Biomass and Bioenergy 109 (2018) 209–220

Contents lists available at ScienceDirect

Biomass and Bioenergy

journal homepage: www.elsevier.com/locate/biombioe

Research paper

Ensuring continuous feedstock supply in agricultural residue value chains: A complex interplay of five influencing factors

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ARTICLE INFO

Keywords:
Agricultural residue value chains
Bio-economy
Continuous feedstock supply
Agent-based modelling
Corn stover

ABSTRACT

While second-generation biomass resources, such as agricultural residues, are crucial for the development of the bioeconomy, value chains and markets of locally available agricultural residues remain uncommon. Current research predominantly provides useful insights into technological or techno-economic aspects of agricultural residue harvesting and processing, but, for investors in bio-refineries, one of the main challenges remains ensuring a continuous feedstock supply to the plant. In this article, we present the results of a mixed-method approach, combining insights from semi-structured interviews with simulation results of an agent-based model. This model simulates the decisions of individual economic actors in the value chain – including farmers, custom harvesters and one processor – under four coordination scenarios (direct sale, a custom harvester, mediated contract and two cooperative structures). Our results provide useful insights in the way different factors influence the ability to ensure a continuous feedstock supply. We find that besides actors' willingness, actors' coordination and supply reliability, also actors' actual participation and economic context play a crucial role. Furthermore, we are able to demonstrate the complex interplay between these factors. Our findings are relevant to guide successful future development of agricultural residue value chains for the bioeconomy.

1. Introduction

The use of agricultural residues will be crucial to realize the shift from a fuel-based economies towards a biobased economies. These second-generation biomass resources are of special interest in Europe given the ongoing food-versus-fuel debate. It was recently estimated that about 84.6 million tonnes (dry matter) agricultural residue could be sustainably harvested and used yearly in Europe [1]. However, looking to reality, their actual use for the production of materials and energy remains limited. Indeed, as long as a continuous feedstock supply cannot be guaranteed, large investments in agricultural residue processing facilities will remain unlikely. As stated by Gold and Suering (2011), biomass sourcing is “a crucial and, at the same time, vulnerable activity” [2]. In this article, we explore the different influencing factors that contribute to ensure a continuous agricultural residue supply, and how these factors influence each other. In this way, we provide insights in why local agricultural residue value chains remain uncommon, which may encourage their development in the future.

1.1. Research rationale

Current research to advance the use of agricultural residues predominantly provides useful insights into technological and techno-economic aspects of their harvest, logistics and processing. In comparison, however, relatively limited effort is spent to address the organizational challenges associated with agricultural residue value chain development. This is surprising, as the specific characteristics of local agricultural value chains demand special attention for their organization. First, due to the seasonal nature, large storage areas are needed [3–6] and equipment and workforce is concentrated in time, which can lead to inefficient use of resources [3]. Second, agricultural residues often require customized equipment for collection and handling, which further complicates the structure of the value chain [3]. Thirdly, agricultural residues generally have low bulk density and high moisture content, leading to high collection, handling and transportation costs [2–4,6]. Therefore, agricultural residue value chains are usually very local, having a typical 80–100 km (km) radius of collection [7].

Abbreviations: ABM, Agent-Based Model; CH, Custom Harvester; CSPP, Cellulosic Sugar Production Plant; DM, Dry Matter; ODD, Overview Design and Details; SOC, Soil Organic Carbon

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https://doi.org/10.1016/j.biombioe.2017.12.024
Received 21 December 2016; Received in revised form 22 December 2017; Accepted 23 December 2017
0961-9534/

Besides these unique characteristics of biomass, agricultural residue value chains are also influenced by the characteristics of the economic agents involved. Indeed, these by-products are produced by a large number of farmers dispersed within the collection area of a relatively small number of processors, which increases transportation and handling costs [4–6]. Moreover, farmers are usually not only driven by rational economic goals. Other social aspects may play a role [8], including risk aversion or the tendency towards conservatism. Furthermore, farmers operate within a context and network of other economic agents, including custom harvesters. Finally, the biomass sector is characterized by a highly variable economic environment because of fluctuations in fossil fuel prices, and changing agronomic conditions and technological factors. Therefore, it is challenging, if not impossible, to create contracts that prevent opportunistic behavior [9].

As a result of these unique characteristics of both the biomass itself and the economic agents involved in biomass value chains, establishing a bioeconomy and developing new agricultural residue value chains will take more than the mere introduction of new or advanced technologies [10]. Furthermore, simply copying the organizational structure of other value chains is not feasible in most cases. Therefore, it is crucial that key stakeholders, investors, and policy makers have an adequate understanding of influencing factors that drive the challenges associated with agricultural residue value chains.

1.2. Influencing factors ensuring constant feedstock supply

According to literature, biomass value chains have two main challenges [2]. First, it is compulsory to keep the biomass input costs under control, as they often are about 50% of the total costs [2], second, a constant feedstock supply to the plant [2,11] is needed. In this article, we focus on the second aspect. Indeed, given the large volumes of biomass required in bio-refineries, they are very vulnerable to an unstable supply [12,13]. As such, biomass sourcing is one of their most important activities. According to literature, this continuous supply depends on: (1) the willingness of the actors to participate, (2) the reliability of supply and (3) the coordination of the actors involved in the value chain [2,14] (Fig. 1).

Previous research on the factors influencing a continuous feedstock supply mainly provided a qualitative perspective. The first factor, the willingness of the actors to participate, was investigated by qualitatively assessing the organizational preferences and/or perspectives of producers on biomass supply either through surveys or semi-structured interviews [15–17]. The second factor, the reliability of supply, was discussed by Ref. [18] who presented a theoretical framework for biomass production contract development in order to “improve contract negotiation processes and improve supply chain stability”. Recently, also the effectiveness of a business plan as a tool to manage several uncertainties in new and innovative firms within the context of the bioeconomy was investigated [19]. The third factor, namely the coordination of the actors involved in the value chain, was predominantly researched from the perspective of transaction cost economics [9, 20–23].

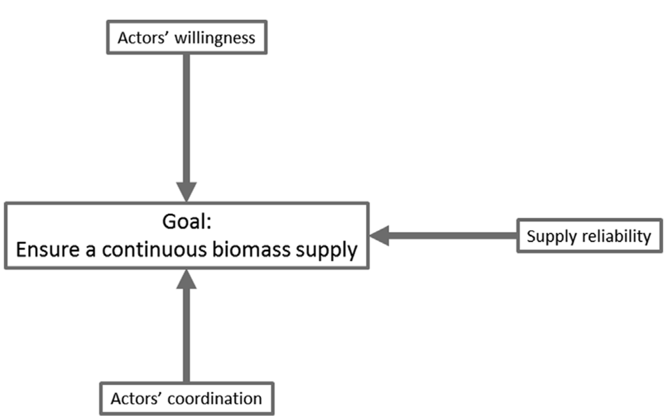

Fig. 1. Three influencing factors determining a continuous biomass supply as found in literature [14].

While these studies provide valuable insights in how these three factors influence the goal of ensuring a continuous supply, they treat each of them separately. Furthermore, they remain mainly descriptive, static and use a qualitative approach to assess the influence of different actors' coordination scenarios on the biomass value chain. In this article, we aim to integrate these three factors and to see whether additional factors also play a role. Furthermore, we investigate how they influence each other and can help in reaching the goal of ensuring a continuous agricultural residue supply, while also taking into account the innovation diffusion process and market dynamics.

1.3. Case-study: the corn stover value chain in Flanders

In order to make our work tangible, we focus on the case-study of corn stover in Flanders, the northern region of Belgium. In this region, it was estimated that yearly about 400,000 Mg (dry mass) of corn stover remains lying on the fields after harvest of the corn grain. This corn stover could potentially be used for feed [24–26], combustion [27], anaerobic digestion [28,29], or to produce bioethanol [30] or cellulosic sugars [31,32]. In order to realize this, a corn stover value chain should be established, in which sufficient farmers cultivate a corn variety of which both the grain and the stover can be harvested, and sufficient custom harvesters invest in a single-pass harvester. Despite multiple attempts to set up a corn stover value chain, this agricultural residue is neither harvested nor processed. The case of Flanders is especially interesting from an organizational perspective, as the region is characterized by a relatively large number of corn producers (about 7500), each cultivating a relatively limited number of hectares (ha) (mean = 7.63 ha) [33]. As such, the actors' willingness to participate, the supply reliability, and adequate coordination between the actors is crucial for a successful value chain. Furthermore, we could wonder whether additional influencing factors could play a role and how these factors interact with each other.

2. Method

The goal of this research is to investigate the different factors that contribute to the challenge of ensuring a stable supply of corn stover to a bio-refinery. In order to realize this, we used a mixed-method approach, integrating qualitative and quantitative research methods. According to [34], a mixed-method approach is advantageous, as it “combines the strengths of the quantitative and qualitative methods and compensates for their respective limitations”. More specifically, for this research, we integrated the results from semi-structured interviews with agent-based modelling. This modelling approach was chosen, as it allows us to explicitly take into account the individual decisions of and interactions between the different stakeholders involved in the agricultural residue value chain. Indeed, as indicated by Ref. [17], the individual decision making of farmers as feedstock providers is often disregarded in official policy documents or research. However, this decision making is crucial. Furthermore, they state that besides economic rational behavior, also non-economic considerations play a role [17]. Agent-based modelling is especially suited to take these non-economic considerations into account. In the following paragraphs, we further discuss the two methods combined.

2.1. Qualitative data to feed the agent-based model

Between March and September 2015, we conducted 14 semi-structured interviews with different experts and possible stakeholders of a corn stover value chain in Flanders (Table 1). Semi-structured interviews are a useful way to obtain a large amount of information in a