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Analyzing animal waste-to-energy supply chains: The case of horse manure

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A B S T R A C T

To reduce human impact upon the environment, a transition from fossil to renewable energy sources such as biomass is imperative. Biomass from animal waste such as horse manure has unutilized potential as it has yet to be implemented at a large scale as an energy source. Research has demonstrated the technical feasibility of using animal waste for energy conversion, though their supply chain cost poses a barrier, as does a gap in research regarding the specific design of efficient horse manure-to-energy supply chains. In response, we investigated the design of horse manure-to-energy supply chains through interviews and site visits at stables, as well as through interviews with transport companies. Our findings show that horse manure-to-energy supply chains have distinct attributes at all stages of the supply chain such as the geographical spread of stables that determines supply chain design and hampers efficiency. They share several such attributes with forest biomass-to-energy supply chains, from which important needs can be identified, including the industrial development of trucks dedicated to the purpose, mathematical modeling to handle the trade-off of cost of substance loss in storage and cost of transport, and business models that reconcile the conflicting goals of different actors along the supply chains.

1. Introduction

In the quest for environmental sustainability, the use of renewable fuels has increased significantly during recent decades. In the global primary energy mix, the most common fuel source is biomass feedstock with low energy density used mostly for heating and electricity. To minimize costs of transportation and associated emissions, the local availability of a particular source of unrefined biomass imposes conditions upon its use. Furthermore, biomass conversion to heat and electricity, for example, generally benefits from economies of scale, which implies that for each region, the amounts of biomass feedstock available affect the type of feedstock used. Consequently, a trade-off exists between, on the one hand, larger plants with lower specific investment costs and more positive scale effects in production but longer transport distances and, on the other, smaller plants with shorter transportation distances but higher specific investment costs and fewer positive scale effects [1,2]. In addition, in many regions in Europe, types of biomass used are mostly by-products of the forest industry and primary forest biomass such as pine and spruce. Whichever biomass is used, however, volumes remain limited, and there is constant pressure to reduce costs and to identify more cost-efficient, sustainable biomass sources. Consequently, locally using other potential biomass energy carriers to satisfy the need for renewable energy is necessary.

One underused source of biomass feedstock is animal manure. Poultry manure, cow manure, and horse manure are examples of manures that are suitable for various energy conversion processes, including anaerobic digestion to produce biogas, in which methane is the major component. Holm-Nielsen, Al Seadi and Oleskowicz-Popiel [3] indicated the considerable potential of producing biogas from animal manure and slurries in Europe and elsewhere. Other authors have quantified such potential at national levels and shown, for instance, that animal waste in Turkey could be used to

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produce 49 PJ of biogas annually [4] and, in Greece, 9 PJ annually [5]. Despite the difficulty of gauging the amount of horse manure produced each year, Kusch [6] estimated that 500–800 million tons of manure are generated globally and 40–70 million tons in Europe. However, the amount of biogas that can be produced from manure depends on several variables, including bedding material used in stables and the selection of technology for energy conversion. There are also examples on a national level, e.g. in Sweden, the overall energy potential from horse manure has been estimated to be 730 GWh per year, which amounts to 17% of the total potential of producing biogas from animal waste [7].

Although horsekeeping is typically practiced for the purposes of equestrian training, competition, and leisure, all of which contribute economic and social value [8], the by-product of horse manure has to be tended to for use as fertilizer in farming, as combustive material to produce heat and electricity, or potentially for biogas production. To that end, horse manure has to be collected at a low cost to be available for energy conversion in the right quality and at the right time and place. This creates a need for a supply chain that facilitates all stages of handling, storage, and transportation in stables, including cleaning and collecting manure from horse stables, handling and storing it in containers or on concrete slabs, and loading it into containers to be transported via road to energy conversion plants, potentially via intermediate storage, or to farmers. Toka, Vlachos and Iakovou [9] concluded that the cost of such supply chains is the most critical bottleneck for increasing the use of animal manure and municipal sewage. However, few papers have addressed those supply chains in terms of the cost of moving manure from the point of origin to the point of consumption or how a change in one part of the chain imposes conditions for efficiency in other parts. In related research, Bekkering, Broekhuis and van Gemert [10] modelled a supply chain for producing biogas from cattle manure, and Flotats, Bonmatí, Fernández and Magrí [11], in analyzing the difference between on-farm versus centralized procedures for treating manure, found that key economic factors affecting location were the density and intensity of farming. More recently, Hadin, Eriksson and Hillman [8] identified key factors that influence volume and quality of manure for biogas production, and taking a slightly broader perspective, Toka, Vlachos and Iakovou [9] identified strategic, tactical, and operational decisions for various types of animal waste and for municipal sewage waste.

A few technical papers have touched upon supply chain issues as well. For instance, Lundgren and Pettersson [12] noted that the water content of manure should be kept low (i.e., less than 50%) in order to yield a good combustion process and that covered storage of horse manure at stables is therefore necessary. Yusuf, Debora and Ogheneruona [13] showed that biogas production with horse and cow dung as feedstock is optimized at a ratio of 3:1, which imposes conditions upon collecting feedstock in the supply chain. Apart from those studies, however, research remains sparse, particularly regarding logistics issues such as storage, handling, and movement from a supply chain perspective. By contrast, significant research has been conducted on the energy conversion process—for example, on the combustion of horse manure [12] and anaerobic digestion to produce methane [14,15].

The importance of understanding supply chains in terms of the cost of moving energy carriers such as biomass from the point of origin to the point of conversion is well understood for other energy carriers such as wood. Extensive research (e.g., Gold and Seuring [16]) has noted numerous key variables along supply chains that shape cost, including transport distance and location of processes. Lessons from those fields are applicable to some extent given similarities—for instance, the low value of low-density goods from dispersed locations for energy production—though each type of biomass exhibits unique characteristics that describe the supply chain and sets condition for its design. For instance, both cow and horse manure are by-products, yet have different physical characteristics. Hadin and Eriksson [17] defined *horse manure* as a mixture of feces, with a dry solid material content of at least 20%, whereas cow manure has a higher moisture content, meaning that different types of trucks and different systems for loading (e.g., hose versus wheel loaders) are needed. In sum, lessons regarding the design of horse manure-to-energy supply chains can be drawn from other fields such as forest biomass-to energy, yet also need to be developed specifically for the unique context of horse manure-to-energy supply chains.

Given that background, the objective of this paper was to investigate the design of horse manure-to-energy supply chains with a special focus on biogas. We first identified key attributes that impose conditions upon the design of efficient horse manure-to-energy supply chains. Second, we pinpointed key variables that require decision making by actors along the supply chain. Third and lastly, we formulated managerial implications and key issues for further research.

2. Materials and method

This paper is an explorative conceptual paper, which is appropriate for reporting an emerging phenomenon in research [18,19], as is the case for horse manure-to-energy supply chains. Conceptual papers provide a foundation for future research, including quantitative studies to further explain the phenomenon and validate earlier findings. To underpin our conceptualization, we drew upon data from a case study of an energy company in western Sweden. The company currently operates a combined heat and power plant, which produces about 100 GWh annually, using forest residues as the main feedstock. The company also has a few smaller pellet boilers to cover peaks in heat demand as well as a windmill that produces 8 GWh electricity per year. The municipality owning the company is also responsible for household waste collection in the area. As co-digesting household waste with manure is particularly beneficial from a chemical process perspective [20], they now see a business opportunity in building a new plant to exploit the local unutilized potential of horse manure in combination with household food waste. A pre-study of a new biogas plant for co-digestion done for the energy company, described in detail in Wennerberg [21], showed that within a radius of 20 km, 10,000 tons of manure (with an estimated methane potential of 68 Nm^3 CH_4/ton) and 5000 tons of household food waste (with an estimated methane potential of 120 Nm^3 CH_4/ton) could be collected to produce 10 GWh of biogas. The calculations included cost of investment and all operating costs such as personnel, maintenance, and cost of feedstock as well as revenue from sold biogas. The estimated amount of manure was based on national statistics of horses in combination with a local mapping of stables and horses identified through a survey carried out in cooperation with a local interest group of stable owners. The sensitivity analysis made in the study showed that key parameters for viability were economies of scale and governmental investment support [21]. The current study further builds on this pre-study by an in depth analysis of the horse manure-to-energy supply chain.

Case studies are a suitable methodology in early exploratory investigations into relatively unknown subjects [22], as is the case for horse manure logistics. A chief strength of the method is the possibility of using different means of data collection [23], and in line with that, we used multiple sources of data from various stages of the supply chain. Data consisted of notes from project meetings involving a consulting project leader, three employees of the energy company, two municipal representatives, two logistics

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