EFFECTS OF SUPPLY HETEROGENEITY IN DECENTRALIZED AGRICULTURAL WASTE MARKETS FOR THE PRODUCTION OF ADVANCED BIOFUELS: SIMULATION IN AN AGENT-BASED MODEL

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Overview

Studies that explore the supply link of value chains present in the discussion of the economic viability of the circular economy focus mainly on the relationship between agents, the development of incentive policies and the advantages and disadvantages of supply contracts with regard to the specifications required by new products.The supply of agricultural residue for the production of advanced biofuels generates a new conception of raw materials. Agricultural residue, which was previously considered waste, is now sold with added value. The use of agricultural residues as a source of biomass for the production of advanced biofuels contributes positively to the development of the bioeconomy in several aspects: (i) it promotes increased productivity in ethanol production without increasing the area, avoiding greater pressure on the food production through land use change; (ii) favors sugarcane production, optimizing the amount of straw left in the field; (iii) reduces the seasonality of ethanol supply, contributing to reducing price variability and; (iv) contributes to the mitigation of GHG emissions both by improving the productivity of biofuels and by replacing fossil fuels. The study comprises the simulation of a decentralized biomass market in the presence of heterogeneous agents and stochastic shocks at different points in the production chain, with different levels of supplier land concentration. The results of this simulation were analyzed in comparison with the results of agent-based models (ABM) studies applied to agricultural waste supply chains for advanced biofuels production.

Methods

Market conditions were simulated using an agent-based model and was developed in software LSD (laboratory of simulation development, version 8.0, copywrite Valente and Pereira). On the demand side, there is a biorefinery that takes ethanol prices and purchases biomass on the market at an internal price. On the other hand, suppliers compare the price offered by the biorefinery with their own reserve price. Suppliers are distributed in different sizes, forming a heterogeneous offer depending on the concentration of land and distance from the biorefinery. Land distribution is simulated using the Gini index of sugarcane producers according to different Brazilian regions. Production costs are referenced in data from the National Supply Company (CONAB).

Results

The complexity of relationships in new bioeconomy markets requires analytical tools that capture the heterogeneity of agents and relationships, highlighting the interconnection and dependence of relationships (Vanni et al., 2019). The results show that the biorefinery's dependence on suppliers is greater under higher levels of land concentration, leading to greater exposure to the risk of biomass supply, therefore greater risk to the consolidation of the market itself. Parallel to this process, there is a tendency for biomass prices to rise, putting pressure on the biorefinery's profit margin. The risk present in the market is observed in the greater variation in ethanol prices and when there is greater bargaining power on the side of suppliers, increasing the biorefinery's dependence on suppliers. On the other hand, a less concentrated market favors a situation that tends towards an equilibrium, in which more suppliers have positive returns and the biorefinery can offer lower prices for biomass. Under these conditions, stability develops in which suppliers do not wish to leave, promoting long-term market sustainability.

The supply of agricultural residue for the production of advanced biofuels implies a new conception of raw materials. Waste which was previously considered agricultural or urban residue is now commercialized, adding value to the production chain. Khanna et al. (2017) developed a study with an emphasis on the specifications of agricultural waste supply contracts for the biofuels sector. Following studies on supply contracts for the biofuels sector, Yang, Paulson and Khanna (2015) built a model to analyze the determinants of the landowner's choice between a land lease contract, a fixed price contract and a contract revenue sharing for energy crop production. Complementary to the results obtained concludes that the viability of the supply chain of energy crops and agricultural residues for the production of advanced biofuels requires the creation of a new market with specific governance mechanisms for the commercialization of these new raw materials. Gerber et al. (2016) found that transaction costs are not observed when seeking efficiency in models under full rationality and maximizing optimization. The “best option” for chain coordination did not generate obvious profitable choices in the use of productive resources.

Weseen, Hobbs and Kerr (2014) analyzed the main governance structures practiced in the ethanol sector in Western Canada with a focus on reducing the risks of production delays. Following the line of studies on governance structures practiced in bioeconomy markets, Altman et al. (2013) analyzed the coordination preferences of the agricultural waste producers market in the states of Missouri and Illinois, in the United States, using a multinomial logit model. Shastri et al. (2011) are among the first to analyze the dynamics of the agricultural waste supply chain using the agent-based method. The objective of the article was to explore the dynamics of the interaction system between farmers and biorefineries, in the light of the theory of complex adaptive systems, seeking to highlight the critical elements of interactions, not specifically a link in the supply developments, but rather, the dynamics of interaction.

Li et al. (2012) developed an ABM model with the aim of analyzing the use of corn and rice straw for advanced biofuels production in China. The dynamics of the straw utilization industry were simulated to analyze the role of technology and subsidies, and provide political references. Zhang, Luo and Tan (2016) carried out a study on agricultural residue derived from corn, rice and wheat straw, and wood residues, based on Li et al. (2012). The objective was to develop an agent-based model to explore the operating mechanisms of the agricultural residue supply chain in comparing the performance of two conventional supply patterns: direct negotiation and cooperative committee of agricultural residue producers. Agusdinata et al. (2014) built an agent-based model to understand the dynamics of the biofuel supply network. This model aimed to provide elements for understanding the dynamics between biofuel consumers, farmers and biorefineries. The model is characterized by distributed control, time asynchrony and resource contention among agents, who make decisions based on incomplete knowledge and delayed information.

Huang et al. (2016) developed an ABM model to analyze farmers' decision-making in the adoption of bioenergy crops and predict the behavior of the group of farmers in the supply of switchgrass and corn in Iowa, USA. Following Huang et al. (2016), Huang and Hu (2018) developed an ABM model to analyze Iowa-USA farmers' decision to produce switchgrass. The authors developed an ABM model to study the pricing of agricultural waste supply contracts and policy formulation in the biofuels industry. Moncada et al. (2017) built a conceptual framework of an agent-based model to analyze biodiesel supply chains in Germany. The model focuses on the rapeseed transformation and supply links of the biodiesel value chain. Similar to Moncada et al. (2017), Mertens et al. (2018) developed an ABM model with the aim of investigating the different factors that contribute to the challenge of ensuring a stable supply of corn stover for a biorefinery located in Flanders, Belgium. Jin, Mendis, and Sutherland (2019) developed an ABM model aimed at simulating the spatial diffusion of switchgrass to investigate its adoption on agricultural land in India from 2015 to 2027, under various biofuel market scenarios to leverage biorefineries producing cellulosic ethanol. Nugroho, Zhu and Heavey (2022) developed an ABM model focused on studying methanol production from rice straw in Indonesia.

Conclusions

Enabling sustainable energy growth is a subject with many connecting links among sectors, agents, interests, intermediary systems. The microdynamic modeling effort contributes to the connection with macroeconomic elements, which are key elements for formulating public incentive policies, evidence from main agents for chain coordination, political strategies, and sectoral coordination.

From the analysis of market simulations and the evolution of studies on bioeconomy supply chains, it was observed that the development of a supply chain for agricultural residues as biomass for the production of advanced biofuels will contribute to: (i) increased availability of biofuels; (ii) increased income for agricultural producers; (iii) reducing pressure on food production due to land use changes; (iv) reducing the negative effects of climate change and; (v) a virtuous cycle of adoption of innovations, by reducing transaction costs and the viability of raw materials supply itself. On the purchasing agent side, the biorefinery can benefit from the dispersion of suppliers, which is a very interesting issue from a microeconomic point of view. A bad result is “it always works out”. If the biorefinery is located in a favorable region with optimized supply, it would always carry out complete spoliation, without stops in ethanol production, so it would have maximum profit, with a prosperous situation, not favoring vertical integration. Therefore, vertical integration would be rejected, as there would be a benefit for the biorefinery in leaving the market with decentralized interaction.

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