

URBAN PRUNING WASTE: CARBON FOOTPRINT ASSOCIATED WITH ENERGY GENERATION AND PROSPECTS FOR CLEAN DEVELOPMENT MECHANISMS

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ABSTRACT – Modern society experiences a progressive transition towards less harmful environmental behavior to foster sustainability. This study evaluated the carbon footprint associated with three types of urban pruning waste disposal: sanitary landfill (usual destination), generation of electricity, and generation of heat. A study case was carried out in the municipality of João Pessoa, Northeast Brazil. The Life Cycle Assessment methodology was applied to the material and energy inputs associated with each urban pruning waste disposal scenario, and the impact evaluation method selected was IPCC 2013 GWP 100y, which expresses environmental impact in terms of greenhouse gas emissions. From the analyses carried out herein, it was concluded that the current practice (sanitary landfilling) presented the highest carbon footprint within the studied scenarios. The best scenario was the utilization of urban pruning waste for the generation of electricity, which presented a negative carbon footprint (avoided emissions).

Keywords: Urban pruning, Life Cycle Assessment, Waste destination.

RESÍDUOS DA PODA URBANA: PEGADA DE CARBONO ASSOCIADA À GERAÇÃO DE ENERGIA E PERSPECTIVAS DE MECANISMOS DE DESENVOLVIMENTO LIMPO

RESUMO – A sociedade moderna passa por uma transição progressiva em direção a comportamentos ambientais menos prejudiciais, para promover a sustentabilidade. Este estudo avaliou a pegada de carbono associada a três formas de descarte aos resíduos de poda urbana: aterro sanitário (destino habitual), geração de eletricidade e geração de calor. O estudo de caso foi realizado na cidade de João Pessoa, Nordeste do Brasil. A metodologia de Avaliação de Ciclo de Vida foi aplicada aos insumos de materiais e energia associados a cada cenário de descarte de resíduo de poda urbana, e o método de avaliação de impacto selecionado foi o IPCC 2013 GWP 100^a, que expressa o impacto ambiental em termos de emissões de gases de efeito estufa. A partir das análises realizadas, concluiu-se que a prática atual (aterro sanitário) apresentou a maior pegada de carbono, dentro dos cenários estudados. O melhor cenário foi a utilização de resíduos de poda urbana para a geração de eletricidade, que apresentou uma pegada de carbono negativa (emissões evitadas).

Palavras-Chave: Poda urbana, Avaliação de Ciclo de Vida, Destino de resíduos.



1. INTRODUCTION

Municipal solid waste (MSW) originates from domestic activities and urban cleaning, and there are significant issues related to its composition, collection, transference, and disposal. Developing countries usually dispose of MSW in open dumps or landfills, but unfortunately, MSW can still be found scattered in empty lots. The situation in some developing countries can be exasperating due to insufficient financial resources and lack of infrastructure, among other reasons, and this causes environmental and health-related problems (Srivastava et al., 2015). In Brazil, 60% of cities still dispose of waste in non-regulated landfills due to the lack of appropriate policies (Leme et al., 2014), but Brazil's "new" national policy on solid waste (established in 2010) brings challenges and opportunities, setting the stage for opportunities and lessons to be learned (Jabbour et al. 2014). Brazilian Law 12.305/2010 Brazil (2010), effective in August 2014, prohibited the landfill disposal of any solid waste that could be reused, reducing the pressure on landfills while repurposing a valuable waste product (Neves et al. 2018).

Urban waste generation and management are still a critical global problem, and a frequently unrecognized environmental issue revolves around urban waste generation, especially in Brazilian cities (Jabbour et al. 2014). Waste composition is influenced by culture, economic development, climate, and energy sources; generally, MSW can be broadly classified into organic and inorganic (Hoorweg and Bhada-Tata, 2012). An effective strategy for the management and treatment of MSW should consider economic and environmental viewpoints simultaneously, whenever possible (Palacio et al., 2019).

According to Lyon and Bond (2014), the term "urban wood waste" can be utilized to describe either waste from wood products, municipal trees, or some combination – however, a universal definition does not exist and depends on the user. Herein the term "urban pruning waste" will be utilized to refer to urban tree and woody yard residues.

Urban pruning is the removal of branches, fruits, inflorescence or foliage, and urban pruning waste represents a significant portion of MSW (7-10% in Brazil, according to Brazilian National Environmental Sanitation Secretary [In Portuguese: *Secretaria*

Nacional de Saneamento Ambiental - SNSA] (2014), which are usually disposed of in landfills and open dumps, or incinerated. Urban pruning waste is usually transported in specific trucks to the landfill, separate from domestic garbage collection, and can entail high costs besides being a waste of energy resource, as it could be used by several industrial sectors (Kimemia and Annegarn, 2011; Gordon, 2017; Khudyakova et al., 2017). The disposal of urban pruning waste to a private landfill costs on average US\$ 22/tonne in Southeast Brazil, but could cost up to US\$ 63/tonne in Northeast Brazil (Meira 2010; João Pessoa 2016).

There are scarce local regulations on the management of urban pruning waste and removal of trees from urban afforestation in Brazil, becoming evident that most municipalities do not count with guidelines or responsibilities for the afforestation and pruning service. Inadequate disposal of MSW creates immediate impacts on the environment and public health and can contribute to climate change (Araújo et al. 2019; Unnikrishnan and Singh 2010). Significant potential impacts could occur during the decomposition stage, with potential contamination of soil and surface water and groundwater, formation of toxic gases, asphyxiants and explosives, and generation of greenhouse gases (GHG) - mainly methane (CH₄) (El-Fadel et al., 1997; Bovea et al. 2010; Cremiato et al., 2018). These potential environmental impacts can be quantified through the development of Life Cycle Assessments (LCA).

LCA is a methodology that evaluates the potential environmental impacts associated with a product, service or activity, throughout its life cycle, from the extraction of raw materials, including processing, manufacture, transportation, use and final disposal (Guinée 2002, Araújo et al., 2018; Coelho Junior et al., 2018). Improvements in a process can reduce adverse effects throughout its life cycle - which can influence positively, negatively (or both) the environmental performance of goods and services (Carvalho et al., 2016; Freire et al., 2016; Abrahão and Carvalho, 2018; Carvalho et al., 2019a; Carvalho et al., 2019b).

Cortez (2011) mentioned that there are scarce reports on the large-scale use of urban pruning waste (for energy purposes or not), and listed the reuse as firewood and charcoal production as disposal scenarios. The work of Morris et al. (2011) reviewed several final disposal scenarios for leaf waste at the

municipality of Red Deer (Canada) and concluded that landfilling with gas recovery for energy was preferable, rather than incineration for electricity production. However, the Environmental Protection Agency (EPA) of the United States highlighted variations in methane collection systems installed in landfills and the differences between technologies commercially available for the production of electricity from waste. A detailed guide for the calculation of landfill gas and verification of its technical liability for the production of electricity was reported by Chacartegui et al. (2015) and Nascimento et al. (2019). The results of the analyses can be significantly affected by these parameters (EPA, 2015). The Leaf and Yard Waste Diversion Technical Committee study Canada (2014) indicated that there were better options for urban pruning waste rather than landfill disposal (e.g., composting), mainly for economic reasons. However, environmental advantages include non-use of space (land use) and reduction of GHG emissions.

There are recent Brazilian studies focused on the viability of energy utilization of landfill gas (Medeiros et al., 2017; Oliveira et al., 2017; Silva et al., 2017; Pin et al., 2018; Santos et al., 2018) and some present considerations on CDM mechanisms (Crovador et al., 2016; Torres, Fermam, Sbragia, 2016; Cruz, Paulino, Paiva, 2017; Fernandez et al., 2017; Mori-Clement et al., 2019).

Recognizing the need more Brazilian studies regarding urban pruning waste management and possibilities of inclusion in Clean Development Mechanisms (CDM), this study evaluated the carbon footprint associated with three types of urban pruning waste disposal: sanitary landfill (Business-As-Usual, BAU), generation of electricity and generation of heat. A study case was carried out in the municipality of João Pessoa, Northeast Brazil.

2. MATERIALS AND METHODS

The Life Cycle Assessment (LCA) methodology is structured and standardized by the International Organization for Standardization (ISO), through ISO 14040 (2006) and ISO 14044 (2006). LCA collaborates to the analysis and interpretation of environmental impacts through the collection and compilation of inputs (production inputs), stages of production, consumption, and outputs of a product

system throughout its life cycle (ISO 14040, 2006). In Brazil, international LCA ISO standards have been translated by the Brazilian Association of Technical Standards (better known by its acronym in Portuguese: ABNT) through ABNT NBR 14040 (2014) and 14044 (2014).

LCA consists of four main interrelated stages (ISO 14040, 2006; ISO 14044, 2006): definition of purpose and scope of the analysis; inventory of the processes involved (definition of the inputs and outputs of the system); application of an environmental assessment method, and interpretation of results. More details on the LCA methodology can be found in Guinée (2002).

Urban pruning waste from the municipality of João Pessoa is collected by the Office of Urban Cleaning and Removal of Municipal Waste (In Portuguese: EMLUR) on weekdays and exceptionally, on weekends (emergencies). Waste is collected by exclusive, specific teams (without mixing with other types of waste), and taken to the Metropolitan Sanitary Landfill of João Pessoa. Once at the landfill, the waste is weighed and disposed of in waste cells.

Transportation covers the distance traveled by the collection truck: from the garage, throughout the collection route, to the landfill. The route traveled by the collection truck was recorded by the drivers (kilometers traveled).

The functional unit of the study, to which all inputs and outputs relate to, is the collection and transportation of urban pruning waste throughout one operational year. Figure 1 summarizes the transportation process included in the study, which is accounted for in terms of (tonne·kilometer). This means that not only the weight of the pruning waste is considered, but also the distance traveled. Then the final disposal method is applied to the functional unit, with the purpose of comparing landfilling, generation of heat, and generation of electricity.



Figure 1 – Processes included in the analysis.

Figura 1 – Processos incluídos na análise.

Software SimaPro 8.2.0.0 (2015) was utilized to carry out the environmental calculations, with the Ecoinvent v 3.2 (2015) database and the IPCC 2013 GWP 100y (IPCC, 2013) environmental assessment method, which quantifies the amount of GHG emitted, expressed in kilograms of carbon dioxide equivalent ($\text{kg CO}_2\text{-eq}$).

Urban Pruning Waste: Five processes were combined to express the variety of woody biomass present in general urban pruning waste (Ecoinvent, 2015): *Cleft timber, measured as dry mass; Bark chips, wet, measured as dry mass; Residual hardwood, wet; Residual softwood, wet; and wood chips and particles.* All processes follow the system model “Allocation at the point of substitution” (APOS system model), which follows the attributional approach where burdens are attributed proportionally to specific processes.

Transportation considered the route traveled during the collection of waste within the urban perimeter (approximately 35 km/day), and then the route to the landfill (approximately 25 km/day). For the sake of clarity, a mean value of 60 km is considered for the overall collection process. Also, for simplification purposes, it is considered that the annual amount of urban pruning waste collected is transported 60 km. Road transportation considered a 7.5-16 tonne truck was utilized (Ecoinvent, 2015), *Transport, freight, lorry 7.5-16 metric ton, EURO3.*

The final disposal scenarios selected included three options for urban pruning waste: disposal at landfill site (without methane management), incineration for electricity generation and incineration for heat generation.

Woody residues decompose slowly in landfills and release methane and carbon dioxide during the first 150 years. Approximately 20% will not decompose, remaining in the landfill as a stable material. The disposal of urban pruning waste in the landfill, without any collection of methane, is the current practice of the municipality. The inventory for this scenario includes the construction of the landfill itself and leachate treatment during the first 100 years. Waste decomposition after 100 years does not generate atmospheric emissions, because by this time the methane production phase is over and no landfill gas is produced.

Incineration for electricity generation considers the construction of the incinerator itself, deposition

of the ashes and all emissions, and consequent treatments for incineration of pruning waste. An average 2010 MSW incineration plant is considered (grate incinerator), with electrostatic precipitator for fly ash and wet flue gas scrubber. Gross electric efficiency technology mix is 15.84%. For electricity, 1.74 MJ/kg of pruning residue was considered (LHV = 13.99 MJ/kg pruning residue).

Incineration for recovery of heat includes the infrastructure (2014 state-of-the-art cogeneration plant, 6667 kW capacity and thermal efficiency 45%), the wood input, the emissions to air, and the disposal of the ashes. Also included are substances needed for operation: lubricating oil, organic chemicals, sodium chloride, chlorine, and decarbonized water. 3.49 MJ/kg of pruning residue was considered for heat generation.

The interpretation of the results was carried out by quantifying the carbon footprint ($\text{kg CO}_2\text{-eq}$) for 2008 regarding each proposed scenario. The carbon footprint per tonne of waste collected was also calculated to facilitate comparison with existing scientific literature. Carbon footprints were then accumulated throughout 13 years (2003 - 2015) for all scenarios for the verification of historical emissions.

3. RESULTS

Figure 2 shows the amount of urban pruning waste received by the Metropolitan Sanitary Landfill of João Pessoa between 2003 and 2015.

Source: João Pessoa, 2016.
Source: João Pessoa, 2016.

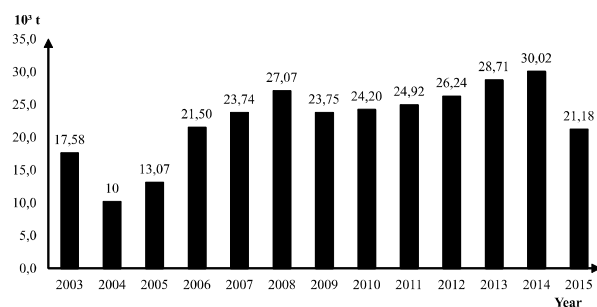


Figure 2 – Amount of urban pruning waste disposed at the Metropolitan Sanitary Landfill of João Pessoa, between 2003 and 2015.

Figura 2 – Quantidade de resíduos de poda urbana dispostos no Aterro Sanitário Metropolitano de João Pessoa, entre 2003 e 2015.

Figure 3 shows the carbon footprints associated with the three final scenarios for urban pruning waste in João Pessoa/PB, for 2008.

Table 1 shows the carbon footprint per tonne of processed urban pruning waste.

According to Figure 3 and Table 1, the use of urban pruning waste for the generation of electricity proved to be the best option, where the results indicate an overall negative balance.

Figure 4 shows the carbon footprint for urban pruning waste disposal scenarios (sanitary landfill/ incineration for electricity generation/incineration for heat generation), for the period 2003-2015, for João Pessoa/PB.

4. DISCUSSION

There is an obvious need for further research on how to maintain environmental quality while searching for energy alternatives to avoid pollution and minimize anthropogenic greenhouse effects.

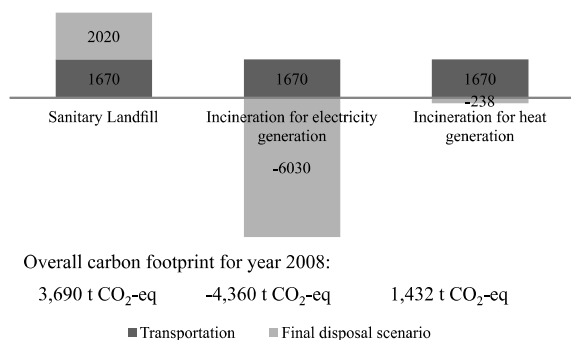


Figure 3 – Carbon footprint associated with different final disposal scenarios for urban pruning in 2008, in t CO₂-eq, for João Pessoa / PB.

Figura 3 – Pegada de carbono associada a diferentes cenários de disposição final da poda urbana em 2008, em t CO₂-eq, para João Pessoa / PB.

Table 1 – Carbon footprint per tonne (kg of CO₂-eq / t) of urban pruning waste in the city of João Pessoa, for each scenario studied.

Tabela 1 – Pegada de carbono por tonelada (kg de CO₂-eq / t) de resíduos da poda urbanos no município de João Pessoa, para cada cenário estudado.

Scenario	Carbon footprint (kg CO ₂ -eq/t collected waste)
Sanitary landfill	136
Electricity generation	-161
Heat generation	53

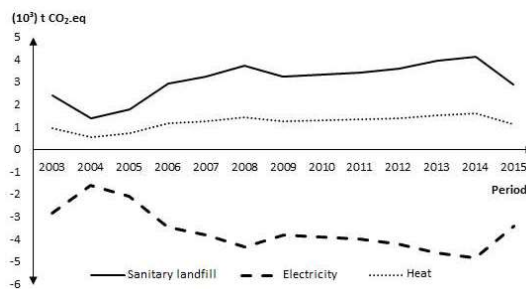


Figure 4 – Carbon footprint for urban pruning waste disposal scenarios (sanitary landfill/ incineration for electricity generation/incineration for heat generation), in the period 2003-2015, for João Pessoa / PB.

Figura 4 – Pegada de carbono para cenários de disposição de resíduos urbanos (aterro sanitário / incineração para geração de eletricidade / incineração para geração de calor), no período 2003-2015, para João Pessoa / PB.

Although Brazil does not have a binding commitment to reduce GHG emissions, it is interesting to verify which disposal alternative presents the highest or lowest carbon footprints, regarding urban pruning waste.

Figure 2 depicts an overall increase in the generation of urban pruning waste throughout time, which could be due to better efficiency of urban pruning waste collection by the municipality or due to an environmental consciousness of the population, who specifically requested the collection services for urban pruning waste.

According to Figure 3, the urban pruning waste that was deposited in the landfill was responsible for the highest carbon footprint. Incineration for electricity generation goes beyond incineration, also reducing the consumption of electricity from the power grid elsewhere (due to the consumption of this type of electricity, electricity from the grid is not consumed). This was the best result, with avoided emissions. These final avoided emissions indicate a possibility of climate change mitigation, as well as a possibility of incorporation within Clean Development Mechanisms (CDM). Regarding incineration for heat generation, this heat can be sold to industries or condominiums, or even used in internal processes of the landfill, avoiding the consumption of fossil fuels in boilers for this purpose. It was considered that the use of the heat prevented the generation of 9,450 MJ of heat from vegetal biomass elsewhere (avoiding the emission of 238 t CO₂-eq).

The steps of collecting and transporting urban pruning waste were common to all disposal scenarios. The scenario with the highest emissions was simple disposal in a landfill, the current practice of the municipality.

Analysis of Figure 4 reveals cumulative emissions of BAU totaling 39,826 t CO₂-eq throughout 13 years; these emissions were generated during the decomposition process of the waste by microorganisms. Comparison of BAU and the best practice highlights the fact that the city of João Pessoa employs a type of waste disposal with the highest carbon footprint. If all urban pruning waste collected between 2003 and 2015 in João Pessoa was used for the generation of electricity, it could have avoided the emission of 47,058 t CO₂-eq. It is herein demonstrated that appropriate waste management (in general) is essential to minimize risks to human health and environmental impacts. Urban pruning waste contains significant amounts of recoverable materials and can be used to generate energy, making waste management a high visibility, high impact target for the improvement of environmental sustainability. Mitigation strategies that affect the composition of the electricity mix, energy price, and greenhouse gas emissions can change the directions of current waste management (Levis and Barlaz, 2013). Urban pruning waste management systems must be adaptable and flexible to different compositions, public policies (not yet a reality in Brazil), and national systems for the production of electricity to guarantee the realization of economic benefits.

4.1 Urban pruning waste and Clean Development Mechanisms (CDM)

According to the United Nations - UN (2014), CDM “[...] allows a country with an emission-reduction or emission-limitation commitment under the Kyoto Protocol (Annex B Party) to implement an emission-reduction project in developing countries. Such projects can earn saleable certified emission reduction (CER) credits, each equivalent to one tonne of CO₂, which can be counted towards meeting Kyoto targets.”. CDM was established as one of the innovation mechanisms that also included Joint Implementation (JI) and Emissions Trading (ET), which was proposed by the Brazilian government during the discussions of the Conferences of the Parties. The proposal is based on

the premise that each tonne of CO₂ that is not emitted (or withdrawn from the atmosphere) by a country can be traded in the world market, attracting interest to the reduction of global emissions (Akinyele et al. 2014).

The contribution of CDM projects in Brazilian landfills covers the economic, environmental, and social areas, going beyond the reduction of GHG emissions and also improving MSW services. Local environmental sustainability can be directly influenced through the development of better working conditions and generation of jobs, in addition to technological advances and regional integration. Brazil presents a high potential for carbon credit generation in the landfill sector, including the municipal sanitary landfill of João Pessoa, which is a promising opportunity to promote local development by supporting the more appropriate management of solid urban wastes. In 2011, Brazil was the third country in the world (behind China and India) in terms of the number of CDM project activities, with 457 projects approved (corresponding to 393 Mt CO₂-eq reduction potential), with landfill projects representing 22.8% of the total CO₂-eq reduction potential (Maciel and Jucá, 2011). The study by Torres et al. (2011) gathered information on CDM projects approved in Brazil and listed by the Ministry of Science, Technology, and Innovation on its website. These authors verified a drop in the registration of new CDM projects, but landfill projects in the waste sector were identified as presenting the highest potential to be exploited in the country, being opportunities to enhance the participation within voluntary carbon markets in Brazil.

In the economic field, CDM projects contribute to the growth of the local economy, as several areas of society are influenced by the maintenance, technical assistance, and service sectors. It is worthwhile mentioning that the resources derived from carbon credit sales can be divided between the entrepreneur and the municipality. The carbon emission certificate market can be an essential source of resources and incentive for public authorities to invest in activities related to waste management, without compromising the environmental quality of the surroundings.

The last auction of gas emission certificates on the São Paulo stock exchange occurred in 2012, at US\$ 3.54/t CO₂ (BM&F Bovespa, 2012). Considering the 2012 urban pruning waste values, if the municipal landfill of João Pessoa counted with CDM, the sale

of carbon emission certificates would have accounted for almost US\$ 15,000. For municipalities that lack financial resources such as those in developing countries, the implementation of CDM is a way to raise funds and reduce dependency on National and State governments.

Collection of LFG is a viable tool for the implementation of CDM schemes, as its utilization for energy purposes does not require extensive adaptations of commercially available equipment - capital costs can be recovered faster, increasing the economic viability of the energy plant. From an environmental viewpoint, the most important benefit of collecting landfill gas (LFG) is the amount of avoided GHG emissions - a considerable share of emissions is due to methane (60% of landfill emissions), which presents a GWP 30,5 times higher than CO₂ (IPCC, 2013) - this means a higher generation of negotiable credits. According to BM&F Bovespa (2012), ongoing LFG recovery initiatives in Brazil could generate certified emission reductions (CERs) of approximately 2.3 MtCO₂ avoided/year. With potential revenue of US\$ 11.4 million/year, this value can be multiplied by five with technically feasible initiatives in the short and medium terms (Torres et al., 2011). The potential for carbon credit generation is very promising, constituting an opportunity to promote social and environmental sustainability, by supporting a better management of solid urban wastes.

Regarding the most environmentally friendly scenario considered herein (electricity production), it must be mentioned that projects aimed at utilizing solid waste for electricity generation often only consider the reduction of methane emissions through capture and flaring of gas. Most Brazilian landfills do not count with systems for recovery and flaring of methane, and therefore capture and distribution on its own already configures itself as a CDM project (Torres et al., 2011). The study of Pin and Barros (2017) verified that the economic feasibility of generating electricity from LFG was only achieved for those scenarios that fulfilled the microgeneration requirements of the Brazilian National Agency of Electricity (ANEEL, in Portuguese). This indicates the need for government incentives to reduce the costs of these projects and to incorporate more cities into the project, increasing the amount of waste available and therefore, the generation of LFG.

In projects aimed at increasing energy efficiency, the better use of electricity and the generation of electricity from renewable sources that is exported into the electric grid are the main topics. The emissions avoided determines the amount of CERs issued and the revenue realized from the sale of carbon credits provided by the project (Rovere et al., 2006).

The first project to implement a CDM scheme in Brazil was *Nova Gerar*, in Southeast Brazil, in 2001. The initial investment consisted of implementing a gas collection system along with a modular electricity generation plant (12 MW), to capture methane from the landfill and use it for the generation of electricity (Rovere et al., 2006). This project can avoid the emission of 14.07 Mt CO₂-eq⁻ throughout 21 years; others benefits include the mitigation of environmental impacts and social benefits such as better working conditions for those employed in waste collection and the creation of jobs (Souza and Ribeiro, 2009).

The Vega Bahia project is expected to avoid the emission of 14.5 Mt CO₂-eq in the period 2003-2019, with an average annual value of 0.653 MtCO₂ (Rovere et al., 2006). In the city of São Paulo (Southeast Brazil), the Municipal Environmental Office receives 50% of the CERs from the concessionary that implemented a CDM scheme for gas capture at two landfills, in addition to a monthly payment for the use of the area and exploitation of LFG (Pin and Barros, 2017). The benefits realized were destined to finance the planning of programs and projects in the area of rational and sustainable use of natural resources and for the control, defense and recovery of the environment and environmental education (Cruz, Paulino, Paiva, 2017). In 2007, the city of São Paulo raised US\$ 10 million with the sale of 808,450 CERs to the Belgian-Dutch bank Fortis, from a CDM project at a landfill. Between 2008 and 2009, the city received the equivalent of almost US\$ 20 million, corresponding to 50% of the sale of 1,521,450 RCEs. In 2008 alone, the municipality raised US\$ 14 million from the sale of CERs to the Swiss company Mercuria Energy Trading (Rizzi, 2011).

Extending the benefits realized with CDM schemes in São Paulo, the implementation of a CDM scheme in the municipal landfill of João Pessoa could originate financial benefits from the sale of CERs. If well directed and managed, the economic resources generated could be used in favor of society, with

environmental actions that improve the population's quality of life and social inclusion.

5. CONCLUSIONS

Based on the analysis, it was concluded that the current waste disposal practice (sanitary landfill) was the worst scenario, from an environmental viewpoint that considered greenhouse gas emissions. Landfilling presented the highest carbon footprint per tonne of urban pruning waste collected (136 kg CO₂-eq / t of urban pruning waste).

When urban pruning waste was utilized for the generation of electricity, an overall negative balance of greenhouse gas emissions was obtained, realizing the most environmental benefits. The utilization of urban pruning waste for the production of electricity demonstrated to be environmentally viable and can contribute to the sustainability of a city, and could even be used as carbon credits in an optimistic scenario. The implementation of Clean Development Mechanism schemes in the landfill for the better usage of urban pruning waste is one of the strategies for proper Municipal Solid Waste management - this can promote significant environmental, social and economic benefits.

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