Cradle-to-Gate Life Cycle Assessment of Jute and Plastic in Bangladesh

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Abstract. Nowadays, with increasing concerns over environmental sustainability and resource management, evaluating the environmental impacts of two prominent materials, plastic and jute from their inception to production (Cradle to Gate) becomes crucial. Recent worldwide discussions on sustainable development and environmental stewardship have raised concerns about manufacturing procedures and materials. This research will evaluate and compare the whole life cycle of these two materials in the context of the nation's industrial environment to answer this vital requirement. The life cycle assessment (LCA) methodology is a technique used to quantify the environmental effects of various manufacturing processes. The software used to conduct the LCA is OpenLCA in combination with the database ecoinvent 3.8. Specifically, this research is aimed to compare the environmental impact of the described material processes. The primary objective of the study is to comprehensively evaluate and compare the environmental impacts associated with the entire life cycle of jute and plastic. The outcomes derived from the use of the software are obtained for a unit mass of 1 kilogram of jute and plastic. The global warming potential (GWP) of jute is 0.0267 kg CO_2-Eq, whereas the GWP of plastic is 0.634 kg CO_2-Eq. This implies that plastic is around 23 times more detrimental to the environment than jute when it relates to causing climate change. In addition, some conclusions and suggestions are provided based on the results of the other impact categories. Since the data are only given by the ecoinvent database, site-specific variations in the data were taken into consideration.

Keywords: Life-cycle assessment, Environmental impact, OpenLCA software, Climate Change.

1 Introduction

In a world where people are becoming more aware of their environmental impact and working toward sustainable behaviours, selecting the right materials for different purposes becomes essential. The evaluation of the life cycles of various materials has emerged as an important tool for understanding the environmental implications that are linked with the production and use of these materials. In Bangladesh, a country known

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for its extensive agricultural history and developing industrial base, a comparison of two materials that seem to be quite different from one another, jute and plastic, serves as an enlightening and fascinating case study in this effort to pursue sustainability [1]. There are few cradle-to-gate life cycle evaluations evaluating the environmental implications of jute and plastic manufacturing in Bangladesh. Bangladesh is a major player in the jute and plastic sectors, but current research concentrates on individual materials rather than entire life cycles. Because of this disparity, it is difficult to evaluate the ecological consequences of these substances and make informed choices on sustainable resource utilization. Bangladesh also faces environmental issues including waste management and resource depletion.

Plastic pollution is one of the most significant challenges that marine ecosystems are experiencing in the modern era [2]. Approximately 14 million tons of trash made of plastic are dumped into the waters of the globe each and every year [3]. This has serious consequences for the health of human life as well as the environment [4]. In general, plastics are manufactured from organic material that is either synthetic or semi-synthetic [5]. cellulose, coal, natural gas, salt, and crude oil are the basic elements that are used in the production of plastic. The majority of the plastics used in manufacturing processes are produced using petrochemical products [6]. But in Bangladesh's perspective, most plastic resins are recycled from plastic products.

On the other hand, jute is a natural fiber that offers a variety of benefits to the surrounding environment. jute, often referred to as the "golden fiber," is a fitting name for this natural vegetable fiber known for its yellowish-brown, shiny appearance [7]. It is a resource that can be renewed every year and has a substantial production of biomass rate per unit of land area. Furthermore, since jute products are biodegradable, they break down into the soil when their useful lives have been completed [8]. Despite the widespread belief that synthetic materials are responsible for many of the world's issues, natural fiber goods have been shown to be completely harmless. However, global warming is now one of the most significant problems that the globe is currently experiencing. Therefore, the cultivation of fiber crops has a restricted effect on the environment. During the post-harvest processing phases, the process of extracting fibers requires the use of fossil energy and water resources, resulting in the generation of waste from biomass [9]. It is seen that fiber crops convey environmental advantages in terms of decreased levels of CO_2 and greenhouse gas emissions, as well as lower use of fossil energy.

The Life Cycle Assessment (LCA) method was developed during the early 1980s [10]. Its end result is a systematic categorization and measurement of the environmental effects and the ecological consequences of a product's complete life cycle. LCA makes it feasible to account for all the substances and energy flows that enter the production systems, while at the same time keeping track of outputs (products, energy, and waste materials) all the way through the production cycle [11]. LCA is also an efficient tool for quantitatively assessing the material flows and environmental implications throughout the life cycle of a production system [12]. Life cycle assessments (LCA) that follow the "cradle-to-gate" methodology assess the environmental impact of a product all the way up to the point at which it exits the manufacturing process. This indicates that the findings of the impact on the environment do not include the footprint of product usage by consumers or the procedures associated with the product's end of life [13].

Life Cycle Assessment of jute and plastic can provide valuable insights into which material has a lower environmental footprint throughout its life cycle. It helps in promoting sustainable practices and aligning material choices with environmental conservation goals [14]. It also evaluates the resource utilization of jute and plastic from cradle to gate and offers insights into how efficiently these materials use natural resources such as land, water, and energy [15]. This information is essential for responsible resource management, especially in a resource-constrained world. It can contribute to consumer awareness by highlighting the environmental implications of choosing products made from jute or plastic. Informed consumers can make choices that align with their values and environmental concerns, potentially driving market demand for more sustainable products [10]. However, conducting a life cycle assessment of jute and plastic is very essential in the context of Bangladesh. Also, this kind of study has remained unstudied yet in Bangladesh.

Thus, the primary objective of the study is to comprehensively evaluate and compare the environmental impacts associated with the entire life cycle of jute and plastic production in Bangladesh. Finally, the objective is to identify a material with a lower impact on the environment in Bangladesh.

2 Methodology

2.1 Methodological approach

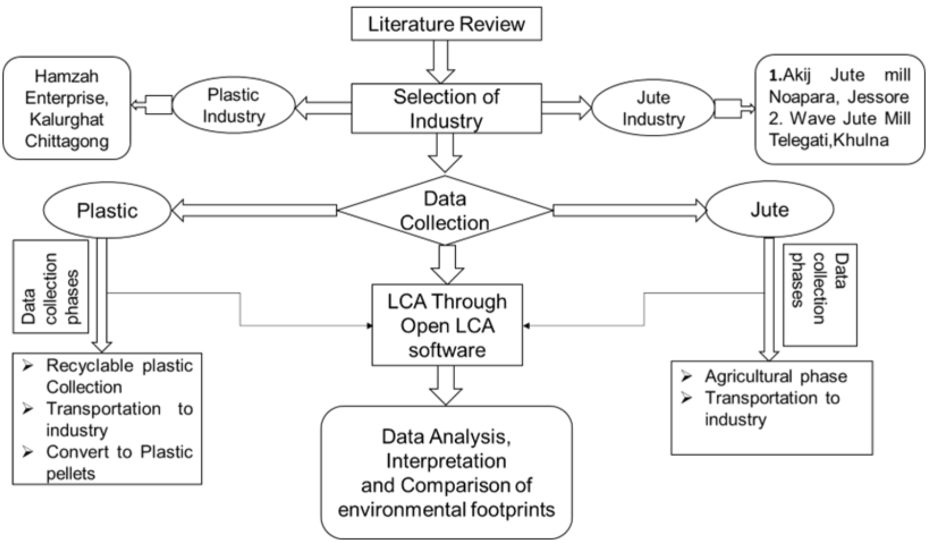

Fig. 1. Flowchart showing the sequential steps in the research work

2.2 Site Selection

The selection of where to conduct the study is an essential component of the overall design. It has been determined with much consideration where and how the data will be gathered and evaluated so that the results of the research will be accurate and relevant to the situation being investigated. The locations that were chosen for this research were chosen to be representative of a wide variety of geographical and economic environments. For conducting an LCA of plastic, Hamzah Enterprise, Kalurghat, Chittagong is selected. The geographic coordinates of this location are 22° 23' 20" N and 91° 52' 10" E. Both Akij Jute Mill and Wave Jute Mill are selected for jute. The Akij jute mill is situated at Noapara in the district of Jessore between latitude 23° 10' 11" N and 89° 12' 49" E. But the head office of Akij Jute Mills is situated at Tejgaon, Dhaka. On the other site, Wave Jute Mills is situated at Teligati, Khulna. The geographic coordinates of wave jute mills are 23° 11' 2" N and 89° 29' 54" E. The necessary data were collected from these two industries and interpreted the data for conducting the LCA of jute. The socio-demographic, climatic, and environmental aspects of these study areas are crucial for contextualizing the jute and plastic cradle-to-gate life cycle evaluation. Jute farming and processing support rural and semi-urban inhabitants in the areas. The socioeconomic dynamics and cultural practices in these places affect jute production resource consumption and trash creation. Jute cultivation strategies and water needs depend on the subtropical climate in both locations, with different wet and dry seasons. Kalurghat near Chittagong, selected for its plastic manufacture, is a busy coastal industrial center. The plastic manufacturing sector affects local employment and economic activity in this urbanized area. The region's tropical climate, with high temperatures and humidity, affects plastic production and energy consumption and may provide distinct environmental concerns.

2.3 LCA Methodology

Life cycle assessment is conducted in accordance with the International Standards Organization's 14040 and 14044 instructional guidelines in four phases. These four phases which are interconnected with each other consist of:

1) Goal and Scope
2) Life Cycle Inventory Analysis
3) Life Cycle Impact Assessment
4) Interpretation

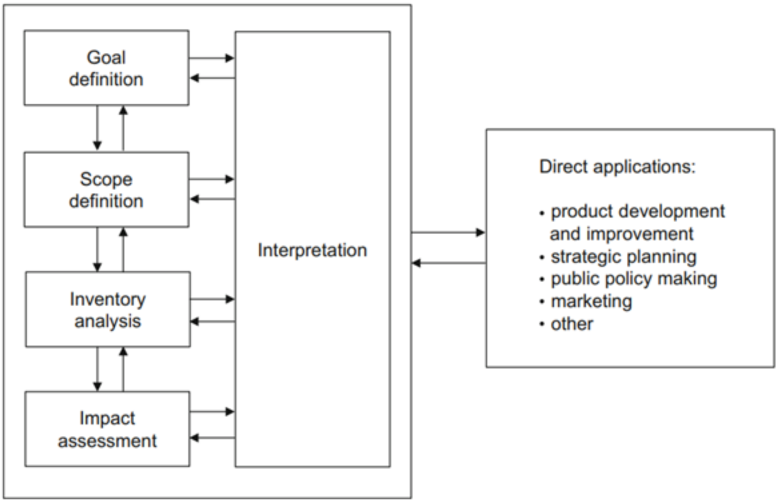

Fig. 2. Framework of LCA [16]

Goal and Scope. The aim of this research is to analyze the environmental footprint of jute and plastic. Another goal is to compare the environmental impact of jute and plastic. Finally, to determine which material has a lower environmental footprint in Bangladesh. The evaluation of the life cycle impact of jute and plastic was carried out using a "cradle-to-gate" methodology. The cradle-to-gate method for jute production may be divided up into two subphases. These include the cultivation of jute plants, the manufacture of jute fiber, and the transport of raw jute from farms to mills where it may be further processed. On the other hand, plastic can be divided into three different sub-phases. These are the collection of recyclable plastic materials, transportation to the plastic factory, and subsequently manufacture of plastic pellets.

Life Cycle Inventory. A preliminary method and fundamental sequence of action for carrying out the LCA research may be derived from the study's declaration of its goals and scope. Data collection and the technique for calculating results are at the basis of the life cycle inventory. An account of all of the mass and energy that goes into and comes out of the life cycle systems defines what the life cycle inventory is. For each functional unit, the inputs and outputs are given in expression form. Data was gathered and input and output were assigned to the separate processes as part of the inventory analysis. The data on inputs and outputs from each step of the life cycle are aggregated and then used to build the inventory table. The life cycle inventory provides a complete overview of the process tree, the system boundaries, the data collecting, the allocation of data, and a table that results in the inventory product-wise.

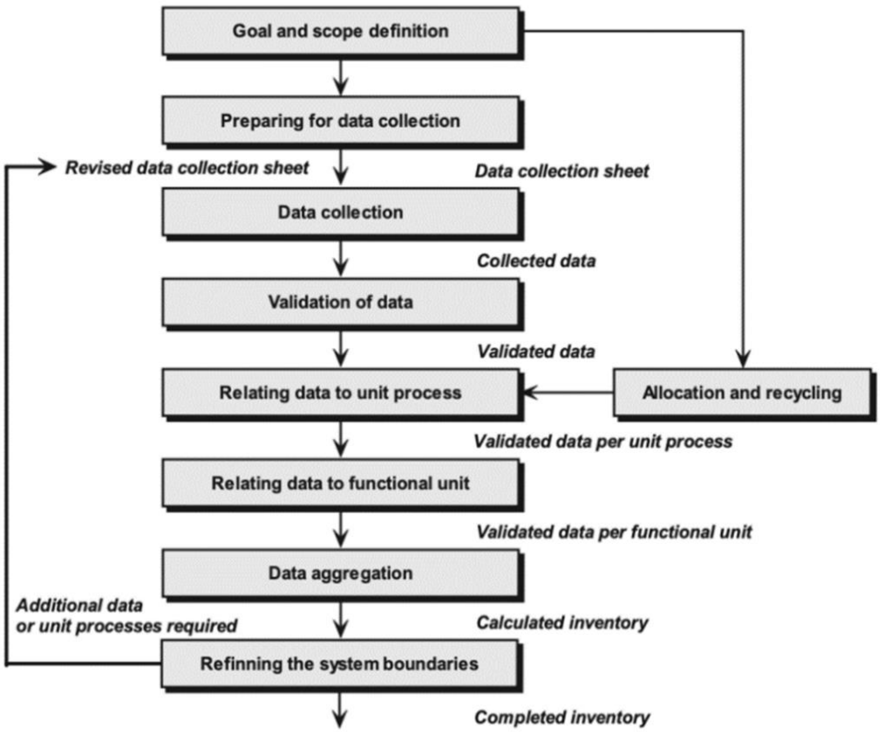

Fig. 3. Life Cycle Inventory operational procedure [17]

Functional Unit. A functional unit refers to a quantitative representation of the function or service being evaluated. It serves as a framework for identifying the reference flow of the product, which in effect governs the data-collecting process in the subsequent phase of life cycle assessment, known as inventory analysis [16].
Functional unit 1: 1kg of plastic
Functional unit 2: 1kg of jute

Life Cycle Impact Assessment. The Life Cycle Assessment (LCA) approach, which permits the thorough evaluation of a product or system's environmental performance across its entire life cycle, includes an important step called impact assessment. During the phase of life cycle impact assessment, several issues relating to the environment, which are referred to as impact categories, are illustrated, and category indicators are used to summarize and interpret the LCI results. These category indicators are supposed to illustrate the potential effect of the product system and reflect the aggregate emissions or resource consumption that are associated with each category.

Following the guidelines established by ISO 14040, the impact evaluation has five parts. These are selection and classification, characterization, normalization, grouping, and weighting. All the elements are considered during the LCA of jute and plastic. Life cycle assessment of plastic and jute are based on ReCipe-Midpoint (H) indicators in this study. Classifying inventory data according to substance flows that may contribute to an identical environmental effect is an important part of doing an impact evaluation utilizing midway impact indicators. A more comprehensive evaluation of the possible effects of environmental actions may be achieved by putting these factors together. Identification qualities that are particular to the impact category in concern are used throughout this evaluation. Eco indicators consist of three distinct harm types: resource consumption, human health, and ecosystems. Each of these types involves one of eighteen impact categories. The impact categories and their units used in this research are shown here.

Table 1. Impact Categories and their Units[19]

Midpoint Impact Categories	Units
Agricultural land occupation - ALOP	m^2
Climate change - GWP100	kg CO_2-Eq
Fossil depletion – FDP	kg oil-Eq
Freshwater ecotoxicity - FETPinf	kg 1,4-DCB-Eq
Freshwater eutrophication – FEP	kg P-Eq
Human toxicity – HTPinf	kg 1,4-DCB-Eq
Ionising radiation - IRP_HE	kg U235-Eq
Marine ecotoxicity - METPinf	kg 1,4-DCB-Eq
Marine eutrophication - MEP	kg N-Eq
Metal depletion – MDP	kg Fe-Eq
Natural land transformation - NLTP	m^2
Ozone depletion - ODPinf	kg CFC-11-Eq
Particulate matter formation - PMFP	kg PM_{10}-Eq
Photochemical oxidant formation - POFP	kg NMVOC
Terrestrial acidification - TAP100	kg SO_2-Eq
Terrestrial ecotoxicity - TETPinf	kg 1,4-DCB-Eq
Urban land occupation - ULOP	m^2
Water depletion – WDP	m^3

Interpretation. The interpretation phase involves the analysis and correlation of the results with the goals and scope of the research. During this phase, conclusions may be generated, limitations can be acknowledged and suggestions can be provided based on the findings from the earlier phases of Life Cycle Assessment (LCA). Hence, it was essential to assess the outcomes in order to determine the scope of the ecological harm caused by plastic and jute materials. Based on the findings of the impact study, it is recommended to practice concern while using plastic and jute materials.

2.4 Data Source and System Boundaries

Accessibility to the data from the Life Cycle Inventory that was used in this evaluation was obtained via the ecoinvent database version 3.8. Ecoinvent is one of the most well-known life cycle assessment (LCA) databases in the world, and it is used by over 5000 corporations all over the globe [19]. There are about 18000 reputable datasets included throughout the database, which includes worldwide industrial life cycle assessment data on the supply of energy, resource extraction, supplies of materials, substances, metals, agriculture, waste disposal services, and transportation services [20]. The ecoinvent database relies on a collected methodology for cut-off, which aims to comprehensively indicate all datasets by including all by-products and potentially recyclable materials.

System boundaries are established in accordance with LCA goals. The establishment of a system boundary is crucial because it establishes the parameters that are pertinent to our research and those that are not. It differentiates the entire product system from its environs, which are negligible to the study and have virtually no effect. In order to accomplish this, cut-off criteria are implemented, which effectively mitigates the system's complexity to a feasible degree. The term "cut-off criteria" is used to define the standards that determine which unit processes or product systems will not be included in a research based on the volume of material or energy flow or the degree of environmental relevance.

3 Results and Discussion

The following section presents the numeric values associated with each environmental impact category. OpenLCA software was conducted to evaluate the environmental impact category and the Re-Cipe Midpoint (H) method was used in the software. The graphs show schematically the comparative results for all the impact categories evaluated for the phase (cradle-to-gate) of 1kg jute and 1 kg plastic. The findings are obtained by doing a life cycle assessment using openLCA software, without include the normalization and weighing procedures (which are not mandatory according to ISO 14040 and 14044), and without completing sensitivity analysis. Nevertheless, they provide a concise evaluation of the environmental feasibility of both jute and plastic materials by simple analysis.

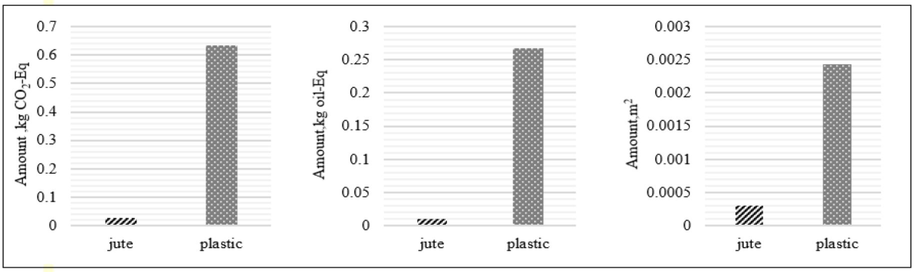

Fig. 4. Impact category results (Climate Change, Fossil Depletion, Agricultural land occupation)

Fig. 4 illustrates the outcome of the effect categories for plastic and jute, which include climate change, fossil depletion, and agricultural land occupation. Climate change refers to the continuous alterations in the typical weather patterns that have impacted the climate of the world. These modifications may arise spontaneously due to phenomena such as major volcanic eruptions or fluctuations in solar radiation. Carbon dioxide and methane are the main greenhouse gases accountable for the indicated climate change. However, in this study, the global warming potential is quantified by expressing it as the equivalent quantity of carbon dioxide (CO2 -Eq) [21]. In the case of climate change, the amount of jute is calculated as 0.0267 kg CO_2-Eq and the amount of plastic is 0.634 kg CO_2-Eq. In the process of producing fuel, energy, and other inputs like mineral fertilizer, the main exploitation of fossil fuels leads to fossil depletion, which in turn reduces the future supply of fossil fuels. For fossil depletion, the value of jute is 0.011 kg oil-Eq and the value of plastic is 0.2672 kg oil-Eq. The value of jute and plastic is 3.027E-4 and 2.426E-3 m^2-Eq. in case of agricultural land occupation.

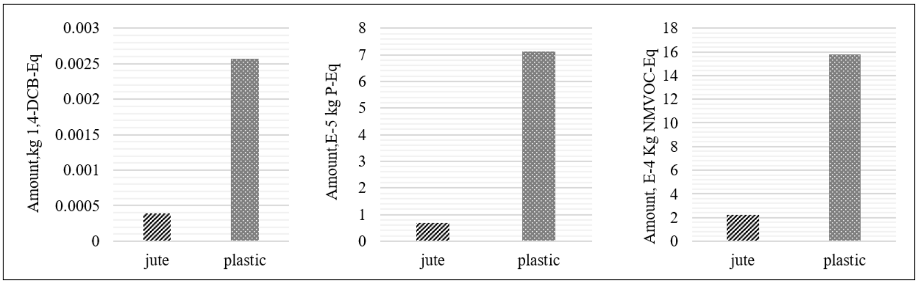

Fig. 5. Impact category results (Freshwater Ecotoxicity, Freshwater Eutrophication, and Photochemical Oxidant formation)

Fig. 5 shows the results of three impact categories. These are freshwater ecotoxicity, freshwater eutrophication, and photochemical oxidant formation. The values of freshwater ecotoxicity are 3.95E-5 and 2.97E-3 kg 1,4 DCB-Eq in the case of the production of jute and plastic. The value of jute for freshwater eutrophication and photochemical oxidant formation are 6.982E-6 kg P-Eq and 2.21E-4 kg NMVOC-Eq. And for plastic, the values are 7.122E-5 kg P-Eq and 1.58E-3 kg NMVOC-Eq. Hence the value of plastic is more than the value of jute.

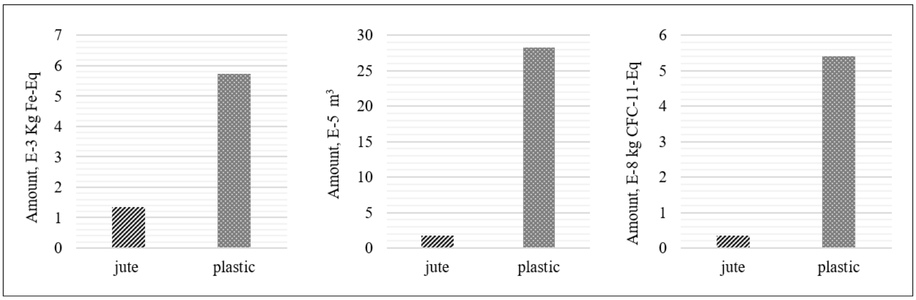

Fig. 6. Impact category results (Metal depletion, water depletion, and ozone depletion)

Fig. 6 shows the different types of depletion like metal depletion, water depletion, and ozone depletion of jute and plastic. Metal depletion is the process by which metal resources in a certain area or the world are diminished or used up as a result of human activity. The value of metal depletion is 1.348E-3 kg Fe-Eq for jute and 5.74E-3 kg Fe-Eq for plastic. Using a 100-year time horizon, The Ozone Depletion Potential (ODP) quantifies the detrimental effects on the stratospheric ozone layer. For water depletion and ozone depletion, the value of plastic is higher than jute.

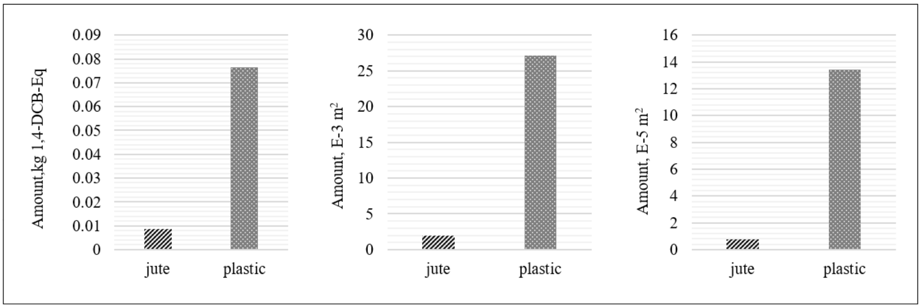

Fig. 7. Impact category results (Human toxicity, Urban land occupation, and natural land transformation)

Human toxicity is the term for the detrimental impacts that chemicals or agents can have on the bodies of people. The value of human toxicity is 8.788E-3 kg 1,4 DCB-Eq for jute and 0.0765 kg 1,4 DCB-Eq for plastic. The value of urban land occupation and natural land transformation is measured in m^2. Both this impact category value of plastic is higher than jute. The value of natural land transformation is 7.7E-6 m2 and 1.34E-4 m^2 for both jute and plastic. In case of urban land occupation, the value of plastic is around 14 times higher than jute.

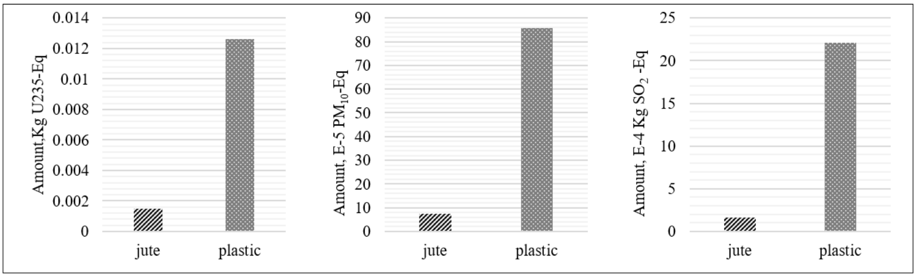

Fig. 8. Impact category results (Ionizing radiation, Particulate matter formation, and Terrestrial acidification)

Fig. 8 shows the impact category result of ionizing radiation, particulate matter formation, and terrestrial acidification. Ionizing radiation is a kind of energy that works by stripping electrons from air, water, and biological tissue, among other things [22]. These materials are susceptible to ionizing radiation, which may move undetected. The value of ionizing radiation in the case of jute is 1.51E-3 and in the case of plastic 0.0126 kg U-235-Eq. The value of PM formation is 7.5E-5 kg PM_{10} for jute and for plastic, the value is 12 times higher than jute.

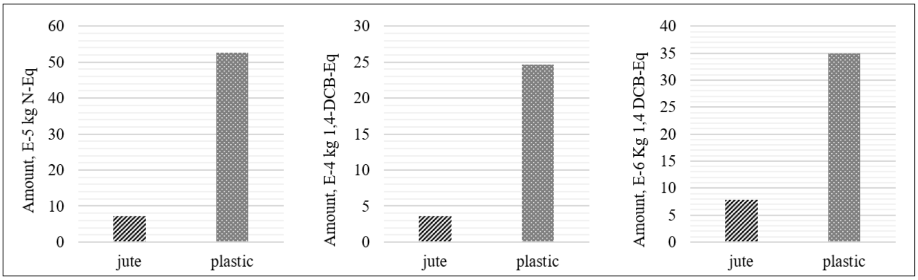

Fig. 9. Impact category results (Marine Eutrophication, Marine Ecotoxicity, and Terrestrial Ecotoxicity)

Fig. 9 shows the impact category result of marine eutrophication, marine ecotoxicity, and terrestrial ecotoxicity. The value of marine eutrophication is calculated by the software and is found 2.278E-5 kg N-Eq for jute and 5.272E-4 kg N-Eq for plastic respectively. The value of marine ecotoxicity is 3.651E-4 kg 1,4 DCB-Eq for jute and for plastic, the value is 2.1E-3 kg 1,4 DCB-Eq more than the value of jute. In the case of terrestrial ecotoxicity, the values of jute and plastic are 7.85E-5 and 3.49E-5 kg 1,4 DCB-Eq respectively.

The findings of the relative indicator analyses for jute and plastic are shown in the following chart. Using the openLCA software, the maximum outcome of plastic is set to 100% for each indication, and the results of the jute are presented in proportion to the result of plastic after comparison. It is seen that plastic has the most impact on the environment compared to jute. Among all the eighteen impact categories jute has the most impact on urban land occupation. Other impact categories are much less than plastic.

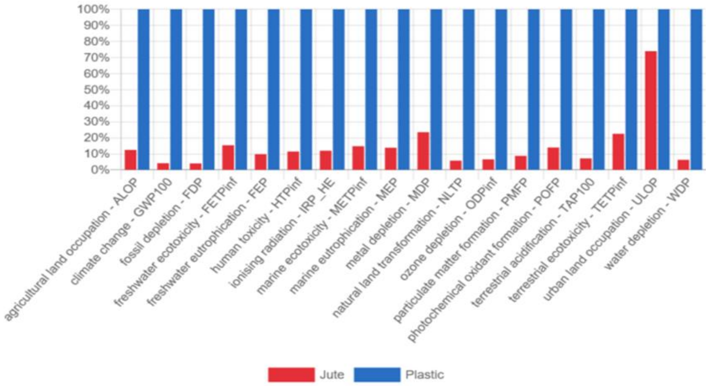

Fig. 10. Relative Life Cycle Impact Assessment (LCIA) results of jute and plastic

4 Conclusions and Recommendations

Research on the environmental effects of plastic and jute in Bangladesh generated important findings from a cradle-to-gate life cycle assessment (LCA). In order to better understand the environmental impacts of the manufacturing process, this research evaluated many steps, beginning with the extraction or cultivation of raw materials and ending at the gate of production. This study compares the environmental impacts of jute and plastic using the cradle-to-gate approach. Depending on the perspective, the assertions change, as shown in the research. Compared to jute yarn, plastic has greater negative effects on global warming when produced in the same amount. Looking at the material's possible future applications and adaptations, LDPE bags may have less of an impact on global warming than jute bags. The various effect categories also cause the assertions to change. In comparison to 1kg jute and 1 kg LDPE plastic, the global warming potential (GWP) of plastic is around 23 times higher than jute. Furthermore, analyzing the other impact categories it is seen that plastic is more harmful than jute. Emissions contributing to global warming are a significant source of concern, and the vast majority of industrialized countries like Bangladesh have pledged to reduce such emissions. This research affects Bangladesh's economic growth, environmental sustainability, and policymaking. A cradle-to-gate life cycle study of jute, a vital part of the economy, reveals environmental concerns and possible improvements. The findings may help the jute industry become more environmentally friendly by promoting sustainable introduction and manufacturing. The alignment of Bangladeshi jute products with global sustainability standards might decrease environmental consequences and boost their market competitiveness. This research examines the environmental impact of plastic manufacture in Kalurghat, Chittagong. Bangladesh has a major plastic waste management problem; therefore, the study's results may help reduce plastic's environmental effects. Policymakers may utilize this data to design sustainable plastic production restrictions and encourage eco-friendly alternatives. In addition, the research may change public perception and consumer behaviour to promote sustainable plastic use. So, the use of jute as a predominant material across various industries has the potential to contribute to a more sustainable and environmentally conscious trajectory for Bangladesh.

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