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Pomace waste management scenarios in Québec—Impact on greenhouse gas emissions

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ABSTRACT

Fruit processing industries generate tremendous amount of solid wastes which is almost 35–40% dry weight of the total produce used for the manufacturing of juices. These solid wastes, referred to as, "pomace" contain high moisture content (70–75%) and biodegradable organic load (high BOD and COD values) so that their management is an important issue. During the management of these pomace wastes by different strategies comprising incineration, landfill, composting, solid-state fermentation to produce high-value enzymes and animal feed, there is production of greenhouse gases (GHG) which must be taken into account. In this perspective, this study is unique that discusses the GHG emission analysis of agro-industrial waste management strategies, especially apple pomace waste management and repercussions of value-addition of these wastes in terms of their sustainability using life cycle assessment (LCA) model. The results of the analysis indicated that, among all the apple pomace management sub-models for a functional unit, solid-state fermentation to produce enzymes was the most effective method for reducing GHG emissions (906.81 tons CO_2 eq. per year), while apple pomace landfill resulted in higher GHG emissions (1841.00 tons CO_2 eq. per year). The assessment and inventory of GHG emissions during solid-state fermentation gave positive indications of environmental sustainability for the use of this strategy to manage apple pomace and other agricultural wastes, particularly in Quebec and also extended to other countries. The analysis and use of parameters in this study were drawn from various analytical approaches and data sources. There was absence of some data in the literature which led to consideration of some assumptions in order to calculate GHG emissions. Hence, supplementary experimental studies will be very important to calculate the GHG emissions coefficients during agro-industrial waste management.

1. Introduction

Agro-food industries generate large quantities of liquid and solid wastes which must be suitably managed before being directly discharged to the environment. In Canada, the majority of fruit processing industries are concentrated in Quebec (about 35% contribution), Southern Ontario, and British Columbia [1]. One third of the total apple production in Canada (449,190 tons/year, 20% contributed by Quebec) is processed to produce juices, flavors and concentrates [2]. The end result of an apple processing industry is a solid residue containing high moisture content (70–75%) and biodegradable organic load (high BOD and COD values) [3]. These wastes have low nutritional value and their high biodegradability causes environmental problems. A typical apple processing industry generates 30–40% apple pomace and 5–11% sludge (liquid waste obtained after clarification). There are large quantities of solid wastes (apple pomace) produced round the world, including 16,209 tons in 2007 in Québec [1]. Apple pomace waste produced in Quebec was selected as the case study. These solid wastes being highly biodegradable, their disposal represents a serious environmental problem and presents many challenges [4,5]. In Quebec, this waste is mainly used as a source of crude animal feed by the farmers. Often only 20% is retrieved as animal feed and the rest 80% goes to landfill or composting sites which results in release of enormous quantity of greenhouse gases. Composting Council of Canada reported about 38% of Canada's methane emissions coming from organics decomposition in landfills [6]. Other modes of management of apple pomace comprise landfilling, composting, incineration and the innovative option of utilization of the apple pomace as a sole raw material for production of high value-added products, such as enzymes, organic acids, ethanol, among other products. In fact, the option of high value-added

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products formation by solid-state fermentation has been tested as a resourceful option in our laboratory as it is able to generate new bio-products and at the same time result in value-addition and management of the wastes [7]. Apple pomace studied in this work has been procured from a reputed juice transformation industry in Quebec. The distance between this industry and management sites was considered to be 25, 200, 100 and 200 km in the case of landfill, incineration, composting, and enzyme production, respectively. Meanwhile, in the case of animal feed, 20% of farmers were situated at 80 km distance from the apple juice industry and 80% of farmers were situated at 50 km from the juice industry.

The management of wastes is a significant source of GHGs [8]. The contribution of the waste management and disposal sector amounts to 4% of the various anthropogenic GHG emissions [9]. Various stages of the management of solid wastes including, collection, transportation, and disposal is generally followed by the release of GHG gases, such as carbon dioxide, methane, and N_2O. These gaseous components by virtue of their physical properties contribute to the GHG effect. Meanwhile, the increase in the concentration of these gases contributes to the global warming phenomenon.

In fact, there are various means to manage domestic or industrial wastes, where by the GHG emissions vary according to the consumption of energy, transportation, and technologies used for the process management [10]. To quantify The GHG emissions during waste management by different strategies, the best way is to conduct a comparative analysis through streamlined application of life-cycle assessment (LCA) model [11]. LCA is an analytical framework for understanding the material inputs, energy inputs, and environmental releases associated with manufacturing, usage, and disposal of a given material [11].

Many studies on environmental performance, especially with regard to GHG emissions, of various waste management strategies have been implemented for most developed countries and some developing countries [12–14]. To the best of our knowledge, there is no study reported till date which discusses the GHG emission analysis of agro-industrial waste management strategies, especially apple pomace waste management. The assessment and inventory of GHG emissions during solid-state fermentation was carried out for the first time in this study to evaluate the repercussions of value-addition of these wastes in terms of environmental sustainability. In the present study, LCA of apple pomace management by different strategies was conducted with an impact assessment limited to GHG emissions. Five apple pomace waste management strategies were used in the present study, namely, apple pomace incineration, landfill, composting, solid-state fermentation to produce high-value enzymes and animal feed.

The main objectives of this study were to develop the inventory of apple pomace management scenarios (incineration, landfilling, composting, animal feed and enzyme production) with details in methods section to assess and compare the environmental impacts of related management scenarios and determine environmentally most respectful scenarios of the environment.

2. Methodology

2.1. Life cycle assessment

Environmental assessment of a product (apple pomace waste) over its entire lifecycle can indicate the extent of the manufacturer's environmental responsibilities beyond the boundaries of its own facilities, and it can help to identify appropriate management options. Life cycle assessment (LCA) is a technique for assessing the environmental aspects and potential impacts associated with a system (product system or service system) by:

(i) compiling an inventory of relevant inputs and outputs of the system;
(ii) evaluating the potential environmental impacts associated with those inputs and outputs; and
(iii) interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study [15].

This methodology has been already used in many studies to evaluate the environmental impact during the management of different wastes such as municipal waste, agricultural waste paper, glass, metal, and plastic materials [12,16,17].

2.2. The goal and scope

The goal of this study is to evaluate GHG emissions of the existing apple pomace management systems based on life cycle perspective. Specifically, GHG emissions are considered in this study as climate change is a priority area in Quebec particularly for policy making..

2.3. Systems boundaries and function unit

The system boundaries include collection and transportation of apple pomace from its source (apple juice industry) to be treated by various management methods in each scenario. It should be noted that equal amount of the apple pomace waste (16,209 tons/year) of the same composition are treated in all scenarios. Besides, direct processes relating to waste management systems, other relevant processes interacting with the waste management systems are also included. Production of energy, i.e., electricity and diesel are also included as such energy is directly used in waste management systems and background systems. In animal feed scenario, the management of manure was not taken in account. The system was considered until enteric fermentation related to animal feed. The energy recycling was taken into account only in the case of incineration as this practice is more popular in Quebec for this scenario. Enzyme production system was considered only until fermentation. Similarly, the composting system was considered until composting process and the compost landfilling was not taken into consideration.

The functional unit (FU) providing a reference to which the inputs and outputs are related is defined as "the total production of apple pomace in Québec at 2007 of 16,209 tons"

2.4. Emission categories

The GHGs from apple waste management using different scenarios are of distinct origin which has been considered for the present study as follows:

(a) Transportation and collection of waste
(b) Landfilling of waste
(c) Composting of waste
(d) Incineration
(e) Animal feed
(f) Solid-state fermentation to produce enzymes

For the above waste treatment practices, the principal basis was for each 16,209 tons of apple waste produced (equivalent to total apple pomace production in Quebec in 2007). For the selection of GHG types, the gases CO_2, CH_4 and N_2O which directly influenced the greenhouse effect were selected for assessment. As each GHG