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Collective agro-energy generation in family agriculture: the ajuricaba condominium case study in Brazil

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ABSTRACT

One of the challenges in the agribusiness sector in Brazil, the 4th largest food producer in the world, is to assess the effectiveness of participatory methods to convert animal manure into economic assets. In this scenario, biogas and biomethane stand out as renewable sources of energy available in all countries and their uses can significantly induce local and regional economic development. This study will present an arrangement known as agroenergy condominium for its multi-services, such as energy generation trough biogas and biomethane, biofertilizer, and mitigation of GHG emissions. The farmer's key motivations to join the project were identified through individual interviews and analyzed using MICMAC and SWOT analysis methods. The most significant drives were environmental and economic aspects, which demonstrated their environmental citizenship, and the less influent variable was social motivation. Despite the challenges to be overcome, the results validate that this arrangement can bring benefits for the local community, enhance the energy security in the region and contribute to a more clean energy matrix. Furthermore, it can be replicated at lower cost and with technologies already known and consolidated. The results demonstrate the implications of the interdisciplinarity between technology, environment, and society.

KEYWORDS: Renewable Energy, Biogas Condominium, Biomethane, Rural Energy.

INTRODUCTION

As the 4th largest food producer in the world, Brazil has a robust and dynamic agricultural and livestock sector (FAO, 2014). Among the states that stand out, in 4th position nationally, Paraná represents 9.3% of the national agricultural and livestock production. These sectors account for 10.5% of the state's GDP and, considering the production industrialization, this share reaches 30% (PARANÁ, 2016).

Despite the difficulties of the Brazilian economy in 2015, the agricultural and livestock sector grew 4.4% per year in the state, more than the double the national average of 1.8% per year (PARANÁ, 2016). In this scenario, it is critical to address waste generation of agricultural and livestock production, which can be major sources of pollution if not properly treated.

This article will present a case study in the Ajuricaba Agroenergy Condominium for Family Agriculture, located in the west of Paraná, which aims to adequately address the waste generated by 33 small properties, transforming them into economic assets for producers. The farms have areas between 10 and 20 hectares, which produce soybean, corn, wheat, 1,072 cattle and 3,082 pigs, generating approximately 821 m3 of biogas per day and 16 thousand tons of waste/year.

In summary, the biogas produced by the 33 properties is channeled through a rural low-pressure biogas collection network (pipeline) to an Environmental Operations Center. The biogas generated is used as thermal energy for heating boilers at a local cooperative that processes poultry.

For its operation, in 2017 it was created an Association of Ajuricaba Biogas Producers, composed by all these farms. Some of the properties use the remaining biogas in stove for cooking, replacing the LPG (Liquefied Petroleum Gas) and also for heating water for cleaning dairy utensils. Additionally, the biogas system produces about 14,000 m3 of biofertilizer per year, important to increase the productivity in the field and contributing to the reduction of 2.4 tons of CO2 equivalent per year. Biogas can still be used as electric energy and can be purified and transformed into biomethane, used as vehicular energy (CIBIOGÁS, 2016).

The main objective of this research is to analyze the main motivations for the farmers to participate in this type of condominium and the main results achieved with the project implementation. As individual projects are often not economically viable, the collective biogas production justifies due to it’s arrangement that dilute costs and propose cooperative work. For this purpose, some individual interviews were held with farmers and professionals who contributed to the implementation of the condominium.

The article concludes that the most significant drivers for farmers to participate in this kind of arrangement is to solve environmental problems and enhance economic returns, which represents “environmental citizenship” of the farmers, as they are concerned about a sustainable growth. The main environmental problems solved were the proper treatment of wastes that earlier polluted water flows, the reduction of greenhouse gases emissions and adequate methods to produce and use biofertilizer. Regarding economic returns, farmers cited the use of the biogas stove and production increase with the use of biofertilizer. The less important motivation was social, such as cooperation with

neighbors, sense of community, etc. These elements are fundamental for other agroenergy condominiums implementation and replication.

Despite having some improvements and challenges to overcome, it was concluded that the agro-energy condominium brought benefits for the local and regional community, contributed to a more rural sustainable development, and enhanced the energy security in the region.

MATERIALS AND METHODS

Considering the objective of this article, the Ajuricaba Agroenergy Condominium for Family Agriculture was selected for a case study. The qualitative and quantitative data analysis was achieved by using primary and secondary sources. Initially, secondary sources were collected from Itaipu Binacional, CIBiogas and CIH's databases and technical reports, besides renowned scientific articles related to the issue. After that, primary sources were composed by interviews, data collection, and on-site visits.

The interviews were conducted with 16 farmers involved since the beginning in the project implementation, 2 farmers who didn't accept to participate in the first phase of the project but will participate in the second phase of the condominium, and 7 professionals (engineers, technicians and managers) who contributed to the implementation of the condominium. The aim of this procedure is to validate the main motivations to participate in the project, the challenges faced during the planning, implementation, and maintenance phases of the condominium, to identify the fundamental benefits achieved after the project implementation.

Only the interviewed farmers' answers were considered for the conclusions, excluding external influences, as it was implemented a deductive approach. This reasoning method goes from the general to the specific or truth-preserving. In essence, a valid deductive argument is one in which the premises—if true—must lead to a true conclusion (WORSTER, 2014).

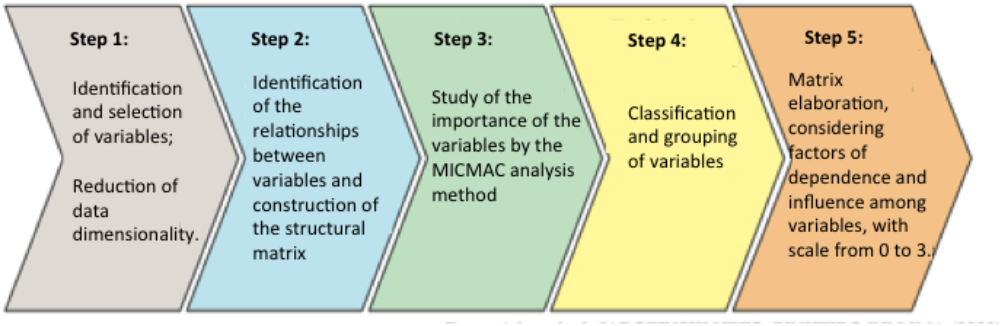
The semi-structured interview method was used in this research, consisting of a permanent list of questions (questionnaire), with a set of predefined issues, but preserving the freedom to place other interests arose in the progress of the interview (MARCONI and LAKATOS, 2008). The questionnaires are comprised of closed and open-ended questions.

Considering a population of 33 properties, it was possible to interview 18 of them due to the farmer's availability, resulting in a confidence level of 95%, and a maximum allowed error of 7% (KISH, 1995). After the interviews, all the collected data were transcribed and tabulated. The content analysis was used as a qualitative data analysis technique, aiming to identify what is being said about a given topic and to decode what is being communicated.

With the rich and consistent compiled information through the content analysis, it was possible to analyse the most significant variables that determined the participation of the farmers in the biogas condominium. The use of MICMAC (Impact Matrix Cross-Reference Multiplication Applied to a Classification) software was selected to give more support and credibility to the analysis made by the researcher, eliminating possible calculation errors (POLACINSKI, 2011). This toll

only serves to facilitate analysis and interpretation (GODET, 1993; FUGII, 2014), not exempting the active action of the researcher in adopting a method of analysis that is coherent and pertinent to the theme and epistemological orientation.

Fig. 1: Steps for the MICMAC matrix construction



Source: The authors.

The process of data analysis itself involves several steps to gain meaning for the data collected (ALVES-MAZZOTTI and GEWANDSZNAJDER, 1998; FLICK, 2009), which is no different in content analysis. For this analysis, it was chosen to organize it in three phases, according to Bardin (1977): 1) pre-analysis, 2) exploration of the material and 3) treatment of results, inference and interpretation.

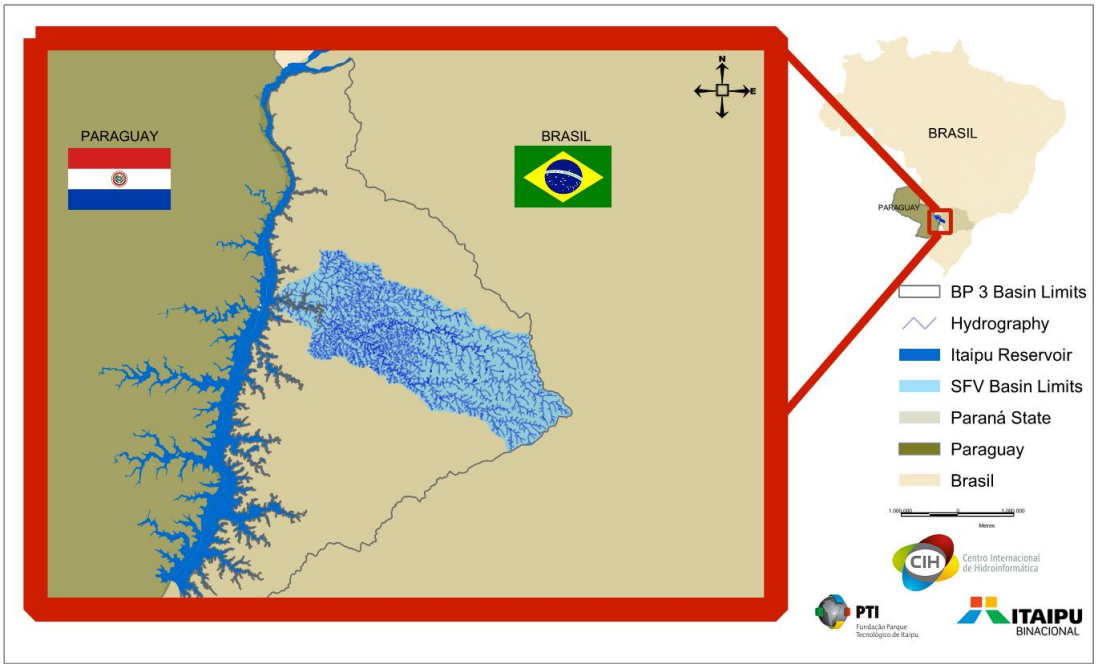
The SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis method was employed (HUMPHREY, 2005), considering the issues highlighted by the professionals about the agroenergy condominium implementation. The results composed meaningful information and recommendations for the project replication in other areas and to support decision makers in their enterprises.

THE CONDOMINIUM CONCEPT AND TERRITORIAL PLANNING

The Ajuricaba Agroenergy Condominium For Family Agriculture was proposed in 2009, with the aim at treating the wasted generated in the area and producing energy for local consumers.

The Itaipu Binacional Hydroelectric Power Plant is located on the border between Brazil and Paraguay. It is the world leader in energy production from renewable sources. The 103 million MWh generated by Itaipu would be enough to meet the Latin America electricity need for 35 days. The plant's installed generation capacity is 14 GW, providing 17.3% of the energy consumed in Brazil and 72.5% in Paraguay (ITAIPU, 2017).

Fig. 2. São Francisco Verdadeiro Basin location and Ajuricaba Agroenergy Condominium influence area.



Source: International Center of Hydroinformatics, 2015. Scale: 1:1,000,000.

Itaipu reservoir covers an area of 1350 km2 and it is located in the Paraná 3 Basin (P3B), an area that comprises about 8000 km2 of tributaries that flow directly into the Paraná River, which supplies the lake. In its surroundings are located 28 municipalities that add up to 1 million inhabitants.

It is a privileged area, rich in natural resources, biodiversity, abundance of water and outstanding soil. However, like most agricultural frontiers, it is affected by the consequences of accelerated deforestation and disorderly territorial occupation, which occurred more intensively after 1950, as result of agricultural policies in the country. Over time, environmental liabilities began to appear, such as deforestation of native forest, soil erosion, and contamination of water with animal waste, agrochemicals, animals manure and wastes.

In the process of the basin's water quality monitoring, Itaipu identified the eutrophication as one of the main problems to be solved as soon as possible. It is the enrichment of a water body with nutrients, usually with an excess amount of nutrients (SCHINDLER and VALLENTYNE, 2004). The surrounding waters were being heavily polluted with fertilizers and organic matter from agriculture, mainly swine and poultry farming, and sewage from urban populations in the region, causing the proliferation of algae and aquatic plants.

In order to propose an appropriate arrangement to mitigate this problem, a deep study of territorial planning was held in the basin, considering a consistent database that was analyzed in conjunction with geographic information systems. It was concluded that the São Francisco Verdadeiro sub-basin – the main tributary of Itaipu reservoir, and more specifically the Ajuricaba micro-basin –, was the most impactful in the area, as along this route the stream and its tributaries pass through small farms, in an area with expressive production of swine, cattle and poultry. Consequently, there is a high concentration of animals in a small area and a large concentration of manure, what is a relevant justification for renewable energy

projects from residual biomass. Besides pollution, there is also a meaningful emission of methane that is harmful to the environment.

Fig. 3. Ajuricaba properties location and territorial management applied for energy distributed generation.

Source: Bley, 2015.

The micro-basin comprehends 111 rural properties. Of this total, 41 properties initially accepted to participate in the condominium, producing mainly swine and cattle. After the project implementation, 33 properties effectually generated biogas, and this will be the universe of the research.

From the energetic point of view, this kind of project is more appropriate in micro-basins scale, as it provides a single connection to the distribution network, rather than a connection for each micro generator. This model serves for small farms and also for its possible neighbors in a larger scale, “which considerably reduces the expected risk of connections overloading on the same distribution network. It is possible that one day it will become a preferred form of connection for bioenergy in general” (BLEY, 2015, p.113).

The first stage of implementation, occurred in 2010, was the physical adequacy and improvements on the properties, such as roof changing to prevent infiltrations and leaks from gutters, and the installation of waste mixing boxes and biofertilizer storage pond. This stage was followed by the installation of biodigestors and primary gas pipelines in each property, for biogas production.

Fig. 4. Biogas collection network construction and small flow biodigestors implementation

Source: Bley, 2015.

Subsequently, in 2012, a main biogas collection network of 25 kilometers was installed. The project for the biogas collection network had as reference São Roque Farm, located in Santa Catarina, which was the first farm to implement a large extension biogas collection network in Brazil. After that, it was constructed the thermoelectric micro central, which concentrates the biogas production of all properties (ITAIPU, 2010). The first arrangement of the project considered the generation of electric energy, thermal energy for cooking and dry grains, and biofertilizer. Due to the lack of public policies and public calls for energy acquisition, the electric energy didn't work as expected and in 2017 a new arrangement was implemented, consisting on the 2nd phase of the project.

It was created an Association of Ajuricaba Biogas Producers and currently the biogas is used as thermal energy for heating boilers at a local cooperative that processes poultry. The farmers keep on using the biogas for cooking and the biofertilizer to increase the agricultural and livestock production. The processes for thermal, electric and vehicular energy generation, as well as biofertilizer, will be presented as follows.

The main partners were Paraná Institute of Technical Assistance and Rural Extension (EMATER), Department of Agriculture, Livestock and Food Supply of Parana, Marechal Cândido Rondon Municipality and Energy Company of Paraná (COPEL), and Brazilian Agricultural Research Corporation (EMBRAPA), who contributed with technical expertise. For the project implementation, the investment was of approximately USD 1.3 million from Research & Development Itaipu's fund (ITAIPU, 2012).

THERMAL ENERGY GENERATION

The conversion of biogas into thermal energy is possible by two ways:

a) Cogeneration, from the installation of heat exchangers in the engine exhaust manifolds for pre-heating the water in the steam generation boiler; and

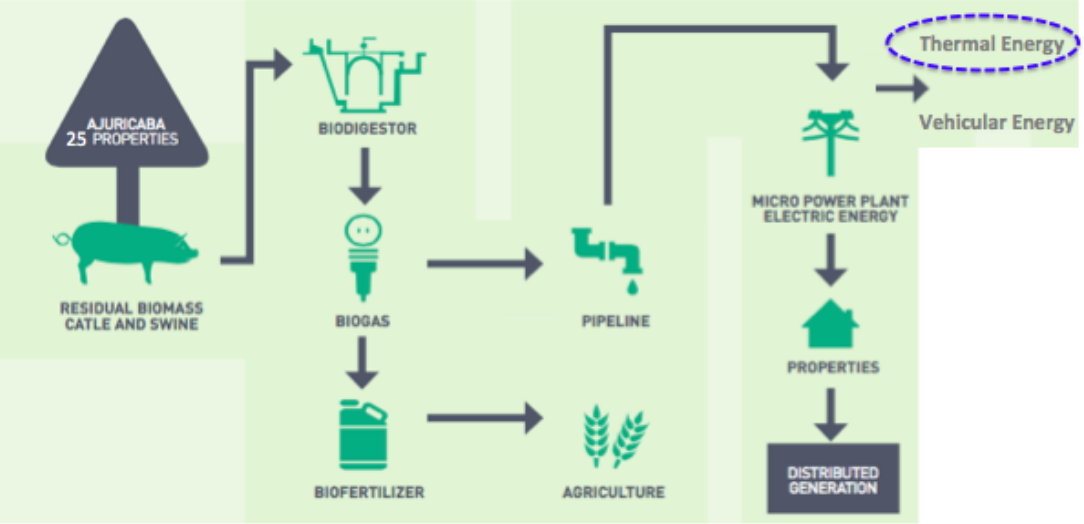
b) Direct use of biogas as fuel in boilers or kilns replacing firewood, sugarcane bagasse, diesel or other fuel used.

In the Ajuricaba condominium, the biogas has direct use, both in the stoves of the farmers and in Copagril. The biogas stoves are fed directly with the biogas produced in the properties. Only properties with swine production have an H2S removal system to prevent corrosion, as the manure's H2S concentration is higher than 1000 ppm (parts per million) and indexes above 500 ppm are harmful to combustion engines. Cattle manure has lower H2S concentration than swine's (about 400 ppm) and currently are not being purified. Before the biogas lights the stove, there is a pressure-reducing valve, in which a filter is installed with iron filings that makes the absorption of H2S. There is also a valve at a lower point of the pipe to remove condensed water, humidity (water extractor).

Some of the properties use the biogas in stoves for cooking foods in place of LPG (Liquefied Petroleum Gas) and also for heating water for cleaning dairy utensils, improving the quality of milk and, consequently, the income generated by its sale.

Regarding the thermal energy from Ajuricaba to Copagril, the biogas is pressurized at the Ajuricaba's Operations Center and sent via the biogas collection network directly to the Copagril boilers. At the boilers entrance there are equipment for pressure reduction and control of firing, as presented in figure 5.

Fig. 5. Biogas processes in Ajuricaba.



Source: adapted from Bley, 2015.

ELECTRIC ENERGY GENERATION

At the first phase of the project, the generation of electric energy by biogas was conducted through a power generator group of 104 kVA and generated energy in the distributed generation (DG) model, which consists of power generation close to where the demand occurs, being used for self-consumption of the farmers and excess compensation.

The DG has some advantages over the conventional generation, as it avoids investments in transmission and reduces losses in these systems, improving the stability of the electricity service and enhancing energy efficiency.

The initial purpose of the condominium was to sell the generated energy to the local energy utility Copel, but there was no call/announcement for contracting this energy. In 2012, after eight years of study, the Brazilian Electric Energy Agency (ANEEL) published the Normative Resolution 482, establishing that the connections in the distribution grid of power generated by mini and micro generators should be made in the compensation scheme within 36 months, or energy balance (net metering).

One year later, it was stated that only two projects were accepted and were in operation in Brazil, which demonstrates not only the complexity of the net metering system, but also the barriers that utilities found to admit connections to their grids.

In 2015, this resolution was modified by the Normative Resolution 687. Consumers are not allowed to sell the energy to the grid, but they are allowed to install small generators in their consumer units and to use the local electricity system to inject excess energy, which will be converted into a valid energy credit for 60 months. These credits can be used to reduce the consumption of the own unit in the following months, in the same ownership, or through an enterprise with multiple consumer units or shared generation, which is the case of biogas condominiums. It was the first time that ANEEL recognized condominiums and energy cooperatives as important actors in the Brazilian energy scenario.

There was also a modification of the limiting power for micro and mini distributed generation: before the microgeneration was for enterprises of up to 100 kW and now is 75 kW, and the minigeration comprised enterprises from 100 kW to 1 MW, changing to 75 kW to 5 MW (ANEEL, 2015).

For a new condominium implementation, currently is important to consider the generation of electric energy, as the regulations had advanced in the last years. Besides that, it is relevant to reflect that the electricity generated by biogas should be seen as complementary, and not exclude the current system, i.e., the generator does not need to be disconnected from the electrical system and, instead, use the energy produced in the own farm and, when needed, consumes from the local utility.

VEHICULAR ENERGY GENERATION

The vehicular application is being studied by upgrading the biogas and converting it into biomethane in substitution of fossil fuels as diesel, natural gas, and gasoline. This can reduce producer's cost of transportation and generate additional income. To get the qualified biogas fuel potential, it is required to refine it in different intensities to obtain the biomethane, which is considered a fuel product whose potential is similar to the CNG (Compressed Natural Vehicular Gas), with expected consumption of 1 cubic meter of biomethane for a 12 km ride.

In the condominium, a biogas refinery for biomethane was implemented for testing. The filtration separates methane (CH4), carbon dioxide (CO2), that works as an anti-flame or non-combustible, and hydrogen sulphide (H2S), which

produces corrosion of essential parts of the engines. Particulate matter or dust, as well as humidity are also removed in the filtering process. This process results in a high purity methane gas, or biomethane, increasing the maximum calorific value of biogas and thereby increasing its efficiency and application possibilities.

Fig. 6. Biogas refinery for biomethane.

Source: the authors.

As the Ajuricaba's biogas production is all being used by the Cooperative and the farmers, the biomethane project is waiting for a production increase, but the results of the biomethane analysis and refining methodology is used in Haacke Farm. The property has 80,000 laying hens and 750 cattle, producing a total of 1000 m3 of biogas per day, as a result of the manure generated and treated into an anaerobic system. The biogas generated on the property is composed of 64% methane.

The biogas refining uses the Pressure Swing Adsorption (PSA) methodology, which the raw biogas is first compressed, following the condensation of water content through a temperature exchange system and finally trace elements, such as hydrogen sulfide (H2S), will be removed with activated carbon.

The conditioned biogas is finally channeled through the PSA filter which is filled with carbon molecular sieves, especially designed for adsorbing the typical elements found in biogas. CO2, H2O, residual H2S, NH3 and odors are then removed and the result is a highly enriched methane gas, or biomethane.

After the refining, the biomethane is compressed into cylinders for transportation, a process carried out in two interconnected cylinders baskets with 280 m3 capacity each. The compressors lift the biomethane from 5 bar to 250 bar pressure.

For the supply of biomethane, Itaipu installed one dispenser, which aims to transfer in a safe and controlled way the biomethane contained in the baskets to the vehicles. The current production of biomethane in the property is 740 m3/ week, and Itaipu uses about 110 m3/day. Through the refining, 98% of biogas is converted into biomethane and achieves the characteristics of CNG, being able to meet the regulations of the National Agency of Petroleum, Natural Gas and Biofuels (ANP) No. 16/2008 and No. 08, published on January 30, 2015, which is 96.5% methane, at most 3% CO2, at most 0.5 O2.

The commercialization of biomethane for third parties still presents a very high control cost, because the regulation requires analysis with in-line chromatograph. It is recommended to use for self-consumption. The biomethane use can be configured as an important alternative when biogas is produced by the same supply chain that will uses it, as it represents fuel autonomy and cost reduction for daily operations, besides fossil fuels dependence mitigation.

Besides biomethane, another possibility is the use of biogas in catalytic reforming for hydrogen production, which would bring a greater appreciation of biogas and increase the feasibility of its use. It is also favourable to use the high quality bio-fertilizer, which is applied to pasture or other crops, further increasing the degree of sustainability of the production system.

BIOFERTILIZER

Another product of biodigestion process is the biofertilizer. Liquid animal waste is composed of faces, urine, feed leftovers, fur, sand and water used to clean the facilities or wasted by the animals. In a general way, these wastes are a mixture of chemical elements that appear in organic or mineral form: carbon (C), nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sodium (Na), manganese (Mn), copper (Cu), zinc (Zn), among others. Due to their higher concentration, C, N, P and K are the elements with the greatest potential to pollute the soil, water resources and atmosphere, requiring proper handling, treatment and disposal.

Applied on fields, the biofertilizer induces a faster growth and consequently improves the feeding of the cattle and, consequently, producing more milk. In the last 12 months, one of Ajuricaba's producers saved about USD 800 in mineral fertilizer and increased milk income by USD 600, a significant impact on the income of a family farmer.

The use of these liquid wastes as fertilizer in agriculture is the main practice for the management of livestock effluents used in Brazil and also in the world, due to its simplicity, low cost and reduction of crop production costs due to the substitution of mineral fertilizers (KUNZ et al. Al., 2005).

According to the Agronomic Institute of Paraná (IAPAR, 2016), and strengthened by the interviewer's answers, the main benefits of using the waste as biofertilizer are: incorporation of nutrients and carbon in the soil; neutralization of acidity; establishment of beneficial microorganisms; improvement of physical and chemical properties; increased productivity and improved product quality (fertilizer value).

The main disadvantage of this practice, however, is the high cost of transportation - when it is done by trucks or tractor tanks - that makes it economically unviable to apply the biofertilizer when it is located far from where it is produced.

The use of waste as biofertilizers should be based on specific technical recommendations that determine the amount of waste to be applied to the soil as a function of the nutrient concentration of the effluent and the demand of these nutrients for the soil and crop to be fertilized. In Ajuricaba, there is a

recommendation for each farm and the technical support is often monitoring the biofertilizer quality and use.

CONTENT ANALYSIS AND RESULTS

This section will present and analyze the interviews with 16 farmers who participated since the beginning in the project implementation and 2 farmers who will participate in the 2nd phase, that consists in the arrangement shift occurred in 2017, where the biogas will be commercialized to Copagril. It will take into account environmental, social and economic aspects.

FARMERS WHO PARTICIPATED SINCE THE BEGINNING IN THE PROJECT IMPLEMENTATION

The project started with 33 properties and due to the shift of production in some of them, such as substitution of livestock for agriculture production, currently there are 25 farms producing biogas. Sixteen farmers were interviewed, representing 48% of the total, and their opinions and suggestions are summarized as follows.

Question 1: What were your main motivations for joining the condominium?			
Aspects	**Categories**	**Keywords**	**Frequency**
Enviromental	Preservation and pollution	I took into account the future, the pollution	4
	Manure's treatment	My swine facilities were improved	4
Social	My son's future	It's a little attitude, but it's something experimental to verify if it works. Someone has to start.	1
Economic	It was for free	It is net profit, in addition to environmental issues. Itaipu has provided material for free, we just needed to provide the workforce/staff.	3
	New income (energy and biofertilizer)	We don't need to buy LPG, which is a fortune nowadays.	4

Source: the authors.

Through the interviews, it was possible to verify that the main motivations were environmental and economic aspects. For the most part, those who answered that environmental issues were motivating considered as 2nd place the economic issues, and vice versa. It was verified that these two aspects are of greater importance in this condominial arrangement and are inter-related.

In Brazil there is the search for economic growth as a classic motivational element, but the environmental concern with the consequences of this growth is also consolidated in the imaginary of the interviewees, and has the same representativeness: that is, the concern for economic growth has the same magnitude of the environmental concern. This is what we call "environmental ethics", which comes from trying to understand the relationship between human beings and other elements of nature, and which values permeate the different relationships established. This concept is linked to the "environmental citizenship" theory, that Waldman (2003, p. 557) defines as:

"The notion of environmental citizenship presupposes the establishment of a more harmonious relationship with nature. This position must be present in the full extent of quotidian life, with each citizen exercising his environmental responsibility whenever he is manipulating goods and materials, seeking the most ecological purpose possible in each attitude adopted in his daily life and with conscience of the impact that the simplest procedures can cause in the natural environment." (own translation)

Another important fact observed is the important women's role in sensitizing this type of project. Some have reported that it was they who encouraged their husbands to participate in the project. They participated in the initial meetings and they are the ones who handle the environmental part.

Question 2: Did you have environmental problems that were difficult to resolve by yourself and were solved with the project implementation?			
Aspects	**Categories**	**Keywords**	**Frequency**
YES	Bad smell and pathogenic vectors	No more smell, which attracts even more cows; With the biofertilizer, you can spread it wherever you want, because there is no more smell or fly; I never need to use poison at home. In neighbors who didn't participate in the project, the smell is very strong and has flies.	9
	Manure's treatment	The manure is now channeled, and before that it was all open;	4
	Property's organization and cleaning	The property's cleanliness has improved a lot. It used to have manure at the entrance and now there's grass.	1
NO	Manure's treatment	The biodigestor didn't work well.	2

Source: the authors.

There was a significant reduction of the pathogenic vectors and bad smell. The properties do not use poison anymore, improving the producer's quality of life. The appropriate manure's treatment facilitated the management of the wastes, besides promoting biofertilizer production. Another improvement highlighted was the better organization and cleaning of the properties, which does not have as many problems with wastes spread out in the field.

There were 2 interviewers who answered that the biogas system didn't resolve their problems. One of them produced cattle at the beginning of the

project and changed to swine production, so the biodigestor didn't work as expected. The other producer complained about the biodigestor's location. It should have been installed somewhere else by gravity and not by pumping.

Question 3: Do you use the biofertilizer produced in the property? Did you increase the productivity?			
Aspects	**Categories**	**Keywords**	**Frequency**
YES	It increased the productivity	Today I cut the hay in 30 days, and previously it took 90 days; It's the first grass the cow wants to eat; Corn production more than doubled; Productivity has increased considerably; This year I produced 188 jars of pickled cucumber, because the cucumber grew very fast.	15
NO	I don't use the biofertilizer	My biodigestor didn't work well and I don't use biofertilizer.	1

Source: the authors.

In all the properties that use the biofertilizer there was a significant increase in productivity, representing the greatest direct gain so far for the producers. Some farmers informed that the biofertilizer use decreased harvest time from 90 days to 30 days, and the annual save with biofertilizer's purchase is about USD 600, which represents a lot for the farmers.

One of the interviewed informed that before the project, the cows didn't have enough grass to eat, and now the grass grows faster and the cows are fatter and healthier.

Question 4: Do you use the biogas stove?			
Aspects	**Categories**	**Keywords**	**Frequency**
YES	It works well	It's great and the pans do not turn black; It's much better than the conventional stove; It is a total evolution; It's was a big present; These days someone told me that the LPG is expensive. For me, it makes no difference, because I do not buy it anymore.	8
NO	I don't use it	The biogas stove installation was charged and it would cost about USD 1,000 in some proprieties, so we couldn't pay for that; It is a high investment and we have lots of wood available, so we use the wood stove.	8

Source: the authors.

Muller Company was partner of the project and installed biogas stoves in the proprieties. The stove was given with no cost and they charged only for the installation. In some proprieties, the houses were far from the biogas generation, increasing the installation costs, so some farmers decided not to use this

technology. In the region, it's very common people use wood stove, because there is a good availability of wood and it is more attractive, not considering environmental issues.

Some users informed that they save about USD 200.00 per year with LPG.

Question 5: Is the technical support adequate?			
Aspects	**Categories**	**Keywords**	**Frequency**
YES	They were always available	When there is a problem, I call the technician and he come very fast; They always come when we need them	15
NO	Some procedures didn't work	The biodigestor didn't work. The technician tried to fix the pump, but it didn't work.	1

Source: the authors.

It was possible to verify that the producers trust a lot in the technicians and they are always available to help them with the biogas system. The biogas production, including biofertilizer, certainly depends a lot of this assistance, either to monitor the farm's performance or even to encourage producers to maintain their commitment.

One of the producers complained about the biodigestor's location. The technician tried to fix the pump, but it didn't work. It was a problem of the biodgestor installation, designed by another company.

Question 6: Where your expectations been met during the design, implementation and maintenance phase of the project?			
Aspects	**Categories**	**Keywords**	**Frequency**
YES	As expected	If it were not for the help of Itaipu and the Prefecture, I do not know how long we would stay here. Now we have an expectation of staying at least until our retirement; Without the project, the property would be worse. With it we could improve it.	8
NO	Not as expected	We expected to generate electricity, but it was never generated; We spend energy to pump the biogas to the central.	3
Partly	Not as expected	We expected to generate electricity, but it was never generated; We spend energy to pump the biogas to the central.	3
	Economic benefits not as expected	We still do not receive for what we produce.	2

Source: the authors.

Eight farmers had their expectations met with the project, mainly due to environmental gains. Some of them got disappointed because they didn't generate electricity as designed at the beginning of the project. Other farmers are partly satisfied with the results, highlighting the environmental benefits and criticizing the economic aspects, as they didn't receive money for the biogas produced until now. If they had received, possibly their opinion would be different for some questions.

Question 7: Will you participate in the 2nd phase of the project?			
Aspects	**Categories**	**Keywords**	**Frequency**
YES	I will participate	I'm really looking forward to it. Everyone will win; I'm excited. With the production we have we will generate more biogas and will invest more; As Copagril is located nearby, it gives us more confidence; I hope the neighbors who participate take care of the biodigestors.	14
NO	I will not participate	I will not participate because of my age. Just me and my wife who work on the property and we do not have much health; I would only participate if I have any legal/ environmental obligations.	2

Source: the authors.

Most of the farmers will continue in the project and they are excited about the biogas sale for Copagril. As the cooperative is near them, they feel they can trust more at this new phase. Two farmers won't participate in the 2nd phase: one of them is due to the advanced age and health conditions and the other one affirms that it is not necessary to invest in environmental projects.

In this 2nd step, some new neighbors got interested to participate in the project and will join the arrangement.

Question 8: Do you recommend this type of project to other neighborhood?			
Aspects	**Categories**	**Keywords**	**Frequency**
YES	For sure I recommend	Everyone wins; There should be more government incentive for everyone to participate. For people who produces milk, energy is very important; All properties should participate. We offered help for some properties, but even so they do not want to participate; After the project we are even more stimulated to take care of the property; People have to pay a little for the project. If it's for free, it does not work.	14
Maybe	It depends	I think it's only worth with swine manure, not with cattle manure;	2

Question 8: Do you recommend this type of project to other neighborhood?			
Aspects	**Categories**	**Keywords**	**Frequency**
		I would have to calculate and see if the system generates profit. Otherwise, no. No clock works for free	

Source: the authors.

Most farmers recommend this type of condominium for other areas as everyone has main environmental benefits. They also indicate that it would be required more government incentives so every rural property would be able to participate and suggested a small financial participation of each farmer, as if it's for free they don't take it serious. Two of those interviewed think that it would be important to participate only with swine manure and if the system generates profits. Otherwise, they wouldn't recommend this arrangement.

FARMERS WHO DIDN'T PARTICIPATE IN THE PROJECT SINCE THE BEGINNING, BUT WILL PARTICIPATE IN THE 2ND PHASE

Two farmers that got interested to participate in the 2nd phase of the project was interviewed and their contributions will be presented as follows.

Question 1: What were your main motivations for not joining the condominium?			
Aspects	**Categories**	**Keywords**	**Frequency**
Social	My son's health	Our son was very sick at the time, so there was no way for us to participate in the project. Thank God he is better now, so we can devote more time to the project	1
Economic	It was not for free	My grandfather decided at the time. We did not participate because we would have to pay the workforce.	1

Source: the authors.

It was possible to verify that one of the farmers, even with the financial support of Itaipu for the 1st phase of the project, didn't want to participate at that moment because he had to invest a little in workforce. He also justifies that at that moment they didn't have enough animal's manure.

The other farmer didn't participate for family health problem motivations, so now he is expecting to contribute with the project and with the neighbors.

Question 2: Do you have any type of waste treatment today?			
Aspects	**Categories**	**Keywords**	**Frequency**
No	Waste treatment	No, we don't have.	2

Source: the authors.

Both properties currently don't have any waste treatment, and reported that they are aware that if one property does not have this treatment, all neighbors are impacted and harmed.

Question 3: Did you have environmental problems that were difficult to resolve by yourself and will be solved with the project implementation?			
Aspects	**Categories**	**Keywords**	**Frequency**
Yes	Waste treatment	The manure odor is strong in the summer and will certainly reduce; It will improve a lot, because we will not pollute the river anymore.	2

Source: the authors.

Both farmers think that their waste treatment will improve environmental issues in their neighborhood and the bad odor will reduce, but this did not influence the decision to participate in the project, as they answered in question 5 that the main motivation was economic.

Question 4: Even not participating in the project, do you realize that the condominium has brought benefits to your neighbors?			
Aspects	**Categories**	**Keywords**	**Frequency**
Yes	Pollution reduction	It has improved a lot, including people's work. Before it was all badly organized, the manure polluted the river, and now this has changed; The bad smell and the flies diminished; When you use biogas, you see how much would be emitted in the air, polluting.	1
	Biogas for cooking and biofertilizer	The neighbors commented on biogas for cooking, so I will not need to buy LPG anymore; We use the biofertilizer of the neighbors and it has a huge difference. You can easily distinguish where is biofertilizer and where is regular manure. The result is quite different.	1

Source: the authors.

The influence of neighbors was very positive to these farmers who decided to participate in the 2nd phase of the project. They proved that some environmental, social and economic benefits were provided by the project.

Question 5: What were your main motivations for joining the condominium?			
Aspects	**Categories**	**Keywords**	**Frequency**
Economic	New income (energy and biofertilizer)	Copagril will start buying biogas. I hope it helps in property energy consumption and LPG, to save on gas purchased, and also with biofertilizer	2

Source: the authors.

Both farmers got interested in the project due to new income and energy costs reduction. The biogas sale for Copagril was an important stimulus and also the use of biofertilizer. One of them spends about USD 600 per year with biofertilizer and USD 200 with LPG, so this would be reduced with the project implementation.

The profile of these interviewees is different from those who took part in the project, as they are not focused on environmental gains as the main motivation. This kind of profile, focused on a single motivation, is very sensitive, because if economic expectations are not met, they will surely leave the project. However, if there is another motivation, such as environmental, they can continue in the project.

Question 6: Do you recommend this type of project to other neighbors?			
Aspects	**Categories**	**Keywords**	**Frequency**
Yes	Environmental: pollution reduction	This kind of project had to be worldwide, not a condominium here and there. If a property does not participate, smell comes and it is not good	1
	Social	For sure this project is important; People have to help more. There are many people who participated in the project and did not play their role.	1

Source: the authors.

Both farmers recommend this type of arrangement in other areas. One of them emphasize that should have more incentives for implementation worldwide and the other affirms that people need to be more involved and committed to the project.

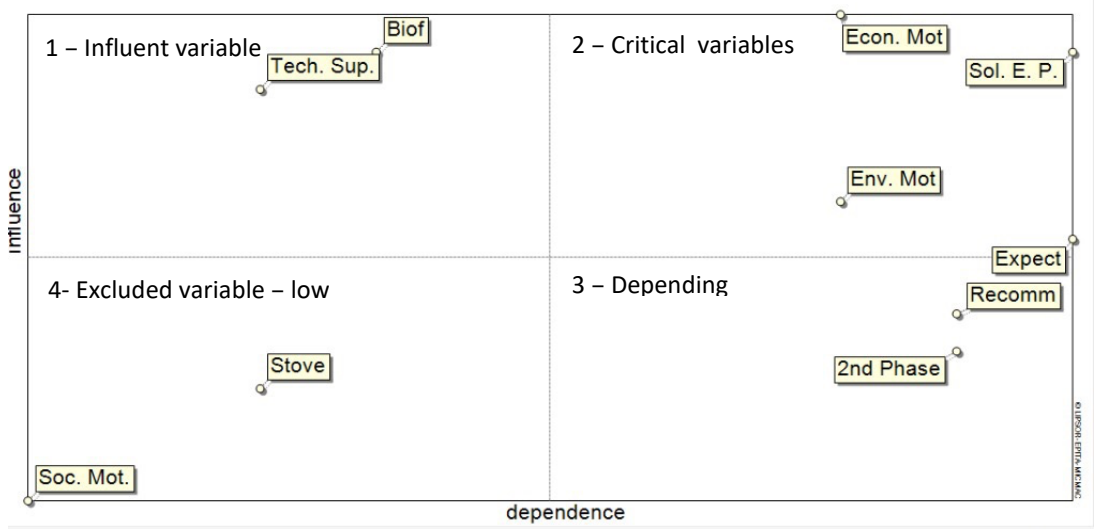
In the following section, a MICMAC analysis is detailed, in order to conclude the main influenced and dependent motivations for the farmers to join the agroenergy condominium.

MICMAC ANALYSIS

Through the results obtained with the farmer's interviews, it was possible to analyze them with the use of MICMAC tool, aiming to structure collective reflection and confirm the main motivations for the farmer's participation in the condominium. Ten strategic variables were analyzed and their global influence

and dependence were indicated by using values between 0 (no influence/dependence) and 3 (strong influence/dependence). Considering the variable's rating, MICMAC software produced the following influence-dependence map, which positions the variables according to their degree of influence and dependence in the system.

Fig. 7: Direct influence-dependence map.



Source: The authors.

The variables Technical Support and Biofertilizer, presented in the quadrant 1, represent high influence and low dependence. This means that the producers are very influenced by the technical support and the use of biofertilizer to join and remain in the condominium. Any change that occurs in this variable will have repercussions throughout the system. Technical support has high ability to influence the system and low ability to be influenced by the behavior of other system variables.

The variables Economic Motivation, Solution of Environmental Problems, Environmental Motivation and Expectations, in quadrant 2, are at the same time very dependent and very influent, having an unstable nature, which means that any action on them will affect the other variables, as well as the opposite effect. Commonly, these variables represent the most challenging areas of the project. Solution of Environmental Problems is the most dependent variable, representing the most important incentive for farmers to participate of the condominium.

Recommendation and the implementation of the 2nd phase of the project, in quadrant 3, are less influential and very dependent, which means, they are the results whose development is linked to the variables of quadrants 1 and 2, mainly influent variables (economic motivation and solution for environmental problems). Recommendation of this type of project to other neighborhood depends a lot on the other variables, and have a low level to influence the other farmer's opinion. With this new phase and the biogas sale for Copagril, they got more stimulated to continue and influenced other neighbors to participate too.

The Biogas Stove and Social Motivation, in quadrant 4, represent less influent and less dependent variables. They constitute a tendency or factor relatively disconnected from the system, due to their autonomous development. Social Motivation is the less influenced and dependent variable. Only one of the interviewed farmers highlighted Social Motivation as essential to participate of an agroenergy condominium.

SWOT MATRIX - ENGINEERS, TECHNICIANS AND MANAGERS WHO CONTRIBUTED TO THE PROJECT

Through the results obtained with the engineers, technicians and managers interviews, who contributed to the project, it was possible to analyze the main strengths, weaknesses, opportunities and threats faced in the biogas agroenergy condominium. To consolidate this analysis, the SWOT method was selected, in order to identify and organize the internal and external factors that are supportive or unfavorable to achieve success in a biogas agroenergy condominium implementation. SWOT methodology is often used as part of a strategic planning process and for decision-making situation when a desired end-state (objective) is defined.

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	POSITIVE	NEGATIVE
INTERNAL	**STRENGTHS** 1) **Environmental:** water quality enhance; reduction of pathogenic vectors; environmental sanitation in the property; better spatial organization of property and cleanliness; anaerobic digestion had an important advance; small-scale fiberglass biodigestor was a great techno. developed; biogas collection network was a new techno. in Brazil and worldwide; biofertilizer and biogas stove for new income. 2) **Social:** biogas for family farming; attractiveness of farmers to stay in the field due to the project; biogas association; associative work; important women's role to convince their husbands and participate actively in the project, better quality of life, biogas was introduced in the farmer's routine. 3) **Economic:** new sources of income through biofertilizer and biogas stove 4) **Institutional:** biomethane solutions to implement in other condominiuns or projects,	**WEAKNESSES** 1) **Environmental:** techno. limitations, such as difficulties to operate the micro thermoelectric central and low performance of the original moto-generator; some materials didn't correspond to their purposes; biogas production was overestimated at the beginning, not considering temperature variations and sanitary void. 2) **Social:** farmer's acting and commitment below the expected, as some of them didn't understand their important role in the project; indirect gains are not so valorized as economic gains; farmer's training and motivation. 3) **Economic:** it was recommended a small financial involvement of farmers for the 2nd phase to valorize the project; as a R&D project, it was designed to develop new technologies, not to generate profit, but farmer's started to demand profit. 4) **Institutional:** farmer's sensibilization was not efficient; more technical assistance is necessary; diffuse interests of the partners; high turn over of technicians and involved suppliers, weakening the farmer's reliability.
EXTERNAL	**OPPORTUNITIES** 1) **Environmental:** implementation of new condominiums to introduce biogas for family farming; both the biodigestors and the biogas collection network have known limits now, facilitating the replication; it was overcome the great difficulty of a large biogas collection network with the installation of drainage of water (*purgadores*); this type of arrangement can mitigate the problematic water-energy-food nexus; 2) **Social:** environmental awareness, better quality of life, and collaborative work 3) **Economic:** new sources of income, 2nd phase with biogas sale to Copagril. 4) **Institutional:** the techno. have known limits now, facilitating the replication and promoting financial return; sustainable solutions; today there is already a regulation for the implementation of condominiums (NR 687 ANEEL); this arrangement has great environmental appeal for medium and big companies.	**THREATS** 1) **Environmental:** implementation of new condominiums to introduce biogas for family farming; cost of equipment and service life; need of efficient corrective and preventive maintenance of the biogas system; 2) **Social:** difficult convincing of farmers to work as a team; capacity of producers to act in an associative way; financial involvement of producers so that they can feel part of the process, not spectator, and with financial return to them; 3) **Economic:** new sources of income through biofertilizer and biogas stove, 2nd phase with biogas sale to Copagril. 4) **Institutional:** lack of specific regulations for rural biogas collection networks as today it only exists for large scale; more legal security; need for training of actors for technical assistance to producers; the companies involved in the project must have more synergy, as the project's success depends on the commitment of all.

All the interviewed engineers, technicians, and managers considered that Ajuricaba was a very important project to breaking paradigms and clarifying doubts of processes and products that could not be clarified without its implementation, such as both the biodigestors and the biogas collection network that have known limits now, facilitating the replication. Certainly several results were below expectation because it was a pilot project, and there were some technologies that didn't' work as expected, needed to be replaced or adapted, such as sale of electric energy and new income for farmers.

For other condominium's implementation, it was suggested to invest in biomethane for urban mobility, mainly due to the good results presented in Haacke Farm project, evidencing that the economic benefits are more interesting for the producers. But for that, the volume of biogas production needs to be higher than the Ajuricaba.

With the experience and results of this first type of arrangement in the world, it will be possible to significantly improve processes and products for upcoming condominiums, reducing the costs for implementation, maintenance and operation. As one of the farmers said "someone has to start. If no one does a project like this, it will never be possible to bring together several producers and bring social, environmental and economic benefits to the community".

CONCLUSION

Through the case study of Ajuricaba Agroenergy Condominium for Family Agriculture, it was possible to conclude that the project achieved relevant environmental benefits to the local community and was considered satisfactory by the farmers.

The main indicators identified were: 87% of the farmers had their environmental problems solved thought the project implementation, mitigating water and air pollution and pathogenic vetors in their farms; 97% of the farmers use biofertilizer, increasing the land productivity, anticipating the harvest from 90 to 30 days, and promoting an annual saving of USD 600; 50% use the biogas stove, saving about USD 200 per year with LPG; 94% affirmed that the technical support was appropriate and the technicians were always available; 50% had their expectations met during the design, implementation and maintenance phase of the project; 88% will participate in the 2nd phase of the project; 88% recommend the agroenergy condominium to other neighborhood and 12% affirm that will recommend only if it is more profitable.

With the MICMAC analysis, it was determined that the key motivators for the farmer's participation in an agroenergy condominium are economic and solution for environemtal problems. So for other agroenergy condominium, it is essential to give a special care to both factors, since the project design.

In this type of cooperative initiative, it is fundamental that the participants have multiple motivations, to turn the arrangement less sensitive to rejections or renunciation. For example, if the farmers are concerned only with economic gains, any financial impact will result in the renunciation of most of them. If they also

have environmental or other concerns, this impact is mitigated, as they know they are having other benefits.

Another important feedback of the interviews is about a counterpart, even if small, of each producer, aiming at greater commitment to the process and to the biogas generation, improving the income for everyone and stimulating family farming.

Taking into account the SWOT analysis, some important considerations about the agroenergy condominiums were made by the engineers, technicians, and managers: this kind of cooperative project supports the mitigation of the problematic related to the increased demand for water-energy-food; strengthens family farming, attracting farmers and next generations to stay in the field due to the project; promotes cooperative work; generates new sources of income through biogas sale, biofertilizer and biomethane; stimulates the decentralization of energy generation; increases the energy security, endorses the implementation of sustainable solutions; reduces methane emissions and greenhouse gases; promotes the use of biomethane for urban mobility, between others. Furthermore, after this pilot project, this arrangement can be replicated at lower cost and with technologies already known and consolidated.

It was also emphasized that for the good performance of this arrangement, the management strategies must take into account the appropriate profile and vocation of the participants, such as type of production in farm and the farmer's willing in join and implement the project, aiming at prioritize committed farmers and enhance the results.

Finally, this research concludes that this kind of arrangement can bring environmental, social and economic benefits for local population and can be replicated in other areas and can also integrate rural and urban areas with the use of biomethane for mobility.

Geração de agroenergia coletiva na agricultura familiar: o estudo de caso do condomínio Ajuricaba no Brasil

RESUMO

Um dos desafios do setor de agronegócios no Brasil, o quarto maior produtor de alimentos do mundo, é avaliar a eficácia dos métodos participativos para converter dejetos animais em ativos econômicos. Nesse cenário, o biogás e o biometano se destacam como fontes renováveis de energia disponíveis em todos os países e seus usos podem induzir significativamente o desenvolvimento econômico local e regional. Este estudo apresentará um arranjo conhecido como condomínio agroenergético devido aos seus multi-serviços, como geração de energia por meio do biogás e biometano, biofertilizante e mitigação de emissões de gases do efeito estufa (GEE). As principais motivações dos agricultores para participarem do projeto foram identificadas por meio de entrevistas individuais e analisadas usando os métodos de análise MICMAC e SWOT. Os motivadores mais significativos foram os aspectos ambientais e econômicos, que demonstraram sua cidadania ambiental, e a variável menos influente foi a motivação social. Apesar dos desafios a serem superados, os resultados confirmam que esse arranjo pode trazer benefícios para a comunidade local, aumentar a segurança energética na região e contribuir para uma matriz energética mais limpa. Além disso, pode ser replicado a um custo menor e com tecnologias já conhecidas e consolidadas. Os resultados demonstram as implicações da interdisciplinaridade entre tecnologia, ambiente e sociedade.

PALAVRAS-CHAVE: Energia Renovável. Condomínio de Biogás. Biometano. Energia Rural.

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