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Research article

Environmental assessment of energy generation from agricultural and farm waste through anaerobic digestion

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A B S T R A C T

While Turkey is one of the world's largest producers and exporters of agricultural goods, it is also, at the same time a net importer of energy carriers. This dichotomy offers a strong incentive to generate energy from agricultural and farming waste; something which could provide energy security for rural areas. Combined with the enhanced energy security for farming areas, the production of energy in this manner could conceivably contribute to the overall national effort to reduce the Turkey's carbon footprint. This study explores the environmental benefits and burdens of one such option, that is, biogas production from a mixture of agricultural and animal waste through anaerobic digestion (AD), and its subsequent use for electricity and heat generation. A life-cycle assessment methodology was used, to measure the potential environmental impact of this option, in terms of global warming and total weighed impact, and to contrast it with the impact of producing the same amount of energy via an integrated gasification combined cycle process and a hard coal power plant. This study concentrates on an AD and cogeneration pilot plant, built in the Kocaeli province of Turkey and attempts to evaluate its potential environmental impacts. The study uses laboratory-scale studies, as well as literature and LCI databases to derive the operational parameters, yield and emissions of the plant. The potential impacts were calculated with EDIP 2003 methodology, using GaBi 5 LCA software. The results indicate that N_2O emissions, resulting from the application of liquid and solid portions of digestate (a by-product of AD), as an organic fertilizer, are by far the largest contributors to global warming among all the life cycle stages. They constitute 68% of the total, whereas ammonia losses from the same process are the leading cause of terrestrial eutrophication. The photochemical ozone formation potential is significantly higher for the cogeneration phase, compared to other life cycle stages of the proposed scenario, due to NO_x being emitted from the gas engine during combustion. Overall, the total environmental impact of the option was determined to be ten times lower than that of a hard coal option and 50% lower than the gasification option, since the latter does not generate digestate that is able to replace mineral fertilizer, thus mitigating the environmental footprint. Finally, the sustainability of energy production from agricultural and farm waste, via AD, was further enhanced by eliminating it from conventional waste management system practiced in the region, i.e. landfilling.

1. Introduction

In the past few decades, the sustainable use of agricultural and farm residues has become a standard practice worldwide, especially in the light of the increasing population as well as the associated food security issues and the increased demand for energy. This use of residues includes energy generation through a number of methods, such as pyrolysis, combustion, gasification, hydrolysis and fermentation. Among these, anaerobic digestion (AD) is a widely used biochemical process for producing biogas from biomass and wastes containing high levels of organic matter. In 2013, the world biogas production has reached 59 billion m^3, which was a 5.5% increase over previous year (WBA, 2016).

Electricity generation from biogases in OECD countries grew from 3.7 TWh in 1990 to 78.8 TWh in 2015, making it the third fastest growing renewable electricity source after wind and solar energy. The driver of this growth is OECD Europe, which accounted

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for almost 80% of OECD production in 2015 (IEA, 2016). 13,378 ktoe of biogas primary energy was produced in the European Union (EU) in the year 2013, of which 69% was generated in decentralized agricultural plants, municipal solid waste methane production facilities and centralized co-digestion plants. As many as 72% of biogas plants operating in EU are installed in farms that use agricultural waste, manure and energy crops. Germany leads the EU countries in biogas production, producing more biogas than all the other member countries combined (6716 ktoe) in 151 biomethane plants with total production capacity of around 93,650 Nm^3/hour (EBA, 2014). The success of European countries in this field can be, in part, attributed to effective legislation and implementation mechanisms installed on national and EU levels. The Renewable Energy Directive published by the European Commission sets a legally binding target of 20% final energy consumption from renewable sources by 2020 for EU, while also specifying national renewable energy targets for each country, taking into account country-specific conditions and potential for renewables. Article 12 of the Directive emphasizes the high greenhouse gas emission saving potential of biogas production from agricultural material such as manure, slurry and other animal and organic waste and its subsequent use for heat and power generation. The Directive also makes note of the fact that the decentralized nature of biogas plants in member countries contributes significantly to sustainable development in rural areas and offers farmers new income opportunities (EC, 2009). Installation of similar policies and closer collaboration with EU countries, including promotion of joint renewable energy projects and support schemes would no doubt accelerate the spread of biogas facilities in Turkey.

Statistics from Turkish Electricity Transmission Company show that in the year 2013, 28.9% of all of Turkey's electricity was supplied from renewable energy resources. Around 85% of this came from hydropower, and the other renewable resources that were listed included; geothermal, wind, solid biomass, biogas and waste. Together that supplied the remaining 15% (TUIK, 2013). In contrast, renewables constituted 22.3% of the world electricity production in the year 2014, of which 73% came from hydropower, 8% from biofuels and waste and the remaining 19% was the sum of geothermal, wind, solar, tidal power sources (IEA, 2016). Farm and agricultural waste are abundant in Turkey, while domestic natural fossil fuel resources are not. After considering these two facts, the need to develop energy production facilities, from farming residues, becomes apparent. This paper evaluates one such option, – i.e. electricity production from biogas obtained from agricultural and farm wastes in a pilot anaerobic digestion plant – in terms of its environmental viability, using life cycle assessment (LCA) methodology. The LCA approach, which is standardized by ISO 14040:2006 and 14044:2006, is a decision support tool for the evaluation of the environmental impacts of products and services. It takes the entire life cycle of the system in question into account, thus providing a holistic approach to the evaluation of complex systems. Two additional scenarios have also been created in order to contrast their impacts with the main scenario: an alternative renewable electricity and heat production option, from the same feedstock via integrated gasification combined cycle (IGCC) and the other as a non-renewable energy production option from hard coal.

1.1. Feedstock availability in Turkey

Agricultural and animal residues, available in Turkey, have been estimated to be roughly equal to 22–27% of the total national energy consumption (Demirbas, 2008). The total calorific value of field crop residues was 228 PJ, with maize (33.4%), wheat (27.6%) and cotton (18.1%) contributing to almost 80% of the total value. In 2002, fruit residues had a collective calorific value of 75 PJ of which hazelnut (55.8%) and olive (25.9%) residues again constituted over 80% of that amount (Bascetincelik et al., 2005). In terms of agricultural production, two main sources of biomass are considered. The first is the residue left on the fields after harvesting and the second is the waste that is produced during the processing of agricultural products into industrial products. Table 1 illustrates the losses for the relevant agricultural and farming products in Turkey, at various stages of the value chain, based on a recent report prepared for the Food and Agriculture Organization of the United Nations (FAO, 2013).

The amount of farm animal wastes and their energy values, that are available annually, are given in Table 2. The total calorific values are calculated, based on a dry manure to biogas ration of 200 m^3 per ton of manure and a calorific value of 22.7 MJ/m^3 for cow, sheep and poultry manure (Bascetincelik et al., 2005). Although the values in the table reflect figures from the year 2002, according to more recent statistics, 14 million head of cattle, 27 million sheep and 250 million poultry birds were reared in 2012, similar to numbers presented in the table (TUIK, 2012). Thus, the amount of farm waste is also expected to be in a similar range, although changes in technology and practices over the past decade, may have affected actual numbers. The geographic distribution of available agricultural plant and farm animal residues is well illustrated on maps, made available by the Ministry of Energy and Natural Resources of Turkey, and expressed as tons of oil equivalent (toe) (Figs. 1 and 2).

Table 1
Agricultural and farm product losses in Turkey (FAO, 2013).

Product	Agricultural production	Postharvest handling and storage	Processing and packaging	Distribution	Consumption
Cereals (Wheat)	5.1%	4%	2%	1%	5%
Vegetables (Tomatoes)	20%	8%	10%	10%	5%
Fruit (Olive oil)	5%	4%	3%	1%	0.1%
Roots and tubers (Potatoes, Sugar beet)	7%	6%	2%	3%	2%
Oilseeds and pulses (Sunflower seeds)	15%	5%	7%	4%	1%
Meat (Red meat)	10%	0.2%	5%	0.5%	1%

Table 2
Available farm animal residues in Turkey (Bascetincelik et al., 2005).

Animal	Animal number	Total dry manure (tons/year)	Available dry manure (tons/year)	Availability (%)	Total heating value (TJ)
Cow	12,838,285	16,211,033	10,537,172	65	47,839
Ship	29,903,590	6,139,581	798,146	13	3624
Poultry	264,784,050	1,932,924	1,913,594	99	8688