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LIFE CYCLE ENERGY USAGE AND GHG EMISSIONS STUDY OF A SUGAR MILL IN INDIA

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Abstract

Day by day, energy resources are diminishing and the concentration of GHG (greenhouse gas) emissions are increasing in the world. So, analysis and waste utilization of industries has a great concern for the society. Sugar mill plays an important role in the context of Indian market. Sugar industry mainly consist of three plants i.e., sugar mill, cogeneration plant and distillery unit. These units i.e. cogeneration and distillery are basic industries for power and chemical sectors which is having a common input from sugar mill. Here four combinations have been considered for the sugar mill having different combination of plants. In the present study, energy usage and GHG emissions have been estimated for different combinations of sugar mill.

Keywords: energy use, GHG emission, LCA, sugar mill

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1. Introduction

Now days environmental problems i.e. global warming, ozone layer depletion, waste accumulation etc. are the critical issues in the world. In the last few decades, global climate is changing rapidly and this process of climatic change will continue with time (Hulme et al., 2002; Tavakoli et al., 2018). So, there is a need to diminish these arising undesirable problems to save our environment and the world. Besides the consumption of energy, a lot of waste is being produced during operation which is thrown into the environment and results in generation of harmful gases which contributes in GHG (greenhouse gas) emissions. The influence of industrial sector on the environment cannot be ignored.

The industrial sector is playing a vital role in the world economy. Industry accounts for more than one-third of all types of energy used in the world. Industries have a lot of moving parts (air compressor, pumps and fans etc.) and these moving parts consume very high power which has several impacts on the environment. Industries also have a variety of highly energy-intensive processes, i.e. production of steam, process heating, and motor-driven equipment (Chauhan et al., 2011). Industrial processes use fossil fuel in the form of diesel oil and electricity in the manufacturing of equipment, construction and installation (Macedo, 1992). Thus, electricity and energy demands are very high in the industry market. Most of the energy that industry utilizes is supplied from conventional electricity generation system (coal, oil, gas) (USDA, 2012). So, the reduction of electricity consumption is very essential to decrease the impacts on the environment.

Today, energy crisis is a major problem of the world. A lot of energy is consumed by the industries which also emit several harmful pollutants in the environment. The application of energy resources in industry increases the polluting contents into the environment such as SO_2 (Sulphur dioxide), NO_X (Nitrous oxide) and CO (Carbon monoxide) emissions

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from boilers and furnaces, CFC (Chloro-fluoro carbons) emissions from refrigerants use, etc. Typical inputs, outputs and emissions for a typical industrial process are shown in Fig. 1.

1.1. LCA methodology

Life cycle assessment (LCA) is an analyzing tool for evaluating possible impact (energy, environment etc.) from birth to grave of a product or system as raw material acquisition, processing, manufacturing, use and finally its disposal. LCA has been a significant and comprehensive method for the analysis of environmental impact of products/services. It consists of four steps i.e., definition of goal and scope, inventory analysis, impact assessment and interpretation of results (ISO, 2006; Ometto et al., 2009). In LCA analysis, assumptions, aim, scope, description of study area, methodologies and output is necessary (Chauhan et al., 2011; Varun et al., 2009a, 2009b).

1.2. Sugar industry scenario

India is having tropical and sub-tropical regions and sugarcane is mostly grown in tropical regions. By crushing of sugarcane several products (sweetening agents) such as sugar, khandsari and gur are produced in India (Renouf et al., 2010; Vijayalakshmi, 1987). Most of the substrates of human diet are dependent upon sugar. So, demand of sugar is very high in Indian market. Sugar is normally produced by sugarcane, corn, cassava, sugar beet etc. But in India, sugar production is mainly dependent upon sugarcane which is having very tall grass with big stems (Contreras et al., 2009). Sugarcane is one of the most important commercial crops in the world (Seabra et al., 2010).

India, Brazil, Thailand, Australia and China are top five nations which produces approximately 40% of the total sugar in the world. Approximately 115 countries are producing sugar all over the world. But out of these, 67 countries are producing sugar from sugarcane, 39 countries are producing sugar from sugar beet while 9 countries are producing sugar from both of them (Chauhan et al., 2011; Javalagi et al., 2010; Lichts, 2007). India holds second rank in the sugarcane production. There are 430 sugar mills which are producing 12 million tons of sugar in India (Yarnal et al., 2009). Sugarcane has several advantages in comparison of corn and sugar beet such as fossil-energy input, GHG emission and acidification (Renouf et al., 2008).

Now days, sugar industry is a combined unit of sugar mill, cogeneration plant and distillery. Sugar mill produces sugar and also produces several by-products i.e. bagasse, molasses, filter cake etc. and various waste products i.e. mud, fly ash, stillage etc. By-products are used as input resources in other plants (units). In sugar mill, bagasse is a waste product which is used as a supplementary fuel in place of coal in boiler for the generation of electricity and steam (Singh et al., 2007).

In sugar industry, bagasse fly ash is a solid waste which is used to remove cadmium and nickel from waste water (Gupta et al., 2003). Filter cake as a by-product of sugar mill is used as a fertilizer. Molasses used as input source in distillery to produce ethanol. In production of ethanol, distillation process separates the ethanol and stillage or spent wash. Ethanol production is increased by using cane trash and bagasse as a supplementary fuel (Seabra et al., 2010). Stillage is also used as a fertilizer which returns minerals back into the soil for the next crop. 1 litre of ethanol produces 12-13 litre stillage. In production of ethanol, stillage which has very high BOD (Biochemical oxygen demand) in range of 30-40 g/L and COD (Chemical oxygen demand) in range of 60-100 g/L is an important residual. In distillery, there are several processes of utilization of stillage. Anaerobic digestion of stillage is the best option for maximum waste utilization (Olguin et al., 1995).

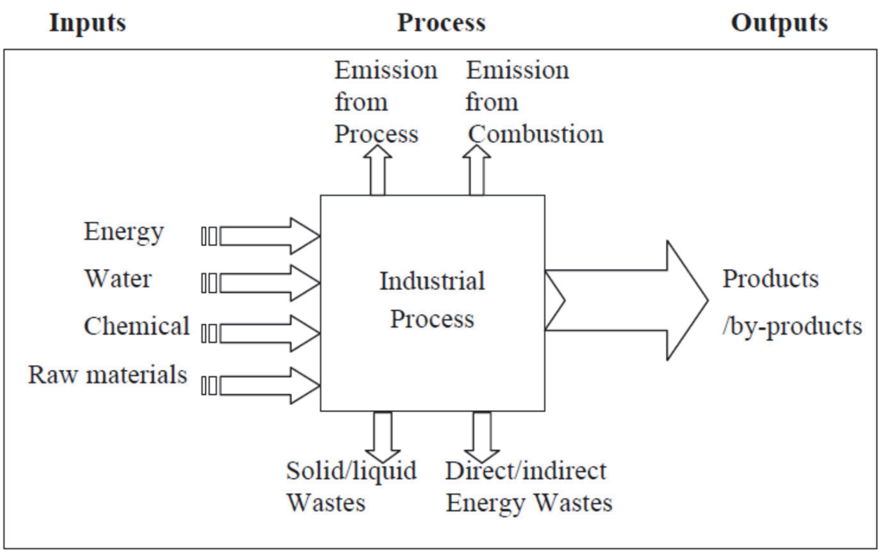

Fig. 1. Input and output of process

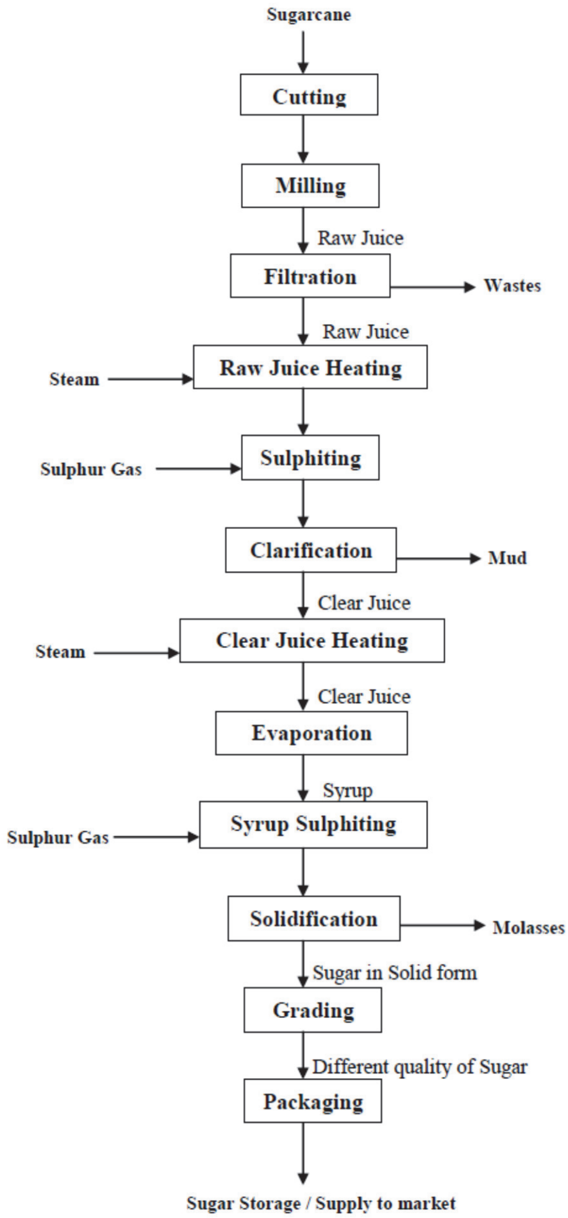

Fig. 2. General layout of sugar mill processes

Stillage generates energy via advanced anaerobic digestion systems such as UASB (Up-flow anaerobic sludge blanket). UASB reactor is a type of anaerobic digestion system which is used to refine stillage into biogas (Nguyen et al., 2008; Tewari et al., 2007). Waste water of sugar industry has several contents such as phosphorous, nitrogen content in ammonia (NH_4-N) and COD which are harmful for human being and environment (Bojcevska et al., 2007; Calero et al., 2000; Hosetti, 1995; Rodriguez et al., 2018).

2. System description

The schematic layout of sugar mill, cogeneration plant and distillery unit is shown in Figs. 2-4. These plants work separately but their functioning depends upon each other. In the present study, capacity of sugar mill, cogeneration power plant and distillery is 12000 TCD (tons of cane per day), 60 MW (mega watts) and 270 klpd (kilo litre per day) (DSML, 2012). The four set of combinations has been studied for the evaluation of energy usage and GHG emissions from sugar mill. In the first combination only sugar mill has been considered. Second combination is of sugar mill and cogeneration plant, third one is the combination of sugar mill and distillery unit and fourth combination consists of sugar mill, cogeneration plant and distillery unit. This study is gate to grave analysis. In this study sugarcane production is not considered. As there are multi output from this system, allocation has an important role in these combinations of sugar mill.

Allocation of resources mainly depends upon the capacity of main plant and production of resource plants. The sugar mill has been allocated 100, 80, 60 and 50% contribution in combination 1, 2, 3 and 4 respectively depending upon the amount of product developed from these systems.

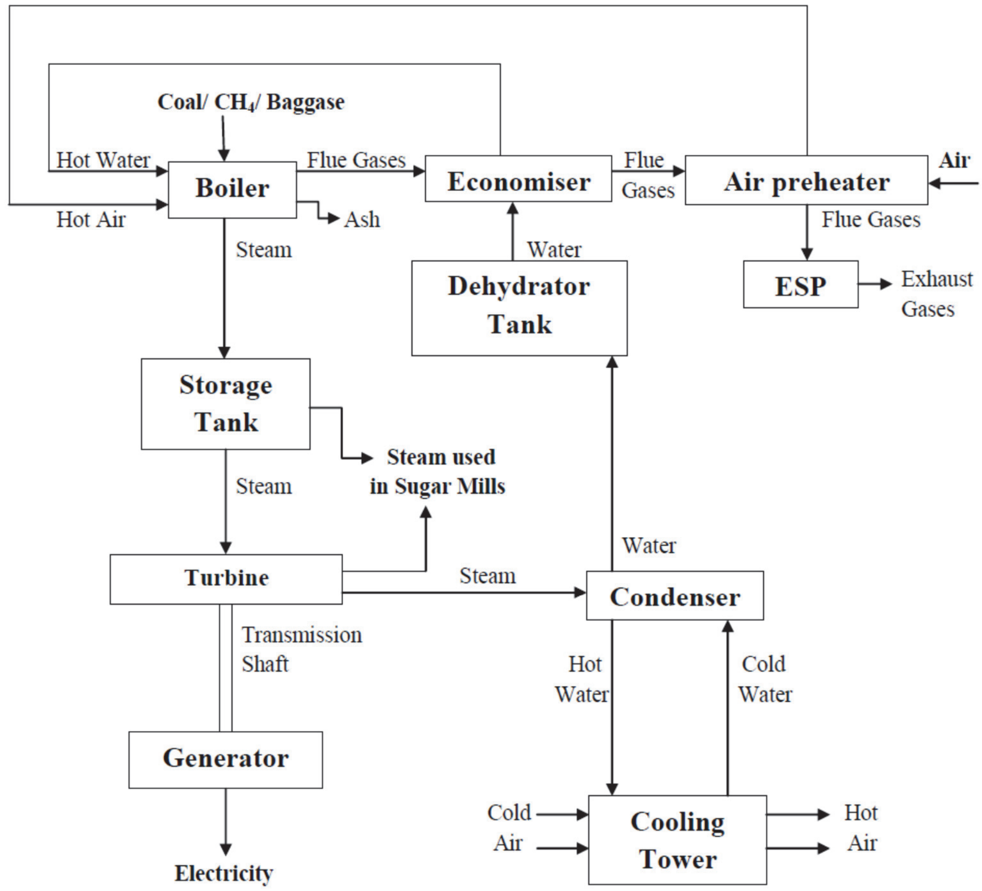

Fig. 3. General layout of cogeneration plant components

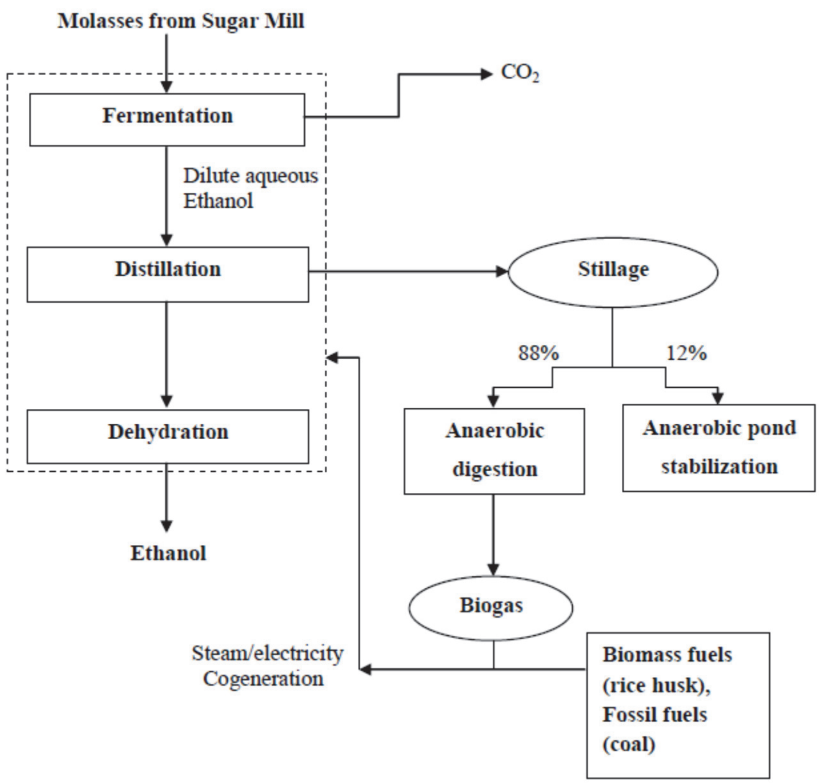

Fig. 4. General layout of distillery

In second combination, 20% of sources are allocated to cogeneration plant. In third combination, 40% of sources are allocated to distillery unit and in fourth combination, 15 and 35% of sources are allocated to cogeneration plant and distillery unit respectively. The schematic layout of sugar mill combinations is shown in Fig. 5. Generally, sugar industry is kept functional for 150 days in a year and its life time has been considered for 20 years. The amount of production of sugar, ethanol, electricity and filter cake is dependent on crushing capacity of sugarcane per day.

2.1. Functional unit

Functional unit is an important parameter to carry out life cycle analysis. In the present study, three functional units were considered as 1 ton (t) of sugar, 1 kWh_e (kilo watt hour electricity) and 1 litre of ethanol. These functional units are different for each unit. Ton of sugar, kWh_e and litre of ethanol were considered as a functional unit for sugar mill, cogeneration plant and distillery respectively.

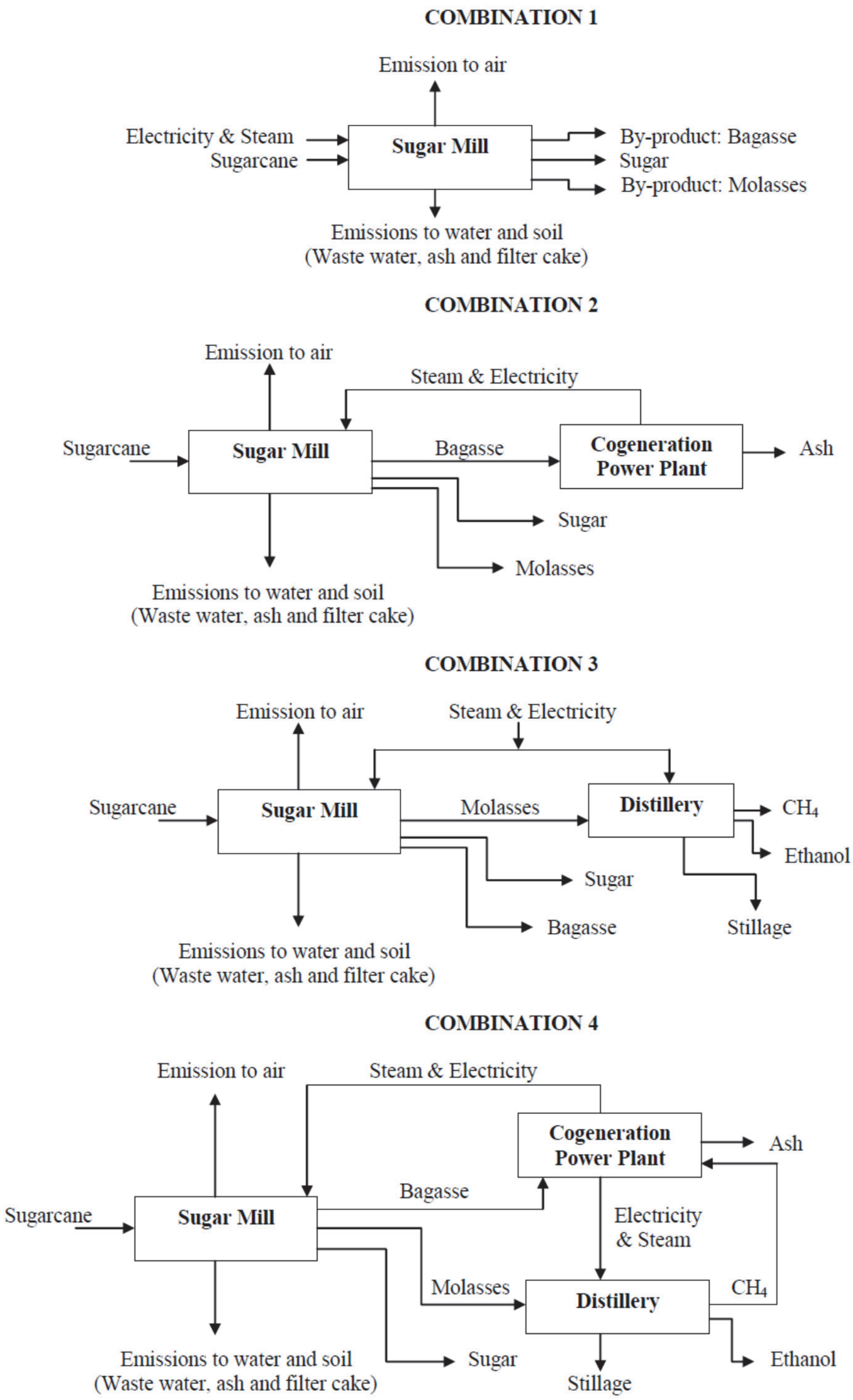

Fig. 5. Schematic layout of sugar mill combinations

3. Methodology

LCA is a valuable tool to improve the environmental performance of sugar industry in strategic decisions and to substantiate green energy claims (Ramjeawon, 2004). There are two primary methods to carry out LCA analysis i.e., PCA (Process chain analysis) and EIO (Economic input-output) method. In this work, LCA study of different combinations of sugar mill has been carried out by using EIO-LCA method.

In EIO-LCA method, product or system that consists of supply chains is modeled using economic flow databases (input-output tables). These tables are based upon economic data and their associated environmental coefficients were used for energy usage and GHG emissions (Bullard et al., 1978). In EIO analysis, there are several advantages such as better in data accuracy, easier data handling and tremendous use of policy application (Chung et al., 2009).

The Carnegie Mellon EIO-LCA model (US Department of Commerce 2002 Industry Benchmark) is used for this analysis of complete sugar mill with its various combinations. In India, no EIO-LCA model is available. So, Carnegie Mellon EIO-LCA model is used in the present study (CMU, 2012). This EIO-LCA model is directly based upon the US economy. For the applicability of this model, Indian costs (Rupees) for all products/systems were converted into its equivalent US dollar ($) by using the relation of PPP (Purchase power parity) as given in Eq. (1) (Varun and Chauhan, 2014).

$$Equivalent\ cost\ in\ USD(2002) = \frac{Cost\ in\ Rs\ (2004)}{PPP\ \ in\ 2004} x$$
$$x \frac{Inflation\ index\ for\ year\ 2002\ for\ US}{Inflation\ index\ for\ year\ 2004\ for\ US} \quad (1)$$

The PPP conversion factor is 9.2 for the year 2004. The inflation index for year 2002 and 2004 is 179.88 and 188.90 respectively. The Carnegie Mellon University Green Design Institute has developed this model which is based on input-output tables of USA (United States of America). The present study is used to account the primary energy requirement and GHG emissions of manufacturing of major materials and equipments used in various combinations of sugar mill.

3.1. Validity of model and limitation

EIO-LCA model of US is used to calculate the primary energy, GHG emissions, toxic releases and air pollutants by using the cost in USD (US Dollar). This USA based EIO-LCA model is used in Indian sugar industry to estimate the primary energy requirement and GHG emission of a plant. For the validation of this model in Indian context two studies were carried out. The average steel bar price in India was 2,700.00 per 100 kg in the year 2004. The equivalent of this amount in USD (US Dollar) was $249.4 for the year 1997 by using PPP and inflation index. This USD value was used as an input to the model which results in energy consumption of 3.9 GJ for the manufacturing of 100 kg of steel bar. This energy estimate very well lies in between 35 and 50 GJ/1000 kg and 42.0 GJ/1000 kg as estimated for Indian steel industry (Chaudhary and Bhaktavatsalam, 1997). The other case has been taken for the estimation of energy requirement from aluminium sheet production. The price of aluminium sheet is around 225.0/kg which is adjusted to year 2004-05 and comes around 1,39,000/1000 kg. The equivalent of this amount in USD (US Dollar) was $12,838.36/1000 kg of aluminium in the year 1997 by using PPP and inflation index. This USD value is used as an input to the model and results in energy consumption of 243.9 GJ for the manufacturing of 1000 kg of aluminium sheet. This energy estimate very well matches with the estimated value for Indian conditions and the value is 236.8 GJ/1000 kg. Hence, it shows that by using US EIO-LCA model for Indian conditions there is around 5% deviation in the values. There is also not much difference in the electricity mix of both the countries (i.e. US and India), hence, this model can be fairly used for the estimation of indicative values of energy usage and GHG emissions for Indian sugar mill as proposed (Varun et al., 2012). These comparison shows that the US EIO-LCA model is easily used with Indian financial cost data by using PPP factor to convert the dollar cost.

The use of US data is one of the limitations in present study because this single point comparison is not sufficient to reply the answer of all objections. But the financial structure and industry energy efficiencies of two countries are not quite different. Because the actual US market prices should not be used for commodities produced and consumed in India as discussed in examples of validation.

The mixes of the two countries are actually quite similar due to the significant impact of the environmental performance of the mix on results of life-cycle studies. For example, fossil fuel supplies 70% in the US versus 81% in China, nuclear supplies 20% versus 1% and 11% versus 18% from hydro and other renewable (EIA, 2001; Yang, 2003; Zhang et al., 2007). Similarly we observed that the energy mix of US and India is approximate 5-10%. Hence these differences are not much significant enough to strongly impact the energy use and emission factors and are certainly less significant than the impact of sector level aggregated data used in the EIO-LCA model. So, we can use this EIO-LCA model for any country which has same mixes.

The EIO-LCA method is a linear model. Thus, the results of $1.00 change in demand or level of economic activity will be 10 times the results of a $10 change in demand. The IO (input-output) models used for the various EIO-LCA models represent economies of a single nation. Imports and exports, though, are a major part of any economy's transactions. Imports are implicitly assumed to have the same production characteristics as comparable products made in the country of interest. Thus, if a car is imported and used by an Indian company, the environmental effect of the production of the car is expected to be comparable to those made in the India. The other limitations are aggregation of data and aggregation of sectors.

4. Result and discussion

In the present study, life cycle analysis has been carried out for the estimation of primary energy usage and GHG emissions. Life cycle analysis study of sugar mill is divided into three parts E&M (Electro-mechanical), civil and O&M (Operation & maintenance) works. So, energy usage and GHG emissions is evaluated for these life cycle steps of sugar mill. O&M works has been considered as 6% of E&M and 3% of civil works. In this study, life cycle analysis of sugar mill has been carried out along with their four combinations have also been studied.

4.1. Results

The result for life cycle energy usage and GHG emissions has been presented for sugar mill.

4.1.1. Primary energy use

Each product/system requires primary energy which is used for manufacturing and establishment of a plant. The total energy use has been separately presented for sugar mill, cogeneration plant and distillery unit were as 2742, 967.87 and 709.55 TJ (Tera Joule) respectively in Table 1.

Energy usage for sugar mill, cogeneration plant and distillery are 761.667 MJ/t of sugar, 228.811 kJ/kWh$_e$ and 161.687 kJ/L of ethanol respectively as shown in Table 2. Primary energy usage shared by E&M equipment is 61, 56, 61 and 53%, civil works share is 2, 4, 2 and 5% and O&M works share is 37, 40, 37 and 42% for combinations 1, 2, 3 and 4 respectively.

Table 3 shows energy usage in E&M equipment, civil work and O&M of sugar industry alternatives. In sugar mill, primary energy requirement is 761.660 MJ/t of sugar for combination 1, 609.328 MJ/t of sugar, 358.458 kJ/kWh$_e$ for combination 2, 456.996 MJ/t of sugar, 411.621 kJ/L of ethanol for combination 3 and 380.830 MJ/t of sugar, 326.048 kJ/kWh$_e$, 380.380 kJ/L of ethanol for combination 4 as shown in Table 4.

Table 1. Total Life Cycle Energy Use and GHG Emissions for sugar industry

S. No.	*Components*	*Energy use (TJ)*			*GHG emissions (t-CO_{2eq})*		
		Sugar Mill	*Cogeneration Plant*	*Distillery*	*Sugar Mill*	*Cogeneration Plant*	*Distillery*
1.	Civil works	69.3	65	94	4408.918	4136.762	598.742
2.	E&M	1662.7	414.87	265.55	97259.276	26222.175	17148.513
3.	O&M*	1010	488	350	65861.612	31751.466	22770.337
Total		**2742**	**967.87**	**709.55**	**167529.806**	**62110.403**	**40517.592**

*Note: * for 20 years life*

Table 2. Energy use and GHG emissions of sugar industry

S. No.	*Plant*	*Capacity*	*Energy use*	*GHG emissions*
1.	Sugar Mill	12000 TCD	761.667 MJ/t of sugar	46.536 kg-CO_{2eq}/t of sugar
2.	Cogeneration Plant	60 MW	228.811 kJ/kWh$_e$	14.683 g-CO_{2eq}/kWh$_e$
3.	Distillery	270 klpd	161.687 kJ/L of ethanol	9.233 g-CO_{2eq}/L of ethanol

Table 3. Energy usage and GHG emissions in civil works, E&M works and O&M works for different combinations of sugar mill

S. No.	*LCIA*	*Unit*	*Comb. 1*	*Comb. 2*	*Comb. 3*	*Comb. 4*
Civil Works						
1.	Energy use	MJ/t of sugar	19.250	15.400	11.550	9.625
		kJ/kWh$_e$	-	18.642	-	17.823
		kJ/L of ethanol	-	-	27.736	26.947
2.	GHG Emissions	kg-CO_{2eq}/t of sugar	1.224	0.979	0.734	0.612
		g-CO_{2eq}/kWh$_e$	-	1.186	-	1.134
		g-CO_{2eq}/L of ethanol	-	-	0.539	0.488
Electro-mechanical Works						
1.	Energy use	MJ/t of sugar	461.860	369.488	277.116	230.930
		kJ/kWh$_e$	-	176.692	-	157.039
		kJ/L of ethanol	-	-	212.066	193.122
2.	GHG Emissions	kg-CO_{2eq}/t of sugar	27.016	21.613	16.209	13.508
		g-CO_{2eq}/kWh$_e$	-	10.798	-	9.648
		g-CO_{2eq}/L of ethanol	-	-	12.772	11.664
Operation & maintenance Works						
1.	Energy use	MJ/t of sugar	280.550	224.44	168.33	140.275
		kJ/kWh$_e$	-	163.124	-	151.186
		kJ/L of ethanol	-	-	171.819	160.311
2.	GHG Emissions	kg-CO_{2eq}/t of sugar	18.294	14.635	10.976	9.147
		g-CO_{2eq}/kWh$_e$	-	10.620	-	9.842
		g-CO_{2eq}/L of ethanol	-	-	11.192	10.441

Table 4. Total energy use and GHG emissions for different combinations of sugar mill

S. No.	*LCIA*	*Unit*	*Comb. 1*	*Comb. 2*	*Comb. 3*	*Comb. 4*
1.	Energy use	MJ/t of sugar	761.660	609.328	456.996	380.830
		kJ/kWh$_e$	-	358.458	-	326.048
		kJ/L of ethanol	-	-	411.621	380.380
2.	GHG Emissions	kg-CO_{2eq}/t of sugar	46.534	37.227	27.919	23.267
		g-CO_{2eq}/kWh$_e$	-	22.604	-	20.624
		g-CO_{2eq}/L of ethanol	-	-	24.503	22.593

4.1.2. GHG Emissions

GHG emission is a critical issue in the current time. GHG emission is calculated in terms of CO_{2eq} (Carbon dioxide equivalent). In manufacturing, establishment, processing etc. products/systems emit GHG emissions. GHG emissions from each life cycle stages of sugar mill have been evaluated. The total GHG emission has been separately presented for sugar mill, cogeneration plant and distillery unit which were as 167529.806, 62110.40 and 40517.59 t-CO_{2eq} respectively as given in Table 1.

GHG emissions from sugar mill, cogeneration plant and distillery were 46.536 kg-CO_{2eq}/t of sugar, 14.683 g-CO_{2eq}/kWh$_e$ and 9.233 g-CO_{2eq}/L of ethanol respectively as shown in Table 2. GHG emissions shared by E&M equipment is 58, 54, 55 and 52%, civil works share is 3, 4, 2 and 3% and O&M works share is 39, 42, 43 and 45% for combinations 1, 2, 3 and 4 respectively. Table 3 also gives the value of GHG emissions from E&M equipment, civil work and O&M for various combinations of sugar mill. GHG emission from sugar mill is 46.536 kg-CO_{2eq}/t of sugar for combination 1, 37.227 kg-CO_{2eq}/t of sugar, 22.604 g-CO_{2eq}/kWh$_e$ for combination 2, 27.919 kg-CO_{2eq}/t of sugar, 24.503 g-CO_{2eq}/L of ethanol for combination 3 and 23.267 kg-CO_{2eq}/t of sugar, 20.624 g-CO_{2eq}/kWh$_e$, 22.593 g-CO_{2eq}/L of ethanol for combination 4 as shown in Table 4.

5. Conclusions

In this study, combination 4 requires higher primary energy use among the various combinations. But this combination produces several products and utilizes wastes of sugar mill which increase overall growth of sugar mill and also emits high GHG emission in comparison to other combinations.

The results also show that the total emissions in combination 4 are still less in comparison to the sum of emissions from these plants separately. So, combination 4 is a best way of waste utilization, production of electricity and several products for sell. This combination is also not harmful for the environment.

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