmentally friendly than virgin pulp in all impact categories. The obtained research results are a valuable source of management information for the decision makers at both company and government levels required to improve the environmental performance of paper production.

5.2 Recommendation

Cradle-to-gate Life cycle assessment of the Manila paper manufacturing process in the LCA study at the midpoint level and identify the ’’ most contributors’’ process should be carried out to evaluate the environmental performance of paper making process in Ethiopia. Cradle-to-grave investigation in to pulp and paper product manufacturing at endpoint level and proposed cleaner production alternatives in order to identify opportunity efficiency improvement,and comparative life cycle assessment with different software like open LCA and Gabi or simapro should be intensified.

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LEMMA A PhD Dissertation Submitted to the School of Chemical and Bio Engineering in Partial Fulfillment of the Requirements of the Degree of Doctor of Philosophy (Process Engineering Stream) PhD Candidate :

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Appendix

Appendix1. Input-Out data related to paper production process.

1. Ethiopian pulp and paper S.C: Standard weight of 150 g/m^2 yellow Manila paper 6 ton produced

A. Data collection questions

Questions from production department for 150 g/m2 yellow Paper production raw material /chemical/energy used

1. What are the life cycle stages of Manila paper production in your industry?

   Answer: Raw material transportation and paper production.

2. What type of processed pulp used as raw material is Kraft (sulfate), chemical and mechanical pulping in white Manila paper manufacture?

   Answer: Kraft (sulfate) pulp

3. Which pulp used bleached, unbleached or both/ hard wood, soft wood or both?

   Answer: used bleached hard wood and unbleached soft wood pulp

   From which country do you import pulp raw material?

   Answer: Sweden

4. What are your suppliers of waste paper?

   Answer: different Ethiopian country

5. What is your factory used sizing agents chemical?

   Answer: Size press starch

6. What is your factory used adhesives?

   Answer: Polyacrylamide

7. What are your factory sources of Electricity energy? Are renewable, hydro, high or low voltage?

   Answer: National grid, Renewable, Hydro, High voltage

8. Do you use water as raw material for manufacturing in your company? What type of water source do you use?

   Answer: YES Awash River water

9. Do you use dyes? What are they?

   Answer: Direct yellow

   Questions from quality department for 150 g/m2 White yellow Manila Paper production waste treatment

1. Do you your factory used waste paper sorted? Before used treat the recycled waste paper /what type of waste out?

   Answer: YES micro plastic waste reject

2. Do you your factory treat the reject micro plastic waste? What type of treatment method used? Where is the disposal site?

   Answer: open dump, industrial soil

3. Dou you your company waste is discharged in to a public sewage treatment system or a surface water body (river lake and sea)

   Answer: water body (river), industrial and agricultural soil

4. Do you your factory treat the reject waste water? What type of treatment method used?

   Answer: aerobic

5. What type of chemical do you use in waste water treatment?

   Answer: Alum

6. Do you your factory treat sludge out from waste water treatment? What type of treatment method used?

   Answer: land farming

Questions from energy department for 150 g/m2 yellow Manila Paper production onsite energy generation

1. What type of energy generate onsite your factory?

   Answer: Steam energy

2. What are the raw materials used to generate steam energy?

   Answer: Water

3. What type of boiler used?

   Answer: electric boiler

4. What kind of energy used generates heat as fuel for boiler burn?

   Answer: electricity

Questions about raw material transportation 150 g/m2 yellow Manila paper production

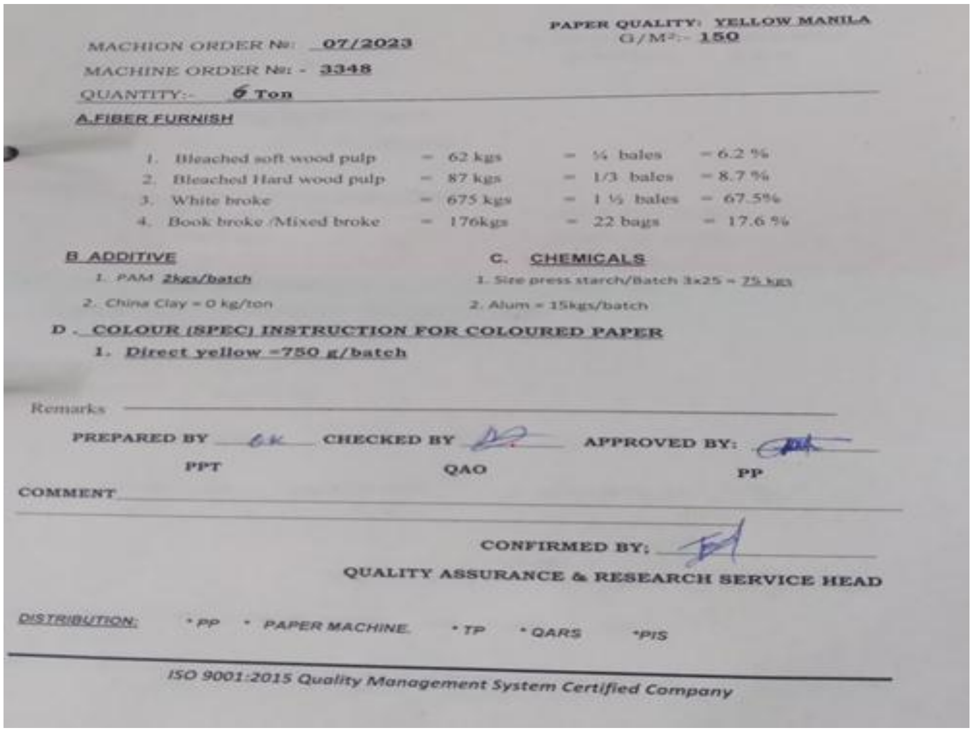
1. What type of transportation do you use to transport pulp from Indonesia to Djibouti? Is road, water/sea, air transport used? What are the distances from Djibouti to manufacturing plant? **Answer: Ship /sea/9,142.5 km**

2. What type of transportation do you use to transport pulp from Djibouti to manufacturing plant? Which one used EURO 1, EURO2, EURO3, EURO4, EURO5, and EURO6? Who many metric ton load? Is road, water, air transport used? What are the distances from Djibouti to manufacturing plant?

Answer: Old low bed truck/ EURO2/16-32 metric ton / road transport/862 km

3. From which one country waste paper suppliers do you get more**?** What type of transportation do you use to transport recycle waste paper from suppliers to manufacturing plant? Which one used EURO 1, EURO2, EURO3, EURO4, EURO5, and EURO6? Who many metric ton load? Is road, water, air transport used? What are the distances from suppliers to manufacturing plant? **Answer: Addis Ababa /truck / EURO3/ 16-32 metric ton/road transport/110 km/**

B. Input quantity of raw material



PAPER QUALITY: YELLOW MANILA
G/M²:- 150

MACHION ORDER №: 07/2023
MACHINE ORDER №: - 3348
QUANTITY:- 6 Ton

A.FIBER FURNISH

1. Bleached soft wood pulp = 62 kgs = ¼ bales = 6.2 %
2. Bleached Hard wood pulp = 87 kgs = 1/3 bales = 8.7 %
3. White broke = 675 kgs = 1 ½ bales = 67.5%
4. Book broke /Mixed broke = 176kgs = 22 bags = 17.6 %

B ADDITIVE

1. PAM 2kgs/batch
2. China Clay = 0 kg/ton

C. CHEMICALS

1. Size press starch/Batch 3x25 = 75 kgs
2. Alum = 15kgs/batch

D . COLOUR (SPEC) INSTRUCTION FOR COLOURED PAPER

1. Direct yellow =750 g/batch

Remarks

PREPARED BY 6K CHECKED BY APPROVED BY:
PPT QAO PP

COMMENT

CONFIRMED BY:
QUALITY ASSURANCE & RESEARCH SERVICE HEAD

DISTRIBUTION: • PP • PAPER MACHINE • TP • QARS •PIS

ISO 9001:2015 Quality Management System Certified Company

Energy input for each unit process

No	Industrial unit process	In put quantity	Unit
1.	Electricity for burn boiler to generate steam	105,651.92	Kwh
2.	Raw material transfer in to milling chest	60	Kwh
3.	Long fiber chest	15,840	Kwh
4.	Short fiber chest	15,840	Kwh
5.	Transfer to Refiner	15,840	Kwh
6.	Blending chest(Mixing)	13,428	Kwh
7.	Machine chest	15,840	Kwh
8.	Fiber bundle removal	21,600	Kwh
9.	First Foreign particles removal	21,600	Kwh
10.	Second Foreign particles removal	13,320	Kwh

11.	Cutting	15,840	Kwh
	Total	254,859.93	Kwh
12.	Steam for dry Paper	107,424	Kwh
13.	Water for steam production	3,781.81	Liter
1.	Water for paper production	114,000	Liter

Out puts from include activity

No	Selected unit process	Type of emission	Quantity	Unit
1.	Waste water reject	COD	204.3	Mg/m ^{3}
		Phosphate	2.3	Mg/m ^{3}
		Nitrate	6.83	Mg/m ^{3}
2.	Paper dry	CO_2	705	µg/m ^{3}
		PM2.5	120	µg/m ^{3}
		PM10	235	µg/m ^{3}
		VOC	8660	µg/m ^{3}
		Heat	31.4	J
3.	Solid waste removal	Plastic waste	260	Kg
4.	Waste water treatment	Sludge (250 Liter)	5,000	Kg

2. Anmole products Ethiopia: Standard weight of 140 g/m^2 white Manila paper 50 ton produced Data collection question

I. Interview questions from production department for 140 g/m2 White Manila Paper production raw material /chemical/energy used

1. What type of processed pulp used as raw material is Kraft (sulfate) pulping, chemical pulping and mechanical pulping in white Manila paper manufacture?
   Answer: Kraft (sulfate) pulp
2. Which pulp used bleached, unbleached or both/ hard wood, soft wood or both in white Manila paper manufacture?
   Answer: both bleached hard wood and unbleached soft wood pulp
3. From which country do you import pulp raw material?
   Answer: Indonesia
4. What are your suppliers of waste paper? From which one do you get more with high distance?
   Answer: Addis Ababa
5. What are your factories used sizing agents chemical?
   Answer: Alkyl ketene dimer
6. Do you your factory onsite Alkyl ketene dimer produce?
   Answer:
7. What are your factory used adhesives are potatoes or maize's starch?
   Answer: maize's starch
8. Do you your factory onsite maize's starches produce?
   Answer:
9. What are your factory sources of Electricity energy? Are renewable, hydro, high or low voltage?
   Answer: National grid, Renewable, Hydro, High voltage
10. Do you use water as raw material for manufacturing in your company? What type of water source do you use?
    Answer: YES Ground water
11. Do you use dyes? What are they?
    Answer: Bismarck brown and AR amine dye

II. Interview questions from quality department for 140 g/m2 White Manila Paper production waste treatment

1. Do you your factory used waste paper sorted? Before used treat the recycled waste paper /what type of waste out?
   Answer: YES micro plastic waste reject
2. Do you your factory treat the reject micro plastic waste? What type of treatment method used?
   Answer: open dump
3. Dou you your company waste is discharged in to a public sewage treatment system or a surface water body (river lake and sea)
   Answer: water body and industrial soil
4. Do you your factory treat the reject waste water? What type of treatment method used?
   Answer: Anaarobic
5. What type of chemical do you use in waste water treatment?
   Answer: Aluminum sulphate powder and Lime
6. Do you your factory onsite produce Aluminum sulphate powder and Lime?
   Answer :
7. Do you your factory treat sludge out from waste water treatment? What type of treatment method used?
   Answer: land farming

III. Interview questions from energy department for 140 g/m2 White Manila Paper production onsite energy generation

1. What type of energy generate onsite your factory?
   Answer: heat and Steam energy
2. What are the raw materials used to generate steam energy?
   Answer: Water
3. What type of boiler used?
   Answer: steam boiler
4. What kind of energy used generates heat as fuel for boiler burn?
   Answer: renewable energy fire wood log
5. Who much kW produce the wood heater?
   Answer: 6 kW

IV. Interview questions from production department about raw material transportation 140 g/m2 White Manila Paper production

1. What type of transportation do you use to transport pulp from Indonesia to Djibouti? Is road, water/sea, air transport used? What are the distances from Djibouti to manufacturing plant? **Answer: Ship /sea/7,991 km**

2. What type of transportation do you use to transport pulp from Djibouti to manufacturing plant? Which one used EURO 1, EURO2, EURO3, EURO4, EURO5, and EURO6? Who many metric ton load? Is road, water, air transport used? What are the distances from Djibouti to manufacturing plant?

Answer: Old low bed truck/ EURO2/16-32 metric ton / **road transport/1020 km**

3. From which one country waste paper suppliers do you get more? What type of transportation do you use to transport recycle waste paper from suppliers to manufacturing plant? Which

Input quantity of raw material

NO	Raw material ,Dye , chemical, energy	In put quantity 50 ton standard weight of 140g/m2 white manila paper produced	In put quantity for 600 ton standard weight of 140g/m2 white manila paper produced (annually)
	Pulp		
1.	Hard wood pulp bleached	75,000 kg	900,000 kg
2.	Unbleached pulp soft wood pulp	7,500 kg	90,000 kg
	Recycle waste paper		
1.	White broke	22,500 kg	270,000 kg
2.	Book broke	57,500 kg	690,000 kg
	Dye		
1.	Bismarck brown dye	150 kg	1,800 kg
2.	Aramine dye	1500 kg	18,000 kg
	adhesives		
1.	Mize Starch	1,250 kg	15,000 kg
	Sizing agent		
1.	Alkyl ketene dimer	600 kg	7,200 kg
	Water		
1.	Water for paper product under study manufacture	3,000,m3	36,000 m3
2.	Water for onsite steam energy generate	150 m3	1,800 m3
	Chemical		
1.	Lime	7,272 kg	87,264 kg
2.	Aluminum sulfate	36,000 kg	432,000 kg
3.	Poly(aryleneethynylene)s P.A.E	7,272 kg	87,264 kg

The primary data obtained from case study factory **APE PLC.**

Energy input for each unit process

NO	Industrial manufacturing process	In Put energy for 50 ton (50,000 kg) quantity	In Put energy for 600 ton (600,000 kg) quantity (annually)
1.	Fresh ground water heat	1,500 kwh	18,000 kwh
2.	Chemical recover	900 kwh	10,800 kwh
3.	Steam energy generation Fire wood as fuel	240 kwh	2,880 kwh
4.	Transfer raw material in to mill chest	1,800 kwh	21,600 kwh
5.	Removal of the rejected plastic	3,000 kwh	36,000 kwh
6.	Raw material Grind	9,600 kwh	115,200 kwh
7.	Mixing chemical & color to pulp	180 kwh	2,160 kwh
8.	Give pulp to paper machine	2,106 kwh	25,272 kwh
9.	Foreign particles removal	1,800 kwh	21,600 kwh
10.	Fiber bundle removal	4,134 kwh	49,608 kwh
11.	Paper Dry	300 kwh	3,600 kwh
12.	Cut the roll size by size	1,650 kwh	19,800 kwh
13.	waste water treatment	3,600 kwh	43,200 kwh

The primary data obtained from case study factory **APE PLC**

ADDIS ABABA ETHIOPIA

Out puts from include activity

NO	Selected process that have high impact	Type of waste	Output quantity 50 ton (50,000kg) standard weight of 140g/m2 white manila paper produced	Output quantity 600 ton standard weight of 140g/m2 white manila paper produced (annually)
1.	Waste water reject	COD (from 750 liter)	658 mg	
		Phosphate (from 750 liter waste water)	0.74 mg	
		Nitrate (from 750 liter)	22.06 mg	
2.	Plastic removal	Micro plastic	6,000 kg	72,000 kg
3.	Paper dry	CO2	911 ug	
		PM2.5	822 ug	
		PM10	1044 ug	
		VOC	14539 ug	
		Heat	31.4 J	
4.	Steam energy generate	CO2	678 ug	
		PM2.5	116 ug	
		PM10	238 ug	
		VOC	18,995 ug	
		Heat	53 J	
5.	Waste water treatment	Sludge	15,000 kg	180,000 kg

The primary data obtained from case study factory **APE PLC.**

Appendix2. Selected completeness and reliability for impact assessment in open LCA 2.0.4

Pedigree matrix

Click on the matrix cells to select entries

	1	2	3	4	5
Reliability	Verified data based on measurements	Verified data partly based on assumptions or non-verified data based on measurements	Non-verified data partly based on qualified estimates	Qualified estimate (e.g. by industrial expert)	Non-qualified estimates
Completeness	Representative data from all sites relevant for the market considered, over and adequate period to even out normal fluctuations	Representative data from > 50% of the sites relevant for the market considered, over an adequate period to even out normal fluctuations	Representative data from only some sites (<< 50%) relevant for the market considered or > 50% of sites but from shorter periods	Representative data from only one site relevant for the market considered or some sites but from shorter periods	Representativeness unknown or data from a small number of sites and from shorter periods
Temporal correlation	Less than 3 years of difference to the time period of the data set	Less than 6 years of difference to the time period of the data set	Less than 10 years of difference to the time period of the data set	Less than 15 years of difference to the time period of the data set	Age of data unknown or more than 15 years of difference to the time period of the data set
Geographical correlation	Data from area under study	Average data from larger area in which the area under study is included	Data from area with similar production conditions	Data from area with slightly similar production conditions	Data from unknown or distinctly different area (North America instead of Middle East, OECD-Europe instead of Russia)
Further technological correlation	Data from enterprises, processes and materials under study	Data from processes and materials under study (i.e. identical technology) but from different enterprises	Data from processes and materials under study but from different technology	Data on related processes or materials	Data on related processes on laboratory scale or from different technology

OK Delete Cancel

Appendix3. Data quality used in open LCA 2.0.4

Data quality

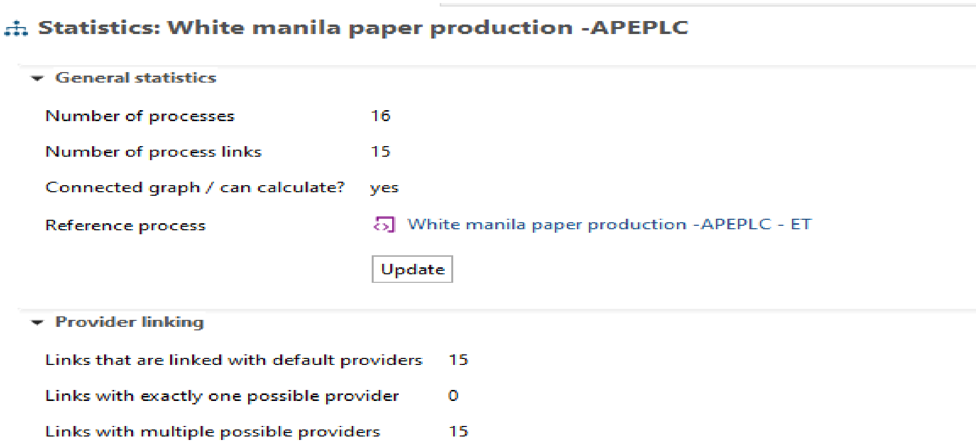
Process data quality schema	
Flow data quality schema	
Aggregation	Weighted average
Rounding mode	Half up
n.a. value handling	Exclude zero values

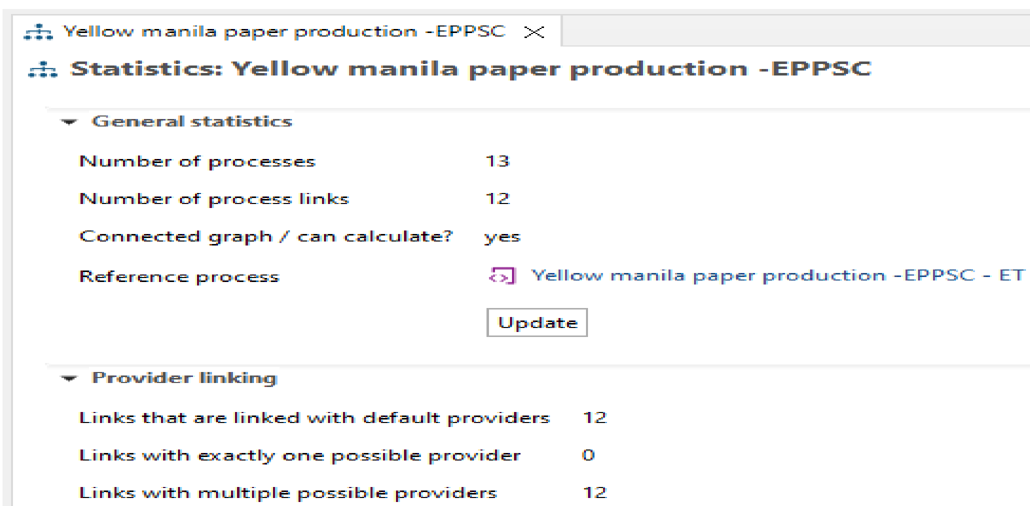
Appendix4. Parameter created in open LCA 2.0.4

Input parameters

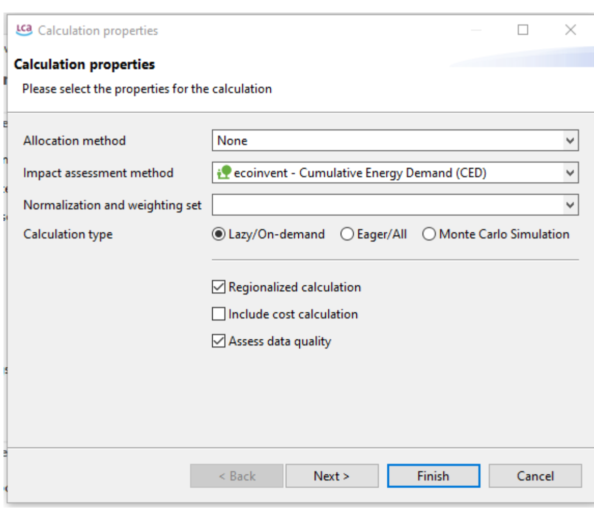
Name	Value	Uncertainty	Description
WPA	0.05	triangular: min=0.0500000 mode=0.0500000 max=0.0500000	Weight of polyacrylamide ,Unit =g
WAS	0.375	triangular: min=0.375000 mode=0.375000 max=0.375000	Weight of Aluminum sulfate ,Unit =g
WBP	1.55	triangular: min=1.55000 mode=1.55000 max=1.55000	Weight of bleached pulp,Unit =g
WMS	1.875	triangular: min=1.87500 mode=1.87500 max=1.87500	Weight of maize starch ,Unit =g
WD	18.75	triangular: min=18.7500 mode=18.7500 max=18.7500	Weight of dye ,Unit =g
WUBP	2.175	triangular: min=2.17500 mode=2.17500 max=2.17500	Weight of unbleached pulp,Unit =g
WW	2.85	triangular: min=2.85000 mode=2.85000 max=2.85000	Weight of water ,Unit =L
WWP	21.275	triangular: min=21.2750 mode=21.2750 max=21.2750	Weight of waste paper ,Unit =g

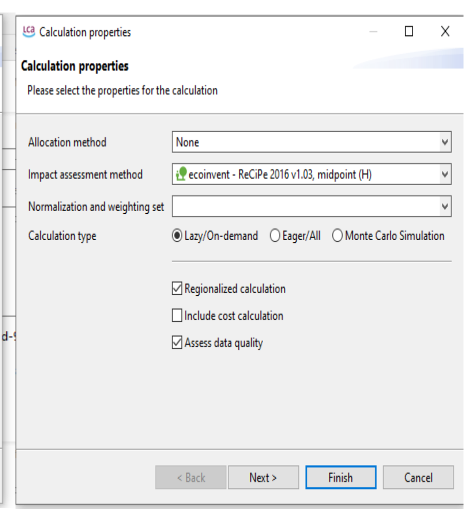
Appendix5. Statistics created in open LCA 2.0 .4





Appendix5. Calculation used in open LCA 2.0.4





Appendix6. Flow and process created in open LCA 2.0.4 used option one .

Inputs

Flow	Amount	Unit	Uncertainty
lime	0.01400	g	triangular: ...
maize starch	3.50000	g	triangular: ...
sulfate pulp, bleached	70.00000	g	triangular: ...
sulfate pulp, unbleached	21.00000	g	triangular: ...
transport, freight, lorry 16-32 metric ton, EURO1	10.64000	kg*km	triangular: ...
transport, freight, lorry 16-32 metric ton, EURO2	92.82000	kg*km	triangular: ...
transport, freight, lorry 16-32 metric ton, EURO4	17.92000	kg*km	triangular: ...
transport, freight, sea, container ship	727.181...	kg*km	triangular: ...
waste paper, sorted	224.000...	g	triangular: ...
Water, well, in ground	840.000	l	triangular:

Outputs

Flow	Category	Amount	Unit
White manila paper produc...		**1.00000**	**Item(**
sludge from pulp and paper ...	382:Waste treatment and dispo...	42.00000	g
waste plastic, mixture	382:Waste treatment and dispo...	16.80000	g

Inputs

Flow	Amount	Unit	Uncertainty
polyacrylamide	0.05000	g	triangular: min=0.05...
Steam energy	2.68600	kWh	triangular: min=2.68...
sulfate pulp, bleached	1.55000	g	triangular: min=1.55...
sulfate pulp, unbleached	2.17500	g	triangular: min=2.17...
transport, freight, lorry 16-32 metric ton, EURO2	3.21526	kg*km	triangular: min=321...
transport, freight, lorry 16-32 metric ton, EURO3	2.34025	kg*km	triangular: min=2.34...
transport, freight, sea, container ship	34.10152	kg*km	triangular: min=340...
waste paper, sorted	21.27500	g	triangular: min=21.2...
Water, river	2.85000	l	triangular: min=2.85...

Outputs

Flow	Amount	Unit	Uncertainty	Provider
Yellow manila paper produc...	**1.00000**	**Item(s)**	**triangular: mi...**	
sludge from pulp and paper ...	0.12500	g	triangular: mi...	treatment...
waste plastic, mixture	0.00650	g	triangular: mi...	treatment...

Appendix7. Energy resources selected for discussion that haven highest contribution to the primary energy demand.

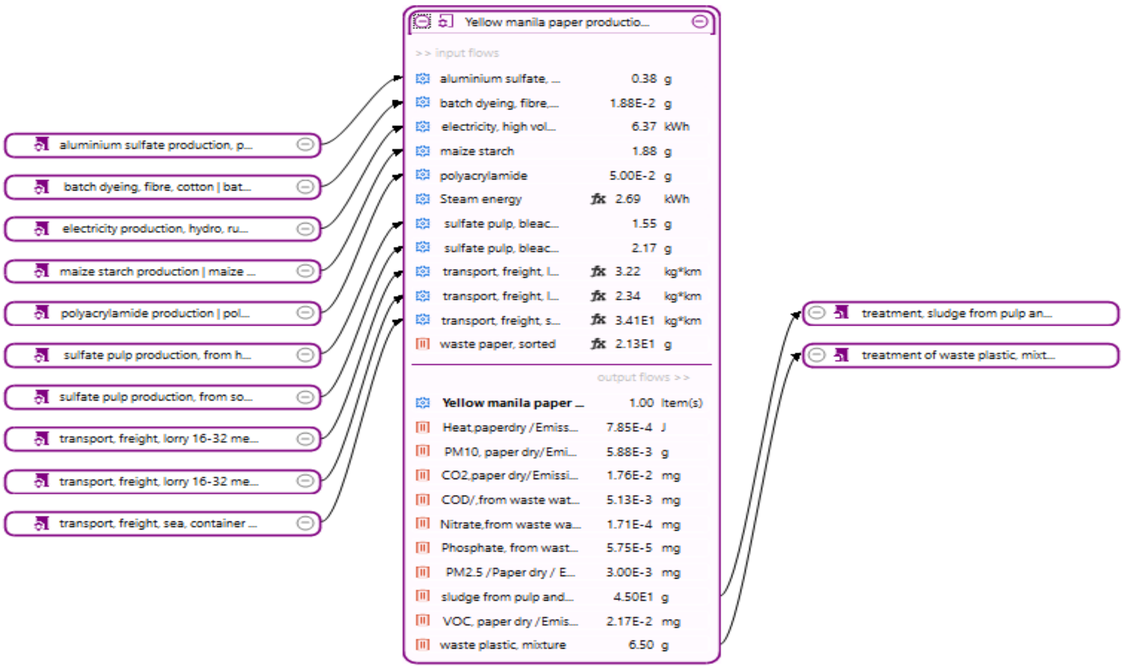
White manila paper production -Anmol products ethiopia plc

Impact analysis: ecoinvent - Cumulative Energy Demand (CED)

Sub-group by: Flows Processes | Don't show < 1 %

Name	Category	Impact assessment result
energy resources: non-renewable - energy content (HHV)	ecoinvent - Cumulative Energy Demand (CED)	0.69661 MJ-Eq
energy resources: non-renewable, biomass - energy content (HHV)	ecoinvent - Cumulative Energy Demand (CED)	0.00569 MJ-Eq
energy resources: non-renewable, fossil - energy content (HHV)	ecoinvent - Cumulative Energy Demand (CED)	0.64469 MJ-Eq
energy resources: non-renewable, nuclear - energy content (HHV)	ecoinvent - Cumulative Energy Demand (CED)	0.04622 MJ-Eq
energy resources: renewable - energy content (HHV)	ecoinvent - Cumulative Energy Demand (CED)	4.39881 MJ-Eq
energy resources: renewable, biomass - energy content (HHV)	ecoinvent - Cumulative Energy Demand (CED)	4.08750 MJ-Eq
energy resources: renewable, geothermal - energy content (HHV)	ecoinvent - Cumulative Energy Demand (CED)	0.00176 MJ-Eq
energy resources: renewable, geothermal, solar, wind - energy content (HHV)	ecoinvent - Cumulative Energy Demand (CED)	0.00605 MJ-Eq
energy resources: renewable, solar - energy content (HHV)	ecoinvent - Cumulative Energy Demand (CED)	0.00021 MJ-Eq
energy resources: renewable, water - energy content (HHV)	ecoinvent - Cumulative Energy Demand (CED)	0.30525 MJ-Eq
energy resources: renewable, wind - energy content (HHV)	ecoinvent - Cumulative Energy Demand (CED)	0.00408 MJ-Eq
total - energy content (HHV)	ecoinvent - Cumulative Energy Demand (CED)	5.09542 MJ-Eq

Appendix8. Model graph result of this environmental impact assessment work from open LCA software analysis



Appendix9. Elementary flow/resource used from Eco invent data base for each unit process of top contributions.

White manila paper production -Anmol products ethiopia plc

Impact analysis: ecoinvent - Cumulative Energy Demand (CED)

Sub-group by: ○ Flows ◉ Processes | Don't show < 1 %

Name	Category	Inventory res...	Characterization factor	Impact assessme...
energy resources: non-renewable - energy content (HHV	ecoinvent - Cumulative Energy Demand ...			0.69661 MJ-Eq
sulfate pulp production, from hardwood, bleached | s	C:Manufacturing/17:Manufacture of pap...			0.22174 MJ-Eq
Gas, natural - RoW	Elementary flows/Resource/in ground	0.00365 Sm3	40.00000 MJ-Eq/Sm3	0.14590 MJ-Eq
Oil, crude - RoW	Elementary flows/Resource/in ground	0.00249 kg	46.00000 MJ-Eq/kg	0.11446 MJ-Eq
Uranium - RoW	Elementary flows/Resource/in ground	7.53851E-8 kg	5.60000E5 MJ-Eq/kg	0.04222 MJ-Eq
Coal, hard, unspecified - RoW	Elementary flows/Resource/in ground	0.00101 kg	19.10000 MJ-Eq/kg	0.01921 MJ-Eq
Coal, brown - RoW	Elementary flows/Resource/in ground	-0.01025 kg	9.90000 MJ-Eq/kg	-0.10149 MJ-Eq
transport, freight, lorry 16-32 metric ton, EURO2 | tran	H:Transportation and storage/49:Land tr...			0.18098 MJ-Eq
Oil, crude - ZA	Elementary flows/Resource/in ground	0.00313 kg	46.00000 MJ-Eq/kg	0.14415 MJ-Eq
Gas, natural - ZA	Elementary flows/Resource/in ground	0.00048 Sm3	40.00000 MJ-Eq/Sm3	0.01939 MJ-Eq
Coal, hard, unspecified - ZA	Elementary flows/Resource/in ground	0.00066 kg	19.10000 MJ-Eq/kg	0.01254 MJ-Eq
transport, freight, sea, container ship | transport, freigh	H:Transportation and storage/50:Water tr...			0.09810 MJ-Eq
Oil, crude - GLO	Elementary flows/Resource/in ground	0.00186 kg	46.00000 MJ-Eq/kg	0.08568 MJ-Eq
Gas, natural - GLO	Elementary flows/Resource/in ground	0.00019 Sm3	40.00000 MJ-Eq/Sm3	0.00768 MJ-Eq
maize starch production | maize starch | Consequentia	C:Manufacturing/10:Manufacture of foo...			0.05490 MJ-Eq
Gas, natural - RoW	Elementary flows/Resource/in ground	0.00103 Sm3	40.00000 MJ-Eq/Sm3	0.04120 MJ-Eq
Oil, crude - RoW	Elementary flows/Resource/in ground	0.00023 kg	46.00000 MJ-Eq/kg	0.01045 MJ-Eq
transport, freight, lorry 16-32 metric ton, EURO4 | tran	H:Transportation and storage/49:Land tr...			0.05224 MJ-Eq
Oil, crude - RoW	Elementary flows/Resource/in ground	0.00093 kg	46.00000 MJ-Eq/kg	0.04266 MJ-Eq

Impact analysis: ecoinvent - Cumulative Energy Demand (CED)

Sub-group by: ○ Flows ◉ Processes | Don't show < 1 %

Name	Category	Inventory result	Characterization factor	Impact assessment res...
energy resources: non-renewable - energy co	ecoinvent - Cumulative Energy Demand ...			0.69661 MJ-Eq
energy resources: non-renewable, biomass -	ecoinvent - Cumulative Energy Demand ...			0.00569 MJ-Eq
energy resources: non-renewable, fossil - ene	ecoinvent - Cumulative Energy Demand ...			0.64469 MJ-Eq
energy resources: non-renewable, nuclear - e	ecoinvent - Cumulative Energy Demand ...			0.04622 MJ-Eq
energy resources: renewable - energy content	ecoinvent - Cumulative Energy Demand ...			4.39881 MJ-Eq
sulfate pulp production, from hardwood, b	C:Manufacturing/17:Manufacture of pap...			3.03167 MJ-Eq
Energy, gross calorific value, in biomas	Elementary flows/Resource/biotic	3.00999 MJ	1.00000 MJ-Eq/MJ	3.00999 MJ-Eq
sulfate pulp production, from softwood, u	C:Manufacturing/17:Manufacture of pap...			0.85720 MJ-Eq
Energy, gross calorific value, in biomas	Elementary flows/Resource/biotic	0.85440 MJ	1.00000 MJ-Eq/MJ	0.85440 MJ-Eq
electricity production, hydro, run-of-river,	D:Electricity, gas, steam and air conditio...			0.29214 MJ-Eq
Energy, potential (in hydropower reserv	Elementary flows/Resource/in water	0.29200 MJ	1.00000 MJ-Eq/MJ	0.29200 MJ-Eq
alkylketene dimer sizing agent production,	C:Manufacturing/20:Manufacture of che...			0.13580 MJ-Eq
Energy, gross calorific value, in biomas	Elementary flows/Resource/biotic	0.13775 MJ	1.00000 MJ-Eq/MJ	0.13775 MJ-Eq
maize starch production | maize starch | C	C:Manufacturing/10:Manufacture of foo...			0.06552 MJ-Eq
Energy, gross calorific value, in biomas	Elementary flows/Resource/biotic	0.07060 MJ	1.00000 MJ-Eq/MJ	0.07060 MJ-Eq

Yellow manila paper production -EPPSC

Impact analysis: ecoinvent - Cumulative Energy Demand (CED)

Sub-group by: ○ Flows ◉ Processes | Don't show < 2 %

Name	Category	Inventory result	Characterization factor	Impact assessment result
energy resources: non-renewable - energy content (HHV)	ecoinvent - Cumulative Energy Demand (CED)			0.15351 MJ-Eq
sulfate pulp production, from hardwood, bleached | sulfate p	C:Manufacturing/17:Manufacture of paper and paper pr...			0.09503 MJ-Eq
Coal, brown - RoW	Elementary flows/Resource/in ground	-0.00439 kg	9.90000 MJ-Eq/kg	-0.04350 MJ-Eq
Uranium - RoW	Elementary flows/Resource/in ground	3.23079E-8 kg	5.60000E5 MJ-Eq/kg	0.01809 MJ-Eq
Coal, hard, unspecified - RoW	Elementary flows/Resource/in ground	0.00043 kg	19.10000 MJ-Eq/kg	0.00823 MJ-Eq
Oil, crude - RoW	Elementary flows/Resource/in ground	0.00107 kg	46.00000 MJ-Eq/kg	0.04905 MJ-Eq
Gas, natural - RoW	Elementary flows/Resource/in ground	0.00156 Sm3	40.00000 MJ-Eq/Sm3	0.06253 MJ-Eq
sulfate pulp production, from softwood, unbleached | sulfate	C:Manufacturing/17:Manufacture of paper and paper pr...			0.03513 MJ-Eq
Coal, brown - RoW	Elementary flows/Resource/in ground	-0.00214 kg	9.90000 MJ-Eq/kg	-0.02118 MJ-Eq
Coal, hard, unspecified - RoW	Elementary flows/Resource/in ground	-0.00019 kg	19.10000 MJ-Eq/kg	-0.00355 MJ-Eq
Uranium - RoW	Elementary flows/Resource/in ground	1.06135E-8 kg	5.60000E5 MJ-Eq/kg	0.00594 MJ-Eq
Gas, natural - RoW	Elementary flows/Resource/in ground	0.00027 Sm3	40.00000 MJ-Eq/Sm3	0.01088 MJ-Eq
Oil, crude - RoW	Elementary flows/Resource/in ground	0.00096 kg	46.00000 MJ-Eq/kg	0.04424 MJ-Eq
maize starch production | maize starch | Consequential, S - R	C:Manufacturing/10:Manufacture of food products/106:...			0.02941 MJ-Eq
Oil, crude - RoW	Elementary flows/Resource/in ground	0.00012 kg	46.00000 MJ-Eq/kg	0.00560 MJ-Eq
Gas, natural - RoW	Elementary flows/Resource/in ground	0.00055 Sm3	40.00000 MJ-Eq/Sm3	0.02207 MJ-Eq
transport, freight, lorry 16-32 metric ton, EURO3 | transport, f	H:Transportation and storage/49:Land transport and tra...			0.00689 MJ-Eq
Oil, crude - RoW	Elementary flows/Resource/in ground	0.00012 kg	46.00000 MJ-Eq/kg	0.00563 MJ-Eq

Name	Category	Inventory result	Characterization factor	Impact assessment result
energy resources: renewable - energy content (HHV)	ecoinvent - Cumulative Energy Demand (CED)			2.62542 MJ-Eq
sulfate pulp production, from hardwood, bleached | sulfate p	C:Manufacturing/17:Manufacture of paper and paper pr...			1.29929 MJ-Eq
Energy, gross calorific value, in biomass - RoW	Elementary flows/Resource/biotic	1.29000 MJ	1.00000 MJ-Eq/MJ	1.29000 MJ-Eq
sulfate pulp production, from softwood, unbleached | sulfate	C:Manufacturing/17:Manufacture of paper and paper pr...			0.81638 MJ-Eq
Energy, gross calorific value, in biomass - RoW	Elementary flows/Resource/biotic	0.81372 MJ	1.00000 MJ-Eq/MJ	0.81372 MJ-Eq
electricity production, hydro, run-of-river, renewable energy	D:Electricity, gas, steam and air conditioning supply/35:...			0.47614 MJ-Eq
Energy, potential (in hydropower reservoir), converted - C	Elementary flows/Resource/in water	0.47592 MJ	1.00000 MJ-Eq/MJ	0.47592 MJ-Eq
maize starch production | maize starch | Consequential, S - R	C:Manufacturing/10:Manufacture of food products/106:...			0.03510 MJ-Eq
Energy, gross calorific value, in biomass - RoW	Elementary flows/Resource/biotic	0.03782 MJ	1.00000 MJ-Eq/MJ	0.03782 MJ-Eq

Appendix9. Elementary flow/Emissions from Eco invent data base for each unit process of top contributions.

White manila paper production -Anmol products ethiopia plc

Impact analysis: ecoinvent - ReCiPe 2016 v1.03, midpoint (H)

Sub-group by: ○ Flows ◉ Processes | Don't show < 1 %

Name	Category	Inventory result	Characterization factor	Impact assessment result
ecotoxicity: terrestrial - terrestrial ecotoxicity potential (TETP)	ecoinvent - ReCiPe 2016 v1.03, midpoint (H)			0.92467 kg 1,4-DCB-Eq
sulfate pulp production, from hardwood, bleached | sulfate p	C:Manufacturing/17:Manufacture of paper and paper pro...			0.50215 kg 1,4-DCB-Eq
Copper ion - RoW	Elementary flows/Emission to air/low population density	2.09810E-7 kg	1.75000E6 kg 1,4-DCB-Eq/kg	0.36717 kg 1,4-DCB-Eq
Nickel II - RoW	Elementary flows/Emission to air/low population density	1.96075E-7 kg	2.71000E5 kg 1,4-DCB-Eq/kg	0.05314 kg 1,4-DCB-Eq
Copper ion - RoW	Elementary flows/Emission to air/unspecified	1.94773E-8 kg	1.21000E6 kg 1,4-DCB-Eq/kg	0.02357 kg 1,4-DCB-Eq
Antimony ion - RoW	Elementary flows/Emission to air/unspecified	3.42999E-8 kg	4.31000E5 kg 1,4-DCB-Eq/kg	0.01478 kg 1,4-DCB-Eq
transport, freight, lorry 16-32 metric ton, EURO2 | transport, f	H:Transportation and storage/49:Land transport and trans...			0.23078 kg 1,4-DCB-Eq
Copper ion - ZA	Elementary flows/Emission to air/unspecified	1.01962E-7 kg	1.21000E6 kg 1,4-DCB-Eq/kg	0.12337 kg 1,4-DCB-Eq
Antimony ion - ZA	Elementary flows/Emission to air/unspecified	1.96580E-7 kg	4.31000E5 kg 1,4-DCB-Eq/kg	0.08473 kg 1,4-DCB-Eq
transport, freight, lorry 16-32 metric ton, EURO4 | transport, f	H:Transportation and storage/49:Land transport and trans...			0.06682 kg 1,4-DCB-Eq
Copper ion - RoW	Elementary flows/Emission to air/unspecified	2.91036E-8 kg	1.21000E6 kg 1,4-DCB-Eq/kg	0.03522 kg 1,4-DCB-Eq
Antimony ion - RoW	Elementary flows/Emission to air/unspecified	5.61397E-8 kg	4.31000E5 kg 1,4-DCB-Eq/kg	0.02420 kg 1,4-DCB-Eq
sulfate pulp production, from softwood, unbleached | sulfate	C:Manufacturing/17:Manufacture of paper and paper pro...			0.03123 kg 1,4-DCB-Eq
Copper ion - RoW	Elementary flows/Emission to air/low population density	6.37073E-9 kg	1.75000E6 kg 1,4-DCB-Eq/kg	0.01115 kg 1,4-DCB-Eq
transport, freight, lorry 16-32 metric ton, EURO1 | transport, f	H:Transportation and storage/49:Land transport and trans...			0.02646 kg 1,4-DCB-Eq
Copper ion - ZA	Elementary flows/Emission to air/unspecified	1.16890E-8 kg	1.21000E6 kg 1,4-DCB-Eq/kg	0.01414 kg 1,4-DCB-Eq
Antimony ion - ZA	Elementary flows/Emission to air/unspecified	2.25351E-8 kg	4.31000E5 kg 1,4-DCB-Eq/kg	0.00971 kg 1,4-DCB-Eq

Results of: White manila paper production -Anmol products ethiopia plc

White manila paper production -Anmol products ethiopia plc

Impact analysis: ecoinvent - ReCiPe 2016 v1.03, midpoint (H)

Sub-group by: ○ Flows ◉ Processes | Don't show < 1 %

Name	Category	Inventory result	Characterization factor	Impact assessment result
human toxicity: carcinogenic - human toxicity pot	ecoinvent - ReCiPe 2016 v1.03, midpoint (H)			0.00243 kg 1,4-DCB-Eq
sulfate pulp production, from hardwood, bleach	C:Manufacturing/17:Manufacture of paper an...			0.00123 kg 1,4-DCB-Eq
Chromium VI - RoW	Elementary flows/Emission to water/surface ...	1.10386E-7 kg	7440.00000 kg 1,4-DCB-Eq...	0.00082 kg 1,4-DCB-Eq
Chromium VI - RoW	Elementary flows/Emission to water/ground ...	3.58787E-8 kg	7440.00000 kg 1,4-DCB-Eq...	0.00027 kg 1,4-DCB-Eq
Nickel II - RoW	Elementary flows/Emission to air/low populat...	1.96075E-7 kg	502.00000 kg 1,4-DCB-Eq/...	9.84297E-5 kg 1,4-DCB...
Chromium VI - RoW	Elementary flows/Emission to air/low populat...	1.19093E-9 kg	2.57000E4 kg 1,4-DCB-Eq/...	3.06068E-5 kg 1,4-DCB...
Arsenic ion - RoW	Elementary flows/Emission to water/surface ...	7.68200E-8 kg	345.00000 kg 1,4-DCB-Eq/...	2.65029E-5 kg 1,4-DCB...
Arsenic ion - RoW	Elementary flows/Emission to air/low populat...	4.54748E-8 kg	575.00000 kg 1,4-DCB-Eq/...	2.61480E-5 kg 1,4-DCB...
Chromium VI - RoW	Elementary flows/Emission to water/ground ...	-9.00511E-9 kg	7440.00000 kg 1,4-DCB-Eq...	-6.69981E-5 kg 1,4-DC...
aluminium sulfate production, powder | alumini	C:Manufacturing/20:Manufacture of chemica...			0.00054 kg 1,4-DCB-Eq
Chromium VI - RoW	Elementary flows/Emission to water/ground ...	5.43307E-8 kg	7440.00000 kg 1,4-DCB-Eq...	0.00040 kg 1,4-DCB-Eq
Chromium VI - RoW	Elementary flows/Emission to water/surface ...	1.62116E-8 kg	7440.00000 kg 1,4-DCB-Eq...	0.00012 kg 1,4-DCB-Eq
transport, freight, lorry 16-32 metric ton, EURO2	H:Transportation and storage/49:Land transpo...			0.00014 kg 1,4-DCB-Eq
Chromium VI - ZA	Elementary flows/Emission to water/ground ...	1.37023E-8 kg	7440.00000 kg 1,4-DCB-Eq...	0.00010 kg 1,4-DCB-Eq
alkylketene dimer sizing agent production, for p	C:Manufacturing/20:Manufacture of chemica...			0.00010 kg 1,4-DCB-Eq
Chromium VI - RoW	Elementary flows/Emission to water/ground ...	9.87341E-9 kg	7440.00000 kg 1,4-DCB-Eq...	7.34581E-5 kg 1,4-DCB...
transport, freight, sea, container ship | transport,	H:Transportation and storage/50:Water transp...			0.00010 kg 1,4-DCB-Eq
Chromium VI - GLO	Elementary flows/Emission to water/ground ...	7.86686E-9 kg	7440.00000 kg 1,4-DCB-Eq...	5.85295E-5 kg 1,4-DCB...
sulfate pulp production, from softwood, unblea	C:Manufacturing/17:Manufacture of paper an...			9.94701E-5 kg 1,4-DCB...
maize starch production | maize starch | Conseq	C:Manufacturing/10:Manufacture of food pro...			8.86324E-5 kg 1,4-DCB...
treatment of waste plastic, mixture, open dump,	E:Water supply; sewerage, waste managemen...			5.94774E-5 kg 1,4-DCB...
batch dyeing, fibre, cotton | batch dyeing, fibre,	C:Manufacturing/13:Manufacture of textiles/...			5.31576E-5 kg 1,4-DCB...

White manila paper production -Anmol products ethiopia plc

Impact analysis: ecoinvent - ReCiPe 2016 v1.03, midpoint (H)

Sub-group by: ○ Flows ◉ Processes | Don't show < 1 %

Name	Category	Inventory result	Characterization factor	Impact assessment result
human toxicity: non-carcinogenic - human toxicity potential (H	ecoinvent - ReCiPe 2016 v1.03, midpoint (H)			0.17507 kg 1,4-DCB-Eq
treatment of waste plastic, mixture, open dump, dry infiltrati	E:Water supply; sewerage, waste management and reme...			0.08184 kg 1,4-DCB-Eq
Zinc II - GLO	Elementary flows/Emission to water/ground water, long...	8.76036E-6 kg	8240.00000 kg 1,4-DCB-Eq/kg	0.07219 kg 1,4-DCB-Eq
Lead II - GLO	Elementary flows/Emission to water/ground water, long...	7.32127E-6 kg	382.00000 kg 1,4-DCB-Eq/kg	0.00280 kg 1,4-DCB-Eq
Arsenic ion - GLO	Elementary flows/Emission to water/ground water, long...	2.97310E-8 kg	8.74000E4 kg 1,4-DCB-Eq/kg	0.00260 kg 1,4-DCB-Eq
treatment, sludge from pulp and paper production, landfarm	A:Agriculture, forestry and fishing/01:Crop and animal p...			0.03804 kg 1,4-DCB-Eq
Zinc II - RoW	Elementary flows/Emission to soil/agricultural	1.01885E-6 kg	3.77000E4 kg 1,4-DCB-Eq/kg	0.03841 kg 1,4-DCB-Eq
sulfate pulp production, from hardwood, bleached | sulfate p	C:Manufacturing/17:Manufacture of paper and paper pr...			0.03255 kg 1,4-DCB-Eq
Zinc II - RoW	Elementary flows/Emission to water/ground water, long...	1.05508E-6 kg	8240.00000 kg 1,4-DCB-Eq/kg	0.00869 kg 1,4-DCB-Eq
Arsenic ion - RoW	Elementary flows/Emission to water/surface water	7.68200E-8 kg	8.74000E4 kg 1,4-DCB-Eq/kg	0.00671 kg 1,4-DCB-Eq
Arsenic ion - RoW	Elementary flows/Emission to air/low population density	4.54748E-8 kg	1.41000E5 kg 1,4-DCB-Eq/kg	0.00641 kg 1,4-DCB-Eq
Lead II - RoW	Elementary flows/Emission to air/low population density	1.14671E-7 kg	2.98000E4 kg 1,4-DCB-Eq/kg	0.00342 kg 1,4-DCB-Eq
Zinc II - RoW	Elementary flows/Emission to soil/agricultural	8.83685E-8 kg	3.77000E4 kg 1,4-DCB-Eq/kg	0.00333 kg 1,4-DCB-Eq
transport, freight, lorry 16-32 metric ton, EURO2 | transport, f	H:Transportation and storage/49:Land transport and tra...			0.00891 kg 1,4-DCB-Eq
Zinc II - ZA	Elementary flows/Emission to water/ground water, long...	5.49203E-7 kg	8240.00000 kg 1,4-DCB-Eq/kg	0.00453 kg 1,4-DCB-Eq
maize starch production | maize starch | Consequential, S - R	C:Manufacturing/10:Manufacture of food products/106:...			0.00355 kg 1,4-DCB-Eq

White manila paper production -Anmol products ethiopia plc

Impact analysis: ecoinvent - ReCiPe 2016 v1.03, midpoint (H)

Sub-group by: ○ Flows ◉ Processes | Don't show < 1 %

Name	Category	Inventory result	Characterization factor	Impact assessment result
ozone depletion - ozone depletion potential (ODPinfinite)	ecoinvent - ReCiPe 2016 v1.03, midpoint (H)			1.47094E-7 kg CFC-11-Eq
treatment, sludge from pulp and paper production, landfarm	A:Agriculture, forestry and fishing/01:Crop and animal pr...			7.02964E-8 kg CFC-11-Eq
Dinitrogen monoxide - RoW	Elementary flows/Emission to air/low population density,...	7.65078E-6 kg	0.01100 kg CFC-11-Eq/kg	8.41586E-8 kg CFC-11-Eq
Dinitrogen monoxide - RoW	Elementary flows/Emission to air/high population density	-1.23919E-6 kg	0.01100 kg CFC-11-Eq/kg	-1.36311E-8 kg CFC-11-...
maize starch production | maize starch | Consequential, S - R	C:Manufacturing/10:Manufacture of food products/106:...			3.06111E-8 kg CFC-11-Eq
Dinitrogen monoxide - RoW	Elementary flows/Emission to air/low population density	2.41455E-6 kg	0.01100 kg CFC-11-Eq/kg	2.65600E-8 kg CFC-11-Eq
Dinitrogen monoxide - RoW	Elementary flows/Emission to air/high population density	3.92890E-7 kg	0.01100 kg CFC-11-Eq/kg	4.32179E-9 kg CFC-11-Eq
sulfate pulp production, from hardwood, bleached | sulfate p	C:Manufacturing/17:Manufacture of paper and paper pro...			2.31002E-8 kg CFC-11-Eq
Dinitrogen monoxide - RoW	Elementary flows/Emission to air/high population density	1.40361E-6 kg	0.01100 kg CFC-11-Eq/kg	1.54397E-8 kg CFC-11-Eq
Dinitrogen monoxide - RoW	Elementary flows/Emission to air/unspecified	3.77742E-7 kg	0.01100 kg CFC-11-Eq/kg	4.15516E-9 kg CFC-11-Eq
Dinitrogen monoxide - RoW	Elementary flows/Emission to air/low population density	2.84735E-7 kg	0.01100 kg CFC-11-Eq/kg	3.13209E-9 kg CFC-11-Eq
alkylketene dimer sizing agent production, for paper product	C:Manufacturing/20:Manufacture of chemicals and che...			1.59941E-8 kg CFC-11-Eq
Dinitrogen monoxide - RoW	Elementary flows/Emission to air/low population density	1.36054E-6 kg	0.01100 kg CFC-11-Eq/kg	1.49660E-8 kg CFC-11-Eq
transport, freight, sea, container ship | transport, freight, sea,	H:Transportation and storage/50:Water transport/501:Sea ...			3.59207E-9 kg CFC-11-Eq
Dinitrogen monoxide - GLO	Elementary flows/Emission to air/low population density	3.01235E-7 kg	0.01100 kg CFC-11-Eq/kg	3.31358E-9 kg CFC-11-Eq
heat production, mixed logs, at wood heater 6kW | heat, cent	D:Electricity, gas, steam and air conditioning supply/35:El...			2.26766E-9 kg CFC-11-Eq
transport, freight, lorry 16-32 metric ton, EURO2 | transport, f	H:Transportation and storage/49:Land transport and trans...			2.11394E-9 kg CFC-11-Eq
sulfate pulp production, from softwood, unbleached | sulfate	C:Manufacturing/17:Manufacture of paper and paper pro...			-2.64147E-9 kg CFC-11-...

White manila paper production -Anmol products ethiopia plc

Impact analysis: ecoinvent - EDIP 2003 (legacy)

Sub-group by: ○ Flows ◉ Processes | Don't show < 1 %

Name	Category	Inventory result	Characterization factor	Impact assessment result
global warming - GWP 20a	ecoinvent - EDIP 2003 (legacy)			0.05844 kg CO2-Eq
sulfate pulp production, from hardwood, bleached	C:Manufacturing/17:Manufacture of paper and paper pr...			0.01411 kg CO2-Eq
Carbon dioxide, fossil - RoW	Elementary flows/Emission to air/unspecified	0.00375 kg	1.00000 kg CO2-Eq/kg	0.00375 kg CO2-Eq
Carbon dioxide, fossil - RoW	Elementary flows/Emission to air/high population density	0.00367 kg	1.00000 kg CO2-Eq/kg	0.00367 kg CO2-Eq
Methane, fossil - RoW	Elementary flows/Emission to air/low population density	5.62922E-5 kg	62.00000 kg CO2-Eq/kg	0.00349 kg CO2-Eq
Methane, non-fossil - RoW	Elementary flows/Emission to air/low population density	4.04234E-5 kg	62.00000 kg CO2-Eq/kg	0.00251 kg CO2-Eq
transport, freight, lorry 16-32 metric ton, EURO2 | tr	H:Transportation and storage/49:Land transport and tra...			0.01259 kg CO2-Eq
Carbon dioxide, fossil - ZA	Elementary flows/Emission to air/unspecified	0.00800 kg	1.00000 kg CO2-Eq/kg	0.00800 kg CO2-Eq
Methane, fossil - ZA	Elementary flows/Emission to air/low population density	3.50390E-5 kg	62.00000 kg CO2-Eq/kg	0.00217 kg CO2-Eq
Carbon dioxide, fossil - ZA	Elementary flows/Emission to air/low population density	0.00191 kg	1.00000 kg CO2-Eq/kg	0.00191 kg CO2-Eq
transport, freight, sea, container ship | transport, fre	H:Transportation and storage/50:Water transport/501:Se...			0.00813 kg CO2-Eq
Carbon dioxide, fossil - GLO	Elementary flows/Emission to air/low population density	0.00631 kg	1.00000 kg CO2-Eq/kg	0.00631 kg CO2-Eq
Methane, fossil - GLO	Elementary flows/Emission to air/low population density	1.83670E-5 kg	62.00000 kg CO2-Eq/kg	0.00114 kg CO2-Eq
maize starch production | maize starch | Consequer	C:Manufacturing/10:Manufacture of food products/106:...			0.00476 kg CO2-Eq
Carbon dioxide, fossil - RoW	Elementary flows/Emission to air/low population density	0.00170 kg	1.00000 kg CO2-Eq/kg	0.00170 kg CO2-Eq
Carbon dioxide, fossil - RoW	Elementary flows/Emission to air/high population density	0.00113 kg	1.00000 kg CO2-Eq/kg	0.00113 kg CO2-Eq
Methane, fossil - RoW	Elementary flows/Emission to air/low population density	1.07927E-5 kg	62.00000 kg CO2-Eq/kg	0.00067 kg CO2-Eq
Dinitrogen monoxide - RoW	Elementary flows/Emission to air/low population density	2.41455E-6 kg	275.00000 kg CO2-Eq/kg	0.00066 kg CO2-Eq
transport, freight, lorry 16-32 metric ton, EURO4 | tr	H:Transportation and storage/49:Land transport and tra...			0.00378 kg CO2-Eq
Carbon dioxide, fossil - RoW	Elementary flows/Emission to air/unspecified	0.00255 kg	1.00000 kg CO2-Eq/kg	0.00255 kg CO2-Eq
Methane, fossil - RoW	Elementary flows/Emission to air/low population density	9.61420E-6 kg	62.00000 kg CO2-Eq/kg	0.00060 kg CO2-Eq
treatment of waste plastic, mixture, open dump, dr	E:Water supply; sewerage, waste management and reme...			0.00360 kg CO2-Eq

Yellow manila paper production -EPPSC

Impact analysis: ecoinvent - ReCiPe 2016 v1.03, midpoint (H)

Sub-group by: ○ Flows ◉ Processes | Don't show < 1 %

Name	Inventory result	Characterization factor	Impact assessment result
eutrophication: freshwater - freshwater eutrophication potential			1.36675E-5 kg P-Eq
batch dyeing, fibre, cotton | batch dyeing, fibre, cotton | Con			5.04685E-6 kg P-Eq
Phosphate - RoW	1.15866E-5 kg	0.33000 kg P-Eq/kg	3.82358E-6 kg P-Eq
Phosphorus - RoW	7.30869E-7 kg	1.00000 kg P-Eq/kg	7.30869E-7 kg P-Eq
Phosphate - RoW	1.38450E-6 kg	0.33000 kg P-Eq/kg	4.56885E-7 kg P-Eq
maize starch production | maize starch | Consequential, S - R			3.72221E-6 kg P-Eq
Phosphate - RoW	5.47436E-6 kg	0.33000 kg P-Eq/kg	1.80654E-6 kg P-Eq
Phosphorus - RoW	1.20498E-6 kg	1.00000 kg P-Eq/kg	1.20498E-6 kg P-Eq
Phosphate - RoW	1.22316E-6 kg	0.33000 kg P-Eq/kg	4.03642E-7 kg P-Eq
Phosphate - RoW	9.23002E-7 kg	0.33000 kg P-Eq/kg	3.04591E-7 kg P-Eq
aluminium sulfate production, powder | aluminium sulfate, p			2.43332E-6 kg P-Eq
Phosphate - RoW	6.71390E-6 kg	0.33000 kg P-Eq/kg	2.21559E-6 kg P-Eq
Phosphate - RoW	6.45557E-7 kg	0.33000 kg P-Eq/kg	2.13034E-7 kg P-Eq
polyacrylamide production | polyacrylamide | Consequential,			2.34741E-6 kg P-Eq
Phosphate - GLO	6.74948E-6 kg	0.33000 kg P-Eq/kg	2.22733E-6 kg P-Eq
Phosphate - GLO	8.34614E-7 kg	0.33000 kg P-Eq/kg	2.75422E-7 kg P-Eq
Phosphorus - GLO	-1.56353E-7 kg	1.00000 kg P-Eq/kg	-1.56353E-7 kg P-Eq

Appendix9. Relative contribution of unit process that have environmental benefit (negative sign) in terms of resource used and emissions

Impact category: energy resources: non-renewable - energy content (HHV)

Contribution	Process
100.00%	White manila paper production -Anmol products ethiopia plc - ET
31.83%	sulfate pulp production, from hardwood, bleached | sulfate pulp...
25.98%	transport, freight, lorry 16-32 metric ton, EURO2 | transport, freig...
14.08%	transport, freight, sea, container ship | transport, freight, sea, co...
07.88%	maize starch production | maize starch | Consequential, S - RoW
07.50%	transport, freight, lorry 16-32 metric ton, EURO4 | transport, freig...
05.30%	sulfate pulp production, from softwood, unbleached | sulfate pu...
03.91%	batch dyeing, fibre, cotton | batch dyeing, fibre, cotton | Conseq...
03.25%	alkylketene dimer sizing agent production, for paper production...
03.01%	transport, freight, lorry 16-32 metric ton, EURO1 | transport, freig...
01.62%	aluminium sulfate production, powder | aluminium sulfate, pow...
00.47%	electricity production, hydro, run-of-river, renewable energy pro...
00.06%	heat production, mixed logs, at wood heater 6kW | heat, central ...
00.00%	lime production, milled, loose | lime | Consequential, S - RoW
00.00%	treatment of waste plastic, mixture, open dump, dry infiltration ...
-04.90%	treatment, sludge from pulp and paper production, landfarming...

Impact category: energy resources: renewable - energy content (HHV)

Contribution	Process
100.00%	White manila paper production -Anmol products ethiopia plc - ET
68.92%	sulfate pulp production, from hardwood, bleached | sulfate pulp...
19.49%	sulfate pulp production, from softwood, unbleached | sulfate pu...
06.64%	electricity production, hydro, run-of-river, renewable energy pro...
03.09%	alkylketene dimer sizing agent production, for paper production...
01.49%	maize starch production | maize starch | Consequential, S - RoW
00.30%	heat production, mixed logs, at wood heater 6kW | heat, central ...
00.07%	transport, freight, lorry 16-32 metric ton, EURO2 | transport, freig...
00.04%	aluminium sulfate production, powder | aluminium sulfate, pow...
00.02%	transport, freight, lorry 16-32 metric ton, EURO4 | transport, freig...
00.01%	transport, freight, sea, container ship | transport, freight, sea, co...
00.01%	transport, freight, lorry 16-32 metric ton, EURO1 | transport, freig...
00.00%	lime production, milled, loose | lime | Consequential, S - RoW
00.00%	treatment of waste plastic, mixture, open dump, dry infiltration ...
-00.03%	batch dyeing, fibre, cotton | batch dyeing, fibre, cotton | Conseq...
-00.04%	treatment, sludge from pulp and paper production, landfarming...

Impact category: :cotoxicity: terrestrial - terrestrial ecotoxicity potential (TETP)

Contribution	Process
100.00%	White manila paper production -Anmol products ethiopia plc - ET
54.31%	sulfate pulp production, from hardwood, bleached | sulfate pulp,...
24.96%	transport, freight, lorry 16-32 metric ton, EURO2 | transport, freig...
07.23%	transport, freight, lorry 16-32 metric ton, EURO4 | transport, freig...
03.38%	sulfate pulp production, from softwood, unbleached | sulfate pul...
02.86%	transport, freight, lorry 16-32 metric ton, EURO1 | transport, freig...
02.69%	maize starch production | maize starch | Consequential, S - RoW
02.36%	alkylketene dimer sizing agent production, for paper production |...
02.00%	transport, freight, sea, container ship | transport, freight, sea, con...
01.07%	aluminium sulfate production, powder | aluminium sulfate, pow...
00.59%	batch dyeing, fibre, cotton | batch dyeing, fibre, cotton | Conseq...
00.16%	electricity production, hydro, run-of-river, renewable energy pro...
00.12%	heat production, mixed logs, at wood heater 6kW | heat, central ...
00.00%	treatment of waste plastic, mixture, open dump, dry infiltration c...
00.00%	lime production, milled, loose | lime | Consequential, S - RoW
-01.73%	treatment, sludge from pulp and paper production, landfarming ...

Impact category: ıan toxicity: carcinogenic - human toxicity potential (HTPc)

Contribution	Process
100.00%	White manila paper production -Anmol products ethiopia plc - ET
50.53%	sulfate pulp production, from hardwood, bleached | sulfate pulp,...
22.11%	aluminium sulfate production, powder | aluminium sulfate, pow...
05.60%	transport, freight, lorry 16-32 metric ton, EURO2 | transport, freig...
04.26%	alkylketene dimer sizing agent production, for paper production |...
04.16%	transport, freight, sea, container ship | transport, freight, sea, con...
04.09%	sulfate pulp production, from softwood, unbleached | sulfate pul...
03.64%	maize starch production | maize starch | Consequential, S - RoW
02.44%	treatment of waste plastic, mixture, open dump, dry infiltration c...
02.18%	batch dyeing, fibre, cotton | batch dyeing, fibre, cotton | Conseq...
01.98%	transport, freight, lorry 16-32 metric ton, EURO4 | transport, freig...
01.16%	electricity production, hydro, run-of-river, renewable energy pro...
00.64%	transport, freight, lorry 16-32 metric ton, EURO1 | transport, freig...
00.15%	heat production, mixed logs, at wood heater 6kW | heat, central ...
00.00%	lime production, milled, loose | lime | Consequential, S - RoW
-02.96%	treatment, sludge from pulp and paper production, landfarming ...

Impact category ⁝☰ :icity: non-carcinogenic - human toxicity potential (HTPnc)

Contribution	Process
100.00%	White manila paper production -Anmol products ethiopia plc - ET
46.75%	treatment of waste plastic, mixture, open dump, dry infiltration c...
21.73%	treatment, sludge from pulp and paper production, landfarming ...
18.59%	sulfate pulp production, from hardwood, bleached | sulfate pulp,...
05.09%	transport, freight, lorry 16-32 metric ton, EURO2 | transport, freig...
02.03%	maize starch production | maize starch | Consequential, S - RoW
01.70%	transport, freight, lorry 16-32 metric ton, EURO4 | transport, freig...
01.53%	aluminium sulfate production, powder | aluminium sulfate, pow...
01.13%	alkylketene dimer sizing agent production, for paper production |...
00.85%	transport, freight, sea, container ship | transport, freight, sea, con...
00.73%	batch dyeing, fibre, cotton | batch dyeing, fibre, cotton | Conseq...
00.58%	transport, freight, lorry 16-32 metric ton, EURO1 | transport, freig...
00.26%	electricity production, hydro, run-of-river, renewable energy pro...
00.17%	heat production, mixed logs, at wood heater 6kW | heat, central ...
00.00%	lime production, milled, loose | lime | Consequential, S - RoW
-01.14%	sulfate pulp production, from softwood, unbleached | sulfate pul...

Impact category ⁝☰ ozone depletion - ozone depletion potential (ODPinfinite)

Contribution	Process
100.00%	White manila paper production -Anmol products ethiopia plc - ET
47.79%	treatment, sludge from pulp and paper production, landfarming ...
20.81%	maize starch production | maize starch | Consequential, S - RoW
15.70%	sulfate pulp production, from hardwood, bleached | sulfate pulp,...
10.87%	alkylketene dimer sizing agent production, for paper production |...
02.44%	transport, freight, sea, container ship | transport, freight, sea, con...
01.54%	heat production, mixed logs, at wood heater 6kW | heat, central ...
01.44%	transport, freight, lorry 16-32 metric ton, EURO2 | transport, freig...
00.54%	transport, freight, lorry 16-32 metric ton, EURO4 | transport, freig...
00.24%	batch dyeing, fibre, cotton | batch dyeing, fibre, cotton | Conseq...
00.21%	aluminium sulfate production, powder | aluminium sulfate, pow...
00.17%	transport, freight, lorry 16-32 metric ton, EURO1 | transport, freig...
00.05%	electricity production, hydro, run-of-river, renewable energy pro...
00.00%	lime production, milled, loose | lime | Consequential, S - RoW
00.00%	treatment of waste plastic, mixture, open dump, dry infiltration c...
-01.80%	sulfate pulp production, from softwood, unbleached | sulfate pul...

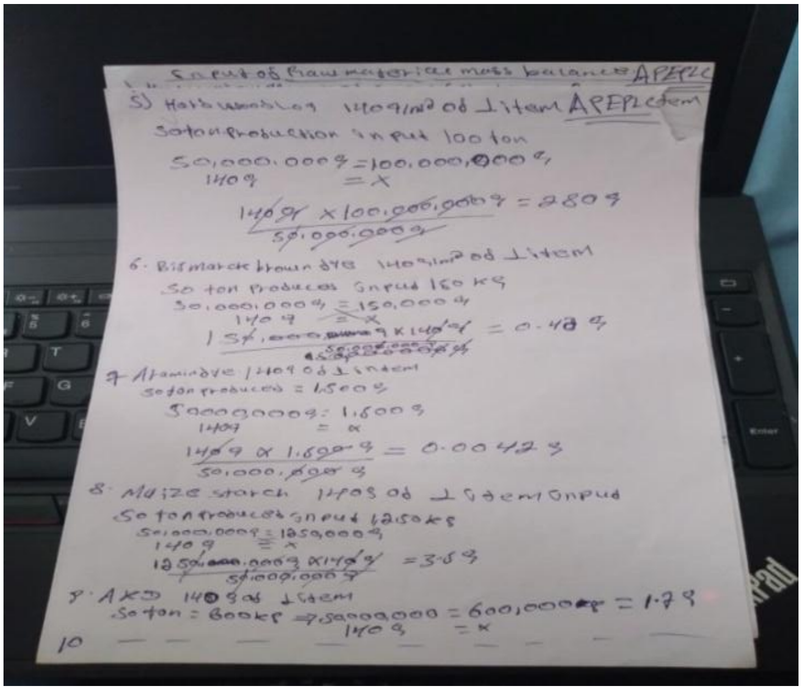
Yellow manila paper production -EPPSC

Flow: Heat,paperdry /Emission/air /low population density - ET

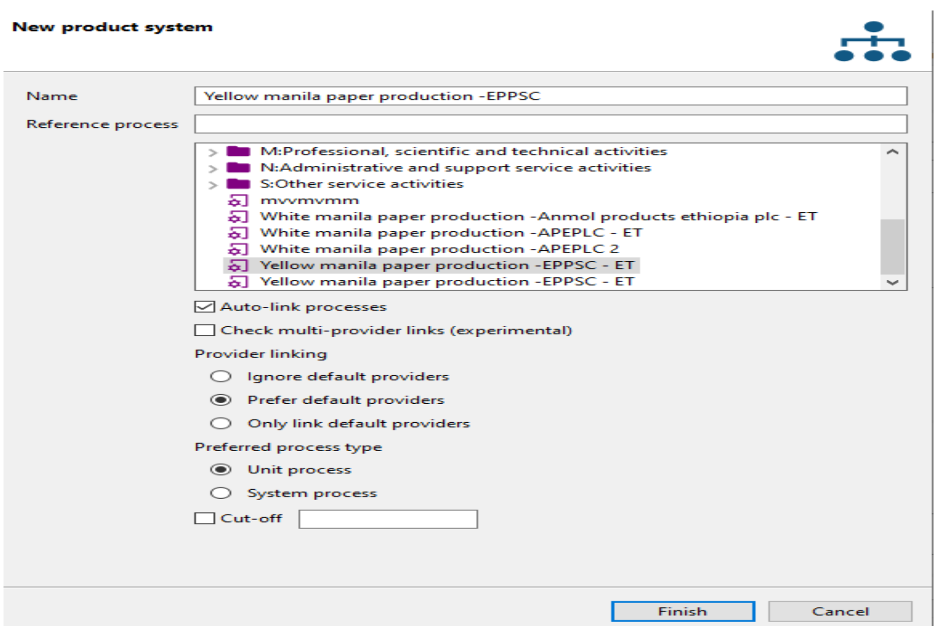
Impact category: ⁝☰ ıtion: freshwater - freshwater eutrophication potential (FEP)

Contribution	Process	Required amount	Total result [kg P-Eq]	Direct contribution [kg P-Eq]
100.00%	Yellow manila paper production -EPPSC - ET	1.00000 Item(s)	2.38257E-5	
42.36%	batch dyeing, fibre, cotton | batch dyeing, fibre, cotton | Consequential, S - RoW	0.01000 kg	1.00937E-5	1.00937E-5
26.27%	polyacrylamide production | polyacrylamide | Consequential, S - GLO	0.00800 kg	6.25976E-6	6.25976E-6
15.32%	aluminium sulfate production, powder | aluminium sulfate, powder | Consequential, S - RoW	0.00900 kg	3.64998E-6	3.64998E-6
12.15%	maize starch production | maize starch | Consequential, S - RoW	0.00700 kg	2.89505E-6	2.89505E-6
03.01%	treatment, sludge from pulp and paper production, landfarming | sludge from pulp and pape...	0.00800 kg	7.17393E-7	7.17393E-7
00.96%	electricity production, hydro, run-of-river, renewable energy products | electricity, high volta...	0.45180 MJ	2.29791E-7	2.29791E-7
00.20%	transport, freight, lorry 16-32 metric ton, EURO3 | transport, freight, lorry 16-32 metric ton, EU...	0.00234 t*km	4.87681E-8	4.87681E-8
00.20%	transport, freight, lorry 16-32 metric ton, EURO2 | transport, freight, lorry 16-32 metric ton, EU...	0.00322 t*km	4.67887E-8	4.67887E-8
00.07%	transport, freight, sea, container ship | transport, freight, sea, container ship | Consequential, ...	0.03410 t*km	1.66539E-8	1.66539E-8
00.00%	treatment of waste plastic, mixture, open dump, dry infiltration class (100mm) | waste plastic,...	0.00650 kg	0.00000	
-00.07%	sulfate pulp production, from softwood, unbleached | sulfate pulp, unbleached | Consequent...	0.00012 kg	-1.66791E-8	-1.66791E-8
-00.48%	sulfate pulp production, from hardwood, bleached | sulfate pulp, bleached | Consequential, S...	0.00055 kg	-1.15484E-7	-1.15484E-7

Appendix10. The converted obtained data to per functional unit example



Appendix11. Selected product system created process in open LCA 2.0 .4



Appendix12 .Manila paper product