Journal of Cleaner Production 41 (2013) 222–231

Contents lists available at SciVerse ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Life cycle assessment of the cogeneration processes in the Cuban sugar industry

Maylier Pérez Gil*, Ana M. Contreras Moya, Elena Rosa Domínguez

Departament of Chemical Engineering, Chemistry and Pharmacy Faculty, Central University "Marta Abreu" of Las Villas, Santa Clara, Villa Clara 54830, Cuba

ARTICLE INFO

Article history:
Received 28 October 2011
Received in revised form
1 August 2012
Accepted 2 August 2012
Available online 31 August 2012

Keywords:
Bagasse
Cogeneration
Energy
Electricity
LCA
Eco-indicator 99

ABSTRACT

The cogeneration process from sugarcane bagasse is an alternative way to reduce fossil fuels consumption. In the environmental assessment of products, processes and services the methodology of Life Cycle Analysis (LCA) is commonly used. This study aimed to evaluate and compare the environmental impacts of the life cycle of different cogeneration technologies currently used in the Cuban sugar industry. For doing this, a combination of nine steam generators models with eight turbogenerators was analyzed, for a total of 72 alternatives, using the Eco-indicator 99 and the software SimaPro. The electricity generated daily (1000 kWh) was the functional unit used for the analysis. The results showed that the reduction of this process emissions to the air, water and soil had a favorable effect on the categories of carcinogenesis, radiation, ecotoxicity and land use. The category of Human Health damages reached higher impacts in the cogeneration stage, which represented about 80% of the total environmental impact of the process. It was evidenced that the largest contribution to this category was the emissions of particulate material from bagasse combustion. The combination of the steam generator German Modified EKE 80 with the Russian turbogenerator 2500 was the alternative that involved a reduction of the total impact compared to the rest of alternatives.

1. Introduction

In the last decades there has been a growing concern about the impact of human activity on the environment which is a receiver of wastes and also a provider of resources and energy. Accordingly, the new environmental culture imposes limits on the acceptance of the uncontrolled exploitation of resources, ending a period in which industrial processes were carried out without concerning about the environmental impact (Rieradevall and Vinyets, 1999; Rodríguez, 2004). Therefore, new strategies are developed to reduce the environmental impact of industrial activity, primarily based on a comprehensive preventive approach that promotes a more efficient use of material and energy resources, increasing productivity and competitiveness. This approach involves the introduction of some technological and management measures for reducing the consumption of materials and energy, preventing waste generation at source, reducing operational risks and other potential environmental impacts throughout the production cycle and all stages of industrial projects development (Contreras, 2007).

Sugarcane is considered a valuable crop, since sugar is an essential product for the human life and hence highly demanded in the world market. In the past, the sugarcane industry produced only sugar but now it also produces electricity from bagasse and ethanol from molasses (Ramjeawon, 2004; Buddadde et al., 2008; Nguyen et al., 2009). Bagasse is considered a useful by-product for steam-electricity combined systems and the main source of energy in the sugar production (Botha and Blottnitz, 2006). The electricity generated from bagasse is commonly used in sugar production and the surplus is exported to the national grid (Van den Broek et al., 2000; Ramjeawon, 2008; Renouf et al., 2008; Buddadde et al., 2008; Nguyen et al., 2009; Nguyen and Hermansen, 2012).

As the sugarcane industry generates serious environmental problems, it is considered a major pollutant, which requires alternative solutions to minimize its impacts. Emissions and fossil fuels consumption in different life cycle stages are among the elements that contribute to environmental pollution (Pérez, 2009; Chauhan et al., 2011; Nguyen and Hermansen, 2012). In this sense, cogeneration processes are implemented using bagasse to generate power at lower cost, which also require the use of several methods to improve their efficiency, such as efficient pumps, motors and equipment for heat recovery as pre-heaters and economizers to improve their efficiency (Ramjatun et al., 1999; Deepchand, 2001).

The current practice of cogeneration can reduce fossil fuels consumption and emissions associated with combustion, preventing global warming. At the same time, the improper disposal of bagasse as a residue from this process is avoided (Van den Broek et al., 2000; Roqueta and Guinda, 2003; Ensinas et al., 2007; Rosen, 2008). However, the use of bagasse as fuel produces

* Corresponding author. Tel.: +53 42 281164; fax: +53 42 281608.
E-mail address: maylier@uclv.edu.cu (M. Pérez Gil).

0959-6526/$ – see front matter © 2012 Published by Elsevier Ltd.
http://dx.doi.org/10.1016/j.jclepro.2012.08.006

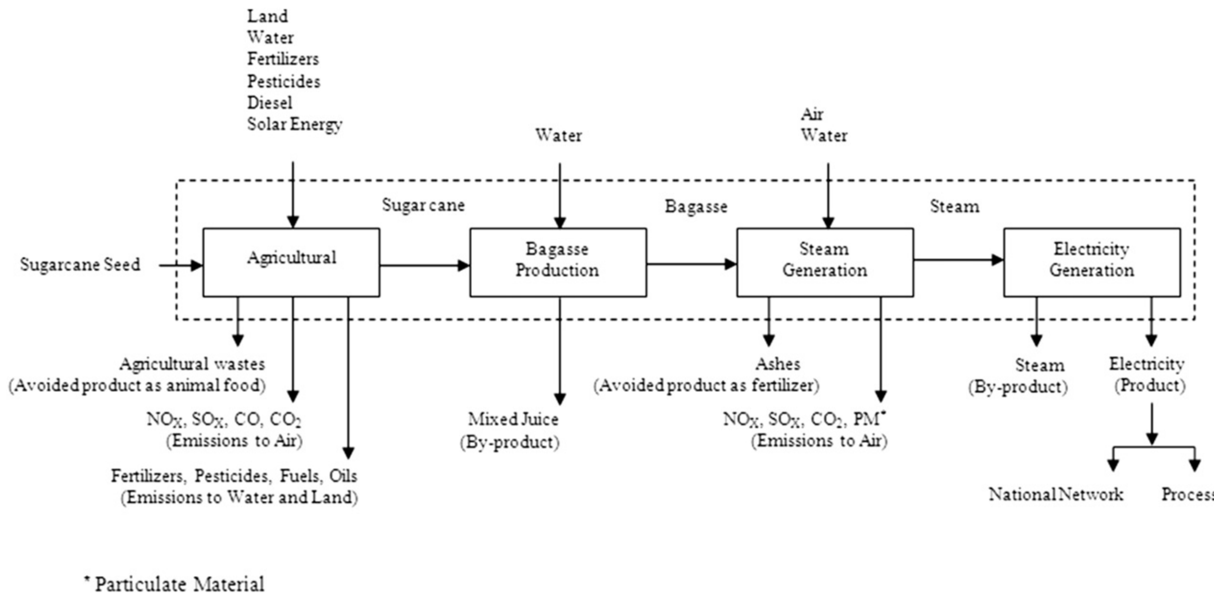

Fig. 1. Life cycle model of the electricity generation from steam in a cane sugar mill.

emissions that cause significant impacts on human health and the ecosystem, which must be quantified (Renouf, 2002; Jafar et al., 2008; Buddadde et al., 2008; Al-Amin et al., 2009; Grillo et al., 2011). In order to quantify the technologies sustainability, the methodology of Life Cycle Analysis (LCA) is commonly implemented which is a tool for the environmental assessment of products, processes and services (Rosen, 2008; Ometto et al., 2009; Chauhan et al., 2011; Grillo et al., 2011, Dewulf and Van, 2005). This methodology integrates the environmental impacts during the life cycle of a product and relates them to specific environmental problems. In addition, it also allows setting certain priorities to define preventive strategies for the improvement of environmental performance (Fullana, 2002; Iglesias, 2005; NC ISO 14040, 2005, Varun et al., 2009).

The LCA methodology is usually applied together with several computational programs, and among them, the SimaPro is the most used (PRé Consultants, 2004; Goedkoop, 2006; Goedkoop et al., 2007a,b). Besides, different studies show that the LCA can be successfully applied in the sugar industry. Chauhan et al. (2011) have analyzed the current situation of this industry applying the LCA for the environmental assessment of the processes involved there.

Others have shown the environmental benefits of electricity generated from bagasse compared with that generated by fossil fuels (Van den Broek et al., 2000; Renouf, 2000, 2002; Botha and Blottnitz, 2006; Contreras, 2007; Ramjeawon, 2008; Contreras et al., 2009; Nguyen et al., 2009). In this vein, Van den Broek et al. (2000) compared the generation of electricity from biomass (bagasse during the sugarcane season and eucalyptus during the rest of the year) by the sugar mills of Nicaragua with electricity generated from fuel oil. The comparison was made considering costs, macro-economic impacts and environmental emissions. The results of this comparison showed that the generation of electricity from biomass has significant macro-economic and environmental advantages.

Renouf (2002) presented the findings of a preliminary LCA of the electricity generation from bagasse in Queensland, Australia. The aim of this study was to determine the environmental benefits of bagasse-derived electricity over the coal-derived electricity and offered recommendations for a model as a basis for future studies of energy systems. Later, Ramjeawon (2008) compared electricity generation systems on the island of Mauritius using different fuels such as bagasse, coal and fuel oil. The results of this comparison indicated that bagasse-derived electricity provides environmental benefits for the categories of greenhouse gas emissions, acidification, non-renewable energy input, human toxicity and photochemical smog but it performs poorly in relation to water consumption and eutrophication. These results were similar to those obtained by Renouf (2000).

In Cuba, some researchers implemented the LCA to compare four different alternatives for the use of by-products and wastes from sugar production. It is interesting to note that all the alternatives considered cogeneration from bagasse for energy production which reaffirmed its environmental benefits (Contreras, 2007 & Contreras et al., 2009).

Nguyen et al. (2009) conducted an assessment following two practical approaches that reduce consumption of fossil energy in the sugar industry: the first approach refers to the efficient extraction of energy, in this case electricity from bagasse and cane straw, emphasizing the use of bagasse. The second suggests the conversion to ethanol from sugarcane molasses, which emphasizes the shift from coal to ethanol. It is considered that both approaches can meet the energy needs of the sugar industry. The presented results provide guidance on the strategies to be applied for optimum utilization of biomass as energy source.

Casas et al. (2011) evaluated the effects of the integration of Solid Oxide Fuel Cell (SOFC) technology with the traditional process

Table 1
Steam generators and turbogenerators analyzed/in the study.

Steam generator	Turbogenerator
1. Retal 45	1. Russian P-2.5-20/2TK
2. Retal 55	2. Russian P-4-20/2TK
3. Retal 60	3. Russian 2500
4. Evelma G-4	4. German G-2
5. Villa Clara	5. German G-3
6. German	6. English ALLEN 4000
7. German EKE 45	7. English ALLEN 2500
8. German Modified EKE 60	8. English ALLEN 1500
9. German Modified EKE 80	