LOGISTIC ANALYSIS OF THE USE OF CARNAÚBA EXTRACTION WASTE FOR CEMENT PRODUCTION

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ABSTRACT
This article analyzes the feasibility of reducing consumption of petroleum coke, raw material used to heat kilns for a cement production plant, by carnauba tree extraction waste. During this research, it is possible to recognize the spatial distribution of waste, the mapping of the production processes, economic analysis of some scenarios and a viability study of a facility using the p-median model. Exploration for co-processing can open up opportunities for improving activity, with the modernization of the sector. It was suggested that the crushed material should be sent directly to the factory in order to carry out co-processing. Although the production of briquettes is interesting for handling the material, the high investment is not justified, since the high demand manages to deal with the seasonal volume offered by the activity of carnauba wax production.

RESUMO
Este artigo analisa a viabilidade da substituição parcial do coque de petróleo, matéria prima utilizada no aquecimento dos fornos para produção de cimento, por resíduos da extração de carnaúba. Durante esta pesquisa, foi realizado o levantamento da distribuição espacial dos resíduos, foram mapeados processos produtivos, análise econômica de cenários e um estudo de viabilidade de um local de suporte usando um modelo de localização de centros. A exploração para o coprocessamento pode abrir oportunidades para a melhoria da atividade, com a modernização do setor. Foi sugerido o envio direto do material triturado para a planta a fim de realizar-se o coprocessamento. Apesar da produção de briquetes ser interessante para o manuseio do material, o alto investimento não justifica-se, uma vez que a alta demanda consegue lidar com o volume sazonal ofertado pela atividade de exploração cera da carnaúba.

1. INTRODUCTION

Changes in the environment have become more and more present to everybody. Business sustainability has been a subject frequently discussed worldwide. That importance was recognized when United Nations (UN) released a guide for sustainable corporations (UN, 2014), this guide leads the sustainable organizations to develop 5 features:

- To be lined up with the principles of Human rights, Labour, Environment, and Anti-corruption;
- To have a protagonist and collaborative action with other institutions in order to mitigate not only local but also, global challenges;
- Leadership commitment to reach solid long term results;
- Transparency in business practice;
- Sustainability development with a local lens.

Companies are currently giving large attention to socio-environmental activities, once used to prioritize orders winning standards that are presented as basement, financial and productive isolated features. More and more, the relationship with stakeholders is being an important factor, such as the impact of their results and the environment where they are involved (UN, 2014). Researching the maximum possible use of renewable resources and reducing the use of nonrenewable ones, Almeida *et al.* (2020) measure impact of different scenarios, in terms of sustainability and productivity, involving the integrated management of the residues.

These activities may result in mutual benefits, both for the society and the companies, having as a bond, sustainability. The companies tend to contribute to the aggravation of Ambiental problems. Common problems can be exemplified as the generation and improper disposal of waste such as smoke and soot, noise, competition for certain resources (such as water), heating, etc.

When it comes to cement production, through these activities of co-processing, the utilization of residues produced in its own region for heat generation, it's an interesting alternative to mitigate externalities created by Apodi cement production in Quixeré. Another immediate benefit is the reduction of pet coke consumption, the cement industry consumes a large amount of this material. Therefore, the substitution of pet coke usage by carnauba wax waste on co-processing should have a relevant vantage such as job creation, reduction of gas emission, reduction of fossil fuel consumption (both coke and diesel to transport it over long distances).

The selected materials for study was the carnauba extraction process, considering that this waste can be plentifully found in the regions near the cement company Apodi, where these waste could be burned. During this research, several analyzes were made, although just a few were selected in order to compose this article (some of them were not included because of non disclosure terms, some analyses have restricted information of the company).

Accordingly, this present paper does a logistical analysis of the use of carnaúba extraction waste to be burned on Apodi factory kilns in Quixeré. Showing economic viability and softening the impacts on nature through the reduction of fossil fuel burning. Another indirect result of the removal of the waste from the farms, so acres of useful land will be cleaned for the next year and reduce the material amount used for intentional fires in the region.

In this document, we present a brief review to cement production (section 2.1) and carnauba extraction (section 2.2). Were also analyzed costs and benefits from both scenarios and features such as briquettes size, vehicles involved, potential transshipment points and changes in the current carnauba cutting process (section 4).

This article adopts the following structure, a introduction, presenting several important matters in order familiarize with this study, followed by a methodology that exposes all the methods and procedures that were used during the article. Posteriorly, it is discussed the execution and validation of this study, by presenting the analysis of the spatial offer distribution and the addition of a facility location. Lastly, the conclusion points out the suggestions that might be accepted as well as the consequences to the proposed scenarios.

2. THEORETICAL REVIEW

2.1. Cement production process and co-processing

According to Chrysostomou *et al* (2011), the process of cement production is made by following ten phases (as seen in figure 1), which begins extracting the main inputs from the mines such as limestone and clay. After being transported and smashed, this material is pre homogenized and it is called clay-limestone, which has an average proportion of 80% limestone and 20% clay. As this material goes through the mixture, a stock will be created waiting for the employee with the stone crusher, where the material decreases to improve efficiency on the next phase – milling. This phase does the milling of the material that does not attend the size requirements, transforming the material in a fine flour that varies according to the standard of each industry, this resulting material goes through a second stocking process.

Therefore, the material enters in a heating tower, passing through four phases, following an average temperature of 45ºC, on the first stage, and approximately 900ºC on the fourth stage.

In this last temperature, the material is prepared to be clinker and will enter the kiln right after being cooked by a flame that can reach a temperature of 2000ºC. After the cooking process, the material is stored in an environment that allows it to lower its temperature.

After this process, a second grinding is carried out, where the final materials that will define the type of cement will be manufactured and added to the clinker. The produced material is the cement ready for consumption by the final customer, passing through a preliminary process of storage, packaging, and transportation.

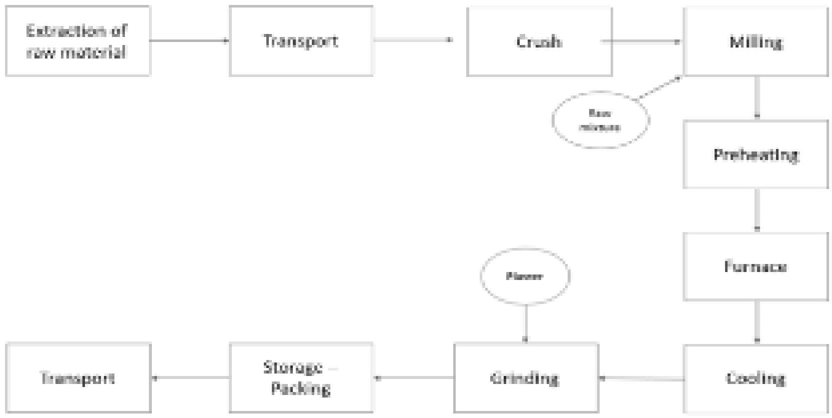


Figure 1: Cement manufacturing steps
Source: adaptation of Chrysostomou *et al* (2015).

In Quixeré, the fuel used for the production of the clinker is petroleum coke (fuel nonrenewable), this fuel keeps the kiln running throughout the whole period necessary for the transformation of the raw material into clinker. In this factory, it is possible to find a modern system for co-processing solid waste, so that materials previously destined for dumps can be used for heat generation.

However, the utilization of these alternative materials, in general, finds some difficulties such as: hard to reach places, non-unitization, lack of adequate handling infrastructures, vehicles not adapted to each material, the volume generated at each location, the geographic dispersion of material generators, lack of legislation on the use of some materials. These and other issues hinder the direct large-scale use of these materials in cement kilns, requiring a specific project so that each material has an appropriate treatment, therefore, it needs to have an integration in the supply chain so that the waste can be used efficiently. It is necessary that the different partners involved with each material adjust their operations in order to make feasible the usage of these alternative materials.

2.2. Carnauba extraction process

This study focuses its attention on the chain until the final stage of this processing that takes place in Brazil with the production of carnauba wax. Thus, as can be seen in Figure 2, the chain starts in the cutting activity, with a work team formed in general by five people. In this team, each person has a defined function and with specific remuneration, consistent with each defined function, normally organized in the functions of removing leaves from the plant, small cuts to prepare the leaves, catch the leaves, grouping the leaves, and transport.

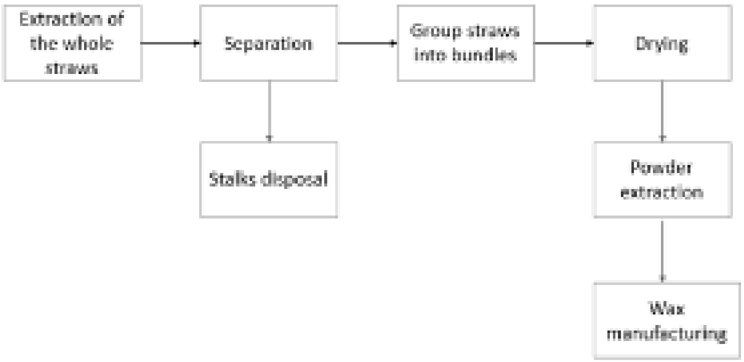


Figure 2: Mapping the production process of carnauba powder extraction
Source: Author

The ways of drying influence directly on the yield of the powder and consequently on the wax, since most rudimentary have a lower yield (see yield in table 1). The drying method will also vary according to the financial conditions of the owner and the availability of physical spaces and equipment. Also there are few solar dryers equipment, that, despite simple manufacture (iron and plastic structures), there are no suppliers and people to provide maintenance.

Table 1: Drying process and yield of one million straw from the carnauba tree.

Specification	Types of straw drying			
	Unity	Beaten floor	Shipyard	Solar dryer
Powder production	Kg	5,5	6,3	7.2
Wax yield	Kg	3,5	4	6,6
Yield	%	64	74	92

Source: Adaptation ADECE (2009).

As for the dust extraction process, in general, there is only one machine, which serves the producers of a community, thus, the person responsible for this processing usually schedules the processing of dry straw so that everyone is attended. The Figure 3, shows a contextualization at the state level of carnauba productivity, emphasizing the importance of this economy to the state as a whole. Finally, it should be noted that the study took place in the Jaguaribe Valley region, the place responsible for the following production volume:

- 20.81 million straws;
- 4,786 tons of stalks;
- 50 thousand cubic meters of crushed material.

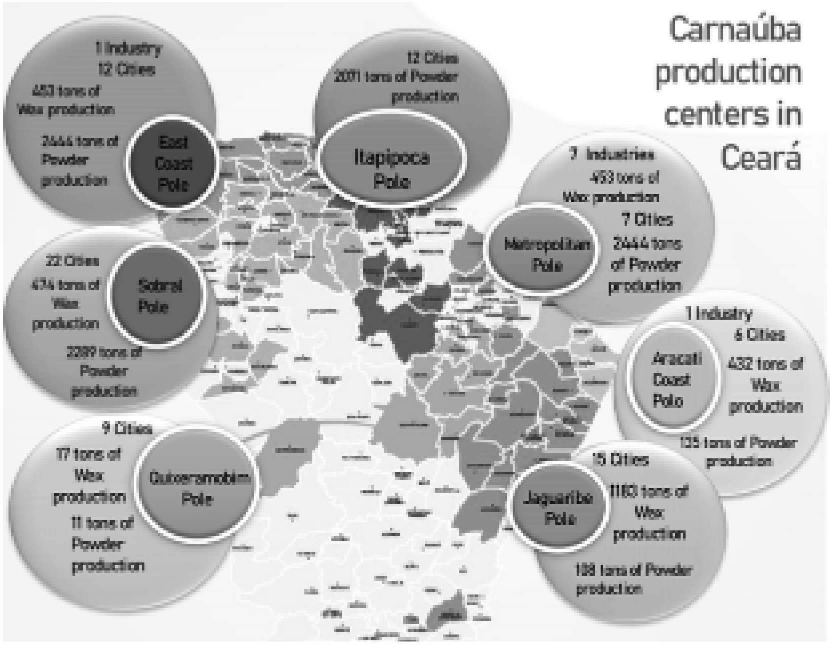


Figure 3: Carnauba production areas in Ceará.
Source: Adapted from ADECE (2009).

3. METHODOLOGY

Analyzing both the feasibility of co-processing waste from the carnauba in cement kilns and the logistical costs of this process. Figure 4 illustrates the methodology used in this work. The characteristics of materials was obtained from Lima *et al*. (2019), the authors analyzed these residues, describing calorific and volumetric characteristics necessary for this research (this information was essential for the economic analysis presented in section 4.4).

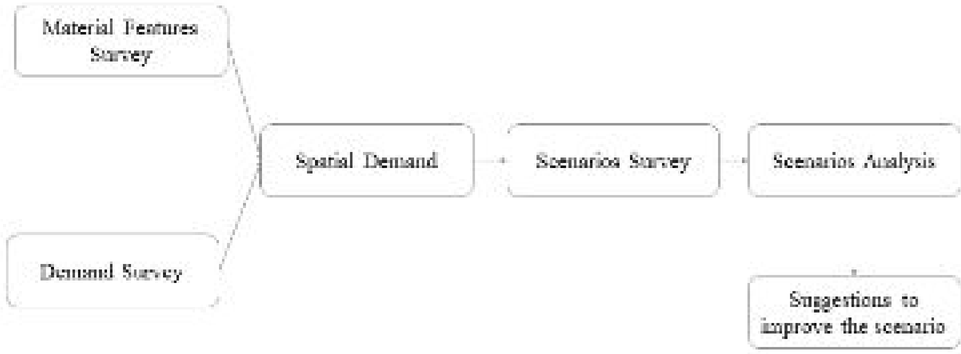


Figure 4: Methods and procedures.
Source: Authors.

For the next activity, "Scenarios Propositions", alternatives were sought in order to propose solutions for the production chain, the proposals took into account the impacts generated for both producers, factories and other important players in the chain. The identified scenarios analyzed the use of equipment, labor, process changes and the use of facility locations. Finally, some of the scenarios discussed in section 4.2 are:

- The use of briquettes, making the briquette in an intermediate location that reduce the *in natura* stalks dislocation distances;
- Shredding the *in loco* material and sending it directly to the factory.

Were investigated the positioning facility location and strategic locations for the reduction of travel distances, where infrastructure can be designed to acquire equipment strategically positioned. For the positioning of these points, the p-median location model was used (BALLOU, 2009), based on the distance between the points, this model proposes the designation of the producing places to each facility location, in order to reduce the distance traveled between visiting places and the factory.

Finally, in section 4.4, the economic analysis was made in order to observe the amount of material offered, transportation costs, acquisition of raw material, equipment, labor work, among other relevant aspects. To finalize the proposed methodology, it was presented a prospecting financial line (section 4.4), concluding the recommendations from the analyzed scenarios, always under the auspices of sustainability.

4. RESULTS ANALYSIS

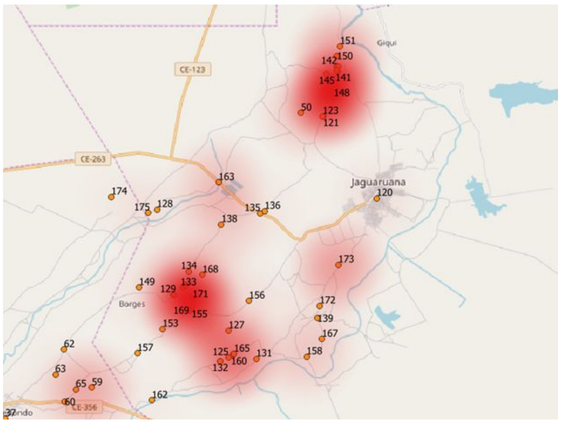
In order to execute and validate this feasibility study, several aspects must be explored, such as the calorific power of the waste, the need for new machinery and/or equipment for its processing, who will be the suppliers of the material, the location of the intermediate displacement points, the estimate of the production of artisans. The feasibility analysis of the project is of paramount importance, once this project requires decisions that involve high financial investments, which will have an impact on the planning of the acquisition of coke. Thus, it is necessary to analyze this project from the perspective of sustainability, analyzing the economic, environmental and social impacts, observing the processes of purchasing the material, transport to the factory, storage, and burning.

In order to achieve the premises of this study, a partnership of three work teams was built, Center of Technology and Industrial Quality of Ceará – NUTEC (Núcleo de Tecnologia e Qualidade Industrial do Ceará), carnauba Memorial (located in the city of Jaguaruana) and Federal University of Ceara – UFC (Universidade Federal do Ceará) – Campus Russas. Every team assigned responsibility to the study. The carnauba Memorial held the mapping of the carnauba producers in the region, assisting in visits for data collection and with pieces of information about the production chain functioning, making intermediation between producers and UFC Campus Russas. NUTEC was responsible for carrying out the tests that resulted in the analysis of calorific components of the carnauba residues and specify the types of equipment required for the manufacture of briquettes, crushing and physical characterization of the material. Finally, when it comes to financial, social and logistical analysis, the UFC Campus Russas took responsibility to identify and analyze the most interesting scenario for this operation.

The inception study carried out a survey of opportunities for the observed improvements, deepened the analysis of three components: materials, equipment, and processes. For the generation of possible scenarios, factors such as material travel costs, material processing costs, machinery purchase costs and labor involved were considered. The project aims to indicate the most promising scenario for everyone involved, observing the environmental and economic features.

4.1. Survey and Spatial Offer Distribution

The following figures illustrate the location of all extraction points considered in this study as well as the places of greatest production, through map heat (the redder the greater the production).



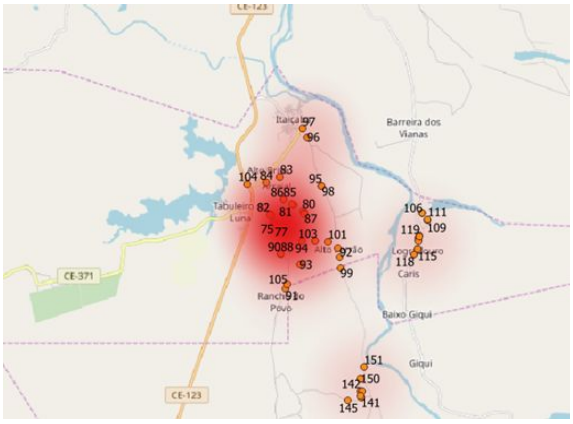


Figure 5: Heat map of extraction sites in Itaiçaba. **Figure 6**: Heat map of extraction
sites in Jaguaruana. **Source**: Author.
Source: Author.

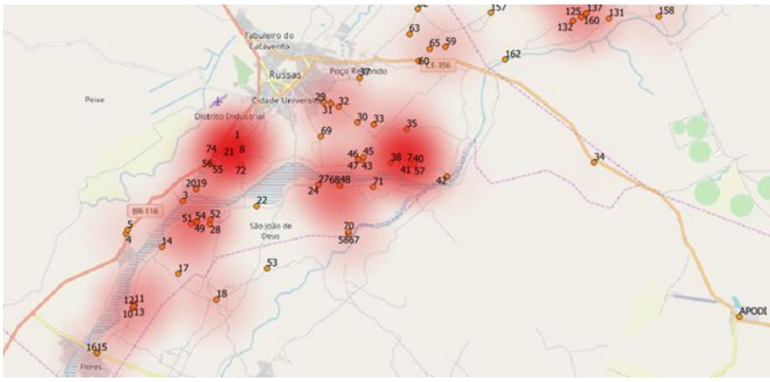


Figure 7: Heat map of extraction sites in Russas.
Source: Author.

4.2. Scenario Proposition

4.2.1 Materials

Petroleum coke, the main fuel used in cement companies, is obtained from the processing of liquid fractions in Delayed Coking Units – UCR (Unidades De Coqueamento Retardado). It is a material with a high fixed carbon content composed of hydrocarbons and low levels of inorganic compounds. In addition, the material has a low sulfur content, is chemically stable, that is, it is not explosive, and is still insoluble in water, reducing the risks of transportation.

In cement industries, a high amount of pet coke is required to keep the kilns functioning, therefore, the environmental impacts, even if reduced compared to other means, exist significantly, which drives the search for alternative forms of fuels.

It was noticed that some materials, available in the regions close to the company, could be used for burning in the kilns, such as carnauba residues (mainly stalks), which are not used in the manufacture of wax. These materials can be used crushed or in briquettes.

The residues from the cut of the carnauba are, in short, stalks left on the ground where the cut took place and the straw that remains after the dust is removed. Straws are used for handicrafts or as fertilizer for the soil, while the stalks have no processing, so they are unused waste. From studies carried out by NUTEC (Center for Technology and Industrial Quality of Ceará) on the calorific power of the residues from the cut of the carnauba, it was seen that the use of it as fuel for cement kilns is feasible. In order to improve the use of waste and facilitate its handling in general, it was decided to use the material in the form of briquettes or benefited by a shredder.

According to the study carried out by NUTEC, it was found that the residues extracted from carnauba, like *in natura* straw, has a calorific value of 17.51 MJ/kg and the stalk has 17.29 MJ/kg of calorific value. Regarding the straw density, there was an increase from 2.98 (*in natura*) to 12.78 kJ/cm3 (briquette), while the stalk had a variation from 2.89 (*in natura*) to 11.33 kJ/cm3 (briquette). Besides that, it was found that the mechanical strength of the materials is satisfactory for the process. With these results, the NUTEC study can conclude that the residues from carnauba have energetic potential to be used as fuel in cement companies.

4.2.2. Equipment
Aiming at the best use of residues, it was observed that the most efficient way in relation to the performance of the material to be used as fuel is in the structure of briquettes or crushed, requiring the use of specific machinery such as briquette machine and crushers, responsible for leaving the material in the appropriate format.

For this study, the specified machinery was: i) A fixed briquette machine of 2 tons/hour, with an acquisition value of R $ 1.1 million; ii) Mobile crushers, with a capacity of 20m3/h, with an acquisition value of R$215 thousand, these crushers are mobile, being coupled to vehicles to be sent to the locations where these residues are present.

In addition to this equipment, support for the modernization of the chain is understood as fundamental, so that the different phases of the productive activity can make use of equipment/techniques that already exist in order to increase efficiency in the sector.

After choosing how the materials will be used in the processing, it is necessary to choose the transport vehicles destined for the movement of this residue to the factory. According to a study carried out by the logistics sector of Apodi Quixeré, the use of trucks was recommended Trucks (14t) or LS Carts (28t). LS carts are justified only in situations of large volumes. The proposal is to have trucks in a dedicated operation – shared analysis of the operation was not considered at the first moment due to the complexity of this operation.

4.2.3. Processes
From the present study, it was seen the need to adapt the current carnauba cutting process in order to make it possible to collect its residues. Then, based on the current process, a new carnauba cutting process was suggested, adding a stage of collecting the discarded stalks, grouping them in bundles and, after crushing, transporting them to the factory in order to manufacture the briquettes. If the briquettes are not produced, the crushed material goes directly to the co-processing stage. The suggested process can be seen more clearly in Figure 8.

This process minimizes the impact of the proposed changes in the way the workers operate today, thus, it is expected to reduce barriers for the implementation of the necessary adjustments for cooperative work. It is expected that only one new person will be added to the teams going to the farm and that this person will be responsible for organizing the stalks in bundles and transporting them to areas of easier access.

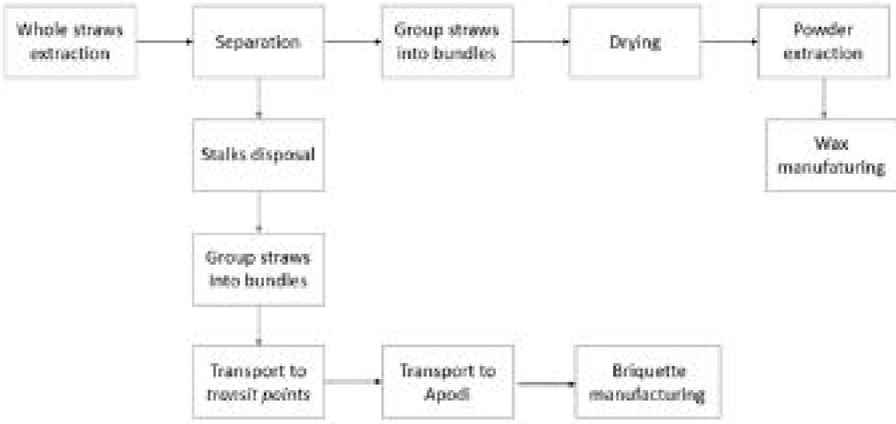


Figure 8: Proposed process for the reuse of waste in coprocessing.
Source: Authors.

4.3. Facility locations

For identify the best place for the facility locations, a Linear Programming Model “p-median” was used, which according to Beasley (1985), aims to find P facilities (p-medians) in a network with N demand of clients, with the purpose to minimize the total distance value from each client to its facility with the nearest median (see equation 1). For each demand client, the sum of the parcel of demand assigned to each facility has to be equal 1 (see equation 2). The equation 3 defines the quantity of clients that have to be selected as facilities. By the end, equation 4 ensures that a facility has to be selected before being assigned to a client. Therefore, the model shows its efficiency for the present study, once the desire is to reduce the distance traveled between the visiting places and the factory. The model used is defined as:

$$min\ Z = \sum_{i \in N} \sum_{j \in N} d_{ij} * h_i * Y_{ij} \tag{1}$$

$$\sum_{j \in N} Y_{ij} = 1, \ \forall i \in N \tag{2}$$

$$\sum_{j \in N} X_j = P \tag{3}$$

$$Y_{ij} - X_j \leq 0 \ \forall i \in N, \forall j \in N \tag{4}$$

$$X_j \in \{0, 1\} \ \forall j \in N \tag{5}$$

$$Y_{ij} \geq 0 \ \forall i \in N, \forall j \in N \tag{6}$$

where: N = set of places with demand associated
h_i = demand on place i
P = quantity of facilities to be located (1 to 5 facility locations will be tested)
d_{ij} = distance between demand i and facility j
X_j = 1 if there is an facility was selected and 0 if not
Y_{ij} = fraction of demand i that is met by facility j

The current model analyzed the waste production that exists in the nodes (extraction farms). In the study, models with up to 5 facilities were tested, however, due the high acquisition costs of support equipment, only the model with 1 facility was considered. To calculate the distances between the demand *i* and the facility *j* were considered many routes (obtained from Open Street Maps and a QGis version 3.10 software). The model was solved in ILOG CPLEX 2019 software, finding which farms would be attended by which facilities.

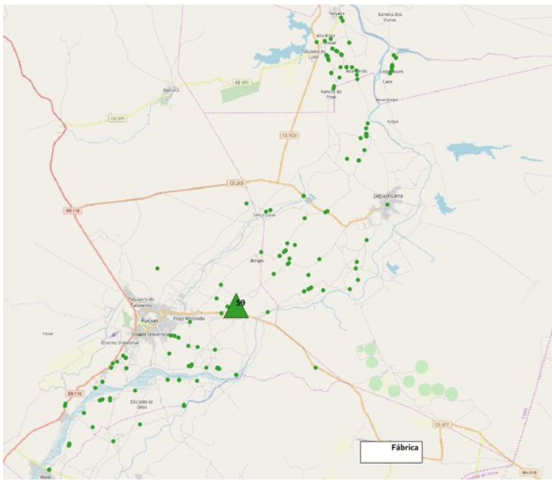


Figure 9: Facility location in case of a single facility (in the case of the briquette machine, this is the ideal location considering the distances). **Source**: Authors.

4.4. Economic Analysis

The economic analyzes can be seen in tables 3 and 4, these tables highlight the calculations made in order to compare the scenarios using briquettes or direct use of crushed material. The scenarios comparison are made in relation to the energy cost (measured in reais per Gcal), comparing the use of coke (which costs 52 R$/Gcal) with the use of carnauba in briquette and with the use of crushed carnauba. It is observed that the costs related to the manufacture of briquettes are high (46.4 R$/Gcal), not justifying the investment, since the direct use of crushed material costs (R$ 37.15 R$/Gcal).

Table 3: Catcher costs of the use of carnauba in briquette and the use of crushed carnauba.

Calculation of Catcher Personnel	Value	Unity
Payment to the catcher	15	R$/thousand
Weight of a thousand stalks	0.23	T
Thousands per ton	4.3478	thousand/t
Final cost with catcher	65.2174	R$/t

Source: Authors.

As can be seen in the tables, direct remuneration to farmers was not initially indicated, it is understood that this variable needs to be studied and negotiated with them and this question must be left out of this analysis. Although, It is important to emphasize that farmers already have a direct gain with the cleaning of the land, which facilitates the extraction in the following years.

In addition, this cleaning can be seen as an economic gain from the moment that they will not have to bear this cost. The briquette construction scenario still has a high initial investment, most part of this investment is given to the purchase of machinery (1.1 million), while the cost of mobile machines for large crushing (20m3/h) cost approximately 215 thousand BRL.

Table 4: Economic analysis of the use of carnauba in briquette and the use of crushed carnauba.

Final financial analysis	Carnauba in Briquette	Crushed Carnauba	Unity
Catcher staff	R$ 65.220	R$65.220	R$/t
Stalks crushing	R$ 0.000	R$45.440	R$/t
Briquette transport	R$ 38.000	R$0.000	R$/t
Briquette Production	R$ 59.390	R$0.000	R$/t
Factory transportation	R$ 38.000	R$38.000	R$/t
Calorific value	4.323	4.001	Gcal/t
Final cost	R$46.404	R$37.155	R$/Gcal

Source: Authors.

5. CONCLUSION

The precarious condition that outsourced workers face when extracting straw is one of the factors that makes the activity unattractive, lined up with low profitability, the absence of support equipment and few policies aimed at training employees.

It is clear that administrative, sustainable and cooperative approaches can result in a closer relationship between stakeholders, through the perception of engagement with income generation and preservation of culture. Along with the development of partnership programs with the Memorial of Carnaúba, promoting events for the communities, courses and cultural presentations in order to strengthen the relationship with the producing communities.

Exploration for co-processing can open up opportunities for improving activity, with the modernization of the sector. The carnauba chain has a strong relationship with the identity of Ceará and nowadays is threatened. The rescue of this chain can add a lot of value to the company's image.

This study did not analyze the environmental gains. However, it is important to understand that there are concrete impacts when it comes to the environment. Here is a list of some examples of these impacts:

- Reduction in the emission of gases emitted by the factory, this gain comes from the direct replacement of fossil fuel;
- Reduction of a susceptible burning material in the farms;
- Increase in gas emissions by vehicles transporting carnauba (negative impact);
- Reduction in the purchase and consequent emission of gases by vehicles transporting coke;
- Cleaning in the carnauba exploration land.

Finally, it is suggested that the crushed material be sent directly to the factory in order to carry out co-processing. Although the production of briquettes is interesting for handling the material, the high investment is not justified, since the high demand manages to deal with the seasonal volume offered by the activity of carnauba.

The use of urban pruning has great potential, however, this was not the object of the analyzes present in this study. In addition, the burning of invasive plants (such as the lion's mouth) can also contribute to the eradication of this problem.

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