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Generation of Renewable Energy (Biogas) in the Western Region of Paraná/Brazil—A Multicase Study from the Viewpoint of Contracts

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Abstract: The growth of Brazilian agribusiness has sparked interest in research and putting forth ideas for repurposing agricultural waste while reducing any negative effects on the environment. Therefore, taking into account the economics of transaction costs, this study aims to analyze the relationships that permeate the governance structure for the generation of bioenergy through swine farming waste in business models implemented in the Western Region of Paraná, Brazil, a region with significant production of pigs and a pioneer in the implementation of biogas production projects. The investigation strategy for this study was the case study methodology. Empirical data, analyzed qualitatively, were obtained through the analysis of contracts and interviews with power plant managers and pig producers. The main findings point to the evolution of business models for bioenergy generation, changes in the sector's governance structure, and improvement in the contractual models used. Changes in the state's conduct, including a decrease in its involvement as a financing agent and an increase in its role in promoting policies that structure the legal system, were also noted. Finally, it is inferred that the sector needs to structure an institutional setting capable of mitigating existing legal insecurities and uncertainties.

Keywords: bioenergy; swine waste; governance; contracts



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1. Introduction

The Western Region of Paraná, Brazil, has swine farming as one of its main economic segments, generating employment and income for a significant part of the population. In this region, there are more than 16 thousand rural properties dedicated to this activity; it has a herd of swine equal to 10.33% of the national total, and it accounts for 70% of the state production of this animal protein [1].

These data related to production make the Western Region an ideal scenario for biogas production, taking advantage of waste generated in industry, agroindustry, and agriculture and reducing environmental impacts. For Baú [2], biogas is one of the alternatives that can promote greater diversification in the country's energy supply, minimizing environmental impacts caused by swine farming and, at the same time, cooperating with economic and social development and sustainability. Thus, public policies and regulations aimed at the development of the sector are often launched at the state and regional levels, especially because, according to Pletsch et al. [3], large-scale pig farming is characterized by the production of an excessive volume of waste in small areas, becoming a source of contamination and pollution of the environment if not properly disposed of and treated.

Due to state and local initiatives and the possibility of using waste in sustainable energy production, bioenergy has gained space in the state of Paraná. Data from CIBiogás [4]

point to the existence of 755 biogas plants in operation in Brazil, of which 146 are located in Paraná and, due to the significant agricultural production, 71 are located in the Western Region of Paraná.

Three of the biogas-producing plants were selected as the object of the present study, given their importance and specificity as business models: the Ajuricaba Agroenergy Condominium for Family Farming in Marechal Cândido Rondon (Ajuricaba Condominium); the Technical and Commercial Arrangement of Distributed Electricity Generation from Biogas Originating from Residual Biomass of Pig Farming in Rural Properties in Entre Rios do Oeste do Paraná—Entre Rios do Oeste Mini Thermoelectric Plant; and EnerDinBo Geradora de Energia Ltda.

The three models of arrangements for bioenergy production mentioned above have as their theoretical construct the precepts of the New Institutional Economy (NEI), specifically from the aspect of Transaction Cost Economics' (TCE) micro-institutional focus that enables the study of efficiency and the main determinants of a given structure.

It is worth noting that the relatively unstudied segment of bioenergy generation brings together characteristics that distinguish it from other sectors [5,6], demanding efficient institutional arrangements for transaction coordination, such as structuring from so-called hybrid forms of governance. These hybrid forms, with an emphasis on contractual relationships, have been revealed to be one of the most visible coordination configurations, permeating, in the agro-industrial sector, the relationships between rural producers and other agents [7]. However, a study by Pereira Ribeiro et al. [8] points to potential gaps in the bioenergy sector, highlighting aspects such as the existence of restrictive regulations and high investment costs for the implementation of plants, as well as the need to develop a network of contracts capable of making the interests of agents compatible and mitigating problems in the established relationship.

In this area, it is also important to look at the role played by the public sector in promoting initiatives aimed at reducing the environmental impacts generated by productive activities, structuring the institutional and legal environment for clean and renewable energies, as well as stimulating the generation of new undertakings in the energy sector [9].

That said, the present study aims to identify and analyze the relationships that permeate the governance structure for the generation of bioenergy from the use of swine waste, focusing on the relationships between biomass producers and bioenergy generation plants (Ajuricaba, Entre Rios, and EnerDinBo). Aiming at a greater analytical depth, this study also analyzes the roles of agents and the public and private sectors in the three models under study.

It should be inferred that it is important to study the governance structure established in the generation of bioenergy through swine farming waste, as this bioenergy, in addition to resolving an environmental liability, can be one of the solutions to energy crises and a source of profit for producers. In addition, a better understanding of the gaps in this form of governance in the sector can contribute to improving the coordination of the system and provide tools that help understand fundamental aspects for the development of the bioenergy sector.

2. Theoretical Framework

2.1. Transaction Cost Economics (TCE)

Transaction Cost Economics (TCE), an analytical current of the New Institutional Economics, focuses on the study of the formation of organizational governance structures. The TCE studies the mechanism by which partners in a given transaction protect themselves from the risks associated with exchange relationships, always considering the existence of transaction costs.

For Farina et al., [10] transaction costs can be defined at four different levels: the costs of elaboration and negotiation of contracts; the costs of measuring and monitoring property rights; the costs of maintaining and enforcing the firm's internal and external contracts; and the costs of agents' adaptation to environmental changes. Rocha Jr. et al. [11] add a fifth

element to this analysis, namely, government failures. These failures can occur through underinvestment by the public sector and the establishment of imperfect institutional rules that can generate debatable interpretations about their impacts and legal uncertainty. “State failures generate disincentives for production, unexploited value, make it difficult to perform contracts, and, in short, increase transaction costs in society” [12] (p. 19).

Transaction costs are influenced by a set of human and transactional factors described as behavioral assumptions and transaction attributes, as well as the governance structure chosen by agents [13]. Among these behavioral assumptions are bounded rationality and opportunism, according to the TCE. Thus, TCE considers that individuals are opportunistic by nature and endowed with a bounded cognitive capacity to process available information [10]. Cheng et al. [14] corroborate the premise of bounded rationality and add that agents also have limited information, which impacts rational and assertive decision making. Regarding the opportunistic behavior of agents, Coleman [7] states that this behavior implies the possibility of ex post contractual breach, as well as the need to create ex ante contractual safeguards. Furthermore, given the limits of the agents’ rational capacity, all contracts are necessarily incomplete [15].

Regarding the dimensions, Williamson [13] defines three dimensions for transactions—asset specificity, frequency, and uncertainty—considered to guide the conceptualization of governance structure. Asset specificity concerns assets that are not redeployable to any other activity, except at a loss in value. The greater the specificity, the greater the risks and problems of adaptation. Frequency is related to the number of times agents carry out the transaction, and its main advantages are the possibility of diluting transaction costs and building reputation on the part of the agents involved. Uncertainty corresponds to a lack of knowledge about possible future events, adding informational asymmetry as an aspect to be considered in uncertainty definitions.

Thus, the complexity that uncertainty imposes on the elaboration of contracts, combined with the frequency of transactions and especially with the specificity of the assets, represents the fundamental triad to characterize a transaction and, consequently, determine the most appropriate governance structure [13].

2.2. Governance by Contracts

Governance structures can be defined as institutional arrangements that induce adaptive and sequential decisions and behaviors in agents, according to the transactional particularities given in time and space.

Williamson [13] suggests three basic types of governance structures (market, hybrid, and hierarchical): market governance (spot market) is characterized by the high level of incentives they attribute to economic agents; hierarchical or vertical integration refers to the extent to which goods and services are produced internally; hybrid governance is characterized by the preservation of the agents’ autonomy and by having intermediary transaction costs between hierarchical forms and markets. It encompasses a diversity of arrangements, such as contracts, agreements between companies, and alliances, among others. According to Zylbersztajn [15], in hybrid structures, institutional arrangements occur through formal contracts supported by law, or informal agreements, supported by reputational safeguards and other mechanisms.

Generally speaking, a contract is a bilateral agreement for the coordination of conducts, a bilateral legal act or transaction that involves two or more parties. The contract is a legal concept that encompasses a series of principles and rules of law, with an impact on socioeconomic relations instrumentalizing transactions [16]. However, under the TCE bias, Coleman [7] (p. 77) states that “contracts are forms of governance that guarantee the incentives for transactions to occur and, given their incompleteness, need safeguards to address the uncertainty of the environment and the possibility of opportunistic behavior”. As governance mechanisms, contracts have the peculiarity of being able to coordinate production more efficiently than other structures.

The contractual governance structure can assume different configurations, from less formal to more formal arrangements. Thus, the higher the level of formalization, the more flexible the requirements regarding cooperation, trust, and formalized governance. Nonetheless, as the parties get to know each other, the contractual structure is characterized by the increased use of informal mechanisms, such as cooperation, reputation, trust, and information sharing, which are used in the coercion of agents.

For Axelrod [17], efficient informal agreements, with trust as one of the pillars of cooperation, are a fundamental aspect of the continuity of the relationship and mutual collaboration between agents. Thus, trust has to be an integral part of the cooperative relationship, being an efficient element for exchanges. Another way to increase cooperation is to increase the benefits or rewards for those involved. Thus, if the incentives for cooperation are lower than the benefits perceived by the parties, cooperative behavior tends to exhaust and terminate relationships.

However, even with a sense of cooperation and reciprocity among agents, informal arrangements tend to be broken more frequently, generating the need to formalize contracts to govern the governance structure. Therefore, it is necessary to understand the hierarchical relationships between economic agents to suggest which rules and institutions could guarantee a more beneficial outcome for all those involved.

3. Materials and Methods

In the present study, the qualitative approach is the predominant methodological framework, both in terms of the nature of the problem and the level of depth desired. Thus, the central ideas of qualitative research are based on the work of authors such as Richardson [18] and Cooper and Schindler [19], in which the qualitative resource is presented as an adequate way to understand social phenomena.

As a research strategy, the case study methodology was used [20]. The cases studied were three different models for the generation of bioenergy, implemented in the Western Region of Paraná. They are EnerDinBo Geradora de Energia Ltd.a., Mini-Thermoelectric Biogas Plant in Entre Rios do Oeste, and the Ajuricaba Agroenergy Condominium for Family Farming in Marechal Cândido Rondon.

As for the objectives, the research can be characterized as exploratory, descriptive, and explanatory. The exploratory research provided the beacons for understanding the dynamics of the bioenergy production system; the descriptive research targeted the description of the variables and the establishment of relationships between them; and the explanatory research made it possible to analyze the existing relationships, as well as discuss the processes involved in the phenomenon under study.

The research universe was composed of the three cases mentioned above, and the choice for these projects was based on their relevance and characteristics, considering aspects such as the amount of energy generated, structuring, regional expressiveness, innovation, the possibility of generating profits, the reduction in environmental impacts, and the structure of the business model.

As for data collection, it was carried out in different ways between June and August 2021. One of them was through primary data obtained through guided interviews with the managers of the three businesses. Additionally, 17 pig producers are involved in the three projects: 6 from Entre Rios, out of a total of 18 linked to the business; 9 from EnerDinBo (41 producers); and 7 from Ajuricaba Condominium (initially with 33 producers). The choice of producers was made by non-probabilistic sampling. The other way of collecting data was through secondary data obtained through the analysis of existing contracts in the sector, specifically contracts signed between producers and the power plant.

The collected data were interpreted using content analysis, since this form of analysis allows for an objective and systematic description of the message content. In this approach, indicators that allow inferring about reality other than the message are evidenced [18,21]. Finally, the results of the investigation are presented according to the specifics of the case, aiming to clarify the relationships and behavior of the variables.

4. Results and Discussion

This sub-item presents the main findings and considerations based on the interconnection with TCE, the background of this study, and the data collected in the field.

From a theoretical point of view, the generation of bioenergy in the cases studied occurs in a hybrid form of coordination through formal contracts and tacit agreements—institutional arrangements that are assertive forms of coordination of activities linked to agribusiness.

It is worth mentioning that, given the specificity of each case, it is not appropriate to establish a comparative relationship between the cases. Therefore, the cases studied, and the relationship between producers and plants, will be analyzed individually.

4.1. Agroenergy Condominium for Family Farming in the Ajuricaba Microbasin

The Ajuricaba Microbasin Agroenergy Condominium for Family Farming is located in the rural area of the municipality of Marechal Cândido Rondon (MCR). It was a pilot project in the Western Region of Paraná to produce bioenergy, which, unfortunately, is in the process of being deactivated. Its implementation took place in 2009, with the installation of biodigesters aimed at the energy use of waste from dairy cattle and swine in 33 rural family establishments.

The project was the result of a partnership between several institutions, including Itaipu Binacional and the City Hall of MCR, among others. According to Manager Interviewee 1, who is currently in charge of the project in the city hall of MCR, the cost of implementation was fully financed by the government. The producers were responsible only for the workforce to carry out the activities.

At its peak, the condominium produced 16,000 tons of organic waste a year of animal origin, and about 266 thousand m³/year of biogas—a representative amount for a pilot project. Part of the gas produced was used on the properties, supplying adapted stoves and donated to families by a partner company; the rest was sent to the Condominium Operations Center, which operated with a generator producing electricity. However, after a period of full activity, the project went into decline. Currently, few families keep the biodigesters in operation, generating only biogas for consumption on the properties, and the Biogas Operations Center is not deactivated.

The main findings of this case initially refer to a reflection on the form of development of the project, which was entirely funded by public funds. The presence of public power in the project's financing presents itself as a mechanism to promote social responsibility and raise awareness of new social demands and democratic exercise. According to Manager Interviewee 1, it was a pioneering project at the national level in which the participation of public power was required without the risks and vulnerabilities being assumed by the producers, who, at the time, were unable to be encumbered due to the pioneering spirit of the project.

For Porto [22], the project represented a fundamental milestone in the structuring of a new business model, planning, coordinating, and implementing the bases for the formatting of public policies for energy generation through biogas, and structuring an institutional, technological, and legal environment for the generation of renewable energy. Another aspect that deserves to be highlighted concerns the fact that there is no establishment of formal contracts between producers and other agents, but only informal agreements, even with high investments on the part of the public sector in specific assets. One of the plausible justifications can be linked to the pioneering nature of the project and, therefore, the insecurity of the agents about the results. Thus, the establishment of a formal contract, with penalties and obligations, could discourage producers from joining the project.

It is relevant to note that, for the interviewed producers, the fact that there was no formal contract did not seem to have influenced their adhesion or commitment to making the project successful. One of the producers interviewed stated that “We participated in the project because all the neighbors participated and because the people of the City Hall and Itaipu said it was important” (Producer Interviewee 1). From their speech, it is

observed that trust between the agents was presented as one of the determining aspects for the success of the transactions. For Balestrin e Arbage [23], in an atmosphere of trust between agents, problems are solved more efficiently because information and know-how are exchanged more freely. This relationship of trust can also be explained by the fact that the project participants lived in the same location, with an established friendship and affinity relationship. For Axelrod [17], in contractual relationships not protected by law, the personal affinities between the participants of the transactions acquire greater importance than in the cases of formal contracts.

However, the project, a successful model at the beginning of operations, is in the deactivation phase. Among the factors for the abandonment of the project, there are frustrations of the producers who envisaged financial gains with the activity, which, given the changes in the legislation and the small amount of biogas generated, was not possible. "As there was no income, many people gave up because they did not think it was feasible to continue with the project" (Producer Interviewee 2). In addition to direct profitability, producers obtained other benefits from the project, such as biodigester structures installed free of charge on the property, biogas used as thermal energy for boilers and kitchen stoves, reduction in environmental impacts with the correct disposal of waste, biofertilizer, among others. For Producer Interviewee 3, part of the producers did not consider that having biogas for consumption and biofertilizer to use in the fields was very advantageous and made participating in the project worth the effort.

In addition, other asymmetries generated by the lack of technical knowledge on the part of the producers, as well as political issues linked to the change in governments and, consequently, the management, were also noticeable and may have culminated in the stoppage of activities. For Producer Interviewee 1, "one of the reasons for the stoppage of activities was the termination of the agreement with CIBiogás, which offered all technical support to producers who, alone, were unable to carry out maintenance on the equipment".

Finally, it is necessary to consider the form of organization of the producers for the generation of biogas through rural condominiums. This form of organization, in addition to being a motivating factor, enables mutual encouragement and facilitates the coordination of relationships between agents [14]. This finding can be evidenced by the fact that, with the weakening of the activities, the producers who participated in the project gathered in an association to reactivate the activities. They currently form the Ajuricaba Biogas Producers Association (Asprobio), with around 20 members, which aims to reactivate biogas production.

4.2. Technical and Commercial Arrangement of Distributed Electricity Generation from Biogas from Residual Biomass from Pig Farming in Rural Properties in Entre Rios, Western Paraná

Inaugurated in 2019, the Entre Rios project is the result of the first public call from the Brazilian National Electric Energy Agency (ANEEL) for distributed generation projects with biogas, and is sponsored by Copel. The choice for Entre Rios do Oeste was because the municipality, with approximately 4900 inhabitants, is prominent in pig farming, being the 4th largest pig producer in the state of Paraná and 16th in Brazil (IBGE, 2020).

The project, which generates an average of 4600 m³ of biogas per day, includes 18 pig producers with farms located near Entre Rios do Oeste and took place in the form of a partnership established between Copel, CIBiogás, Itaipu Technological Park (ITP), Entre Rios do Oeste City Hall, and pig producers, which are responsible for the structures necessary for the transformation of waste into biogas in their properties.

For the project, the rural properties were connected to a collection network of 20.6 km that transports the biogas to Mini-Thermoelectric Plants (MTPs). According to Manager Interviewee 2, secretary of Basic Sanitation, Renewable Energy, and Public Lighting of Entre Rios do Oeste responsible for the project, at the plant, biogas is transformed into electrical energy, which, in turn, supplies more than 40 public buildings in the municipality. Producers are paid per Nanocubic meter (Nm³) of biogas generated. This remuneration

varies depending on the amount of waste produced and, consequently, on the biogas generated and injected into the collection network.

In this business model, the relationships between the agents were carried out entirely through the establishment of formal agreements, including contracts, cooperation terms, and public calls, among other legally established forms.

The selection of participating producers took place through a Public Call made by the City Hall with the purpose of accrediting producers for the acquisition of biogas. This public call contained requirements for producers, such as the need to adapt the properties and install the equipment necessary to produce biogas, among others.

It is worth highlighting the Cooperation Agreement signed between CIBiogás and the City Hall to support the execution of actions in favor of the project. Entre Rios City Hall is responsible for granting the land for the construction of the MTC and other secondary aspects such as the removal of trees, cleaning, and maintenance of the land. At CIBiogás, the competencies are of a technical and managerial nature.

Regarding the agreement established and the contract signed between Copel and CIBiogás, it is important to highlight the role of the public sector in establishing this new business model by injecting financial resources and providing know-how and human capital to the sector's development, as seen in the case of the Ajuricaba Condominium. Furthermore, the presence of the public sector encouraging the generation of biogas is driven, on the one hand, by global pressure for decarbonization and, on the other hand, aims to create a basis for the production of clean and efficient energy and, based on these models of established businesses, make the sector attractive for private investment.

As for the contract signed between the biogas producers and the Municipal Government, the analysis carried out focuses on the main safeguards, incentives, cooperation, and control structures for the actors involved. This is a single model of contract, signed between the City Hall and each of the producers, differing only in relation to the amount of biogas contracted per month. The amount of biogas generated depends on the production capacity installed for the production of pigs on each property, ranging from 800 pigs (smallest producer) to larger farms with 7400 pigs, as well as the raising stage. According to Manager Interviewee 2, "The income for the pig producer is certain, however, it differs between producers due to biogas production and size of the property".

Concerning the attributions and prerogatives of the parties, although they fall in greater quantity to the contractors, there are no abusive aspects that denote opportunistic behavior among the agents, only technical and operational issues necessary for the development of activities. For producers, the contract establishes a monthly quantity in nano cubic meters (Nm^3) of biogas and specifies the minimum quality characteristics for the product.

However, included in the clauses on obligations, there is an indication that the amount of biogas to be acquired per month will depend on the demands of the municipality for the supply of biogas. Such a clause can generate uncertainties and threaten the frequency of transactions, since the contracting party points out the possibility of not purchasing the entire contracted production. According to Producer Interviewee 4, "If the City Hall does not buy the biogas, or even in case of surplus production, it is burned through the flare" (equipment responsible for burning the biogas). In this case, the generated biogas is lost, reducing investment payback time.

The contract also establishes aspects inherent to the price paid per Nm^3 of biogas, mentioning that the price may be readjusted after a period of 12 months and that the billing amount will be made monthly through cash to the contracted party. It also establishes the individual limit for the sale of biogas by the producer. Both the form of payment and the possibility of expanding production and commercialization can be considered important mechanisms to encourage investments in pig production, in the correct disposal of waste, and in the structuring of an economically and environmentally viable business model.

Although it is a business model with a high level of asset specificity, the investments made for the production and commercialization of biogas are largely the same as those of producers who only invest to fit the current legislation about pig production. Interviewee

5 reports that investments in biodigesters and treatment ponds were necessary to fulfill their duty to environmental legislation and that, by participating in the project, it was possible to obtain financing to carry out these adjustments, in addition to financial returns and gains in the organization of the activity and an improvement in the quality of life. Manager Interviewee 2 reinforces this statement, stating that “In other cases, the producer makes this investment to adapt the property, but does not have any kind of return”.

It is noteworthy that in this case, although formal relations had been established, the producers organized themselves and formed the Entre Rios do Oeste Biogas Producers Association (Aprogás), bringing together all the producers participating in the project, which denotes the presence of cooperation in this business model as well.

Finally, it is inferred that this business model is recent, with contracts formalized in mid-2019. Therefore, there is still some time for further consideration of existing gaps, incentives, or adjustments in the form of governance established.

4.3. *EnerDinBo Geradora de Energia Ltda.*

The hybrid biogas and photovoltaic power plant, EnerDinBo, founded in October 2020, is located in the municipality of Ouro Verde do Oeste, in the Western Region of Paraná. It is a private company that aims to produce electricity on a large scale in the country and, in this way, contribute to the development of the Western Region of Paraná.

EnerDinBo works in a hybrid system (biogas and solar energy) to better use the plant’s potential. According to Manager Interviewee 3, technical director of EnerDinBo, this form of action allows for a much greater permanence, because during the day, solar panels are used to generate electricity while biogas is stored, which will be used at night when there is no incidence of sunlight.

The biogas unit can process 700 tons of swine manure per day (20,000 m³ of biogas on average per day), generating 1 megawatt/hour, and the photovoltaic unit has an installed capacity of 500 kilowatts/h. The structure integrates 40 pig producers from the Western Region of Paraná, who contribute to the production of waste from more than 100,000 pigs. These partner producers transfer the swine manure free of charge to EnerDinBo, which collects it at no cost to the producers and, in return, guarantees the correct disposal of animal waste. In addition, organic biofertilizers produced are returned to producers as an alternative to chemical fertilizers. All these transactions are governed by contracts established between the parties (Manager Interviewee 3).

The energy produced both by sunlight and by biogas is injected into the distribution network of Paraná Energy Company (Companhia Paranaense de Energia—Copel) and distributed to users throughout the state. As for the commercialization of energy, this is carried out through an energy cooperative, of which EnerDinBo is a member.

It is worth mentioning that this hybrid model is seen as a novelty in the energy market. According to Manager Interviewee 3, this business model is recent at the national level and still lacks policies for its implementation and expansion—so much so that the company was created in a legal environment with legislative gaps. This is because ANEEL approved the regulation for the operation of Hybrid Generating Plants (UGH) and associated generating plants only in November 2021, defining rules for these projects.

In relation to the contract signed, this is called an “Agreement of free partnership and cooperation for the collection of swine manure”. Its purpose is to establish a free partnership and cooperation between the parties, taking into account the destination of the supplier’s swine production waste, which will be collected by EnerDinBo. The contract establishes that the collection of manure will be performed in an environmentally correct way, allowing the pig producer to expand its herd (pig production), and that EnerDinBo undertakes to collect, transport, and receive, at no cost to the supplier, the waste from swine production; the producer undertakes to transfer, free of charge, the waste from his swine production to the collecting partner. It also provides for the granting of an environmentally correct property seal to the producer.

Regarding this aspect of the free transfer, it is a new form of relationship between agents for the bioenergy sector, with strengths and weaknesses for the parties. For the producer, the main potential and advantages lie in the fact of not having to invest in waste treatment systems, having the guarantee of the correct destination, and being adjusted to environmental standards, without running the risk of fines and suffering punishments and restrictions about pig production. This form of transaction can minimize gaps in the pig industry, which has the costs of correct waste disposal as one of its obstacles. This finding is supported by the statements of the producers under investigation. “The fact of not having to worry about manure and knowing that I am within the law is very good and advantageous” (Producer Interviewee 5). “The waste was used as fertilizer, however, in the off-season, it was a problem because it accumulated a lot, especially in the rainy season” (Producer Interviewee 6).

For EnerDinBo, the advantages of this system are equally positive, since the costs for the acquisition of biomass are only those of collecting and transporting this waste from the rural property to the plant’s headquarters. However, according to Manager Interviewee 3, logistics costs are high and, in an attempt to reduce them, contracts establish the minimum amount of waste loads that each producer must give away weekly. Additionally, as a way of reducing costs and increasing the plant’s sustainability, EnerDinBo is developing a project to use biogas as fuel for trucks that transport waste.

In relation to possible weaknesses, the fact is that the sector is under development, has legal gaps, and is in the process of incorporating experimental technologies. Another weakness concerns the fact that, in the case of the implementation of other power plants using the same system, the producer will have the option of competition, which could arouse interest in the sale of waste since, from an environmental perspective, these wastes can become a source of income. According to Manager Interviewee 3, “Some producers have already questioned the transfer of waste. However, given the costs of investing in a biodigester, producers still prefer the transfer and return via biofertilizers”.

Finally, other contractual clauses that deserve to be highlighted refer to the possibilities of alterations or contractual termination and the short period of validity of the contracts. Drawn up for only one year, the contract establishes the possibility of contractual termination at least 90 days in advance without any right to indemnification for either the supplier or the collecting partner. Such clauses can generate uncertainties for the parties, putting the business at risk.

4.4. Analysis of Findings in the Cases under Study Considering the TCT

The Transaction Cost Theory is concerned with identifying aspects that may impact the choice of an efficient governance structure, using the transaction as the analytical unit. Williamson [11] argued that the choice of governance structure can be affected by three dimensions present in transactions: asset specificity, uncertainty, and frequency. For Silva and Brito [24], the variation of these dimensions exposes the limits of human rationality and facilitates the opportunistic action of economic agents, directly affecting transaction costs.

Given the importance of these dimensions and the analysis carried out on the three business models for the generation of bioenergy in the Western Region of Paraná, a summary table was developed, presenting the main aspects of the form of governance undertaken and the intensity with which the dimensions of transactions and behavioral attributes are present in the cases studied. These findings are shown in Table 1:

Table 1. Summary of the main aspects identified in the cases studied.

Analysis Variables	Ajuricaba Condominium	Entre Rios do Oeste	EnerDinBo
Foundation	2009	2019	2020
Current situation	Disabled	Active	Active
Form of financing	Partnership between public institutions	Public–private partnership	Private company
Number of producers	33	18	40
Average amount of biogas produced	730 m ³ /day	4600 m ³ /day	20,000 m ³ /day
Governance structure	Informal agreements	Formal contract—“Contract for the acquisition of biogas”.	Formal contract—“Free partnership and cooperation contract for the collection of swine manure”.
Transaction	Pig and cattle producers and public authorities	Pig producers and the City Hall	Pig producers and EnerDinBo
Form of organization	Rural condominiums	Producers Association	There is no formal organization—registered producers participate.
Asset specificity	High—public sector investments in structure, equipment, and training of producers.	High—investments by the public sector and producers in structure and equipment.	High—private sector investments in structure and equipment.
Transactions frequency	High—recurring; dependent on technical support and the amount of waste.	Medium—technical support; intermediation of negotiations via association; short operating time.	Medium—waste collection on properties; short operating time.
Degree of uncertainty in transactions	High—institutional insecurity; absence of formal contracts; breach of trust between agents.	Medium—institutional insecurity; existence of formal contracts; short-term contracts; trust between agents.	Medium—institutional insecurity; establishment of formal contracts; short-term contracts; existence of contractual gaps.
Bounded rationality	High	Medium	Medium
Opportunism	Medium	Low	Low

Source: survey data (2021).

From the findings in the field research, evolution and improvement in the analyzed business models can be observed, highlighting the relevance of the pioneering model, since the gaps observed in this case were remedied, improving the business model and governance structure used. Advances can also be observed in the installed capacity for biogas production, energy generation, and, consequently, the reduction in environmental impacts caused by swine farming in the region.

Concerning the dimensions of transactions, it was found that there was high asset specificity in the three models evaluated. However, this asset specificity is not present in equal intensity for all agents: for the Ajuricaba Condominium, these assets have a greater impact on public power agents (City Hall, Copel, Itaipu, and CIBiogás, among others) because they were the ones who invested in equipment, human resource training, and technologies, among other aspects required for the project’s development and which are now idle. In the case of Entre Rios, the specificity of assets is shown equally between the parties, as the investments were made by both agents; in the case of EnerDinBo, it falls more heavily on the company, since the producers only deliver the waste, without the need for any investments for that. As a result of the high specificity of the assets present in

the transactions, the choice of the governance structure through contracts, migrating from informal contracts to formal contracts, can be justified.

However, as the frequency of transactions increases, there is also an increase in the degree of trust between the parties, which impacts the reduction in expenses associated with the collection of information, elaboration, and monitoring of more complex contracts, making it possible to curb opportunistic actions and, consequently, reduce transaction costs.

Another analytical point of the TCT refers to the behavioral attributes of the agents: bounded rationality and opportunistic behavior, which are noticeable elements in all transactions. Such attributes were perceptible with greater intensity in the case of the Ajuricaba Condominium, which can be explained by the fact that it was an innovative model in an institutional environment still fragile in terms of legislation and other policies, and by the fact that there was the abandonment of the project structures on the part of the producers, who, for lack of obtaining direct financial advantages, did not continue the project, even though they received the entire structure for the generation of biogas. Such results, however, are in line with other studies carried out on renewable energy generation, such as a study developed in China [25], in which the results indicate that due to the uncertainty of the institutional environment and regulatory limitations, agents only have rationality limited and incomplete information, which represents limitations to the development of the sector.

4.5. Research Limitations

There are limitations to this study, including the fact that qualitative research can present obstacles in terms of the accuracy of the information collected. In addition, the analysis can be subjective due to the researcher's interpretation of the interviewees' statements.

Another limitation refers to the fact that only three bioenergy business models from the Western Region of Paraná, Brazil, were analyzed. Although they are representative, they do not represent all businesses of this nature in the region.

4.6. Future Research

It is suggested that future studies expand the sample of businesses aimed at biogas generation in the Western Region and combine qualitative research with aspects and models of quantitative research to increase the level of assertiveness. It is also suggested that they analyze the relationships between other agents, such as contracts between plants and distributors, energy cooperatives, condominiums, and other existing transactions that were not within the scope of this study. Likewise, studies approaching the legal perspective would be opportune.

5. Conclusions

This article has as its main focus analyzing the existing contractual models for the generation of bioenergy from swine farming waste in the Western Region of Paraná, using both qualitative research resources and methodological tools. The choice for a bioenergy generation project installed in Western Paraná was because the region is known for its thriving agricultural production and for emerging in the development of business models generated from the waste of this production.

The main findings of this study of the three important business models in the region (Ajuricaba, Entre Rios, and EnerDinbo) indicate that the models are of fundamental importance for the structuring of the bioenergy sector, especially with regard to the transformation of waste from swine production, with high polluting potential, into a sustainable activity, reducing environmental impacts, generating clean energy, and providing development to the region.

It was also discovered that these business models evolved and that Ajuricaba Condominium, a pioneering national project, served as a beacon for the sector's development in terms of both technical and legal as well as institutional improvement. The models

developed in sequence, Entre Rio do Oeste and EneDinBo, with greater potential for biogas generation, were structured to incorporate the lessons learned from the pioneering model. These adjustments made it possible to remedy gaps identified in the pioneering model and meet new demands and advances in relation to legislation and international pressure on reducing environmental impacts and sustainable production.

Furthermore, in the evolutionary aspect, there is a change in the role of the state in the sector. Initially, in the case of the Ajuricaba Condominium, the state assumed the role of fully financing the pioneering project. In the case of Entre Rios, the role of the state as a financial agent is reduced, resulting in a public/private partnership. In the case of EnerDindo, the state is only the driving agent of public policies, regulating and promoting the activity without directly injecting resources for the generation of bioenergy. However, it should be noted that in the case of the Ajuricaba Condominium, public-sector investments were plausible. It is the function of the state to create public policies to reduce environmental impacts, and these initiatives could not, at an early stage and without an established institutional environment, burden small rural producers with a reduced capacity to produce waste and pollution.

Concatenating the results of field investigations with the study's base theory (TCT), it was observed that, even if it is about three different models for the generation of bioenergy, there is convergence in relation to the choice of the hybrid form of governance, advancing from informal contractual relations to more complete contracts with less margin for risks and uncertainty, pointing to an evolution of the current models. However, insecurities in relation to the legal and institutional environment still hinder the development of the sector and give rise to uncertainties—an aspect observed in the three models under study. Convergences were also noticeable in relation to asset specificity, transaction frequency, and uncertainties in the relationships between agents, although in some cases the degree of these variables was not presented with equal intensity.

Supported by the research findings, it can be concluded that, regardless of the business models used, all of them allow for a better destination for agricultural production waste (mainly from highly polluting swine), reduce environmental impacts, and contribute to the increase in energy supply in the country. However, it is suggested that these models be the object of constant research, development, and innovation linked to the establishment of credit policies, technical assistance, and the structuring of an institutional and legal environment that reduces uncertainties and enables sustainability and profitability for all agents.

Author Contributions: I.D.C.—investigation—conducted the research and investigation process, specifically performing data/evidence collection. Formal analysis—application of formal techniques to analyze or synthesize study data. Validation—verification of the overall replication, reproducibility of results, and other research outputs. Project administration—management and coordination responsibility for the research activity planning and execution. Data curation—management activities to annotate, scrub data, and maintain research data. Resources—provision of study materials and other analysis tools. Writing—preparation, creation, and presentation of the published work, specifically writing the initial draft and final version. M.C.P.R.—conceptualization—ideas, formulation, or evolution of overarching research goals and aims. Supervision—oversight and leadership responsibility for the research activity planning and execution, including mentorship to the core team. Project administration—management and coordination responsibility for the research activity planning and execution. W.F.d.R.J.—visualization—preparation, creation, and presentation of the published work, including substantive translation. Funding acquisition—acquisition of the financial support for the project leading to this publication. Methodology—development of methodology. Resources—provision of study materials and other analysis tools. R.M.d.S.F.—writing—review and editing—preparation of the work, critical review, commentaries, and revisions. C.M.S.—writing—review and editing; writing—final version. All authors have read and agreed to the published version of the manuscript.

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References

1. IBGE—Instituto Brasileiro de Geografia e Estatística Pesquisa da Pecuária Municipal. 2020. Available online: <https://www.ibge.gov.br/estatisticas/economicas/agricultura> (accessed on 16 August 2021).
2. Baú, B.G. Desenvolvimento Sustentável: Análise dos Impactos da Usina Termelétrica de Biogás em Entre Rios do Oeste. Master's thesis, Universidade Estadual do Oeste Paraná—Unioeste, Toledo, Brazil, 2020.
3. Pletsch LM, M.; Casali MD, S.; Baggio, D.K.; Turcato, J.C. Desenvolvimento sustentável na suinocultura e bovinocultura: A experiência das propriedades do município de Três Passos-RS. *Informe GEPEC* **2019**, *23*, 51–73. Available online: <https://erevista.unioeste.br/index.php/gepec/article/view/18759> (accessed on 14 September 2021). [[CrossRef](#)]
4. CIBIOGÁS—Centro Internacional de Energias Renováveis—Biogás. Energias Renováveis: Principais Tendências de Avanço do Biogás no Brasil. 2022. Available online: <https://cibiogas.org> (accessed on 14 July 2021).
5. Pica, C.Q.; Toniolo, M.L. Sistemas cooperados de produção de biogás e geração de energia: Análise de casos e modelagem de negócio de projeto em Santa Catarina. *Rev. Gestão Sustentabilidade Ambient.* **2015**, *4*, 330–346. [[CrossRef](#)]
6. Mariani, L. Biogás: Diagnóstico e Propostas de Ações Para Incentivar Seu Uso no Brasil. Tese de Doutorado, Universidade Estadual de Campinas, Faculdade de Engenharia Mecânica, Campinas, Brazil, 2018.
7. Caleman, S.M.Q. Contratos e Coordenação. In *Gestão de Sistemas de Agronegócios*; Zylberstajn, D., Neves, M., Caleman, S.M.Q., Eds.; Atlas: São Paulo, Brazil, 2015.
8. Pereira Ribeiro, M.C.P.; Paglia, N.C.; Rocha Júnior, W.F.; De Sousa, R.M.; Lindino, C.A. Institutional and Legal Framework of the Brazilian Energy Market: Biomass as a Sustainable Alternative for Brazilian Agribusiness. *Sustainability* **2020**, *12*, 1554. [[CrossRef](#)]
9. Cheng, L.; Yin, L.; Wang, J.; Shen, T.; Chen, Y.; Liu, G.; Yu, T. Behavioral decision-making in power demand-side response management: A multi-population evolutionary game dynamics perspective. *Int. J. Electr. Power Energy Syst.* **2021**, *129*, 106743. [[CrossRef](#)]
10. Farina, E.M.M.Q.; Azevedo, P.F.; Saes, M.S.M. *Competitividade: Mercado, Estado e Organização*; Editora Singular: São Paulo, Brazil, 1997.
11. Rocha, W.F., Jr.; Bittencourt, M.V.L.; Ribeiro, M.C.P. *Análise das Características dos Contratos no Agronegócio do Brasil*; Revista Brasileira de Planejamento e Desenvolvimento: Curitiba, Brazil, 2015; pp. 94–118. [[CrossRef](#)]
12. Zylberstajn, D.; Giordano, S. Coordenação e Governança de Sistemas Agroindustriais. In *Gestão de Sistemas de Agronegócios*; Zylberstajn, D., Neves, M., Caleman, S.M.Q., Eds.; Atlas: São Paulo, Brazil, 2015.
13. Williamson, O.E. *The Economic Institutions of Capitalism: Firms, Markets, Relational*; The Free Press: New York, NY, USA, 1985.
14. Cheng, L.; Chen, Y.; Liu, G. 2PnS-EG: A general two-population n-strategy evolutionary game for strategic long-term bidding in a deregulated market under different market clearing mechanisms. *Int. J. Electr. Power Energy Syst.* **2022**, *142*, 108182. [[CrossRef](#)]
15. Zylberstajn, D. Estruturas de Governança e Coordenação do Agribusiness: Uma Aplicação da Nova Economia das Instituições. Ph.D. Thesis, Tese (Livre Docência), FEA, Universidade de São Paulo, São Paulo, Brazil, 1995.
16. Gomes, O. *Contratos*, 20th ed.; Forense Jurídica: São Paulo, Brazil, 2002.
17. Axelrod, R. *A Evolução da Cooperação*; Leopardo Editora: São Paulo, Brazil, 2010.
18. Richardson, J. A Pesquisa Qualitativa Crítica e Válida. In *Pesquisa Social*, 3rd ed.; Richardson, R.J., Peres, J.A.d.S., Wanderley, J.C.V., Correia, L.M., Peres, M.d.H.d.M., Eds.; Atlas: São Paulo, Brazil, 2012.
19. Cooper, D.R.; Schindler, P.S. *Métodos de Pesquisa em Administração*, 12th ed.; AMGH: Porto Alegre, Brazil, 2016.
20. Yin, R. *Estudo de Caso: Planejamento e Métodos*; Bookman: Porto Alegre, Brazil, 2005.
21. Bardin, L. *Análise de Conteúdo*; Edições: São Paulo, Brazil, 2016.
22. Porto, B.H.C. Impactos Ambientais e Socioeconômicos da Produção de Biogás: O Caso do Condomínio de Agroenergia Para Agricultura Familiar Ajuricaba. Master's Thesis, Faculdade de Agronomia e Medicina Veterinária, Universidade de Brasília, Brasília, Brazil, 2019.
23. Balestrin, A.; Arbage, A.P. A perspectiva dos custos de transação na formação de redes de cooperação. *RAE Eletrônica* **2007**, *6*, 162. [[CrossRef](#)]
24. Silva, A.A.; Brito, E.P.Z. Incerteza, racionalidade limitada e comportamento oportunista: Um estudo na indústria brasileira. *Rev. Adm. Mackenzie* **2013**, *14*, 176–201. [[CrossRef](#)]
25. Fang, D.; Zhao, C.; Yu, Q. Government regulation of renewable energy generation and transmission in China's electricity market. *Renew. Sustain. Energy Rev.* **2018**, *93*, 775–793. [[CrossRef](#)]

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