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Life cycle assessment of a medium commercial scale biogas plant and nutritional assessment of effluent slurry

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ABSTRACT

The present study is addressing the life cycle assessment of a novel design multi-digester anaerobic bioenergy plant. Notably the impacts regarding bioenergy generation and utilization of bioenergy and digestate are reviewed with reference to three different feed stocks used and experimented in this typical plant i.e. slurries of; 100% cow-dung, 75% cow-dung+25% potato-pulp and 100% potato-pulp respectively. The results depicted that concentrations of NPK and heavy metals (Cu, Ni, Mn and Fe) were highest in feedstock comprising 75% cow-dung+25% potato-pulp. The comparative LCA of said feed stocks was further deliberated in three representative environmental impact categories i.e. climate change potential (CO_2 equivalent), fresh-water eutrophication potential (Phosphorous equivalent) and acidification potential (SO_2 equivalent). The results revealed that feedstock comprising 100% cow-dung had highest savings in-terms of climate change i.e. 70 kg, lowest acidification potential i.e. 5 kg and considerably more fresh-water eutrophication potential i.e. 0.022 kg. The second best proven feedstock was 100% potato-pulp having potentials regarding climate change, acidification and fresh-water eutrophication as; 70.5 kg, 6.5 kg and 0.021 kg respectively. Whereas the feedstock comprising 75% cow-dung+25% potato-pulp had the highest comparative life cycle impacts i.e. 200 kg, 6.9 kg and 0.034 kg against climate change, acidification and fresh-water eutrophication categories.

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1. Introduction

A series of problems like environmental pollution and greenhouse gases are being faced as a result of using nonrenewable resources [1]. Globally energy supply and shortages are the most critical issues [2]. Such issue can be solved by using clean and renewable energy sources which are abundant and environmental friendly [3,4]. Biodegradable wastes and biomass like crops are the immense sources of renewable energy. Production of bio-energy in the form of heat and electricity is one best option to reduce the energy shortages with the minimum amount of ecological impacts [5]. The end product of biogas plants is nutrient rich digestate that can be used as bio fertilizer and also reduces the use of energy intensive fertilizers [6]. The use of biofuels has been rapidly expanding such as other alternatives i.e. natural gas, fuel cells and electric automobiles. The factors that promotes the biofuel production are its renewable nature, climate change mitigation and energy security supplied by varying supply [7]. Biofuels are referred as the fuels obtained from biological resources either made directly or indirectly from photosynthesis. Biofuels are gained from crops such as sugar beets, sugarcane, wheat, barley, soybeans and corn [8–10].

Anaerobic digestion of animal waste converts the organic matter into biogas, a renewable energy source digested slurry known as digestate that can be used as bio fertilizer in agriculture [11]. Biogas production by anaerobic fermentation is another promising method of producing energy from renewable resources providing multiple environmental benefits [12]. Past researches indicated that slurries contained right amount of micro and macro nutrients for better crop yields and they can be used in place chemical fertilizers [13]. Furthermore these slurries are considered to be the soil conditioners as they restore the fertility of soils by adding essential nutrients to it resulting in an increase in the soil aeration and improved water holding capacity [14].

Waste production included various categories of waste like livestock husbandry waste, waste from agricultural sector, animal manure and waste from other sectors. Waste management and energy shortage problems can be resolved by biogas energy generation [15]. Due to the availability of the technology and the inputs biogas processes have modernized and changed [16]. Furthermore, the inputs have also changed from animal manure to vegetables and crop wastes, accordingly the digestate composition and waste to digestate phenomenon have also been changing and more research is required to understand and estimate such nutrient rich digestate potential as fertilizer [17,18]. Bio energy processes also have some environmental impacts and there is it is need to understand the related qualitative and quantitative impacts and consequences of biogas plants [19,20]. These ecological effects can be monitored and measured by various tools and techniques. The most modern and developed method is the life cycle assessment (LCA). LCA is “environmental impacts analysis or cradle to grave analysis of a given product during whole of its life cycle”. A very sophisticated framework has been devised by the International Standardization Organization (ISO) for the conduct such eco-balance assessment persistently. The steps included in LCA are goal and scope definition, inventory analysis (LCI), impact assessment (LCIA) and interpretation or improvement analysis [21,22].

In a study life cycle assessment was used to compare the impacts of ethanol production from sugarcane and biodiesel from soybean and palm oil in Brazil. Environmental impacts were analyzed and were categorized into Abiotic Depletion Potential (ADP), Global Warming Potential (GWP), Human Toxicity Potential (HTP), Acidification Potential (ACP) and Eutrophication Potential (ETP). It was concluded that biofuel production systems are proved to be best with higher agricultural yields and production of wide co-products in its life cycle [23].

The main objective of study is to perform life cycle assessment which includes detection of heavy metals, potential of freshwater eutrophication, terrestrial acidification and climate change, focusing on the disposal stage of plant slurries, nutrient analysis of the plant slurries and potentials of such slurries as bio-fertilizer.

2. Methodology

2.1. Study area

Biogas plant used in the study was a medium scale biogas energy plant. The plant was a fix dome shaped having three connected digester wells with continuous feedstock. Total feed stock capacity of plant was 20 t whereas the daily requirement of feedstock was 4 t. Three feedstock scenarios were studied (Table 1) [24].

Table 1
Life cycle inventories for all three scenarios (mass balances per 20,000 kg slurry).

Description	Quantities (kg)					
	Scenario-1 100% cow-dung		Scenario-2 75% cow-dung + 25% potato-pulp		Scenario-3 100% potato-pulp	
	Slurry ex-plant	Digestate ex-plant	Slurry ex-plant	Digestate ex-plant	Slurry ex-plant	Digestate ex-plant
Total mass	20,000.00	24,076.40	20,000.00	25,282.00	20,000.00	18,538.80
Total Solids	1574.00	1789.20	1345.80	1568.00	1345.80	1307.00
Organic matter	1051.60	862.00	832.60	896.00	832.60	715.00
Total Nitrogen	138.80	145.20	111.00	130.20	111.00	118.20
Ash	499.40	896.20	499.40	646.60	499.40	568.80
Phosphorous (P)	23.00	31.20	23.00	25.40	23.00	23.20
Water Content	18,326.80	22,168.40	16,074.40	23,607.40	16,074.40	17,130.80