Final Project Report

Environmental impact Assessment of Jute bags vis-à-vis PP/HDPE based alternatives for packaging:

A Life Cycle Perspective

The Energy and Resources Institute

...towards global sustainable development

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Foreword

In today's world with rapid growth in consumption worldwide, the demand for packaging materials is increasing at a rapid rate. Consequently, the amount of packaging materials used is increasing at a high rate which can be attributed to changing lifestyles and population growth; this has given rise to various ecological and environmental problems. As a result, packaging needs to ensure that it does not become a problem in itself while also ensuring that it prevents contamination of or damage to the material packaged, or alteration of its properties.

In view of environmental concerns, that have been raised in recent times, proper waste management and disposal strategies of packaging materials have been explored to minimize their environmental impacts. However, disposal is only one aspect that needs to be addressed; it has to be seen within the context of the entire life cycle of packaging material, from cradle (raw material) to grave (disposal). The use of non-biodegradable packaging in large quantities is creating an ecological hazard which has become unmanageable, largely because the management of this is expensive to society on a life cycle basis. It has been a delight for us at TERI to have worked with the Indian Jute Mills Association and National Jute Board to prepare this report, which we believe, is the first step in a longer campaign to enhance the use of jute and other environmentally friendlier packaging materials. The approach to packaging management therefore, worldwide is also to move away from pollution control to pollution prevention.

This report looks at life cycle impact of jute sacks vis-à-vis its plastic alternatives in order to come out with more environmentally friendly alternative for packaging industry.

In this context, we note that jute sacks produced from jute fibres have been used extensively in India (and around the world) for packaging of food grains, and are an example of best practice in the packaging sector. Jute fibres are 100 per cent biodegradable and provide breathability to the material packed in it. Its resilience to insects and other vermin allow farmers to use fewer pesticides during jute production, which in turn means less pollution of soil, water, and air by pesticide by-products. Jute, during its growth is also known for its high upstake of carbon dioxide, making its production beneficial for mitigating climate change. Furthermore, jute can be grown on harsh soils, such as that of saline-alkaline lands, and, after a few years of cultivation, it transforms the soil into arable land that can be used for food production. Jute is also 100 per cent recyclable, making it an excellent substitute for plastic in the production of home textile products. Finally, the waste from jute production can be used as a replacement for artificial fertilizers in compost.

Ajay Mathur
Director-General, The Energy and Resources Institute (TERI)
June 2017

Acknowledgement

The Energy and Resources Institute (TERI) and TERI University acknowledge the support provided by Indian Jute Mills Association and National Jute Board who commissioned this study and for facilitating visit of TERI/TERIU to Jute Mills and retting sites to understand the process of jute retting and manufacturing of jute sacks and providing data support. We are also indebted to research organisations – Central Research Institute for Jute & Allied Fibres (CRIJAF), Indian Jute Industries' Research Association (IJIRA) and National Institute for Research on Jute & Allied Fibre Technology (NIRJAFT) for sharing data and research concerning production and processing of jute fibres.

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1. Introduction

It has been very well understood that anything which is extracted from nature goes through a cyclic process called life cycle until it is again returned to nature in one form or another. The same is true for the packaging materials too along with the main products used in our day to day life. In today's world with rapid growth in consumption worldwide, the demand for packaging materials is increasing at a rapid rate, which is altering the economy of packaging materials at the regional and global level. Packaging is very important because of differential production and consumption pattern of goods over the globe, due to which goods have to be transported over long distances before they are finally utilized and consumed. Packaging should be such that it doesn't alter the properties or adds contamination to the material packaged, as well as it should not become a problem in itself. Presently, the amount of packaging materials used is increasing at a high rate which can be attributed to changing lifestyles and population growth; this has given rise to various ecological and environmental problems. Earlier, this was not perceived as such a big problem, because the amount of such waste generated was not so much as it has been today, and now it's becoming unmanageable. Therefore, environmental concerns have been raised in recent time as packaging materials, proper waste management, and disposal strategies have been explored to minimize the environmental problems. However, disposal is not the only problem to be addressed to minimize the environmental impacts of packaging, with this an emphasis should be given to it's the entire life cycle from cradle (raw material) to grave (disposal). The use of non-biodegradable packaging in large quantities has made it ecological hazard by itself and has become unmanageable, even if managed, it is expensive to the society on the life cycle basis. The approach worldwide is also to move away from pollution control to pollution prevention.

The current study aims at analyzing the life cycle impact of jute sack (B. Twills, ~580 gram bag)and HDPE woven sack (~135 gram bag, IS 14887-2000) production with packaging capacity of 50 kg of material.

2. Background

India accounts for more than 52 per cent of world's raw jute production, which stands at estimated 90 lakh bales (1620 thousand tonnes in 2016–17) as per the data of Jute Advisory Board. Out of this approximately 81 per cent of the production comes from state of West Bengal followed by ~12.4 per cent from Bihar, ~6 per cent from Assam, and remaining from other states such as Odisha and Madhya Pradesh. The soil and climatic conditions along with high humidity in West Bengal provide the best conditions for the growth of jute in such abundance. West Bengal being the highest producer of jute in India also has the highest number of jute mills because of easy availability of raw material within the state and workforce/workers. West Bengal is home for around 70 composite jute mills[1] out of total 93installed in India (JCI, 2015). Many researchers (Islam and Ahmed, 2012; Afrin, 2011; IIT Kharagpur, 2000) have observed that as compared to the huge negative impacts of the non-biodegradable materials, use of jute helps conserving the environment in many ways. This LCA study seeks to examine and compare the impacts of food grain bags made with jute as against other synthetic alternatives.

Polypropylene (PP) and high density polyethylene (HDPE) on the other hand are co-products of petroleum/natural gas industry produced either from naphtha (petroleum industry co-product) or natural gas. In India, PP demand increased from 1,535 KTA in 2006 to estimated 4715 KTA for the year 2016-17. It further observed that RIL continued to dominate in the Indian market with a major share of ~64 per cent.[2]

Major feedstock used in Indian petrochemical industry is Natural gas (~59 per cent) and Naphtha (~40) to which Gujarat contributed 59 per cent, Maharashtra 17 per cent, West Bengal 12 per cent, and remaining from other states. Natural gas is mainly used for olefin production and Naphtha is used for aromatic compound production (Ansari et al., 2008). Global polymer consumption of PE was 36 per cent and PP was 24 per cent out of the total polymer consumption. In 2010–2011, 269 KT of HDPE out of total 1481 KT was used in Raffia+MF, Similarly, 899 KT, of total 2,635 KT Polypropylene (PP) is used in Raffia industry (GOI, 2012). Out of total market share in plastic products, polyethylene has approximately 33.5 per cent share as compared to Polypropylene (19.5 per cent). In Asia and India, approximately 60 per cent of ethylene is produced from Naphtha (Basak *et al.*, 2001; Bhat *et al.*, 2010).

India has a ~2.9 MnTPA of PE production capacity out of which 1.6 MnTPA is HDPE capacity, 1 MnTPA is LLDPE and rest is LDPE capacity. PP and PVC also have the large production capacities, i.e., 3.7 MnTPA and 1.3 MnTPA respectively. PVC is one of the major products where capacity growth in past had been significantly lagging demand growth[3].

For production of 1 tonne of ethylene, 1.25 tonne of ethane is required; whereas, 3.17 tonnes of Naphtha is required for producing 1 tonne of ethylene (Bhat et al., 2010). Approximately 1.04kg of ethylene is required for production of 1 kg of HDPE and 1.02 kg Propylene is required for production of 1 kg of Polypropylene (Ansari et al., 2008). It is observed that ~2 per cent of HDPE is lost as waste at the HDPE sack manufacturing unit (MSME, 2011).

Literature suggests that the studies carried out to quantify the total impacts of jute and PP/HDPE sack manufacturing over their life cycle lacks comprehensiveness and there is scope to address the quantification of various environmental and ecological impacts over their life cycle. Knowing the fact that if anything has to be managed or corrected, first of all, it has to be quantified. The present study therefore covers the whole life cycle of jute and PP/HDPE sack production and quantifies and presents their comparative impacts on environment, human health, and ecosystem.

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[1] Composite jute mills are those where jute is processed into yarn and then yarn is woven into finished products

[2] http://www.businesswire.com/news/home/20140317005560/en/Research-Markets-India-Polypropylene-Report---Demand#.VXwbj_mqqko as accessed on 9th June 2015>

[3] FIICI report on plastic industry

3. Scope and objectives of the study

The main objective of the study is to estimate the overall environmental impact of jute bags vis-à-vis PP/HDPE-based alternative bags on the basis of their life cycle (Figure 1). This study considered all the life stages of bag production from the cradle (extraction or agricultural phase) to grave (end of life) and their impacts on human health as well as the quality of the ecosystem. The overall life cycle of bag manufacturing has been divided into the following four important stages with transportation of materials connecting all of them with each other and then finally to the end of life stage.

- **1st Phase:** Production of raw material (Agricultural/industrial extraction stage)
- **2nd Phase:** Manufacturing of sacks
- **3rd Phase:** Usage/Consumer (transportation of finished packaging material to the usage site/consumers)
- **4th phase:** Reuse and disposal of used packaging material

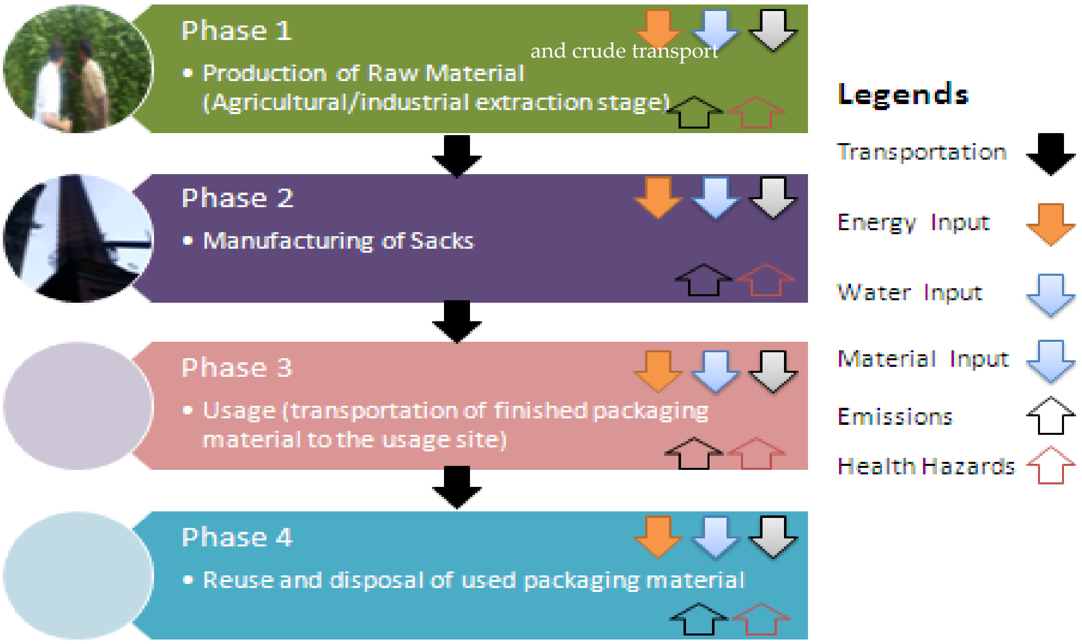

Figure 1: Life Cycle Phases of Jute/PP-HDPE bags

4. Methodology

The life cycle approach has been used by various researchers for assessing the environmental impact of various commodities over their production, use and disposal phases. It has been very well established as one of the key tools/methodology to help and guide on issues regarding adoption and continuation of various products, policies as well as for internal use of companies and industries to reduce their environmental footprints. The life cycle assessment (LCA) methodology has been well established as per the ISO 14040& 14044[4]/ series of standards which include

- ISO 14040:2006, Environmental management—Life cycle assessment—Principles and framework

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[4] http://www.iso.org/iso/home/news_index/news_archive/news.htm?refid=Ref1019

- ISO 14044:2006, Environmental management—Life cycle assessment—Requirements and guidelines, which replaced:
    - ISO 14040:1997, ISO 14041:1999, ISO 14042:2000 and ISO 14043:2000
    - International Standard ISO 14041:1999 for goal and scope definition and inventory analysis
    - International Standard ISO 14042:2000 for life cycle impact assessment
    - International Standard SO 14043:2000 for life cycle interpretation

ISO 14040 approach comprises of four basic steps to be carried out for carrying out a life cycle assessment study as shown in the Figure 2.

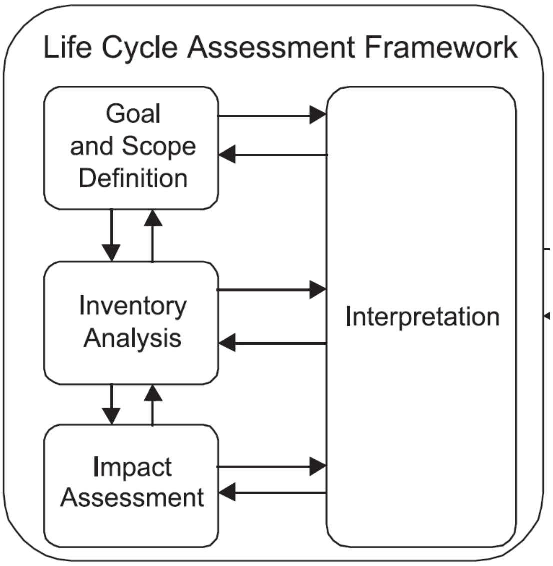

Figure 2: Phases of LCA (ISO 14040, 2006)

The goal of the study is to carry out a life cycle assessment of jute bags vis-à-vis PP/HDPE bags including the end of life phase (i.e. final disposal to land or recycling etc., in both cases) from cradle to grave.

The functional unit for the study is 50 kg bag/sack (bag with 50 kg packaging capacity) made up of jute and PP-HDPE. The weight of a jute bag used for packaging 50 kg of material is ~580 g[5]. So the reference flow of jute required for a 50 kg packaging bag manufacturing is 580 g. A typical PP/HDPE food grain packaging bag (50 kg capacity) weights around 135 gram, so reference flow for PP/HDPE bag is taken as 135 gram. Therefore, the current study will compare 580 gram jute sack with 135 gram PP/HDPE sack over the life cycle to highlight the environmental and ecological impacts associated with them.

In the current study, ReCiPe 2008 methodology has been used for calculating environmental impacts at midpoint and endpoint levels. Midpoint impact assessment method is based on the problem oriented approach and quantifies various impacts such as acidification, eutrophication, global warming potential, and human toxicity; whereas, endpoint impact method is based on damage oriented approach and gives results for various major impact

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[5] The jute industry has developed lighter 580 g bags for packing food grains. This has further increased the positional advantage of the jute vis-à-vis synthetic alternatives.

categories in terms of DALY (disability adjusted life year) for human health impacts, ecosystem quality and resource depletion. The Figure 3 below shows the relations between life cycle inventory results with midpoint and endpoint indicators while assessing damage to human health and ecosystem.

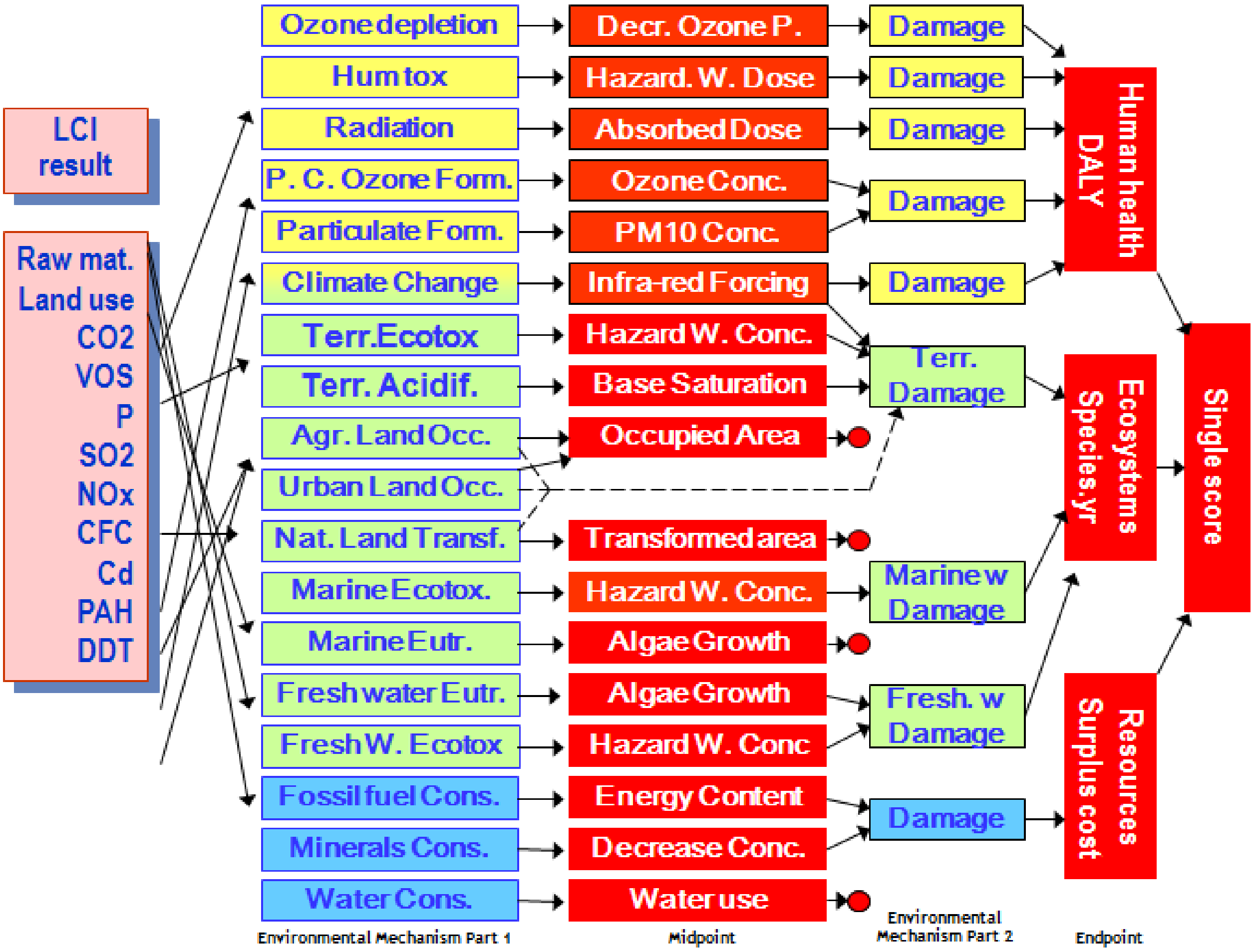

Figure 3: Relationship between midpoint and endpoint indicators in LCA

The endpoint indicators would also be influence by emission of sulphur dioxide (SO_2), oxides of nitrogen (NO_x), particulate matter, etc. from use of incinerator for managing waste discarded in the end.

5. Mass, energy and emission in the life cycle

5.1 Jute sack manufacturing

In the current LCA study, the system boundary chosen for jute sack manufacturing covers the operational phase of jute sack manufacturing from cradle (jute cultivation) to grave (disposal). The infrastructure phase (construction and de-commissioning of the buildings and machines) of any facility or technology has not been considered in the current study.

Based on the system boundary and functional unit, the data was collected to prepare Life Cycle Inventory (LCI) for jute sack manufacturing process. Before the start of data collection process, an intensive literature survey was undertaken regarding jute cultivation, its geographical distribution as well as jute sack manufacturing process and distribution of related industries in India. Literature survey indicated that West Bengal has the highest share in jute fibre production which stands at approximately 81 per cent (total 8,870,000 Bales or 159.7million tonnes) of total raw jute production in 2014–15, as well as ~75 per cent of the jute mills are located in West Bengal out of the jute sack manufacturing industry established in India (Jute Advisory Board). The literature review also helped in understanding various life cycle stages and processes involved in the jute sack manufacturing which resulted in preparation of basic data collection input sheets for a number of life cycle stages of the processes. The details of jute production and processing mills are presented in Tables 1 and 2 below.

Table 1: Raw jute production in India

S. No.	State	Raw jute production (2014–15) (000 Bales)[6]	% Production of raw jute
1	West Bengal	8870	80.8
2	Bihar	1365	12.4
3	Assam	656	6.0
4	Odisha	18	0.1
6	Others	75	0.7

Table 2: Geographical distribution of jute mills in India[7]

State	Number of jute mills	% Share of jute mills
Andhra Pradesh	9	9.68
Assam	2	2.15
Bihar	3	3.23
Chhattisgarh	2	2.15
Odisha	3	3.23
Tripura	1	1.08
Uttar Pradesh	3	3.23
West Bengal	70	75.27
Total	**93**	

Field visits were conducted in the agricultural fields in 24 Parganas North, Howrah, and Hooghly districts of West Bengal for data collection. In the first phase, interviews were conducted with people, which include fertilizer and pesticide dealers, farmers, aggregator (between farmers and jute mills), Jute Corporation of India (JCI), and daily wage labourers working in agricultural fields. In the second phase, visits to the jute mills were conducted in the 24 Parganas North district to collect industry specific data. During these visits,

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[6] One Bale is equivalent to 180 kg of raw jute fibre

[7] According to the data available with The Office of the Jute Commissioner, Kolkata in 2015

interviews and interactions were also conducted with the research institutes (including personal interviews with the scientists as well as group discussions) and different bodies functioning in the jute sector such as Indian Jute Mills Association (IJMA), Indian Jute Industries Research Association (IJIRA), Central Research Institute for Jute & Allied Fibres (CRIJAF), Jute Corporation of India (JCI), etc. For the usage and end of life phase of jute bags, questionnaire-based survey and interviews were conducted with the end user of the jute bags such as farmers, FCI, scrap dealers, etc. The data collected using combinations of methods adopted as mentioned above helped us to make comprehensive life cycle inventory for both processes at various life cycle stages. The important parameters from Life Cycle Inventories are highlighted in the subsequent sections.

Jute cultivation (Agricultural) phase

Based on available basic details about jute cultivation and review of literature, the mass and energy consumption in terms of various inputs (water, seeds and nutrients) is presented in Table 3 below.

Table 3: Mass and energy per kg of jute cultivation

Products[8]			**Resource Consumption**			**Material Consumption**[9]		
	Amount	**Unit**		**Amount**	**Unit**		**Amount**	**Unit**
Jute fibre	1	kg	**CO_2**	6.3[10]	kg	Urea, as N	0.009	kg
Jute stick	2.42	kg	**Water**	0.9[11]	m3	Pesticides	0.0006	kg
					m3	Phosphate , P_2O_5	0.002	kg
						Potassium Chloride, K_2O	0.0007	kg
						Jute seed for sowing	0.003	kg

The agricultural (jute cultivation) phase includes land preparation, seed sowing, irrigation, fertilization, pesticide application as well as retting to extract jute fibre from the plant as summarized in Figure 4. After land preparation through tillage and ploughing,~6.5 kg seeds are sown per hectare of land. This is followed by fertilizer application of ~50 kg urea and ~10 kg of phosphate and ~2 kg potassium chloride per hectare. There is very less requirement of pesticide application but at places based on need and the diseases prominent in the area, ~1.5 kg of pesticides are used which includes kelthane, quinalphos, and chlorpyriphos, etc.

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[8] Calculations are based on data collected through primary interactions with farmers as well as supported by research from Ingold and Thomsan, 1993, etc.

[9] Calculated and modified based on personal interview and ecoinvent database for jute cultivation in India.

[10] Calculated from Inagaki, 2000 and IJSG, 2003 "On an average in approximately 120 days of jute plant cycle, it absorbs ~15 MT of CO^2 at the same time liberating 11 MT of O2/hectare"

[11] Water consumption in Jute cultivation is mainly met by the surplus water availability from rain in the monsoon season. The water from the monsoon is also conserved in ponds nearby agricultural fields which at a later stage are used for retting purpose. Water consumption is adapted from Ecoinvent database of jute cultivation in India.

Figure 4: Jute cultivation (Agricultural)

The average cultivation cycle of the jute crop takes around 120 days from sowing till harvesting of the crop. After harvesting, the crop is left in the field for around 3–4 days where it sheds its leaves and then the stems are taken to the nearby water source (mostly small ponds and pits in West Bengal) for retting. The jute stems are left in the water for retting for around 18–20 days after which the fibre is extracted and washed manually. The extracted fibre is dried and sold to either the aggregator or to the JCI store on or above maximum selling price (MSP). The retting process results in release of CH_4 emissions and other pollutants which has potential adverse impact on the environment (Box 1); however, nutrients such as P, N, etc., released in water during retting process would be beneficial for the next crop as it enhances the soil fertility when this water is used for irrigation. Fertilizer application and the soil-crop relationship also results in exchange of nutrients between various spheres of the environment. Some of the emissions arising out of the agricultural phase are listed below in Table 4 for 1 kg of fibre production from the field.

Box 1: Methane Emissions from Jute: Perspective on the total methane emissions

The global methane emissions from anthropogenic sources from all sectors in 2010 were estimated to be 6,875 million metric tons CO_2 eq. ($MtCO_2eq$) of which agricultural sector accounted for 52.5 % (3,520 $MtCO_2eq$). Of which enteric fermentation (livestock rearing) contributed ~53%, rice cultivation ~18%, other agricultural activities ~18% and manure management ~11% to the total global agricultural sector methane emissions (Yusuf et al., 2012). Annual production of jute fibre in India in 2014-15 was 11182000 Bales, i.e., 2.0×10^{11} kg of jute fibre; methane emission per kg of jute fibre production is 4.754 g, so a total of 956866 (0.0095 $MtCO_2$ eq) kg of CH_4 is released from jute fibre production in India. So total contribution of jute cultivation to anthropogenic methane emission is 0.00014 %, which is insignificant as compared to other sources of methane emission.

Table 4: Emissions per kg of jute cultivation

Emissions to Air[12]			**Emissions to Water**[13]			**Emissions to Soil**[14]		
	Amount	**Unit**		**Amount**	**Unit**		**Amount**	**Unit**
NO_x	0.0001	kg	DOC	0.03	Kg	Nickel	0.0000002	kg
CH_4	0.005	kg	PO_4^-	0.00005	Kg	Zinc	-0.00003	kg
Water	0.4	m^3	COD	0.07	Kg	Parathion	0.00006	kg
NH_3	0.002	kg	Water	0.3	m^3	Cadmium	0.00000006	kg
N_2O	0.0006	kg	PO_4^-	0.0001	Kg	Oils	0.0005	kg
CO_2, fossil	21.3	g	TOC	0.3	Kg	Copper	-0.000003	kg
			Phosphorus	0.003	Kg	Mercury	-0.00000002	kg
			BOD_5	0.06	Kg	Lead	-0.000002	kg
			Nitrate	0.007	Kg	Chromium	0.00001	kg

As can be seen is this table, emissions to air, water and soil are negligible in jute cultivation phase.

The agricultural phase of jute cultivation results in two products, i.e., jute fibre and sticks which are locally used as fuel, so all material and energy can't be contributed to the jute fibre production alone, to avoid over estimation of life cycle impacts of jute fibre production, the

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[12] Calculated based on Bhatia et al., 2004 and Ecoinvent database for jute cultivation in India.

[13] Calculated and modified from ecoinvent database on rainfed jute cultivation in India.

[14] Emissions to the soil are adapted from the Ecoinvent database for rain fed jute cultivation in India.

* http://jute.org/IJSG%20Publications/Jute%20&%20kenaf%20Stat%20at%20a%20glance_ijsg.pdf

**http://jutecomm.gov.in/statewise%20P%20&%20R%20jute.htm

*** http://envfor.nic.in/sites/default/files/EXECUTIVE%20SUMMARY-PS%2BHRP.pdf field economic allocation method was adopted for estimating material and energy contribution for jute fibres. In the economic allocation method, the material and emissions are allocated to by-products based on their mass production from unit area as well as economic value of that product. The economic allocation coefficient was calculated using the following formula (Chen *et al.*, 2010):

$$C_e = \frac{(\$.m)_{by-product}}{(\$.m)_{main\ product} + (\$.m)_{by-product}}$$

Where, \$ = price per unit of material (in rupees) and m = mass of material produced. The price and per hectare production of raw jute in this case was taken from the average data on price and production of raw jute fibre over the past five years as provided by National Jute Board (NJB, 2013c – Table 5). Allocation values for jute fibre are presented in Table 6 below.

Table 5: Raw jute production and price in India

Production of Raw Jute					Price of Raw Jute	
Period	**Area (1000 Hectares)**	**Production (1000 Bales)**	**Yield (Bales/ Hectare)**	**Yield (Kg/Hectare)**	**Year**	**Average Price (Rs/Quintal)**
2008-09	786	9640	12.3	2207.6	2008-2009	1858.0
2009-10	811	11239	13.9	2494.5	2009-2010	2708.4
2010-11	774	10009	12.9	2327.7	2010-2011	3169.2
2011-12	809	10736	13.3	2388.7	2011-2012	2309.5
2012-13	777	10340	13.3	2394.0	2012-2013	2614.7
2013-14	756	11083	14.7	2646.0	2013-2014	2798.5
2014-15	760	10982	14.5	2601.0	2014-2015	3137.6
2015-16	-	10402	-	-	2015-2016	5044.4

Source: Directorate of Jute Development and Jute Bailer's Association

Table 6: Allocation value for jute fibre and jute sticks

Economic allocation		
	Jute Stick	**Fibre**
Average Yield per Ha[15]	5.8	2.4
Price per Ton[16]	2250.0	50444
Y x P	13050.0	121065.6
% Allocation	9.7	90.3

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[15] Jute to stick ratio is considered to be 1:2.42, this results into 5750.536 kg of stick production per hectare. (Also given to be around 5 by Ministry of textile http://texmin.nic.in/policy/Fibre_Policy_Sub_%20Groups_Report_dir_mg_d_20100608_3.pdf).

[16] Price for jute sticks is based on Based on discussion with National Jute Board. Jute sticks are used for making briquettes and used as fuel. Jute fibre price is not averaged as the price for 2015-16 has risen dramatically over past years.

Transportation of raw jute

Raw jute is grown all by lakhs of small farmers who do not have enough space to store jute fibre for long. Also, most of the jute crop is grown as cash crop and the farmer needs immediate money after the jute fibre harvest, so most of the jute is either sold to the aggregator or to JCI (JCI procures less than 10 per cent of the raw jute and rest ~90 per cent is traded through aggregator) who stores the jute fibre and deliver to the jute mills as and when required after preprocessing (Khanom *et al.*, 2012; Nayak *et al.*, 2013; Begum and Kumar 2014). In India, jute is mainly grown in West Bengal, Assam, and Bihar. India also imports some quantity of jute from Bangladesh. The raw jute is transported from the farm to the aggregator storage shed through small lorries. As most of the jute mills are located in in the southern part of West Bengal; this jute is transported from the JCI store or aggregator storage facility to the jute mills through a 9tonne lorry. The average data collected for jute procurement from jute mills has been summarized in Table 7:

Table 7: Transportation of raw jute from field to jute mill

Place	Average % of raw jute received from different Places	Amount of raw jute received for 1.03 kg of raw jute receipt at mill (kg)	Average distance of travel (km)	Transportation from aggregator to mill, tkm= (kg of raw jute transported x 1000) x (average distance of travel x 2)
Assam	10	0.0001	1025	0.1
North Bengal	25	0.0003	390	0.1
South Bengal	65	0.0007	63	0.04
Total				0.2
Total Distance travelled from farm to the aggregator[17]				**0.03**
Total Distance travelled from aggregator to the mill				**0.2**

Jute sack manufacturing

The process for jute sack manufacturing starting from processing of jute fibres, spinning, weaving, cutting and sewing is presented in Figure 5 below.

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[17] Local transportation is taken for an average distance of 30 km (farmer's interview) between farm and aggregator location. Although there is significant usage of bullock cart for local transportation of raw jute fibre, but it is assumed in the study that the aggregator storage facility is located at district centers and town centers, so the average distance of 30 km will be travelled using 6 ton capacity lorry.

Figure 5: Jute mill processes

The raw jute received at the jute mill is either stored at the mill or used directly in the process based on raw jute availability and sack demand at the mill end. Major material consumption at the jute mill is in the form of raw jute fibre. Small amount of emulsion is used in the softening process with starch application at a later stage along with electricity consumption in jute sack manufacturing. Small amount of dyes are used for printing the logo and name of the mill as well as other technical specifications after sewing the sack. In case of diversified and modified products, depending on the demand, trace amounts of bleaching agents and other dyes are also applied, but for the current study these dyes and bleaching agents are not considered because the same are not required in jute sack manufacturing. The main processes which take place at the jute mill for conversion of raw jute into jute sack are presented in Figure 5. The processes have not been described in detail because it has already been done at various platforms and by various institutions in their reports. Emphasis of the current study is on the life cycle environmental impacts of jute sack production, so focus of the report is on overall impacts on the environment due to production of sack using jute fibre or PE/HDPE alternatives. Tables 8 and 9 present mass and energy consumed per kg of jute sack produced and emissions from the same.

Table 8: Mass and energy per kg jute sack produced[18]

Products			Electricity and Fuel			Material[19]		
	Amount	Unit		Amount	Unit		Amount	Unit
Jute Sack	1	kg	Raw Jute transportation from aggregator to Mill	0.2	tkm	Jute	1.0	Kg
			Raw Jute transport from farm to aggregator	0.03	tkm	Soap	0.003	Kg
			Electricity from grid	0.5	kWh	JBO	0.03	Kg
			Electricity from diesel generator	0.007	kWh	Water	0.5	Kg

Table 9: Emissions per kg jute sack produced

Emissions to Air		Emissions to Water		Emissions to Soil	
Amount	Unit	Amount	Unit	Amount	Unit
0.1	m^3	0.4	m^3	Nil	m^3

It can be seen from Table 9 that emission to air and water from production of jute sack is very low and is not observed for soil.

5.2 PP/HDPE sack manufacturing

The system boundary chosen for the current study involves only the operation phase of HDPE/PP sack manufacturing process from cradle to grave (disposal). The input/outputs related to infrastructure development are excluded from the study. Similarly organic pollutants in the form of air and water emissions at the HDPE/PP sack manufacturing unit are not included in the present inventory, but all other upstream processes are included. Transportation (imports and within production unit) of raw material i.e., crude oil and natural gas used as feedstock is included in the study. It is important to highlight that various types of ink and dyes used for printing HDPE sacks has not been considered in this study due to non-availability of data. Most of the data used in the study is secondary in nature which has been collected from various reports and research papers as well as from the international databases available for LCA i.e., Ecoinvent and European Life Cycle Database (ELCD), etc.

PP Woven Sacks are generally manufactured and printed as per the Customers' demands/needs. The Process of manufacturing PP Woven Sacks involves following three steps: extrusion, weaving and finishing &stitching

The process of manufacturing PP woven bags involves mixing raw materials starting with PP pellets and other additives, extruding the raw materials into a yarn PP resin is heated

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[18] Data in Table 8 & 9 is based on data collected from jute mill through personal interviews and annual resource and material consumption reports.

[19] *An emulsion of JBO (hydrocarbon petroleum product) and non-toxic detergent (emulsifier) is prepared in hot water

** Trace amounts of sizing chemical (Starch) which is TKP and Sodium Silicofhside (antifungal) are also used in jute industry but due to use of negligible amount, this has been ignored in the analysis part.

with feeler of $CaCO_3$ and pigment, melted and extruded as a flat film. It is then slit into tape yarn by the slitting unit and stretched and annealed. Next, a take-up winder winds the heat oriented tape yarn onto a bobbin. The raw material (PP & Filler) in the granules form is fed to a Raffia Tape Manufacturing Plant to obtain the Raffia Tapes of PP. The raw material mix is prepared in a tray adjacent to the feed hopper. The prepared mix is sucked in to the hopper by vacuum. The raw material mix is fetched to the extruder of the plant; where the same is melt by applying controlled external heat on the barrel. The molten mass is forced out through a die head into a cooling tank, in the form of sheet/film. The cooled & solidified sheet/film is passed through the knives to obtain Raffia Tapes of higher Denier (a Unit by which the fineness of a yarn is measured). PP granules are first converted in to 2.5 mm wide tapes by extrusion process. The Raffia Tapes received from the plant are stretched and annealed. These are then wound on cheese pipes with the help of the sets of winders.

Weaving the yarn into a fabric is a process similar to the weaving of textiles. These flat tapes are then woven into circular fabric by circular weaving machine. Thus woven circular fabric is then cut in to required dimension. Thread from the bobbin in the circular loom's creel stand is woven into tubular cloth. Weaving of Raffia Tapes into sheets is carried out in Circular Looms, which produce circular sheet of desired width. The process of weaving is automatic and continuous in nature. Number of circular looms are installed so as to match the effective output of the Raffia Tape manufacturing plant. The sheet produced by each loom is continuously wound on rotating pipes.

The rolls of woven sheets are carried out to the finishing &stitching section of the unit. The cloth is cut into desired size and the printed. After printing the cut pieces are sent for stitching. The woven sacks passed through the quality control test are bundled in 500 or 1000 Nos. and pressed on a bailing press. The pressed woven sacks are wrapped, bundled, packed and dispatched.

The life cycle of the HDPE sack manufacturing starts with extraction of crude oil and natural gas from the earth followed by ethylene extraction which is then polymerized to produce HDPE granules. HDPE is usually regarded as a polyethylene with a density>940 kg/m^3, produced in low pressure reactors and so is referred to as high density polyethylene. The starting material, ethylene, is called the monomer and the final product consisting of many thousands of bound ethylene units is called the polymer. Two main techniques are used for the production of HDPE are - slurry polymerisation in which the polymer is produced at relatively low temperature (70-110°C) and low pressure(1–5 MPa) in a saturated hydrocarbon medium. The polymer forms suspension or mobile slurry. The reaction medium is removed and the polymer separated from the hydrocarbon inert diluents. The obtained powder is mixed with stabilizers and generally extruded into pellets.

Gas phase polymerisation in which a gas phase reactor - a fluidised bed of dry polymer particles is maintained either by stirring or by passing gas (ethylene)at high speeds through it. Pressures are usually relatively low at ~2MPa and temperatures are usually in the range70-110°C. The obtained powder is mixed with stabilizers and generally extruded into pellets.

The HDPE granules are produced near to oil and natural gas extraction/refinery sites, then transported to the units where these granules are drawn into films and converted to sacks of desired size for packing materials. After this stage the sacks are transported to the end user, where after ~3 uses they are disposed of at the end of life through either incineration or disposal at the landfill. HDPE sack production steps are summarized in Figure 6 below and material consumption in Table 10 below.

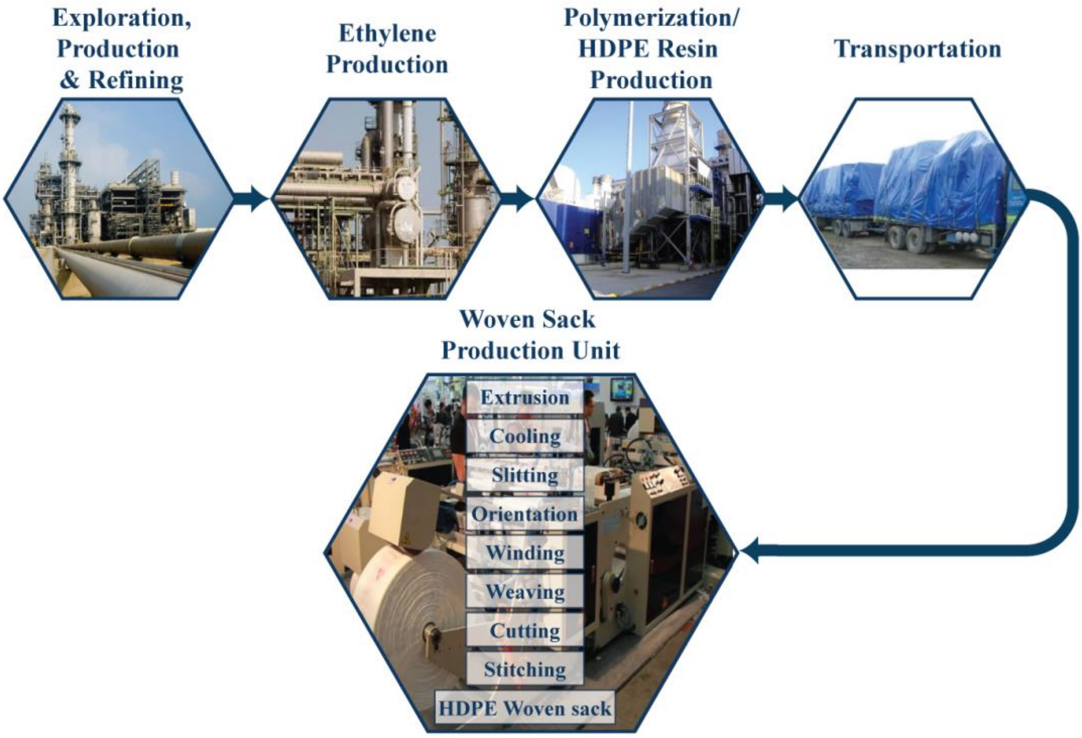

Figure 6: HDPE Sack Production

Table 10: Material and Resource consumption for 1 kg HDPE resin production at plant[20]

S. No.	Material/Resource	Amount	Unit
1	Natural Gas[21]	0.03	m^3
2	Ethylene[22]	1.0[23]	kg*
3	Electricity	0.5	kWh

The material and energy inputs are provided for HDPE sack manufacturing at various life cycle stages, which results in environmental emissions. Electricity consumption at sack manufacturing unit from HDPE/PP resins is ~ 0.853 kWh/kg of sacking material produced. The emissions from producing one Kg of HDPE sacks are given in Table 11.

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[20] As the both PP and HDPE are produced from the common feedstock, i.e., Naphtha (60 per cent in India), LCI of HDPE is assumed to represent the conditions for PP.

[21] Natural gas is measured in normal cubic meters (corresponding to 0°C at 101.325 kPa) or in standard cubic feet (corresponding to 60°F/16°C and 14.73 psi)

[22] One kg ethylene production requires, ~240 g naphtha and 1.074 m^3 natural gas as raw material. Apart from this ~34 g of naphtha and 300 m^3 of natural gas as energy source in combustion process within ethylene production unit.

[23] Direct and indirect loss of ~2 per cent ethylene occurs at the resin production unit with ~1.95 per cent of the raw material lost as waste and volatile emissions at the sack production unit.

Table 11: Emissions per kg HDPE sack produced

Emissions to Air		Emissions to Water		Emissions to Soil	
Amount	Unit	Amount	Unit	Amount	Unit
16.7[24]	g/Kg	NA	g/Kg	NA	g/Kg

NA: Not available

6. LCI of jute sack Vs. HDPE/PP sack manufacturing

The section below present output of LCA for the two alternatives in terms of mid-point and end-point impacts for manufacturing of 1 million sacks of jute and HDPE/PP, respectively for following aspects:

- Climate change
- Ozone depletion
- Human toxicity
- Photochemical oxidant formation
- Particulate matter formation and
- Terrestrial, freshwater and marine eco-toxicity

6.1 Mid-point Impacts

The climate change related midpoint impacts are presented in Figures 7 and 8 below.

Climate Change

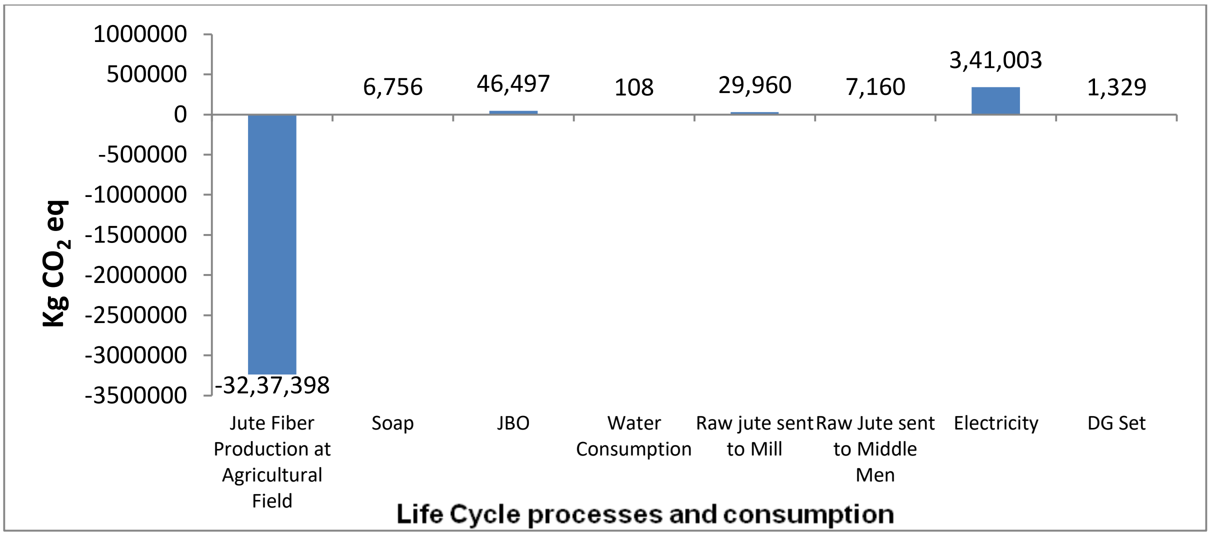

Figure 7: Midpoint climate change potential impacts from one million jute sack production

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[24] Source: https://books.google.co.in/books?id=ATHSBwAAQBAJ&pg=PA307&lpg=PA307&dq=emission+per+kg+of+hdpe+sacks&source=bl&ots=8LZugA1H_w&sig=TQ-2F0p3C0hFMw2bP2A8VO72TN0&hl=en&sa=X&ved=0ahUKEwin6f26qKvUAhVILsAKHZBkDjw4ChDoAQhAMAU#v=onepage&q=emission%20per%20kg%20of%20hdpe%20sacks&f=false

Climate change is the most important aspect in the context of the global environment. Climate changes have had a widespread impact on human health and the natural ecosystem. Therefore, climate change potential has been considered as an important impact category for jute and HDPE/PP sack production throughout its life cycle. Climate change is a phenomenon which is considered at a global scale resulting from emissions of greenhouse gases (GHGs) such as CO_2, CH_4, N_2O, CFCs, etc. To account and relate these GHG emissions to climate change, the Intergovernmental Panel on Climate Change (IPCC) has developed a characterization model. The factors developed through this method are expressed as Global Warming Potential (GWP) for a time horizon of 100 years (GWP_{100}), and are expressed in kg CO_2 eq./unit product.

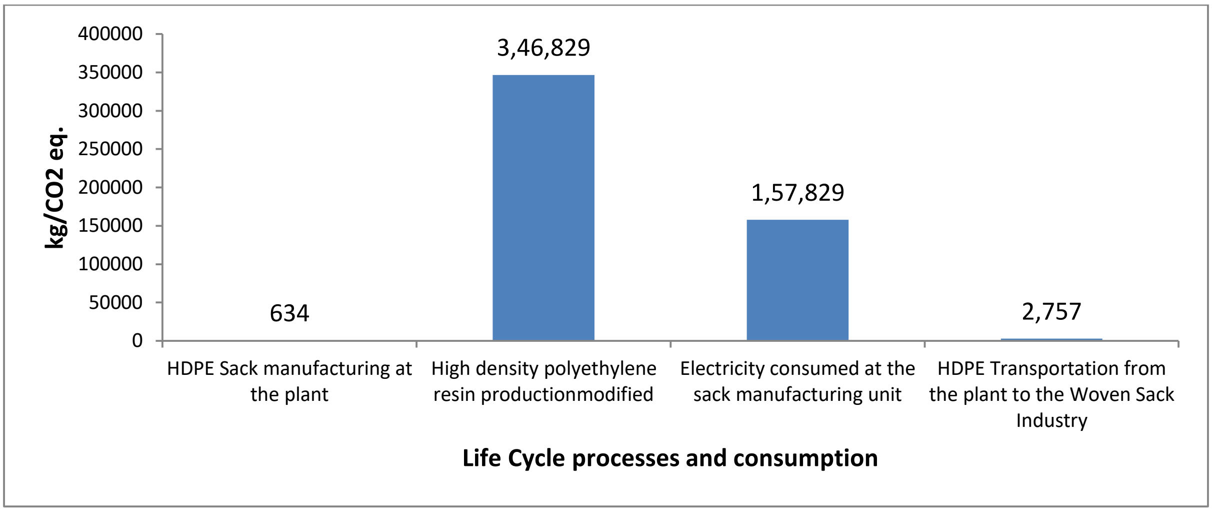

Figure 8: Midpoint climate change potential impacts from one million HDPE sack production

The GWP for production for million jute sack production is approximately -3 million kg CO_2 eq., the negative sign indicating that jute sack production process is a net sequester of the atmospheric CO_2. On a unit scale, approximately 3.53 kg/CO_2 eq. is absorbed at the agricultural stage with release of 0.06 kg/CO_2 eq. methane during jute retting process; 0.03 kg/CO_2 eq. and 0.02 kg/CO_2 eq. of N_2O and CO_2 emissions, respectively, from urea utilization at the agriculture field. The processes involved in formulation of JBO and soap and electricity consumed at the mill,[25] respectively, contributed 0.05, 0.006 and 0.34 kg CO_2 eq. to the climate change impact category. Raw jute transportation from the agricultural field to the mill premises contributed 0.04 kg/CO_2 eq. to the impact category. In addition, jute sticks and jute caddies are locally used as a fuel (Boxes 2 and 3) which further helps mitigating GHG emission in terms of replacement of equivalent fossil fuel.

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[25] Impacts from electricity consumption, means the impacts caused due to processes taking place at the power plants as well a

s other upstream processes involved therein, so interpreted as mentioned below in the subsequent parts of the report.

Box 2: Fuel wood replacement by Jute stick/stem: Perspective on avoided CO_2 emission

Approximately 70-80% of the sticks are mainly used as domestic fuel for cooking purposes. Usage of jute sticks as fuel wood reduces the burden of deforestation in the nearby areas (Chapke, 2013). Calorific value of jute sticks is assumed to be 18.4 MJ/kg whereas the calorific value of wood is around 18.7 MJ/kg, which shows that an equivalent amount of less wood would be required from the forest because of usage of jute sticks as fuel wood. This will avoid cutting of equivalent amount of wood from the forest, which once cut will never be able to carry-out photosynthesis and purify air by consuming atmospheric CO_2 and releasing O_2 for the life time. The amount of such CO_2 sequestration and O_2 release is difficult to quantify over the life time of avoided wood cutting from the forest, but an inference can be drawn from the facts presented above.

Box 3: Jute caddy as avoided emissions

Jute caddies are un-spinnable waste generated (short fibres) in the jute mill looms during jute processing (Kundu and Ray, 2012). Calorific value of jute caddy was estimated to be 16.42 MJ/kg (3923.4 k cal/kg) by Gunjan et al., 2013 whereas calorific value of coal is ~ 23.62 MJ/kg of coal. Burning 1 kg coal releases 2.8 kg CO_2eq into the atmosphere (calculated from Aggarwal et al., 2014), so 1 kg coal is replaced by 1.44 kg jute caddy (based on calorific value).

In case of HDPE, the GWP for million sacks is ~0.5 million kg CO_2 eq. released in the atmosphere. On a unit scale, nearly 0.35 kg CO_2 eq. emissions are released during HDPE resin production processes, including import of oil as well as processing at the refinery, 0.16kg CO_2 eq. from the electricity consumed at the woven sack production unit, and remaining from the raw material transportation at the sack manufacturing unit, etc. Out of the total GWP impacts for HDPE sack production, ~77 per cent of the impacts were due to CO_2 emissions at various stages (~48 per cent from HDPE resin production and ~29 per cent from electricity consumption), ~14 per cent from CH_4 emissions released at the HDPE resin production and raw material extraction stages. The comparative GHG emissions from jute and HDPE are presented in Figure 9 below.

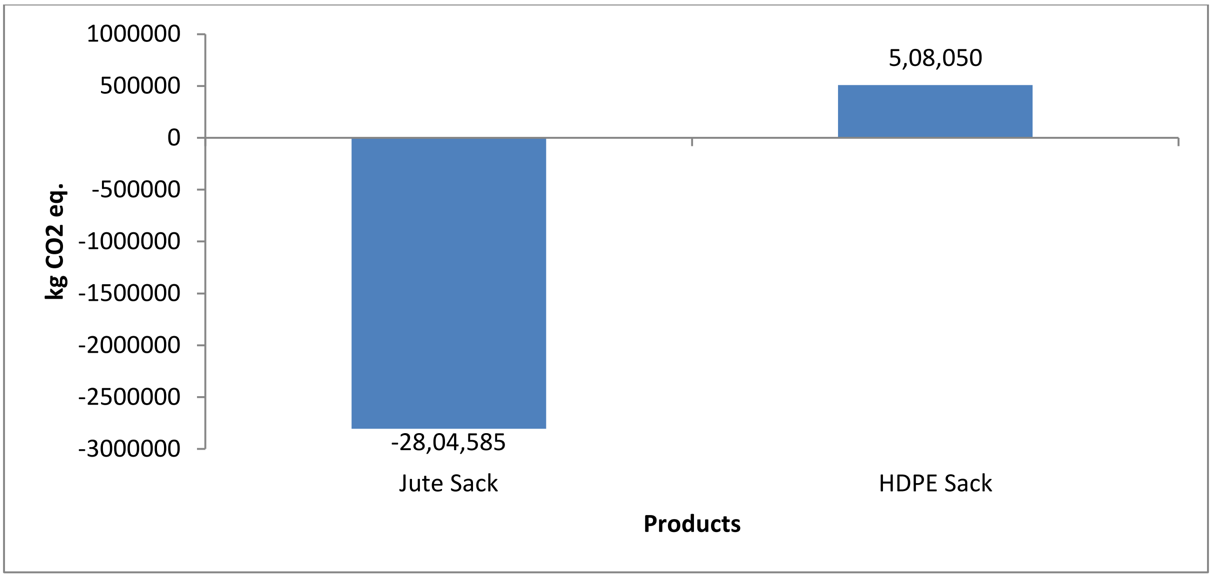

Figure 9: Comparative midpoint climate change potential impacts from jute and HDPE sack production

Ozone Depletion

Stratospheric ozone protects a larger fraction of UV-B radiation reaching the Earth's surface and is a very useful constituent of the atmosphere which makes this planet habitable. Depletion of this layer leads to penetration of UV-B radiations to the surface of the earth which can cause serious impacts on human health, animal health, terrestrial and aquatic ecosystems, biochemical cycles, and on materials as well. The characterization model to define Ozone Depletion Potential (ODP) of different gases (kg CFC-11 equivalent/ kg emission) for ozone depletion is developed by the World Meteorological Organization (WMO). This indicator is taken at global scale with respect to geographical scope.

The total ODP of jute sack production is 0.007 kg CFC-11 eq., out of this nearly 0.003 kg CFC-11 eq. of the impacts are caused due to electricity consumed at the mill premises, 0.002 kg CFC-11 eq. due to raw jute transportation from agricultural field to mill premises through a lorry (which runs on diesel), 0.0009 kg CFC-11 eq. from jute fibre production and operations involved at the field, 0.0007 kg CFC-11 eq. due to usage of JBO[26] at mill, and remaining from other material consumptions and processes such as water and applied emulsions. In terms of substance contribution to the impact category, ~66 per cent of the impacts were due to CH_4-, bromotrifluoro-, Halon 1301 emissions from various processes (~33 per cent of total being from transportation lorry, ~18 per cent from electricity consumption at the mill;), ~14 per cent from ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114; ~8 per cent from CH_4- bromochlorodifluoro-, Halon 1211, and remaining from other substances such as CH_4, tetrachloro-, CFC-10, Methane, monochloro-, R-40, etc.

Whereas the total ODP of HDPE sack production[27] is 0.03 kg CFC-11 eq. out of this nearly 95 per cent of the impacts are caused due to HDPE resin production process and raw material

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[26] Though most of the jute mills are in process of shifting to bio based alternative to JBO

[27] Organic pollutants in the form of air and water emissions at the HDPE/PP sack manufacturing unit are not included in the present inventory, but all other upstream emissions are included. So, the results of impact

extraction, ~4 per cent from the electricity consumed at woven sack production unit and ~1 per cent from transportation of HDPE resin to the sack production unit. In terms of substance contribution to the impact category, ~88 per cent of the impacts were due to CH_4-, bromochlorodifluoro-, Halon 1211 emissions (mainly from HDPE resin production process and raw material extraction), ~5 per cent from CH_4-, bromotrifluoro-, Halon 1301, and remaining from other substances such as ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114, CH_4- bromochlorodifluoro-, Halon 1211, Methane, monochloro-, R-40, etc.

Human Toxicity

Toxic substances have impacts on human health as well as ecological environment through their fate and exposure to various subjects and environment. Human toxicity impact category considers the effects of toxic substances on the human environment. Based on the toxicity, persistency, bio-concentration, fate and exposure of various toxic substances, Human Toxicity Potentials (HTPs) through exposure via air, soil, and surface water are expressed as 1,4-dichlorobenzene eq.

The human toxicity impacts of jute sack, HDPE sack and comparative assessment are presented in Figures 10, 11 and 12, respectively. The health hazards of crude oil ingredients are presented in Box 4. Over the life cycle of jute sack production, 97800 kg 1,4-dichlorobenzene eq. of human toxicity impacts are caused. Out of these nearly 93 per cent of the total impacts are caused due to electricity consumed at the mill premises (out of this ~69 per cent of the impacts are due to manganese emissions to the water, ~11 per cent from arsenic emissions to air and water and remaining from other heavy metals such as barium, selenium, lead, etc.). The agricultural phase also contributes to ~4 per cent of the impacts in the impact category which arises due to barium, cadmium, vanadium, manganese, etc., due to their presence (consumption upstream) in the fertilizer, pesticide, etc.

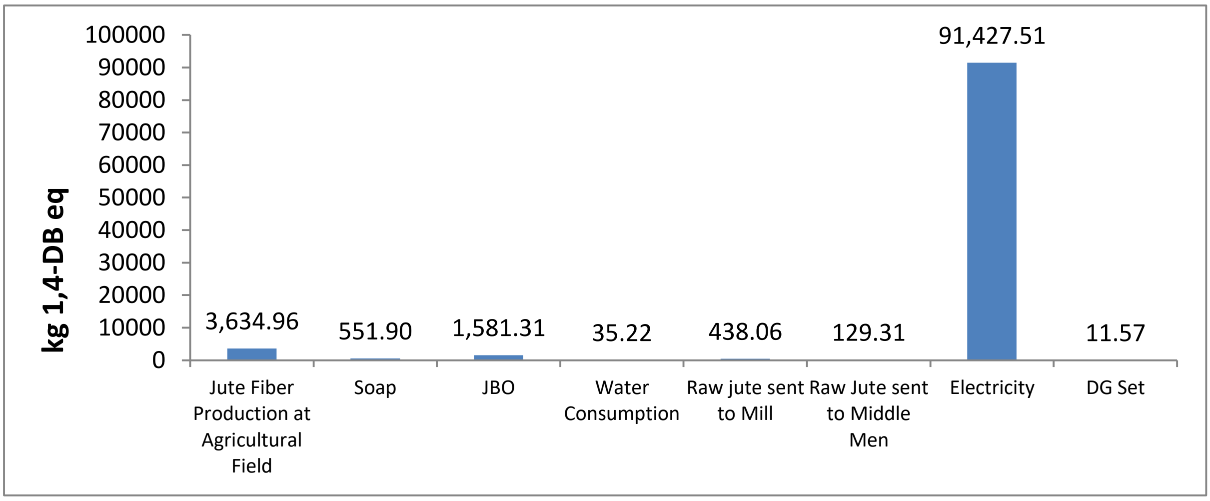

Figure 10: Midpoint human toxicity potential impacts from jute sack production

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categories studied are underestimated for HDPE/PP sack due to incomplete inventory for organic emissions at the final sack manufacturing unit (HDPE/PP resin to sack production unit).

Over the life cycle of HDPE sack production, 265000 kg 1,4-dichlorobenzene eq. of human toxicity impacts are caused. Out of these, ~84per cent of the impacts are caused due to HDPE resin production and raw material extraction (out of this ~67per cent of the impacts are due to barium emissions to the water, ~11per cent from manganese emissions to water, and remaining from other heavy metals such as arsenic, selenium, lead, etc.). Approximately, 16per cent of the total impacts also arise from electricity consumed at the woven sack production unit and remaining from other processes including direct emissions at the woven sack production unit and transportation of HDPE resins.

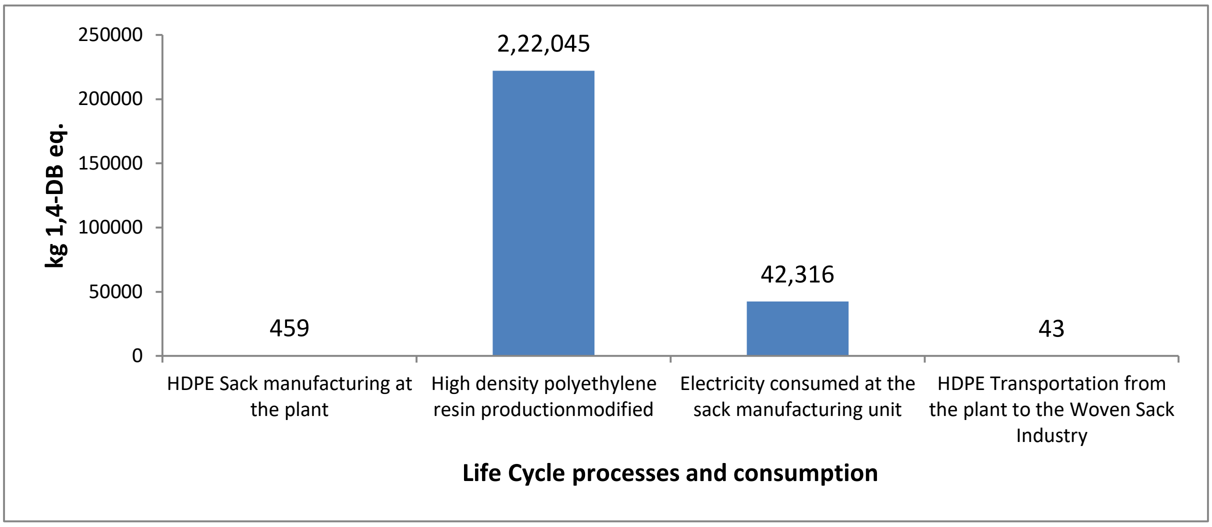

Figure 11: Midpoint human toxicity potential impacts from one HDPE sack production

Box 4: Health Hazards of Benzene: An Ingredient of Crude oil (Feedstock for petrochemical Industry)

Benzene, a sweet smelling ingredient occurs naturally in the crude petroleum at levels up to 4g/l, activities involving use of petroleum lead to human exposure of benzene (WHO, 2010). Human exposure to benzene has been associated with diseases namely leukemia and aplastic anemia (benzene poisoning) and also termed as carcinogenic to humans. There are evidences that benzene can cause bone marrow not to produce sufficient red blood cells which can lead to anemia (Infante, 2001). A worker exposed to 10 ppm of benzene for 40 years is 155 times more likely to die from leukemia than an unexposed worker. There are reported cases of deaths due to benzene exposure: John Thompson, 70, working in a petrochemical industry in Texas was in close contact of benzene for more than a decade and died due to leukemia. In Athens, Georgia, a child died of leukemia after living in vicinity of 12 petroleum storage tanks for six years. For

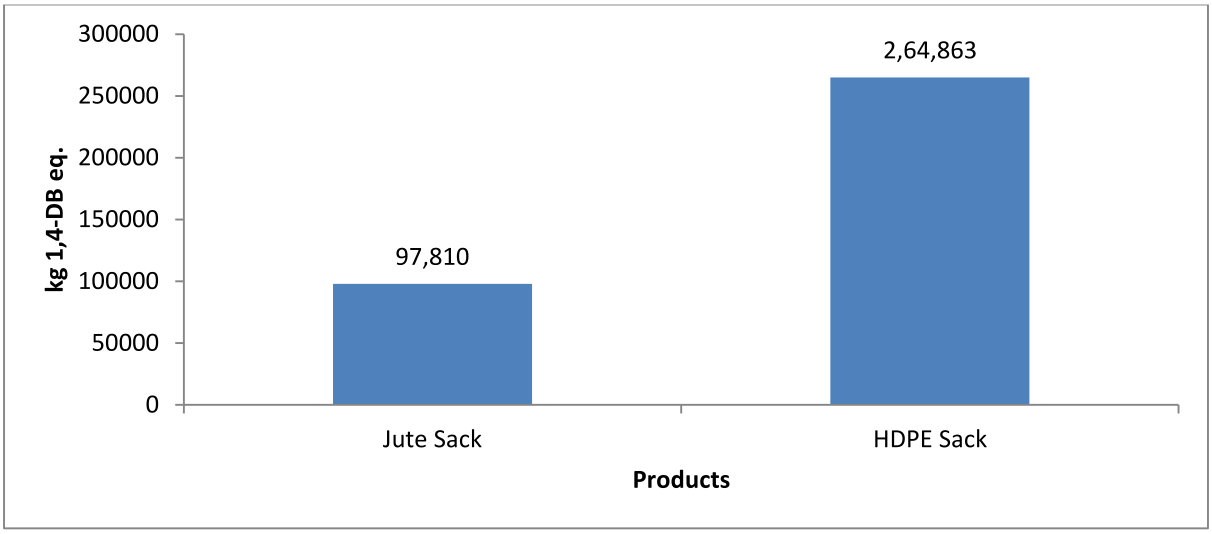

Figure 12: Comparative midpoint human toxicity potential impacts from jute and HDPE sack production

It is clearly seen in the Figure 12 that midpoint human toxicity impacts for HDPE sacks are more than double as compared to jute sacks.

Photochemical oxidant formation

Reactive substances such as ozone have the potential impact on human health and ecosystem. These reactive substances help in formation of photochemical oxidants. The impact category indicator is expressed in kg NMVOC eq. (Non-Methane Volatile Organic Compounds).

Photochemical oxidant formation potential of jute sack production is 1720 kg NMVOC eq. and out of this, ~61 per cent of the impacts are caused due to NO_2, SO_2, and NMVOC emissions from electricity used at the mill followed by ~18 per cent from the transportation of raw jute from field to the mill, ~12 and ~7 per cent from agriculture phase and JBO consumption at mill respectively (Figure 13). Approximately, 81 per cent of the total impacts were due to NO_2 emissions from various processes followed by ~8 per cent from SO_2 and ~4 per cent from NMVOC.

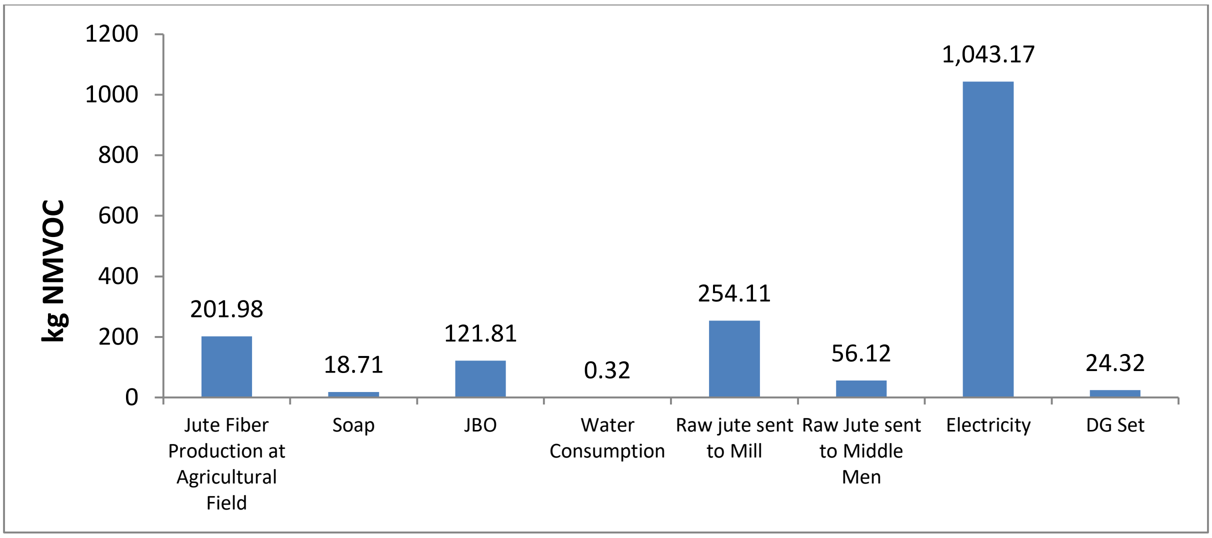

Figure 13: Midpoint POF potential impacts from jute sack production

The Photochemical oxidant formation potential of HDPE sack along with comparative assessment is presented in Figures 14 and 15, respectively. Photochemical oxidant formation potential of HDPE sack production is 1780 kg NMVOC eq. and out of this, ~72 per cent of the impacts are caused due to HDPE resin production and raw material extraction, ~27 per cent from electricity consumed at the woven sack production unit. In terms of substance contribution to the impact category, ~59 per cent of the impacts are caused by NO_2, ~25 per cent by SO_2, and remaining due to other substances such as CO, NMVOC, and toluene, etc.

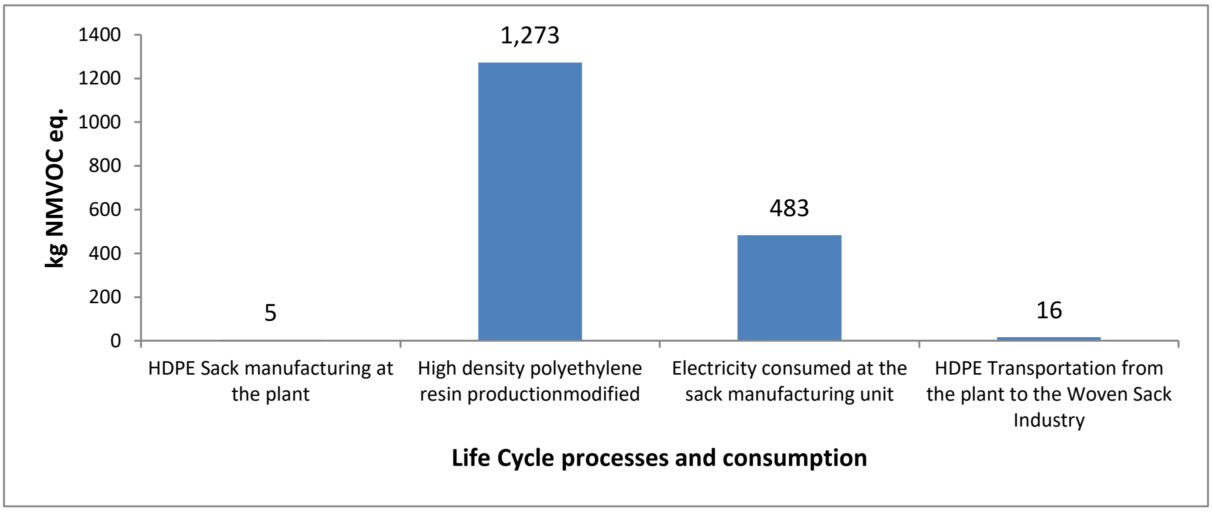

Figure 14: Midpoint POF potential impacts from HDPE sack production

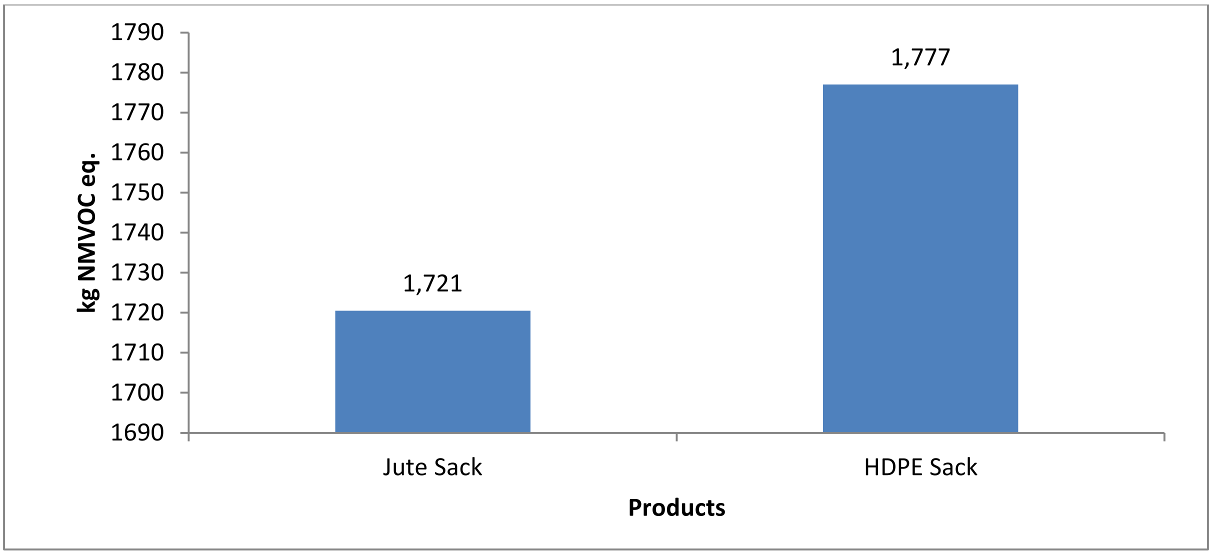

Figure 15: Comparative midpoint POF potential impacts from jute and HDPE sack production

It is clear from Figure 15 that photochemical oxidant formation potential is again higher for HDPE sacks as compared to jute sacks.

Particulate matter Formation

Due to various sources and processes, particulate matter is emitted in the atmosphere which can be organic or inorganic in nature. These fine particles are harmful for human health as well as ecosystem quality, because of their penetration in the human body as well as reducing efficiency of the ecosystem to perform their natural functions such as photosynthesis, etc. The potential of any system or process to emit such particles is expressed in terms of kg PM_{10} eq. through Particulate Matter Formation (PMF) impact category.

The PMF emission potential of jute sack and HDPE sack along with comparative assessment is presented in Figures 16, 17 and 18, respectively. The PMF potential of jute sack production is1480 kg PM_{10} eq. over the life cycle out of which, electricity consumed at the mill contribute to ~69 per cent of the total impacts followed by ~21 per cent from the agriculture phase and ~5 per cent from raw jute transportation from the field to the mill. In terms of substance contribution to the impact category, ~33 per cent of the impacts arise from $PM_{2.5}$, ~24 per cent from SO_2, and ~21 per cent from NO_x (mainly due to electricity consumed at the mill). Nearly ~17 per cent of the total impacts are due to ammonia release at the agriculture field due to use of urea as fertilizer.

The PMF potential of HDPE sack production is 1840 kg PM_{10} eq. over the life cycle, out of which HDPE resin production and raw material extraction contribute to ~74 per cent of the impacts followed by ~26% from electricity consumed at the woven sack production unit. In terms of substance contribution, ~60 per cent of the total impacts arise due to SO_2, ~21 per cent from $PM_{2.5}$, and ~12 per cent from NO_x) and remaining from other substances.

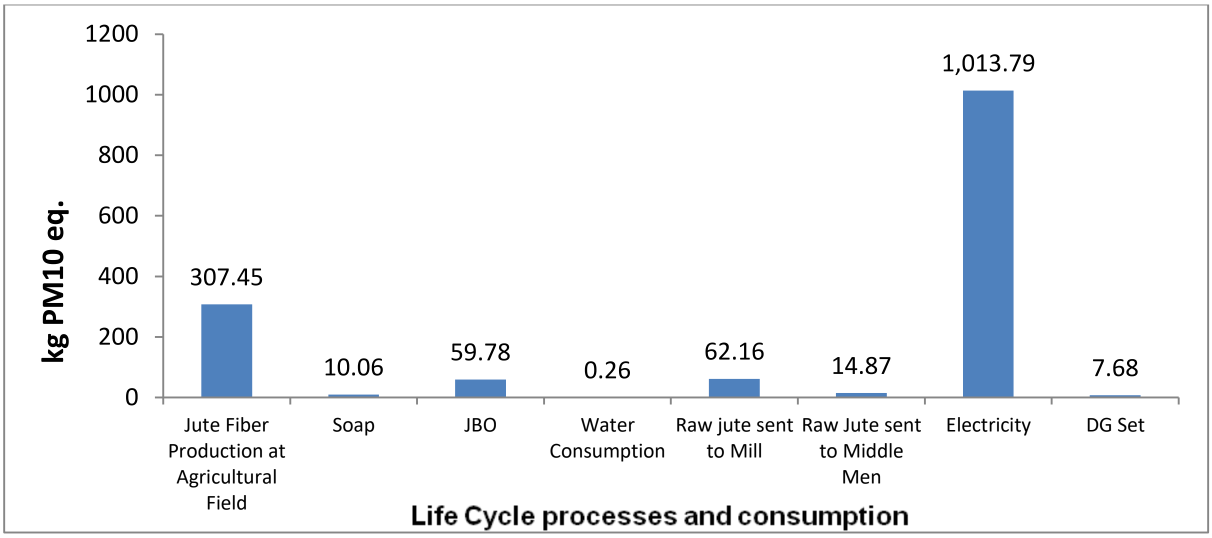

Figure 16: Midpoint PMF potential impacts from jute sack production

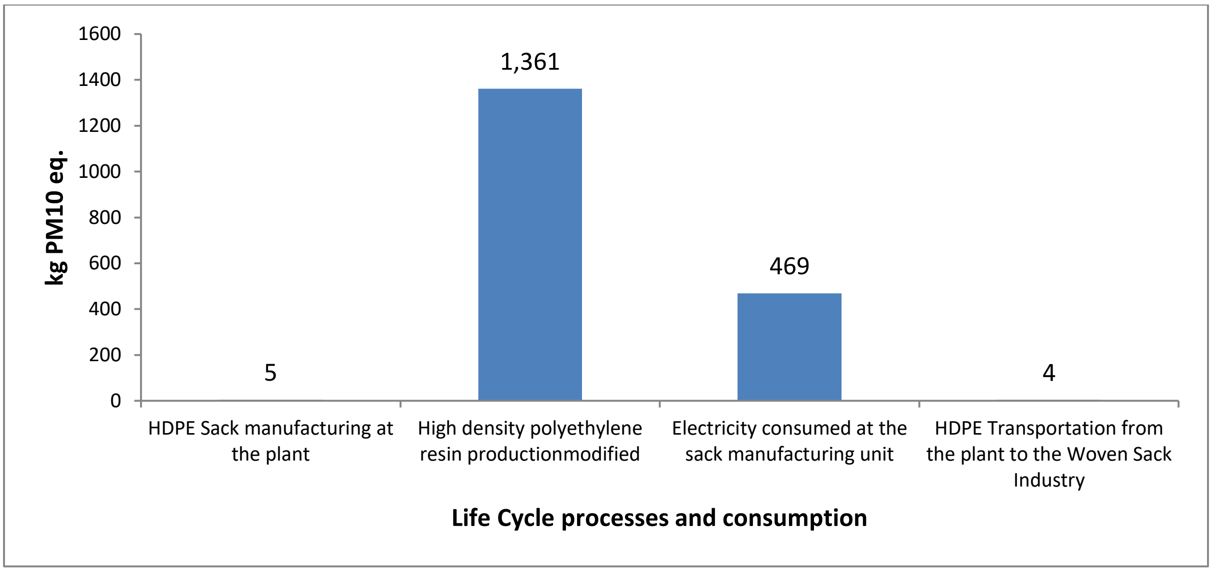

Figure 17: Midpoint PMF potential impacts from HDPE sack production

Chattopadhyay *et al.*(2003) and Braungart *et al.* (1992) have reported the presence of high concentration of dust particles in the jute mills but due to lack of comprehensive data and measurements of dust concentrations, the data on dust emissions at jute mills is not included in the inventory used for life cycle analysis of jute sack manufacturing. Similarly the inventory data on particulate matter emission at the HDPE/PP sack manufacturing unit is also not included because of limitations of the reliable authentic data at the manufacturing unit.

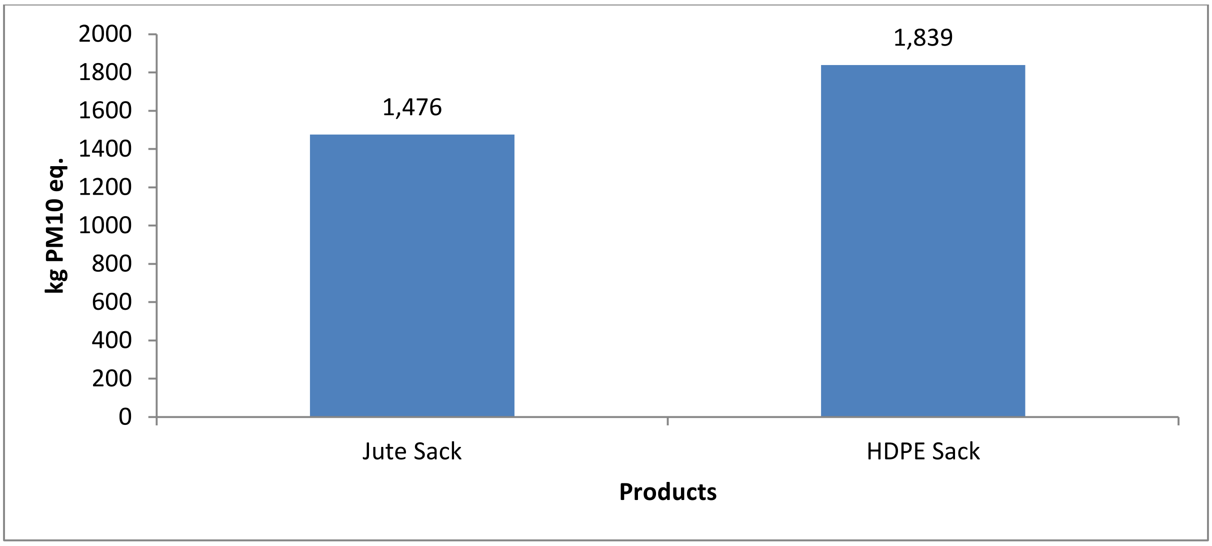

Figure 18: Comparative midpoint PMF potential impacts from jute and HDPE sack production

Terrestrial, Freshwater and Marine Ecotoxicity

Various heavy metals released in air, water or soil causes toxicity to flora and fauna. Impact of such substances is studied through terrestrial, freshwater and marine ecotoxicity potential assessment. The impact of this impact category are measured in terms of kg 1,4-DB eq. The terrestrial, freshwater and marine eco-toxicity potentials for jute sacks, HDPE sacks and comparative assessments are presented in Figures 19, 20 and 21, respectively.

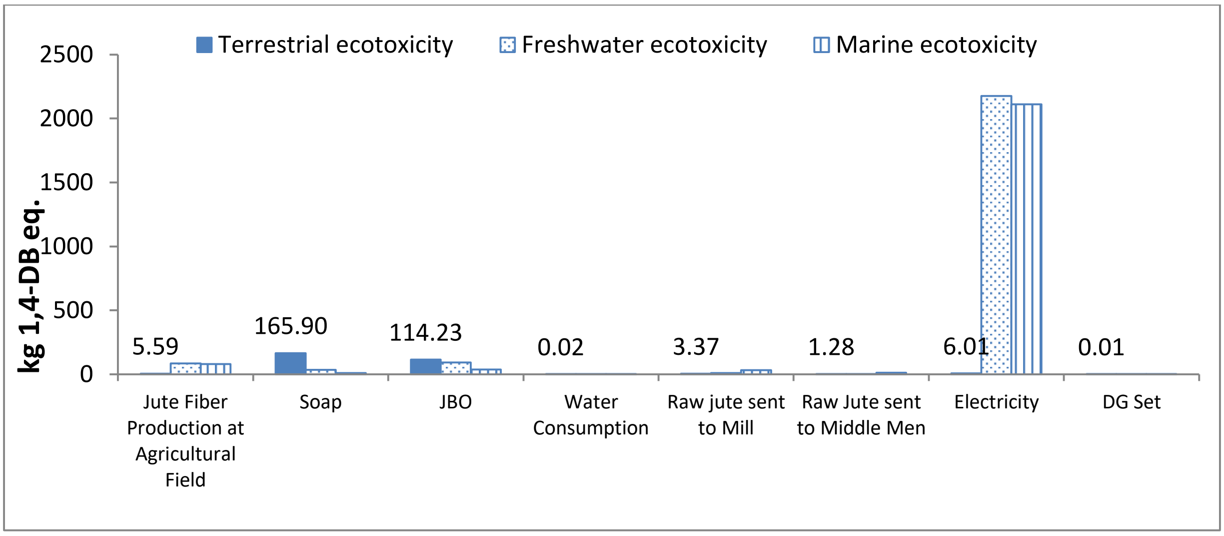

Figure 19: Midpoint eco-toxicity potential impacts from jute sack production

The eco-toxicity potential of jute sack production is 296, 240 and 228 kg 1,4-DB eq., respectively, for terrestrial, freshwater, and marine eco-toxicity. Out of the total impacts in the case of terrestrial eco-toxicity, ~56 per cent of the impacts are caused due to production and transportation of emulsions used at jute mill, ~39 per cent from JBO usage, and remaining ~5 per cent from agriculture phase and other processes and materials consumed.

Nearly 53 per cent of the impacts in this category are due to cypermethrin emissions to the soil, majorly from emulsion consumption (including upstream process for this), and ~23 per cent from diflubenzuron emissions to soil due to consumptions of JBO at the jute mill premises. In freshwater and marine eco-toxicity impact category, ~91 per cent and ~92 per cent of the total impacts arise from electricity consumed at the mill and ~3.5 per cent from the agricultural phase in both freshwater as well as marine ecotoxicity. The major contribution to both freshwater and marine ecotoxicity impact categories were due to nickel, manganese, copper and cobalt emissions, etc.

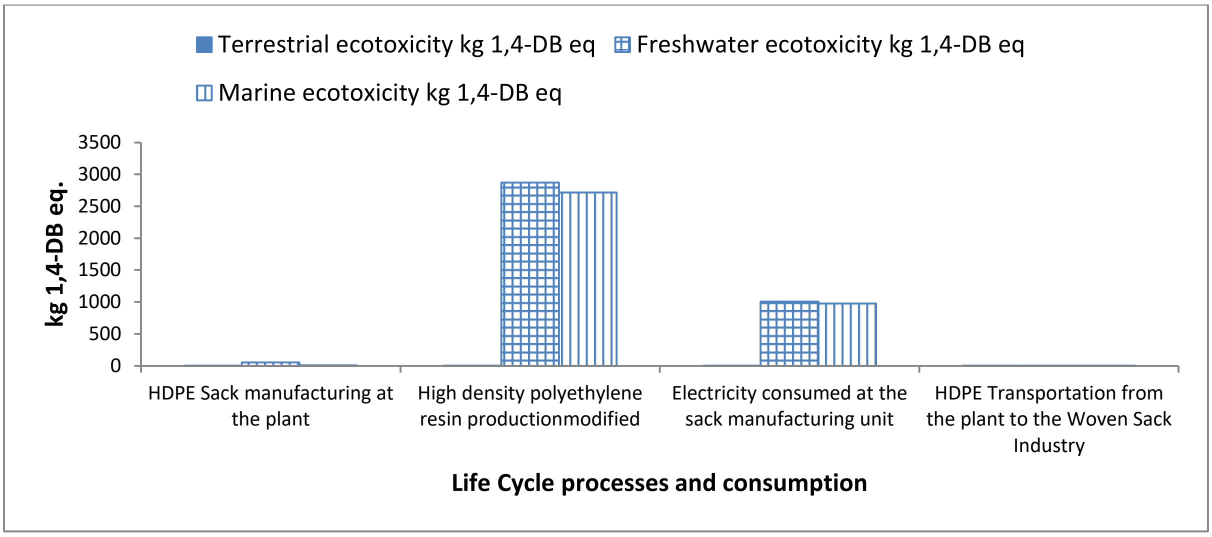

Figure 20: Midpoint eco-toxicity potential impacts from one HDPE sack production

The eco-toxicity potential of HDPE sack production is 7.73, 3930 and 3700 kg 1,4-DB eq., respectively, for terrestrial, freshwater and marine eco-toxicity. Out of the total impacts in case of terrestrial eco-toxicity, ~48 per cent of the impacts are caused due to HDPE resin production and raw material extraction, ~36 per cent due to electricity consumed at the woven sack production unit, ~13 per cent from direct emissions from the woven sack production process, and remaining from other processes and consumption. Around 16 per cent of the impacts in this category are due to vanadium, ~19 per cent from bromine, ~13 per cent from chlorine, 11 per cent from selenium, and remaining from other substances such as nickel, copper, mercury, cobalt, cypermethrin, zinc, etc. In freshwater eco-toxicity, approximately 73 per cent of the impacts are caused due to HDPE resin production and raw material extraction followed by ~26 per cent from electricity consumption at the woven sack production unit; major contributors to the impact category are nickel, silver, barium, manganese, etc. In marine eco-toxicity impact category, ~73 per cent of the total impacts arise from HDPE resin production and raw material extraction, followed by ~26 per cent from electricity consumption at the woven sack production unit. The major contribution to the impact category are nickel, manganese, silver, barium, etc.

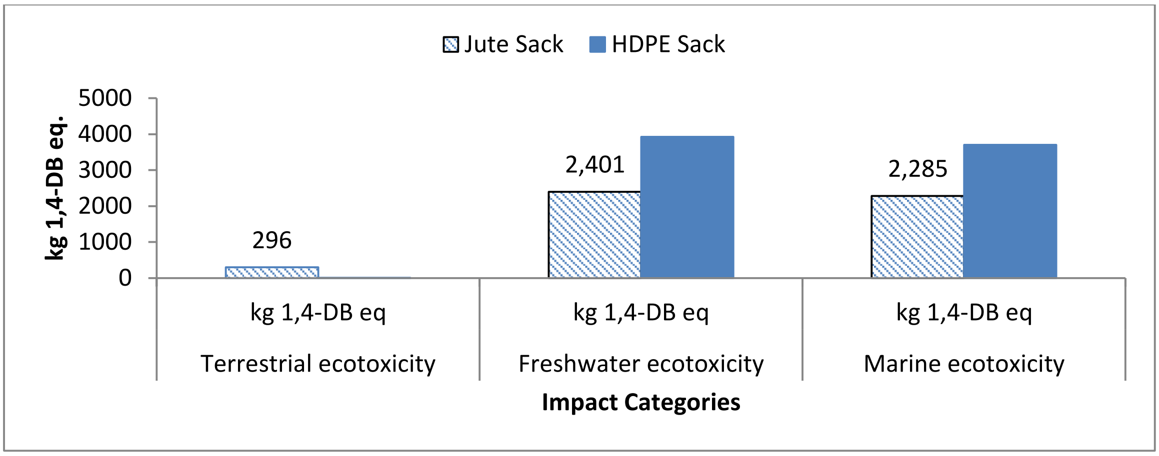

Figure 21: Comparative midpoint ecotoxicity potential impacts from jute and HDPE sack production

The figure above indicates that HDPE sacks manufacturing has more fresh water and marine ecotoxicity impacts but less terrestrial ecotoxicity impacts as compared to jute sacks

6.2 End-point Impacts

The end-point impacts give results for various major impact categories in terms of DALY for human health impacts. For plants and animals, the impacts would be used to assess the species lost over unit area in unit time in relation to the concentration of toxic substances (ReCiPe, 2008). The DALY is the number of disability years caused by exposure to toxic materials multiplied by the "disability factor", a number between 0 and 1 that describes the severity of the damage (0 for being perfectly healthy and 1 for being fatal). For example, the impact of 1 DALY means, one life year of one individual is lost, or one person suffers four years from a disability with a weight of 0.25 (PRé Consultants, 2001). The damage to ecosystem diversity is measured using the potential disappeared fraction (PDF) of species due to various toxic chemicals in the environment such as terrestrial, fresh and marine water ecosystem. The impact of 1 PDF×m^3×yr means all species, in 1 m^3 area are living under stress during one year. The PDF is also expressed as PDF×m^3×yr.

Human Health Impacts

End-point impact analysis shows that jute sack has net positive impacts on human health compared to HDPE/PP sack by having a negative DALY (Daily Adjusted Life Years) factor. When human health damage potential was analyzed category wise, the impacts of climate change on human health were having a very high negative value suggesting that the carbon sequestration by the jute plant has a net positive effect on the overall human health. Figures 22 and 23show the overall and impact category wise human health impacts of jute sack vs HDPE/PP sack production.

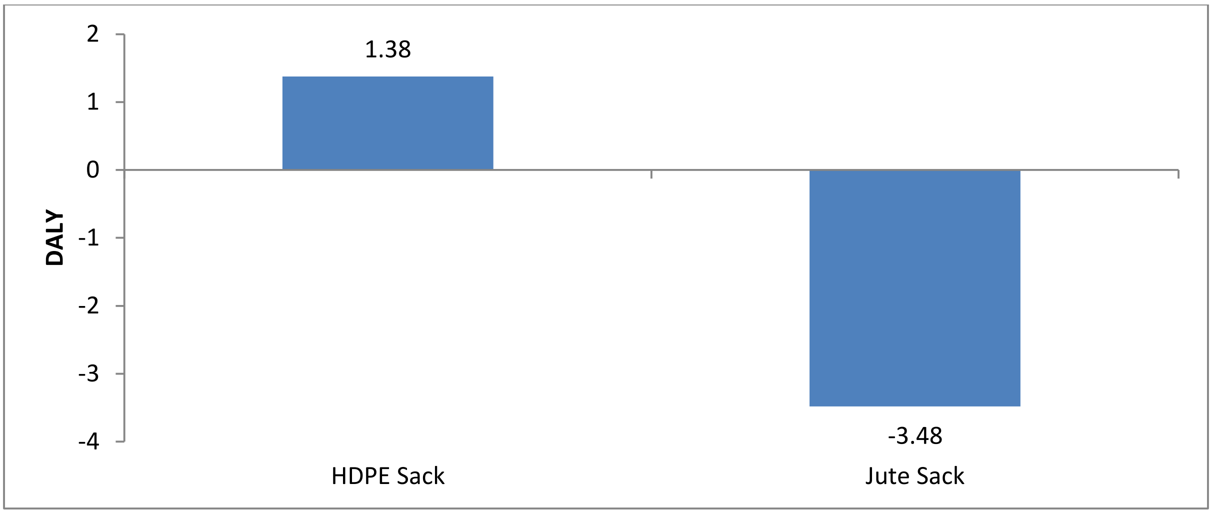

Figure 22: End Point Human Health Impacts of Jute vs HDPE/PP Sack manufacturing

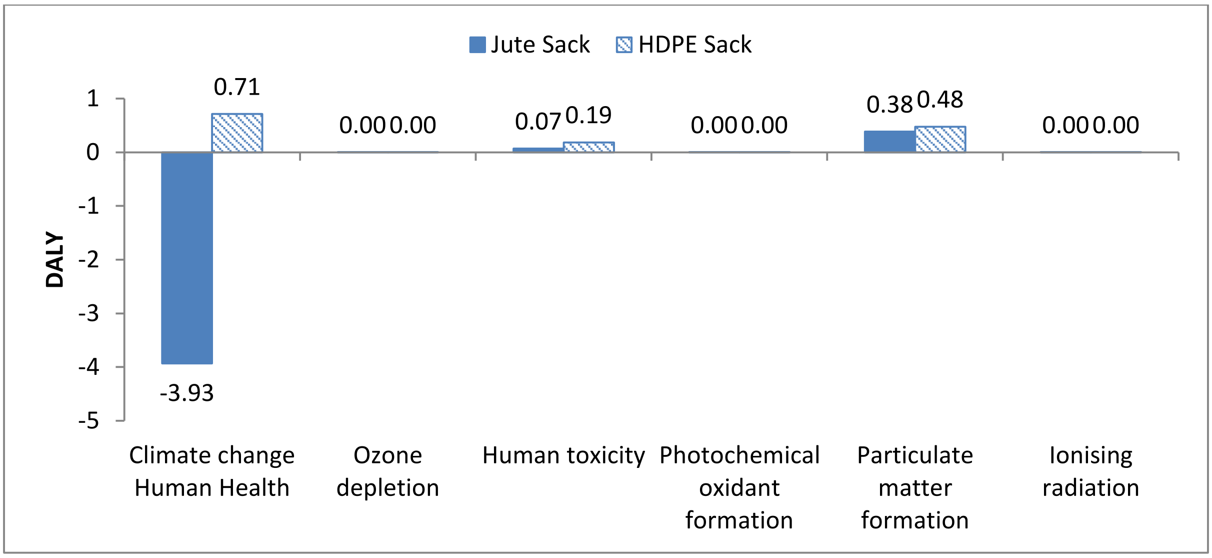

Figure 23: End Point Human Health Impacts of Jute vs HDPE/PP Sack manufacturing (Per Impact Category)

Ecosystem Quality Impacts

In the case of overall ecosystem quality impacts, the jute sack manufacturing has net positive impacts compared to HDPE/PP sack while comparing at end point impacts level. This suggests that jute sack results in net positive impact on the ecosystem quality as compared to HDPE/PP sack by having a negative speciesyr. factor (species lost over unit area in unit time). Climate change impact on ecosystem quality were having a very high negative value suggesting that the carbon sequestration by the jute plant has net positive effect on the overall ecosystem quality of the species present on the planet. Figures 24 and 25 show the overall and category wise ecosystem quality impacts from jute sack and HDPE/PP sack production, respectively.

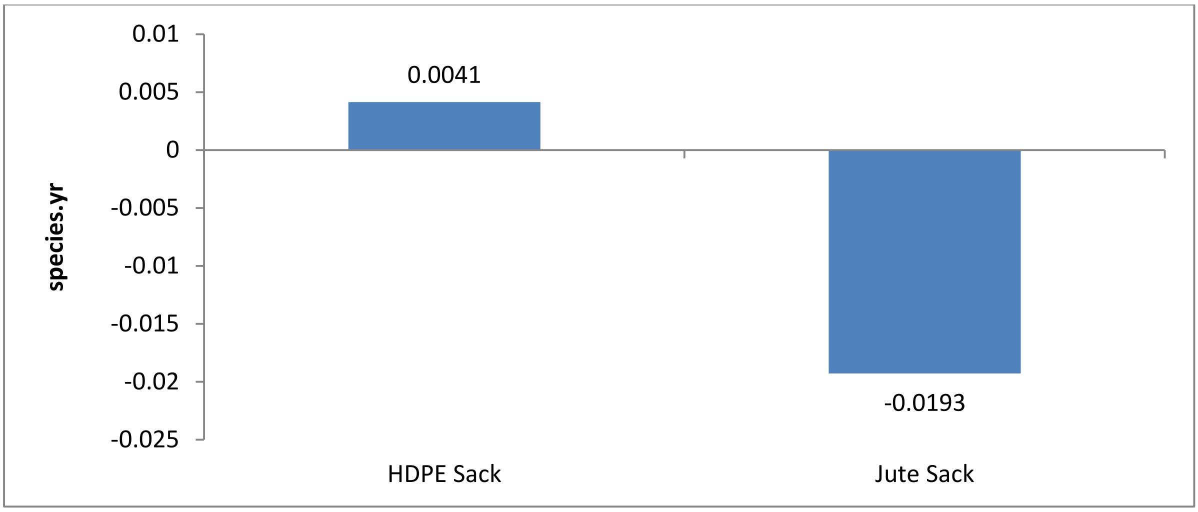

Figure 24: End Point Ecosystem Quality Impacts of Jute vs. HDPE/PP Sack manufacturing

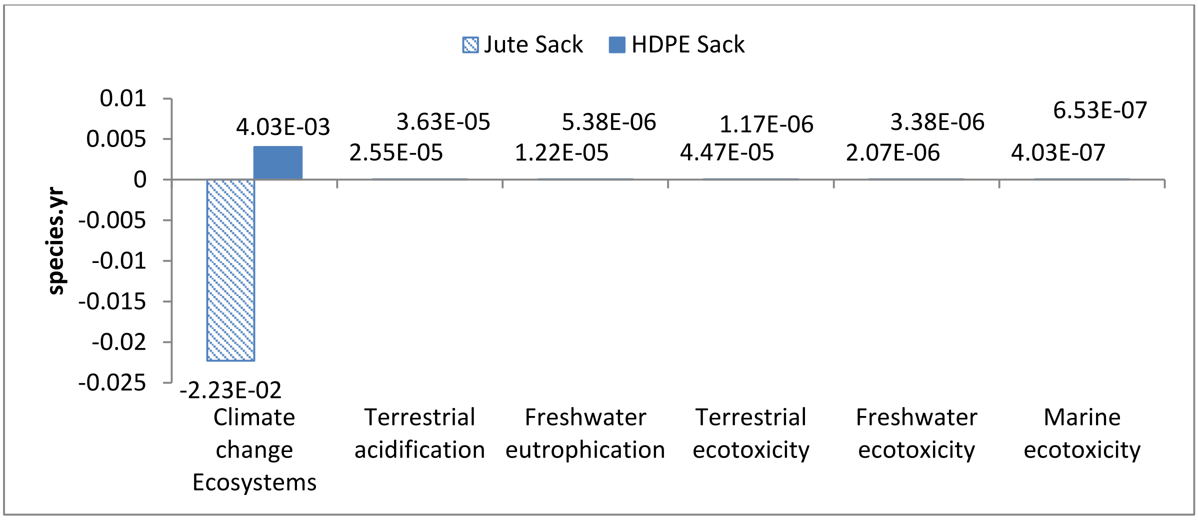

Figure 25: End Point Ecosystem Quality Impacts of Jute vs HDPE/PP Sack manufacturing (Per Impact Category)

Resource Depletion Impacts

The results further shows that jute sack requires fewer resources compared to HDPE/PP sack at end point and hence results in more depletion of natural resources when compared to jute sack production. Resource depletion is expressed in terms of Dollars ($)where HDPE/PP sack scored 49368 as compared to jute sack which scored 16690. It might be due to the reason that HDPE/PP sack being highly dependent on fossil fuel-based raw material during its life cycle stages, compared to jute which is a natural agricultural product. In case of agriculture stage for jute sack, the natural resources or material consumption originates from consumption of electricity, fertilizers, pesticide usage, and transportation of jute using fossil fuel-based transportation modes. Figures26 and 27show the overall and category wise resource depletion impacts which originate from jute sack and HDPE/PP sack production, respectively.

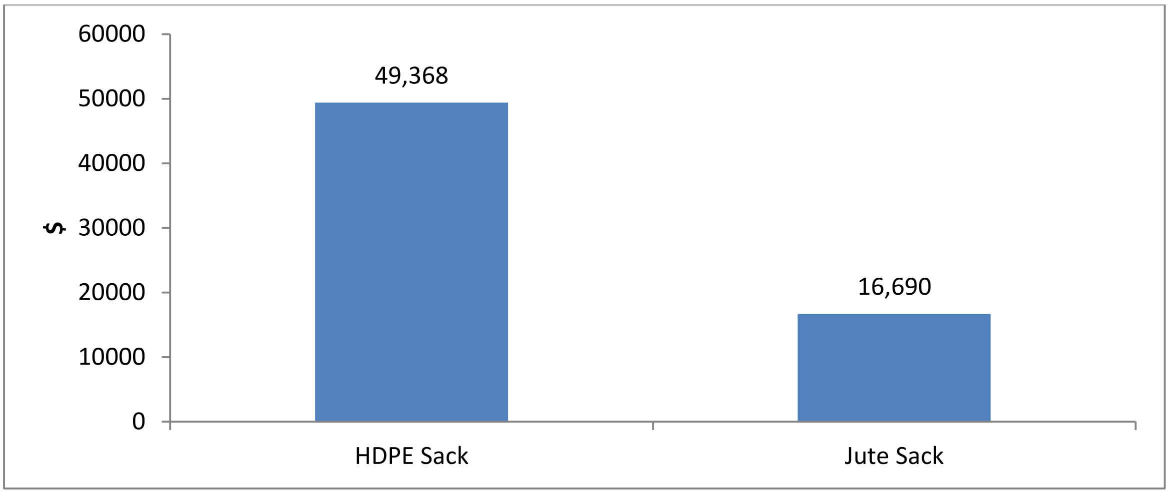

Figure 26: End Point Resource Depletion Impacts of Jute vs HDPE/PP Sack manufacturing

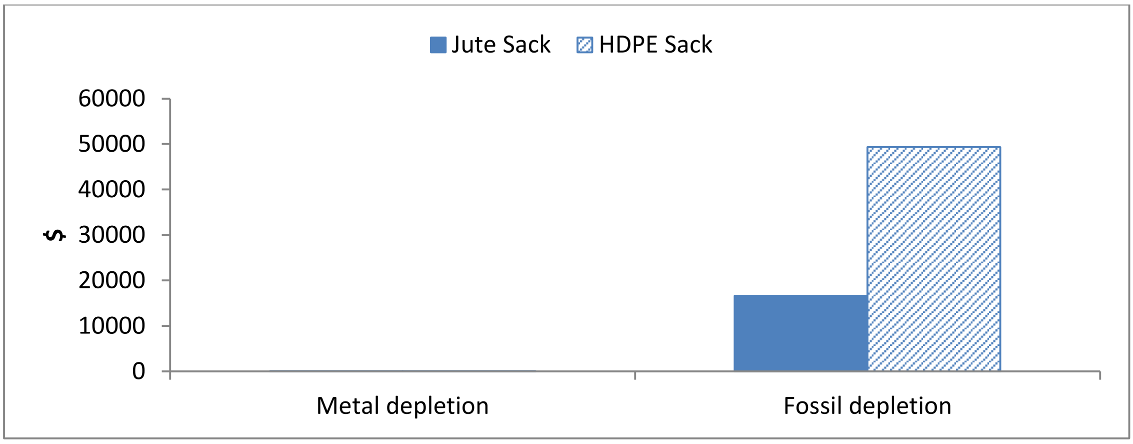

Figure 27: End Point Resource Depletion Impacts of Jute vs HDPE/PP Sack manufacturing (Per Impact Category)

7. Transportation of jute sack and HDPE sack from the production site to the usage site

After the jute/HDPE sack production, the sacks are transported using lorry, train or sea route to the site of their usage. Most of the sacking products are consumed in India by various governments and central agencies for food grain packaging, etc., and a small amount of nearly 10 per cent is exported to foreign countries. Table 12 provides the overall consumption of jute sacks by end user during the last five years.

Table 12: Jute sack procurement during last 5 years[28]

State	Punjab	Haryana	FCI	UP	Bihar	MP	Odisha	Others	Total
% Procurement	32.58	13.18	7.91	6.27	2.57	12.11	3.82	21.56	100

LCA shows the following results for various impact categories at mid-point and end-point impact categories for jute and HDPE sack transportation:

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[28] NJB, 2015,2016

Table 13: Life cycle (mid-point) impacts of jute/HDPE woven sack transportation using freight train and lorry[29]

Impact category	Climate change (kg CO2 eq)		Ozone depletion (kg CFC-11 eq)		Terrestrial acidification (kg SO2 eq)		Freshwater eutrophication (kg P eq)		Marine eutrophication (Vkg N eq)		Human toxicity (kg 1,4-DB eq)	
	Jute Sack	HDPE Sack	Jute Sack	HDPE Sack	Jute Sack	HDPE Sack	Jute Sack	HDPE Sack	Jute Sack	HDPE Sack	Jute Sack	HDPE Sack
Value for per km transportation, freight train	44.1	8.9	0.000003	0.0000005	0.4	0.08	0.00009	0.00002	0.0003	0.005	0.2	0.04
Value for per km transportation, 16-32 ton lorry	158	32.0	0.00001	0.000002	0.6	0.1	0.001	0.0002	0.0003	0.007	2.6	0.5

Impact category	Photochemical oxidant formation (kg NMVOC eq)		Particulate matter formation (kg PM10 eq)		Terrestrial ecotoxicity (kg 1,4-DB eq)		Freshwater ecotoxicity (kg 1,4-DB eq)		Marine ecotoxicity (kg 1,4-DB eq)		Ionising radiation (kBq U235 eq)	
	Jute Sack	HDPE Sack	Jute Sack	HDPE Sack	Jute Sack	HDPE Sack	Jute Sack	HDPE Sack	Jute Sack	HDPE Sack	Jute Sack	HDPE Sack
Value for per km transportation, freight train	656	133	163	33.3	11.4	2.3	36.9	7.49	113	22.9	5950	1210
Value for per km transportation, 16-32 ton lorry	0.8	0.1	0.2	0.03	0.0009	0.0002	0.007	0.001	0.01	0.002	2.3	0.5

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[29] Based on telephonic interviews, it has been observed that 16–32 ton lorry carries approximately 11.7 ton of jute sacks (65 bales) as compared to 6.7 ton (maximum of 50000 sack of 135 gram each) of HDPE sack because of difference in density and volume of the sacks. So a factor of 1.75 is applied to correct the carrying capacity of Jute and HDPE sack by a fixed volume container, i.e., wagon/lorry.

Table 14: Life cycle (end-point) impacts of 1 jute/HDPE woven sack transportation using freight train and lorry

Human Health Damage (in terms of DALY)														
Impact Category	**Climate change Human Health**		**Ozone depletion**		**Human toxicity**		**Photochemical oxidant formation**		**Particulate matter formation**		**Ionizing radiation**		**Total**	
	Jute Sack	HDPE Sack	Jute Sack	HDPE Sack	Jute Sack	HDPE Sack	Jute Sack	HDPE Sack	Jute Sack	HDPE Sack	Jute Sack	HDPE Sack	Jute Sack	HDPE Sack
Value for per km transportation, freight train	3.53E-11	1.25E-11	4.07E-15	1.45E-15	8.73E-14	3.10E-14	1.78E-14	6.32E-15	2.52E-11	8.96E-12	2.14E-14	7.58E-15	6.07E-11	2.15E-11
Value for per km transportation, 32 ton lorry	1.26E-10	4.50E-11	1.54E-14	5.46E-15	1.02E-12	3.64E-13	2.09E-14	7.42E-15	3.47E-11	1.23E-11	7.97E-14	2.84E-14	1.62E-10	5.76E-11
Ecosystem Quality (in terms of species. yr)														
Impact Category	**Climate change Ecosystems**		**Terrestrial acidification**		**Freshwater eutrophication**		**Terrestrial ecotoxicity**		**Freshwater ecotoxicity**		**Marine ecotoxicity**		**Total**	
Value for per km transportation, freight train	2.00E-13	7.11E-14	1.36E-15	4.85E-16	2.22E-18	7.88E-19	8.13E-17	2.89E-17	3.36E-18	1.20E-18	1.19E-18	4.22E-19	2.02E-13	7.16E-14
Value for per km transportation, 32 ton lorry	7.16E-13	2.54E-13	1.90E-15	6.74E-16	3.00E-17	1.07E-17	1.41E-15	5.01E-16	2.59E-17	9.21E-18	1.63E-17	5.78E-18	7.20E-13	2.56E-13

With the help of Tables 13 and 14 and based on the distance of the end use and mode of transport, the impacts of each impact category in transportation of sack phase can be added to the life cycle impacts of production of one million jute/HDPE sack at the mill/production unit boundary to calculate the overall impacts of the sack used by the end user.

8. Reuse of sacks

According to Braungart *et al.* (1992), a jute bag can be used 15 times for the primary purpose, i.e., sacking; IIT Kharagpur (2000) estimated it to be around six times and PWC (2007) mentioned it to be around 6 to7 times for storage of food grains based on their survey results and HDPE bags were cited to be used for ~3 times. The primary survey conducted in this study shows that a jute sack can be reused for packaging for at least 7 times for its primary use (packaging) as compared to HDPE bag which can be used three times. The frequency of reuse depends on conditions such as handling, storage time, infrastructure (storage place is in cemented place or mud house), etc. Apart from the primary use of jute sack for packaging, there are various multiple uses such as floor mat; for covering animals in winters; for wheat, rice husk transportation, and storage, etc. In case of reuse of product, HDPE/PP sacks would have almost more than double impacts on human health, ecosystem, and resource depletion compared to jute sacks. These observations show that jute sacks would definitely have less damage to human health and environment compared to HDPE sacks. If the reuse of sacks in taken into account (7 times for Jute sacks and 3 times for HDPE sacks) for original intended uses, the impact of jute sacks further reduces as compared to HDPE sacks as shown in Tables 15, 16 and 17 below. The data table 15 is captured in Figure 28 on next page.

Table 15: Midpoint impacts of PP/HDPE and Jute Sacks

Impact category	Unit	PP/HDPE Sack (Million Sacks, With 3 Reuses)	Jute Sack (Million Sacks, With 7 Reuses)
Climate change	kg CO_2eq	169349.8	-401378.1
Ozone depletion	kg CFC-11 eq	0.01	0.001
Human toxicity	kg 1,4-DB eq	88287.8	13973.6
Photochemical oxidant formation	kg NMVOC	592.3	245.8
Particulate matter formation	kg PM10 eq	613.0	210.9
Terrestrial ecotoxicity	kg 1,4-DB eq	2.6	42.3
Freshwater ecotoxicity	kg 1,4-DB eq	1309.5	343.1
Marine ecotoxicity	kg 1,4-DB eq	1234.8	326.4

In terms of climate change impacts which is the most important in current global context, the impact of production of PP/HDPE sacks in much higher as compared to Jute sacks. The negative sign in the case of Jute sacks indicates that in fact over the life cycle Jute sacks sequester net CO2 from atmosphere. In all other cases, jute sacks fare better than PP/HDPE alternative except in the case on terrestrial eco-toxicity due to cultivation process and use of JBO in the jute sack manufacturing.

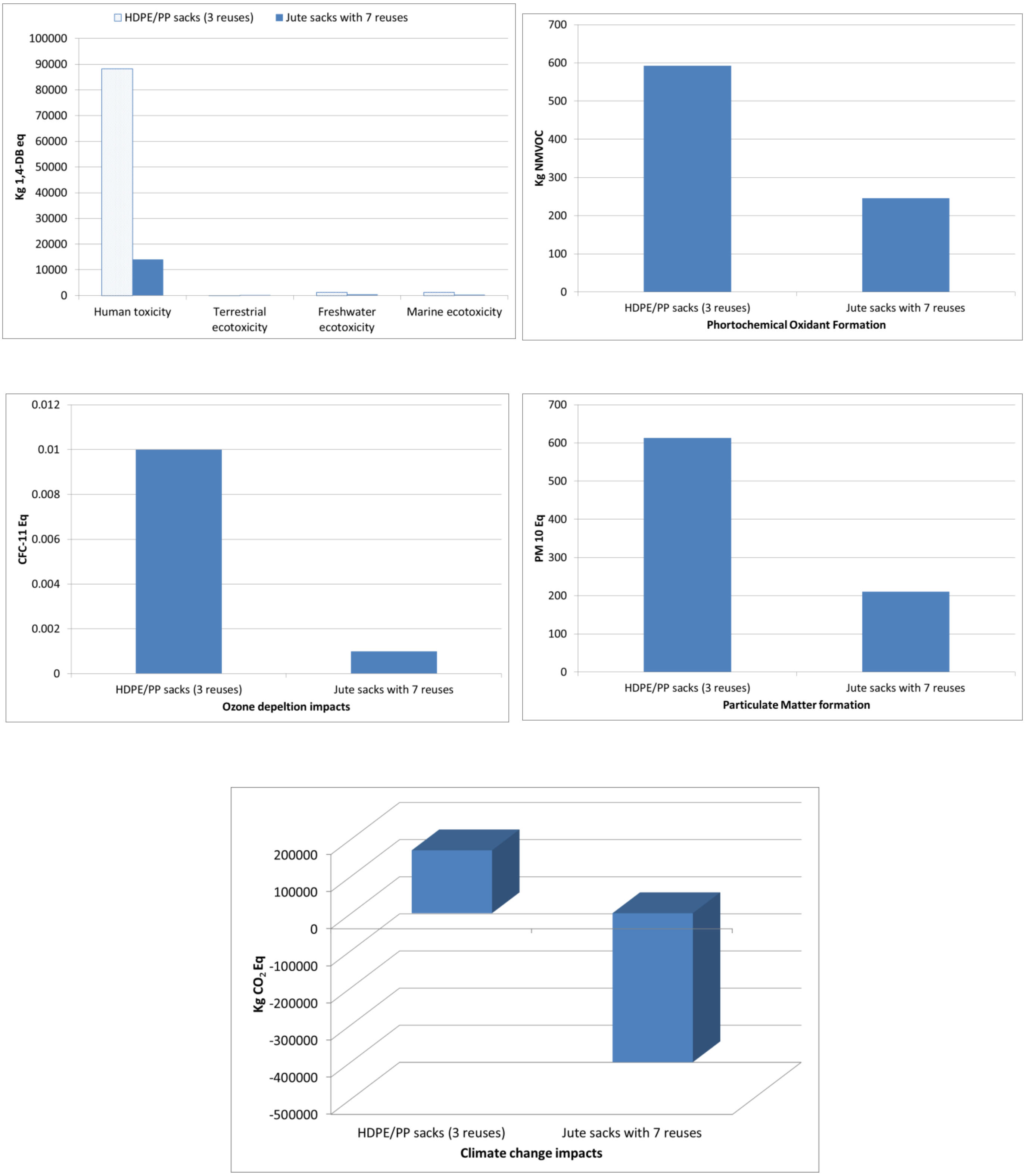

Figure 28: Midpoint impacts of PP/HDPE and Jute Sacks

To arrive at damages caused by particular activity on human health, ecosystem and resource depletion, the end point impact characterization was carried out which is presented in Table 16. The end point characterization impacts are presented either in terms of DALY (Daily Adjusted Life Years) or loss of species or in terms of financial loss due to pollution.

Table 16: Endpoints impacts (Characterisation) of HDPE and Jute Sack

Impact category	Unit	PP/HDPE Sack (Million Sacks, With 3 Reuses)	Jute Sack (Million Sacks, With 7 Reuses)
Climate change Human Health	DALY	0.2	-0.6
Ozone depletion	DALY	0.00003	0.000002
Human toxicity	DALY	0.06	0.009
Photochemical oxidant formation	DALY	0.00002	0.000009
Particulate matter formation	DALY	0.1	0.05
Ionising radiation	DALY	0.00006	0.00003
Climate change Ecosystems	species.yr	0.001	-0.003
Terrestrial acidification	species.yr	0.00001	0.000003
Freshwater eutrophication	species.yr	0.000002	0.000002
Terrestrial ecotoxicity	species.yr	0.0000004	0.000006
Freshwater ecotoxicity	species.yr	0.000001	0.0000003
Marine ecotoxicity	species.yr	0.0000002	0.00000006
Metal depletion	$	6.0	4.9
Fossil depletion	$	16449.9	2379.3

Here also the jute sacks fare better than PP/HDPE alternatives in all the case and have much less impact and the environment and the ecosystem. The endpoint impacts of the two alternatives in terms on damage caused over the life cycle are presented in Table 17.

Table 17: End points impacts (Damage Assessment) of HDPE and Jute Sack

Damage category	Unit	HDPE Sack (Million Sacks, With Reuse)	Jute Sack (Million Sacks, With Reuse)
Human Health	DALY	0.4	-0.5
Ecosystems	species.yr	0.001	-0.003
Resources	$	16456.0	2384.2

Finally the scores on endpoint impacts on damage assessment to human health, loss of species (ecosystem impact) and financial losses due to resource depletion also favour jute sack over the synthetic, fossil fuel derived PP/HDPE alternatives. Overall looking at life cycle impact of jute sack manufacturing over the PP/HDPE sacks, jute a material for packaging of food grains should be preferred over synthetic alternatives from life cycle perspective especially from climate change perspective where Jute sack production is net sequester of CO2 over the life cycle whereas PP/HDPE alternatives contribute to global warming as they are derives from non-renewable fossil fuel sources.

9. End life of sacks

Disposal of jute sacks

Jute being an agricultural and bio-degradable product is considered to be environment friendly. As jute cultivation requires lesser input of fertilizers and pesticides, so the chemical composition of jute sack doesn't have heavy metals, etc. (Inagaki, 2000 and IJSG, 2003; Afrin 2011). Out of total dry weight of the product, dry fibre has ~0.43 per cent N, 0.19 per cent P_2O_5, and 1.65 per cent K_2O (IJSG, 2003 and Demsey, 1975 as quoted by Islam and Ahmed, 2012). Ultimate analysis of jute yarn also shows that it has 42.3 per cent C, 5.46 per cent H, 0.21 per cent N, 0.01 per cent S, 40.77 per cent O, and 4260 HHV (PWC, 2007). So if the jute sack is disposed in open landfill, it will degrade and return all these nutrients to the soil without release of any toxic elements in higher concentrations. The degradation of jute bag in the ambient environment depends on the temperature and moisture; under normal conditions if mixed with soil jute bag degrades in ~150 days (IJIRA, 2013).

Jute bags can either be recycled in the form of raw material for pulp and paper industry, or used as for soil stabilization and soil conditioner. Earlier there was no facility to collect the used jute sack from the farmer or end user, therefore the waste, unusable jute sacks were generally ending up at disposal sites. Over the last decade, the value of jute as raw material for paper industry has been realized and proper collection facility for jute sack is arranged through organized and decentralized scrap and waste dealers. The waste dealer buys the jute bag at rupees ~2 per bag and sells it to the aggregator who in turn trades the old unusable bags to the paper industry to be used to make insulation paper, etc. In general, most of the discarded jute sacks are recycled for pulp and paper industry and negligible percentage of the sacks goes to landfill for final disposal. The use of jute as raw material for pulp and paper industry makes it a more environment friendly and sustainable product, because it reduces burden on other resources and raw materials. Also being environment friendly, biodegradable and non-toxic, the impacts of jute disposal are very small or insignificant.

Disposal of HDPE sacks

HDPE bags are made from non-renewable, exhaustible resource, i.e., natural gas and crude oil, which are already scarce in India which so places extra pressure on the available resources. HDPE sacks are non-biodegradable in nature and do not degrade easily in the open environment and it will remain in the system for longer duration and create unnecessary pressure on waste management systems. It is also important to highlight that disposal of these sacks in open environment/drains, etc., results in clogging of waterways as well as decrease aesthetic value of the place. Derraik (2002) has highlighted that plastic litter constitutes 60–80per cent of the total marine debris, which are causing greater threats to the aquatic life and there is an urgent need to address the issue. Various researchers around the world have emphasized the high concentration of toxic elements such as heavy metal in the HDPE bags, which at the end of life phase are returned to the environment causing a threat to human health and the ecosystem quality. Muller *et al.*(2001), Tansel *et al.* (2011), and Arutchelvi *et al.* (2008)have suggested that in buried application such as solid waste landfill life, expectancy of HDPE can be up to 100 years whereas in exposed applications such as in floating covers, its life expectancy can be ~20 years. It is also important to highlight that this product is generally non-biodegradable; however, it could be recycled for other products such as low grade plastic products or incinerated for production of heat and electricity. However, if incineration could be done inappropriately, it may result in toxic emissions in the ambient environment which could be more harmful and result into various ill-effects on human health and the ecosystem.

10. Other beneficial impacts of jute sack production life cycle

- The jute crop like any other crop requires carbon dioxide ($CO_{2)}$ from the atmosphere to carryout photosynthesis and synthesize organic matter. On an average, in approximately 120 days of jute plant cycle, it absorbs ~15 MT of $CO_{2;}$ at the same time liberating 11 MT of oxygen ($O_{2)}$. Thus, jute cultivation also functions as air purifying agent and acts as a sink of the atmospheric CO_2 (Inagaki, 2000 and IJSG, 2003).
- On an average approximately 5.74 ton/hectare of jute sticks are produced from jute cultivation, out of which approximately 80 per cent are used as firewood in household cooking by the rural people (Inagaki, 2000 and IJSG, 2003).
- Jute is one of the major cash crops grown in West Bengal.
- Jute is mostly grown in India by marginal farmers (marginal farmers 65 per cent and small farmers 25 per cent in West Bengal), being a high human labour intensive crop (approximately 60–70 per cent of the cost of cultivation goes to labour) it involves all family members in the agricultural activities, which provides them a chance to get some monetary incentive in their locality. This also reduces the burden of migration of marginalized and poor farmers to cities by providing them additional income in their cultural and local setup.
- More than 40 lakh families are connected to the jute cultivation activities in India which provides direct employment to more than 2.6 lakh people in jute industry and to more than 1.4 lakh people in connected activities (Ernst & Young, 2010).
- Approximately 5–6 ton/hectare of green leaves is shed by the jute plant in 3–4 days in the field after harvesting of jute plant. Jute leaves have very high mineral concentration (2.85–3.60 per cent N, 0.85–1.20 per cent P, and 2.5–3.10 per cent K) which acts as manure for the next crop grown in the field.
- Also, the roots left in the field hold nutritional and manure value for the next crop, which adds to the fertility of the soil and reduces soil erosion
- Sludge from the retting tank is used as organic manure for the next crop such as paddy

After multiple primary and secondary uses, jute sack is recycled and used as raw material for the paper industry to make insulation paper which reduces the import of wood pulp for the same.

11. Future Outlook

Overall jute sacks come out as eco-friendly and renewable natural fibre based packaging material when compared to HDPE based alternative over its lifecycle. It also provides packaging alternative which is breathable and much recommended for food grains. The plastic or HDPE sacks if left on their own in environment do not degrade and can be found in environment for hundreds of years. Moreover they are sourced from scarce and non-renewable fossil fuel resources so it is time to look for eco-friendly alternative in terms of jute.

The Government along with jute mills should work towards developing eco-label for jute based products including sacks and promote its use over synthetic fossil fuel based alternates.

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A unique developing country institution, TERI is deeply committed to every aspect of sustainable development. From providing environment-friendly solutions to rural energy problems to helping shape the development of the Indian oil and gas sector; from tackling global climate change issues across many continents to enhancing forest conservation efforts among local communities; from advancing solutions to growing urban transport and air pollution problems to promoting energy efficiency in the Indian industry, the emphasis has always been on finding innovative solutions to make the world a better place to live in. However, while TERI's vision is global, its roots are firmly entrenched in Indian soil. All activities in TERI move from formulating local- and national-level strategies to suggesting global solutions to critical energy and environment-related issues. TERI has grown to establish a presence in not only different corners and regions of India, but is perhaps the only developing country institution to have established a presence in North America and Europe and on the Asian continent in Japan, Malaysia, and the Gulf.

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