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Threshold herd size for commercial viability of biomass waste to energy conversion systems on rural farms

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HIGHLIGHTS

- Threshold for commercial viability is 80 dairy cows and 1200 swines.
- Manure co-digested with food waste.
- Revenue from electricity sales, food waste tipping fees and use of by-products.

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ABSTRACT

We determine the threshold herd size at which a biomass waste to energy conversion system becomes commercially viable. The threshold herd size is found by optimisation of the biomass waste to energy conversion system for different herd sizes. Manure is co-digested with food waste. The optimisation takes into consideration revenue from electricity sales, use of the by-products of the digestion and food waste tipping fees. The cost implication of cleaning the biogas combusted in the internal combustion engine is also investigated. The threshold herd sizes for two different types of farms is determined.

1. Introduction

Biomass waste to energy conversion systems have been traditionally installed on rural farms to manage manure disposal. These systems are increasingly being viewed as sources of additional revenue. From a literature review done (Section 1.2), the methods of determination of the commercial viability of biomass waste to energy conversion systems do not optimise the systems, prior to determination of commercial viability. Estimates of commercial viability are given as 500 cows, for example [1], a value which is based on digestion of manure only. This estimate does not consider co-digestion, which would bring in additional revenue from tipping fees, in addition to increasing the biogas yield. This estimate does not also consider the economic benefit of the by-products of the digestion. The geographical location of the farm is also ignored in the estimate. The geographical location of the farm is important as this is what will determine the electricity tariff and the heating load, based on the average temperatures of the region. The research carried out in this paper seeks to address these gaps. The objective of the research is to determine the threshold herd size at which biomass waste to energy conversion systems become commercially viable. The geographical region selected is Quebec province of Canada, and hence the climatic data and electricity tariffs of Quebec province are used. The biomass waste to energy conversion system is optimised prior to the determination of its commercial viability. The methodology can be replicated to determine the threshold herd size for different regions by using the respective electricity tariffs and climatic data.

1.1. Motivation for determination of commercial viability

The motivation for determination of the threshold herd size at which biomass waste to energy conversion systems become commercially viable is twofold. Firstly, it is to prevent the shut down of biomass waste to energy conversion systems due to low or no return on investment, and secondly to encourage farmers to take up the technology in regions like Quebec where there are very few

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installations. The rate at which biomass waste to energy conversion systems cease operation in the United States is relatively high [2,3]. Since 1981, 23% of the biomass waste to energy conversion systems installed in the United States have been shut down [4]. The number of systems installed and shut down in the United States is illustrated in Fig. 1. Although the digester shut downs can be attributed to multiple factors like: failure due to poor design, poor system installation and poor management [3], farmers have also chosen to cease operations due to the high cost of operation and maintenance, compared to the return on the investment [2]. In Quebec province there are no biomass waste to energy conversion systems on dairy farms. There are however biomass waste to energy conversion systems on swine farms [5,6] and in cheese factories [7,8]. There was a biomass waste to energy conversion system installed on a dairy farm in Quebec, [9,10] that has since ceased operations. Overall, Quebec has fewer biomass waste to energy conversion systems compared to Ontario, Wisconsin and New York state. By providing a guideline on the threshold herd size for both swines and dairy cows, at which biomass waste to energy conversion systems become commercially viable, farms in Quebec will be encouraged to install these systems.

1.2. Literature review

A literature review of research undertaken on determination of commercial viability of waste to energy conversion systems was carried out. In addition to biomass waste to energy conversion systems that use manure as a primary source of waste, exhaust heat waste to energy conversion systems were reviewed, in order to compare optimisation techniques. This is because from the literature review undertaken, biomass waste to energy conversion systems were not optimised prior to determination of commercial viability. This is one of the differences between the research reviewed and that undertaken in this paper. The following is a discussion of previous research reviewed. There are four marked differences with the research in this paper and the research reviewed. These are: (i) optimisation of the biomass waste to energy system prior to determination of commercial viability, (ii) use of the Tabu Search heuristic for optimisation of waste to energy conversion systems, (iii) mathematical modelling based on the energy conversion processes, and (iv) method of determination of commercial viability.

From the literature reviewed, optimisation is done for exhaust heat waste to energy conversion systems, but it is not done for biomass waste to energy conversion systems that use manure as a primary source of waste. The difference between the optimisation of exhaust heat waste to energy conversion systems reviewed, and that done in this paper will be discussed later in this section. The following is a discussion of biomass waste to energy conversion systems reviewed, whose primary source of waste is manure. In [11] the commercial viability of a biomass waste to energy project in a dairy farm community in Ludhiana, India was determined. The NPV (Net Present Value) of the project was calculated for a life cycle of 20 years. The biomass waste to energy conversion system was however not optimised, prior to determination of its commercial viability. Similarly an economic analysis of a biomass waste to energy conversion system operating on a minnesota dairy farm was carried out in [12]. It was concluded that the system was commercially viable, however the system was not optimised prior to determination of its commercial viability. In [13] the impact of the by-products on the commercial viability of a biomass waste to energy conversion system on a Washington State farm was analysed. This analysis however did not include optimisation of the system. An investment decision tool for economic evaluation of biogas plant projects was developed in [14]. Three digester feedstocks were analysed, and the results were used to develop a set of rules for estimating the performance of larger capacity digesters using different feedstocks. The commercial viability of the larger biogas plants was determined using NPV and IRR (Internal Rate of Return). This analysis did not involve optimisation of the biogas plants prior to determination of their commercial viability. The concept of modular biogas plants was applied in [15] to determine the threshold farm size for commercial viability of biomass waste to energy conversion systems in Ontario province. The biomass waste to energy conversion systems were not optimised however, prior to determination of their commercial viability. In [16] a decision-making tool was developed, that considers the geographical location of the biomass waste to energy conversion system in determination of its commercial viability. The research work undertaken in this paper also considers the geographical location of the biomass waste to energy conversion system, and in addition optimises the system prior to determination of commercial viability. The impact of non-market co-benefits on the commercial viability of biomass waste to energy conversion systems was studied in [17]. The non-market co-benefits considered were: mitigation of green house gases emissions, by-products of the anaerobic digestion process, cost savings in manure management and use, nutrient conversion, manure odour reduction, and pathogen reduction. Just like the other research reviewed in this section, [17] did not optimise the biomass waste to energy conversion system prior to determination of its commercial viability.

The second difference between the research undertaken in this paper and the research reviewed is in the optimisation techniques used. As explained previously, in order to compare optimisation techniques used, studies on exhaust heat waste to energy conversion systems were reviewed. The study in this paper on the

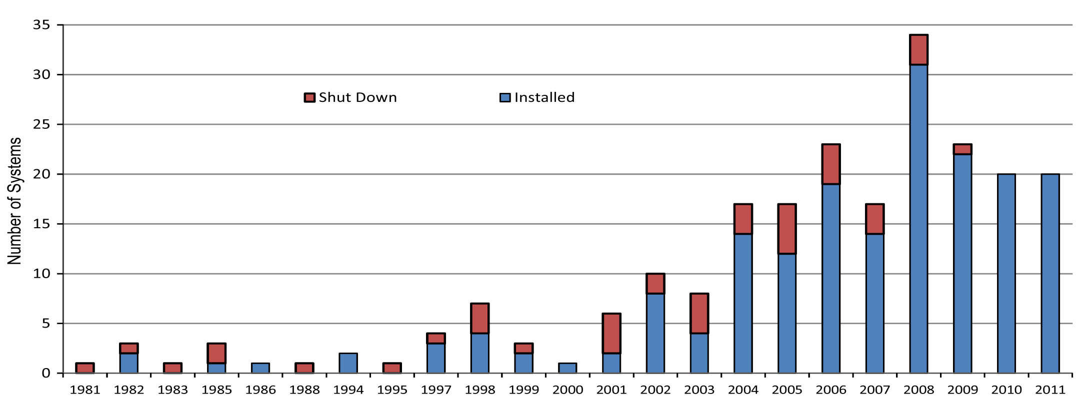

Fig. 1. Biomass waste to energy conversion systems in the U.S.Source: AgSTAR, United States Environmental Protection Agency, March 2012.