BIOMETHANE FOR SUSTAINABLE URBAN MOBILITY IN BRAZIL AND THE U.S.: OPPORTUNITIES FOR URBAN MANAGEMENT AND CLIMATE CHANGE

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Abstract- The predictions of rapid economic growth, increasing population and urbanization by 2050 indicate an increasing water demand of 30%, requiring 45% more energy, and 60% more food. This research focused on a renewable source of energy, the biomethane generated from organic waste, and aims to present current and future perspectives of this source for Brazil and the United States. The implementation of condominial production of biomethane from livestock waste with application in urban mobility was assessed, based on the "farm to fuel" concept. This arrangement converts animal manure into electric, thermal, and vehicular energy use, and biofertilizer, providing multiple economic, environmental, and social benefits in rural and urban areas, such as reduction of ground and surface water pollution, decrease of fossil fuels dependence, mitigation of greenhousegases emissions (85% compared to diesel), among others. Biomethane can supply the total amount of diesel and gasoline imported in Brazil and 44% of the total diesel demand. The U.S. biomethane potential can replace 16% of diesel demand and significantly diversify the energy matrix, which is especially relevant considering that the U.S. has one of the highest power consumptions in the world. Besides that, the use of biomethane for urban mobility would avoid the emission of 28,423,983 kg CO2e per year in Brazil and 74,327,145 kg CO2e in the U.S.

Key words- biomethane, climate change, urban sustainable mobility.

I. INTRODUCTION

In a world of increasing urbanization, territorial management is rapidly becoming the focus of international efforts for sustainability. According to the World Urbanization Prospects report produced by the United Nations Department of Economic and Social Affairs (2014), only 10% of the world's population used to live in cities a hundred years ago. Today, this rate is of 54% and is likely to increase in the coming years, possibly reaching 66% by 2050. Urban population grew from 750 million in 1950 to 3.9 billion in 2014.

The Organization for Economic Co-operation and Development (OECD, 2011) estimates that by 2050, 86% of the population in developed countries and 67% of the people in developing countries will be living outside the countryside. This means that three-quarters of the world's population will occupy areas that are now covered by vegetation, devastating forests to create tiny spaces of survival or slums, using natural resources without restriction and dumping their waste on the soil. This scenario entails a dramatic boost in the demand for new infrastructures, with emphasis on urban mobility and an increase in the consumption of energy, water and food, also causing other problems related to social and cultural aspects, and implying a number of challenges to the public and the private spheres and to the citizens themselves.

According to the United Nations Environment Programme (UNEP, 2011), urban areas account for 75% of total waste generation and generate 60% to 80% of all greenhouse gas emissions, consume 75% of natural resources and account for two thirds of energy consumption. However, these areas occupy only 3% of the Earth's surface, all of which represents a considerable concentration of waste generation and energy consumption, having impacts not only on urban but also on rural areas.

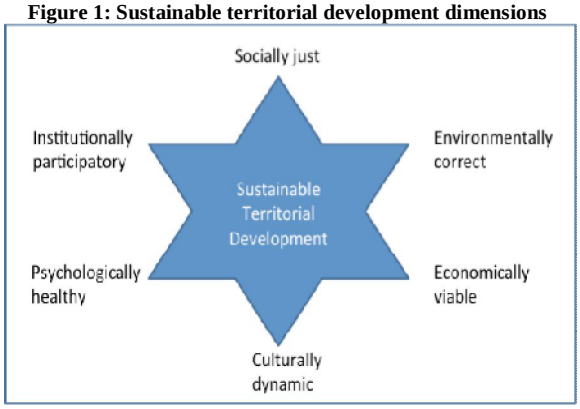
To accommodate this growing number of people, municipalities and local communities need to become more organized and sustainable, aiming at reducing poverty, ensuring education and health, managing and optimizing natural resources, protecting the environment and dealing with climate change. Based on an expanded understanding of sustainability, a number of dimensions are recognized as necessary for a sustainable territorial development process. The main dimensions are:

- "Socially just", proposing equal value of all the participants of a society, aiming at reducing social inequalities;
- "Environmentally correct", considering the ecosystem's ability to support receiving anthropic activities, while preserving its environmental functionality. It includes minimizing the waste generated and maximizing the treatment and its reuse;
- "Economically viable", involving the "internalization of externalities" or the consideration

and incorporation of the environmental and social costs of productive processes (SACHS, 2002);

- "Culturally dynamic", improving the links between people and the environment in which they live. It will appear as a direct consequence of the encounter of cultural practices and values in an open, evolutionary, very diverse scenario, aimed at improving the social bonds between its participants and these towards the environment that surrounds them;
- "Psychologically healthy", representing an important factor in the search for sustainability since it bases the individual and collective demands that as a rule are satisfied with the appropriation of goods and services that have direct or indirect effects on the matrix of natural resources; and finally,
- "Institutionally participatory", incorporating the need of all segments of society. For the effective democratic participation of the citizen in a community destiny, it is necessary to emerge from a passive condition to a condition of proactive action based on individual achievement and negotiation that seeks solutions to collective problems (BOLLMANN, BRACHT, 2006).

Figure 1: Sustainable territorial development dimensions



Source: the authors.

The OECD (2011) argues that sustainable growth is necessary because the challenges are increasing as population growth continues to deplete natural capital. If this is not taken into account, it will mean an increase in water scarcity, the strangling of natural resources, increased pollution, climate change and unrecoverable loss of biodiversity.

At this juncture, effective territorial management is necessary, contemplating both rural and urban areas in the search for integrated solutions to many global challenges. Initially, it will be presented an overview about the three axes that support the existence and survival of human life and are thus inseparable: water, energy and food.

Water is an essential natural resource for human life and is also an input for the production of agricultural goods in the fields and along the supply chain. Energy is needed to produce and distribute water and food: to pump water from underground sources or surface water, to propel tractors and irrigation machines, to process and transport goods, and to transport people. Food production is constantly under pressure to meet the increasing demand caused by population growth, needing to be concerned not only with the production, but also with the waste generated. These three axes are under constant pressure, as food, water and energy supply for all are priorities and human needs of the same greatness and complexity.

The water–energy–food nexus explores interfaces of multiple sectors across multiple scales, taking into account local, regional, and transboundary settings, "and the trade-offs and synergies created by competing resource use and policy agendas, requiring cross-sector and cross-scalar coordination and integration of resource management and environmental governance" (SCOTT et al., 2016, p. 15). The UN University (2014) points out that increasing food production in 50% by 2050 will require 45% more energy and 30% more water, which demonstrates that greater efficiency in energy production and use of other renewable sources other than water will be required.

Another challenge is how to secure energy for current and future generations, considering the unlimited and unsustainable increase in production and consumption of goods across the globe. According to the Brazilian Electric Energy Agency (ANEEL, 2010), the strong growth of energy consumption, while reflecting economic warming and improving quality of life, has some negative aspects: the possibility of a depletion of resources used for energy production, the environmental impact produced by this activity and high investments required in researching new sources and building new power plants. To mitigate these negative aspects, it is necessary to use renewable sources and alternative energy, which do not deplete existing natural resources and reduce environmental pollution.

In this scenario, biogas stands out as a systemic source of energy, being generated by the appropriate treatment of vegetable, animal, human and industrial waste, transforming environmental liabilities into economic assets through two main results: a direct one, by electric, thermal, and vehicular energy use (biomethane) and biofertilizers; and an indirect one, with the reduction of greenhouse gas emissions and, consequently, the mitigation of climate change.

Biogas is the source that most closely resembles hydraulic energy, since it can be stored and dispatched continuously – unlike solar and wind sources, which are characterized by intermittent input into the grid, and can also be purified and transformed into biomethane, which is similar to the Natural Gas Vehicule (NGV) and can be used as a substitute for fossil fuels for sustainable urban transportation. It emits 86% less CO2 if compared to gasoline (EUROPEAN COMISSION, 2013, p. 60). Biomethane is also known as "renewable natural gas". It is worth mentioning that the energy generated

by biogas and biomethane must be considered complementary and not exclusory to the other sources of energy, contributing to the diversification of the energy matrix.

In addition to promoting these environmental and economic benefits, biogas promotes local and social development, since the process for its production constitutes and sustains a relatively complex supply chain. It also requires specialized local labor, technical and scientific support, and awareness and empowerment of the local population related to the biogas and biomethane process of production and management.

The present paper analyzed the biogas and biomethane production potential in Brazil and in the United States, both of them sharing similar scenarios regarding the opportunities for using this source of energy: they are among the five countries with the largest population in the world and largest territorial extension (5^{th} and 3^{rd} position, respectively) (WORLD BANK, 2016), are leaders in food production (4^{th} and 3^{rd} place, respectively), representing 9% and 10% of all world production (FAO, 2014); they stand out for high energy consumption, with the 9^{th} and 2^{nd} positions (EIA, 2015), and occupy the 1^{st} and 2^{nd} places in highest availability of water in the world (CENTRAL INTELLIGENCE AGENCY, 2011).

These countries also have a representative agricultural sector, corresponding to 23% of Brazil's GDP in 2014, which greatly favors the development of technologies for biogas use, exploiting the waste generated by these activities and making the diversification of its energy matrix possible (MAPA, 2014). The utilization of the existing residual biomass in these countries can be carried out individually or collectively, with the association of several neighboring rural properties, named “condominiums” for agroenergy generation and commercialization. The collective agroenergy generation emerges as a way of making the implementation of projects in some localities feasible.

As an example, this research evaluated one of the projects being developed by Itaipu Binational, the International Center for Renewable Energy (CIBiogás) and the International Center for Hydroinformatics (CIH) in the Paraná Basin 3, located in the West of Paraná State- Brazil, named Ajuricaba Agroenergy Condominium for Family Agriculture. The project is the first in the world to comprise small rural properties in order to compose an agroenergy condominium. It was also taken into account the biomethane process implemented in Haacke Chicken Farm, which could benefit rural and urban through this renewable source of energy for mobility.

With the results obtained in these projects, it was possible to analyze the opportunities and benefits of a condominium model of agroenergy for sustainable territorial development, to demonstrate the integration of rural and urban areas trough the applicability of biomethane for sustainable urban mobility, and to evaluate the main strengths, weakenesses, opportunities, threats, and limitations for this arrangement implementation in Brazil and the United States.

RESULTS

The Ajuricaba Condominium is composed by 33 small properties, with areas between 10 ha and 20 hectares, which produce soybean, corn, wheat, 1,072 cattle and 3,082 pigs, generating approximately 821 m^3 of biogas per day and 16 thousand tons of waste/year. It has one digester installed in each property for waste degradation, and the producers can use the biogas directly in the properties to cook food or to heat water for cleaning dairy utensils, and the surplus is sent by pipeline (25 km) to a micro-thermal station.

The biogas generated can be converted into electrical energy, thermal energy (grain dryer) and vehicle power. Currently, the electric generation is of 350 kWh/day.

Another project that uses biomethane for mobility is Haacke Farm, located in Santa Helena, Paraná, Brazil, has 84,000 laying hens and 750 beef cattle, producing a total of 1,000 m3 of biogas per day, as a result of the manure generated and treated into an anaerobic system. The farm uses biogas to produce biomethane as vehicular energy and to generate electricity through a 112 kVA motor generator (without turbine). The onsite-generated electricity is used during peak hours when the cost of energy is higher. The farm also has a stand by system that guarantees the permanence of electric power in the cooling of the laying hens, avoiding sudden falls and consequent death of the animals.

The biogas generated in the digesters has a high energy potential, but it is considered a raw material, not a product. To get to the real and qualified biogas fuel potential, it is essential to upgrade it to obtain the biomethane, which was considered a fuel product whose potential can match the one from natural gas. For this aim, a refinery was installed in the property to perform the removal or reduction of compounds, such as H_2S, CO_2 and water vapor, promoting the increase of the calorific value and raising the concentration of methane on the biogas.

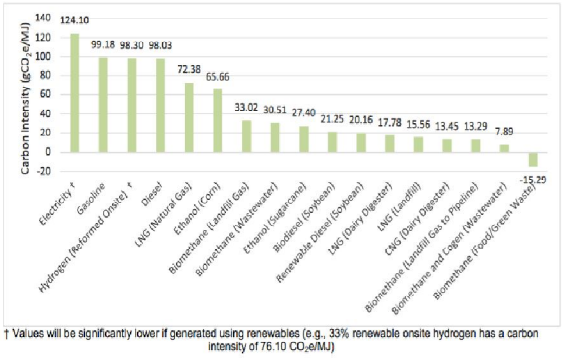
A partnership between Haacke Farm, Itaipu Binational and Scania, in one of the most modern buses in the world (Euro 6), used this biomethane to transport employees and visitors in Itaipu Binational and in some cars that originally operated with CNG. The bus carried 3,250 passengers in Itaipu complex, ran 3,000 km and consumed 745.58 m3 of biomethane, in 19 days of monitored tests. The average yield was 1.90 km/m3, number equivalent to the consumption of CNG and 40% more efficient than diesel. Furthermore, it avoided the emission of

100 tons of CO2 equivalent7 with a 70% reduction if compared to a diesel-powered bus. Another important advantage is the biomethane cost, as it is 56% lower than the diesel cost (CIBIOGAS, 2016).

This pilot project proved the connection between rural and urban areas, where the livestock waste are converted into biomethane and used for urban mobility.

Analyzing other sources of energy for urban transportation, it is possible to conclude that the lowest carbon intensity fuels are derived from biomethane, from 13 to -15 gCO2e/MJ, as represented in Figure 2.

Figure 2: Pathways and fuel carbon intensities



† Values will be significantly lower if generated using renewables (e.g., 33% renewable onsite hydrogen has a carbon intensity of 76.10 CO_2e/MJ)

Source: California Energy Commission, 2015.

An European Union (2014) study sustains that the biogas and biomethane greenhouse gas footprint have the lowest levels if compared to other renewable sources of energy for vehicular use. However, it can be adversely affected "if the residue after digestion is stored in the open air as it continues to produce methane". The most appropriate is to have a closed digester to methane storage and recovery.

Biomethane must be considered a complementary renewable fuel and the raw material for the digestion process (rural or urban waste) can be found in all the places and regions of the globe. If compared to the main fuels used for urban mobility, mainly buses (diesel, CNG, electric, hybrid-electric5), biomethane has some environmental and economic advantages, as presented below.

Table 1: Biomethane comparison to other fuels (considering urban buses)

Fuels	Diesel	CNG	Electric	Hybrid-Electric	Biomethane
Yield [1]	2.2 km/L [1]	1.8 km/Leq [2]	4.8 km/Leq [3]	3.7 km/Leq [4]	2.1 km/Leq [1]
CO_2 emissions (grams/km)	134 [5]	103 [5] 23% lower than diesel	20 [5] 85% lower than diesel	65 [4] 50% lower than diesel	20 [5] 85% lower than diesel
CO_2 emissions per passenger [5] (grams/person/km)	9	7	1	1	1

Sources: (1) CIBiogás, 2015. (2) Brazilian Association of Production Engineering - ABEPRO, 2016. (3) Brazilian Committee of the Regional Electric Integration Commission, 2016. (4) Volvo, 2017. (5) MOBILIZE, 2016a.

If compared to diesel, biomethane has a similar yield, emits 85% less CO2 to the atmosphere and avoid other pollutant emissions in its production chain, as it is produced from waste and manure that could not be properly treated if there were no biogas and biomethane production system. If compared to CNG, biomethane bus emits 80% less CO2.

Electric buses are often considered one of the cleanest vehicles for urban mobility, but it is important to take into account that the production of electricity is based in sources of energy that are not always clean and renewable.

Brazil and the U.S. have great potential for biomethane generation, mainly from livestock, as they are among the largest producers in the world. Taking into account that Brazil has a biomethane potential in livestock of 7,413.23 billion liters per year, it represents the replacement or complement of 6,302.85 million liters of diesel or 6,986.73 million liters of gasoline (Pasqual et al., 2017). This equivalence is presented in the following figure.

Figure 3: Equivalence of avoided GHG emissions with biomethane's use in Brazil.



Source: EPA- GHG calculator, 2017.

In the U.S. the biomethane potential in livestock is 19,385.10 billion liters per year, which is equivalent to 16,481.59 million liters of diesel or 18,458.84 million liters of gasoline. The country has one of the highest power consumptions in the world, so the diversification of the energy matrix is very relevant (Pasqual, Bollmann, & Scott, 2017). This equivalence is presented in figure 4.

Figure 4: Equivalence of avoided GHG emissions with biomethane's use in the U.S.



Source: EPA- GHG calculator, 2017.

CONCLUSION

The current pattern of mobility centered on individual motorized transportation is unsustainable in terms of both environmental protection and meeting the urban displacement needs that characterize modern urban life, so it is stimulated the use of public transportation and renewable sources of energy. Brazil and the United States' urban transportation are still highly dependent of fossil fuels. The main fuels used in Brazil are diesel (45%) and gasoline (29%), while in the U.S. they represent 25% and 59%, respectively. The transportation sector is responsible for issuing 42% of total CO_2 emissions associated with the Brazilian energy matrix, and 26% in the U.S.

One alternative to reduce the fossil fuels dependence and the GHG emissions in the urban transportation is increasing the use of renewable sources, such as biomethane, that has the lowest levels of GHG footprint if compared to other renewable sources of energy.

It has similar yield to a bus-powered diesel and emits about 85% less CO2. Besides being environmental friendly, it enhances fuel diversity and security of energy supply, can promote the improvement of local infrastructure and employment, generating employment in the rural areas, and can integrate rural and urban areas, as it can be generated from livestock and agriculture, for example, and fuel urban buses.

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