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Abstract: In this study, the objective is to analyze the economic viability of municipal household solid waste (organic matter + paper) for the production of gas, coke and biofuel through the pyrolysis and distillation process. The waste was collected in the city of Belém do Pará-Brazil and pre-treated at UFPA. The analyzed fraction (organic matter + paper) was subjected to pre-treatment of drying, crushing, sieving and was subsequently subjected to proximate characterization and finally pyrolysis of the organic fraction (organic matter + paper) in a fixed bed reactor. Initially, it was necessary to review the literature and with the yields obtained by pyrolysis of the fraction, economic feasibility analyzes were carried out. The economic indicators for evaluating the most viable pyrolysis process were: simple payback, discounted payback, net present value (NPV), internal rate of return (IRR), and profitability index (IL). The analysis of the indicators showed the economic viability considering an analysis horizon of 10 years, of materials based on organic material and paper. The break-even point obtained was 0.96 US$/L and the minimum biofuel sales price (MFSP – "Minimum Fuel Sale Price") obtained in this work was 1.30 US$/L. The sensitivity analysis demonstrated that material costs (organic matter + paper), bio-oil yield, total project investment and electricity, respectively, are the variables that most affect the minimum biofuel sales price (MFSP).

Keywords: municipal household solid waste; pyrolysis; biofuels; economic analysis; technical feasibility

1. Introduction

The production of urban solid waste (MSW) has increased exponentially over the years, taking into account this growth, public policies, laws, federal and international agreements such as the Kyoto Protocol, the Paris agreement and more recently the Sustainable Development Goals. (SDGs) established by the United Nations (UN), emerged to establish criteria and limits for a previously unrestrained generation. The increase in waste generation and inadequate management from production to final disposal have generated numerous problems for society. Problem that affects the global scenario, aggravated by inadequate material management, generating negative impacts at a social, environmental, economic and even public health level [1,2].

According to the current consumer goods production scenario, MSW production will increase worldwide and is estimated to reach 3.4 billion tons by 2050, mainly due to population growth, increasing average incomes and accelerating urbanization rates [3,4].

Solid waste management affects everyone, but those who are most compromised by the negative impacts of poor management of this service are, in most cases, the most vulnerable in society. The dominant development model traditionally follows a linear economic approach, called extract, produce and suppress. Efforts to optimize linear management practices are generally limited to the R's of sustainability (rethink, reject, reduce, reuse and recycle), without considering the great potential to maximize the value of solid waste [5].

Opposing the traditional approach, which still eliminates waste in an environmentally inappropriate way, we present the circular economy, which seeks to maximize the value of using materials through the creation of a closed-loop economy. In other words, it is a regenerative system that minimizes resource input and waste by slowing, closing and narrowing the cycle, and this can be achieved through maintenance, repair, reuse, recovery and recycling of materials [6,7].

Opposing the traditional approach, which still eliminates waste in an environmentally inappropriate way, we present the circular economy, which seeks to maximize the value of using materials through the creation of a closed-loop economy. In other words, it is a regenerative system that minimizes resource input and waste by slowing, closing and narrowing the cycle, and this can be achieved through maintenance, repair, reuse, recovery and recycling of materials [8].

All this reflection coincides with a new concept of urban planning that has emerged in recent decades, which proposes a change in models of spatial, social and environmental organization, which are "sustainable cities", also called "green cities" or "smart green cities". Urban waste management is a fundamental factor in this new urban vision, but unless these new paradigms are enshrined in legislation, they will drive real changes in urban planning. Little progress will be made towards the recommended sustainable management [9].

With these changes in mind, the National Solid Waste Policy (PNRS) was sanctioned in Brazil, created by law 12.305/10 to regulate the management of urban waste in Brazil. This law is very broad, with modern concepts, including shared product life cycle and reverse logistics. It places responsibility on producers and government agencies for the production and proper disposal of waste. However, even after its introduction, challenges remain significant. Many municipalities do not comply with the requirements, especially when it comes to eliminating open dumps [10].

Among the many factors that impede these adjustments, one of them is the high costs of environmentally appropriate management of this waste. Currently, municipalities have limited budgetary resources and municipal accounts are difficult to balance [11].

In Brazil, MSW management is the third expense item in the budget of a medium-sized municipality, and may correspond to the main expense in municipalities with a maximum of 50 thousand inhabitants [12].

In addition to the strong demand for public resources necessary for solid waste management, the economic situation of Brazilian municipalities stands out. Low capacity to generate own revenue to finance administrative structures and services together with high budgetary rigor, considered a situation of structural financial crisis [13].

However, solutions must be discussed and implemented to mitigate the factors that hinder the adequate management of urban solid waste. We know that implementing correct management is not an easy task, as it involves multiple social actors, whether they are individuals or legal entities, public or private, who are directly or indirectly responsible for the solutions [14], and of course, the need to understand some definitions contained in the PNRS, are fundamental for a better basis in decision-making, as mentioned *in verbis* (article 3 of the PNRS):

"VII - environmentally appropriate final destination: waste destination that includes reuse, recycling, COMPOSTING, RECOVERY AND ENERGY USE or other destinations admitted by the competent bodies of Sisnama, SNVS and Suasa, including final disposal, observing specific operational standards in order to avoid damage or risks to public health and safety and to minimize adverse environmental impacts;

VIII - environmentally appropriate final disposal: orderly distribution of WASTE in landfills, observing specific operational standards in order to avoid damage or risks to public health and safety and minimize adverse environmental impacts;

XV - waste: solid waste that, after exhausting all possibilities of treatment and recovery using AVAILABLE AND ECONOMICALLY VIABLE TECHNOLOGICAL PROCESSES, does not present any other possibility than environmentally appropriate final disposal;

XVI - solid waste: discarded material, substance, object or good resulting from human activities in society, whose final disposal is carried out, is proposed to be carried out or is obliged to be carried out, in solid or semi-solid states, as well as gases contained in containers and liquids whose particularities make their release into the public sewage system or bodies of water unfeasible, or require solutions that are technically or economically unfeasible in the face of the best available technology;"

Based on the definitions of solid waste, rejects, final destination and final disposal, the PNRS clearly states that any new treatment system implemented must meet the basic process guidelines before final disposal of the waste. This basic sequence can be described as follows: All waste must be reused and/or treated and only waste from these processes can be deposited in landfills. It is important to respect the criteria defined by the PNRS to become a final destination and ensure greater reintegration of waste into the production system, always respecting the technical feasibility and economic and financial viability of the projects [15].

Among the technologies available for the adequate treatment and transformation of urban solid waste, we have biological, physical-chemical and thermal treatment, and pyrolysis, as a thermal treatment, has great potential not only for the thermochemical transformation of fractions such as residual biomass, polymers thermoplastics, plastics (hard, soft), cardboard, recycled paper, non-recycled paper and organic materials, but also for MSW, and the literature includes numerous studies on the subject. The advantages of pyrolysis over bioprocesses and other thermochemical processes include the production of liquid fuels and charcoal, a solid phase with adsorbent properties, the production of non-condensable gases with combustion properties, and the process occurs at moderate ambient temperature and pressure [16–18].

In this scenario, the present work analyzed the economic viability of producing biofuels (bio-oil, bio-coal and gas), by pyrolysis and catalytic thermal cracking of the fraction (organic matter + paper) of municipal household solid waste (MSW) from the Municipality of Belém-Pará-Brazil.

Recently, some work has been carried out to evaluate the economic viability of producing biofuels from the most diverse types of waste through the pyrolysis process. A summary of the latest works cited in the literature are listed below.

In [19] a plant was developed for technical and environmental assessment of the use of pyrolysis in the treatment of hospital waste (RSS) in the city of Lindo Horizonte. Productivity 3000 liters RSS per cycle. The evaluation process showed several benefits in waste management, such as mass reduction of 46.75–58.77%, use of low-cost supplementary fuel (biomass) in wastewater treatment plants. From an economic point of view, it seems possible to produce bio-oil from pyrolysis to be sold at prices similar to mineral oils. This possibility is accentuated if comparatively large installations are used and if it is possible to sell the bio-oil at a price lower than that of distilled fuel oil, but higher than the price of residual fuel oil. In January 2017, the ideal price would be between US$1.119 and US$2.632 per liter.

Already in [20] the thermal treatment of solid hospital waste (RSH) using a pyrolysis catalyst resulted in an oil content of 67.5% by weight, a density of 0.82 kg/L and a viscosity of 2318 mm^2/s. These characteristics allow it to be used as a fuel in thermal processes or to create electrical energy in internal combustion engines. The production result expressed in money was verified with an economic balance comparing the two income-generating alternatives. The final balance (result of revenue subtracted from operating costs) from the sale of oil was estimated at 3968.58 R$/t

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(corresponding to 2678.79 R$/t RSH). Revenue from the sale of electrical energy was calculated taking as a reference the sales value of MWhe of electrical energy produced from a renewable source (combustion of sugarcane bagasse). In this case, the revenue from the sale of electricity was calculated at R$ 2896.94 R$/t (corresponding to 1955.43 R$/t of RSH). Consequently, oil sales are economically more attractive than electricity sales, as they provide higher revenues than electricity sales, of 1071.64 R$/t, that is, 723.36 R$/t of RSH.

In [21], it can be concluded that the slow pyrolysis process using urban solid waste (MSW) offers many advantages not only for the city of Mossoró, but also for other forms of treatment and use in environmental and economic terms, which applies most Brazilian municipalities. The aforementioned municipality served as a basis for making an approximate estimate of the financial gains with the possible installation of a pyrolysis plant capable of processing 30% of the MSW generated per day, receiving R$ 3941586.0 per year from the sale of energy and biofuels. coal produced, saving approximately R$5623393.50 over the plant's 25-year useful life.

This study [22] estimates the energy efficiency product costs and environmental impacts of biomass pyrolysis oil using life cycle assessment (LCA). As a case study, a factory with annual production of 10.000 t was selected that uses Cryptomeria (Japanese cedar) as a raw material. The results show that production occupies the majority of the biomass oil life cycle, regardless of input costs, energy consumption or environmental impact. Pyrolysis oil costs approximately 9.74 U$$/L (including bio-char) and the selling price (assuming 17% corporate income tax and 7% internal rate of return) is 19.6% higher than that of an equivalent amount of energy from low sulfur fuel oil. The ratio of output energy to input energy is approximately 13.2 (including biochar) or 7.3 (not including biochar), which indicates the high energy efficiency of pyrolysis oil.

The aim of this research [23] is to systematically study the economic analysis of the thermal catalysis process of crude palm oil (CPO) and palm oil neutralization sludge (PONS). The yields of biofuels produced by fractional distillation were also presented. Analysis of the main factors/indicators using the CPO and PONS thermocatalytic process shows economic viability for both crude palm oil (*Elaeis guineensis*, Jacq) and palm oil neutralization sludge. The minimum fuel selling price (MFSP) obtained in this work for biofuels was 1.59 US$/L using crude palm oil (CPO) and 1.34 US$/L residual neutralization of palm oil (RNOP). The best balance point obtained was 1.24 US$ /L considering the RNOP.

In the economic situation at the end of 2019 and the first half of 2020, the production of bio-oil from the three proposed biomasses is technically and economically viable. The raw material that has been most interesting is sugarcane bagasse, as it is the most economical raw material. The multifunctional plant developed in this study had an installation cost of approximately US$31.40 million and was shown to be capable of handling these and other biomasses with chemical and biological properties similar to those of the present study. Considering the raw materials considered in this process individually or a mixture of them, the annual production cost remains between US$ 18.53 million and US$ 80.49 million. In Scenarios 1 (conservative) and 2 (optimistic), the possibility of circularity between raw materials is presented. The project is viable for 20 years of operation, followed by 3 years of construction. In both situations, these plants are more profitable than investing in fixed assets with a minimum attractiveness of 25%. The internal rate of return (IRR) of scenario 1 was 68% per year, and the internal rate of return (IRR) of scenario 2 was 98% per year. The payback time in Scenario 1 was 4.43 years, considering three years of construction, and in Scenario 2 this time would be reduced to 3.74 years, which is a very good result [24].

We chose coconut biomass due to the large amount of residual biomass in the state of Alagoas. 33906.0 tons of biomass were constructed with an energy potential of approximately 60800.0 MJ. The energy obtained from the pyrolysis of coconut biomass is significant considering that the fresh mesocarp biomass containing higher calorific value (PCS) is 17.466 MJ Kg^{-1} will produce biochar with PCS of 26,587 MJ kg^{-1} pyrolysis at 400 °C and PCS 27.020 can be obtained by pyrolysis at 600 °C. Coming from the natural biomass of the endocarp with a PCS of 19,401 MJ kg^{-1}, a biochar with a PCS of 31.062 MJ kg^{-1} obtained by pyrolysis at 400 °C and a biochar with a PCS of 32.403 MJ kg^{-1} obtained by pyrolysis at 600 °C . The best performance obtained 56.38% of bio-oil by pyrolysis of the endocarp at a temperature of 600 °C. Therefore, the best performance and highest PCS were obtained at a temperature of 600 °C. Energy gains can reach 4.841 MJ kg^{-1}. The evaluation results with a profit of 6%, NPV of R$ 268710.0 and positive IRR of 17.10% suggest viability of the investment [25].

Going beyond the technical conclusions, compared to the viability of the urban solid waste treatment unit, the two models investigated, both the slow rotation drum pyrolysis unit and the pyrolytic gasification unit, are viable. The main thing would be for the municipalities to compensate for the treatment of their waste (which already happens today) and the value of R$ 196.48 which the current value makes viable and, in addition, profitable for the facilities to be installed. This leads us to believe that there is a very interesting scope for the private sector to enter this area strongly, because there is achievable profitability and with very robust values. Another scenario would be to consider a public investment where the municipality would have to bear the initial value of the unit and a minimum value per ton for the projects to be viable, in the case of the 141 t/d unit it would be 133.00 R$ /t while a 120 t/d factory R$/t/day would be 88.00 R$/t [26].

Activated carbon is very important in the adsorption process in wastewater treatment plants. In particular, malt bagasse, a residue from the brewing industry, can be used to obtain charcoal, which has been applied on an industrial scale to remove drugs from aqueous systems, due to its removal potential. To determine the minimum selling price of coal per kilogram, I used a literature analysis focusing on net present value and internal rate of return, with pre-determined assumptions. An analysis of a charcoal production unit from a brewery (on-site) and a bagasse and charcoal supply company (off-site) resulted in an on-site selling price of 1.78 US$/kg and 1.84 US $/kg for external products, both confirmed the economic viability of the project. Furthermore, with an annual production of 108 tons of coal, you can pay your costs with a minimum selling price of US$1.78, generating a return of 9% [27].

Even though previous projects developed to evaluate the economic viability of producing biofuels from waste through the pyrolysis process presented positive results, the innovation of this study is the demonstration of the economic viability for the production of bio-oil from the organic fraction (organic matter + paper) of municipal household solid waste, based on economic indicators: simple payback, discounted payback, net present value, internal rate of return and profitability index, with the aim of analyzing the viability of the project. A sensitivity analysis was used to evaluate bio-oil sales prices, to measure the economic impact of varying the parameters used in the project analysis, such as: initial investment, costs, expenses and revenues.

2. Materials and Methods

2.1. Materials

2.1.1. Organic fraction (organic matter + paper)

The organic matter, a mixture of carbohydrates, lipids, proteins, fibers and paper, selected from urban solid waste (MSW) from the Municipality of Belém-Pará-Brazil, was submitted to pre-treatment (drying, crushing, sieving) and conditioned in freezer to avoid physical-chemical and microbiological degradation, as described in the literature [28] (Figure 1).

The dry fraction was crushed and sieved (organic matter + paper) and was subsequently subjected to proximate characterization [28].

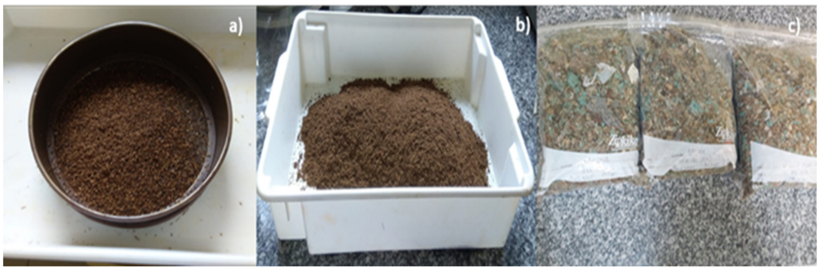

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Figure 1. Pre-treated organic matter + paper used as raw material by thermal processing in laboratory scale. Organic matter after crushing and sieving retained on a 12 mesh sieve (a), mixed organic matter after sieving with 4, 6, 12 and 14 mesh (b), organic matter + paper after drying/crushing/sieving packed in plastic bags (c) [28].

2.2. Pyrolysis of Materials

By pyrolysis of the pre-treated solid mixture of organic matter + paper, coming from municipal solid waste (MSW) from the Municipality of Belém-Pará-Brazil, they were treated in detail by [28]. Bio-oil yield increases with pyrolysis temperature as more energy is available to promote the fragmentation of strong organic chemical bonds (Table 1).

Table 1. Process parameters, mass balances and yields of reaction products (liquids, solids, H2O and gas) by thermocatalytic cracking of the fraction (organic matter + paper) at 475 °C, 1.0 atm, 5.0, 10.0 and 15.0% (by weight) Ca(OH)2, on a laboratory scale [28].

Process parameters	**475 (°C)**			
	0.0 (wt.)	**5.0 (wt.)**	**10.0 (wt.)**	**15.0 (wt.)**
Mass of the organic fraction of municipal solid waste (g)	50.49	40.0	40.0	40.0
Cracking time (min)	70	75	70	70
Initial cracking temperature (°C)	318	220	206	268
Mass of solids (Coke) (kg)	17.82	14.11	13.56	12.16
Mass of liquid (Bio-oil) (kg)	4.75	2.21	2.27	3.16
Mass of H2O (kg)	14.43	14.15	13.72	13.73
Gas mass (kg)	13.49	9.53	10.45	10.95
Bio-oil yield (by weight)	**9.41**	5.52	5.67	7.90
H2O yield (by weight)	28.58	35.37	34.30	34.32
Coke Yield (by weight)	**35.29**	35.27	33.90	30.40
Gas Yield (in weight)	**26.72**	23.82	26.12	27.37

2.3. Gerenciamento e os Critérios de Avaliação de Projetos

Project management is the application of knowledge, skills, tools, and technicians to project activities to meet project needs. Project management is carried out through the application and integration of the following project management processes: initiation, planning, execution, monitoring and control, and closure [29].

Therefore, for a better understanding of the project management process and the assessment of economic viability, a biofuel production flow through thermal processing of pre-treated material (organic + paper) was created, shown in Figure 2.

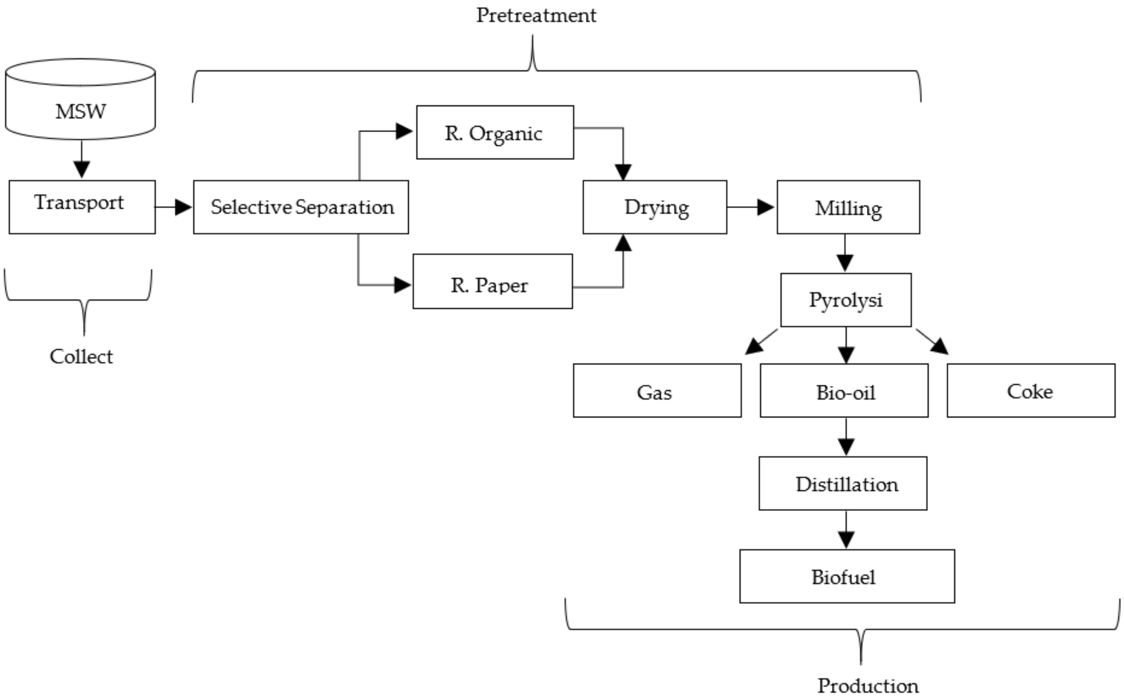

Figure 2. Steps for converting organic material + paper into biofuel.

Making a decision on the conception, design and evaluation of an industrial project requires some economic criteria [30]. The most effective way is to simulate the investment according to some decision-making indicators or economic models, as described in details by Amaral et al. [31], such as *Simple Payback [31–33], Discounted Payback [30,31], Net Present Value (NPV) [30–34], Internal Rate of Return (IRR) [31]*, and *Profitability Index (IL)* [31,33–35]. In this way, the cash flows generated with the investment made are compared. In addition, the calculation methodology, taking into account the main decision-making indicators, must be proposed and/or constructed for each particular case, as described by Amaral et al. [31].

2.4. Calculation Methodology

All data used to calculate feasibility for decision-making on project viability are listed in Table 2.

Table 2. Data used to calculate economic viability indicators.

Process Parameters	Value	Unit	Reference
M = is the mass of organic material + paper	2.610	Kg/ day	author
Nsh = number of shifts per day	3	-	author
d = density of organic material + paper	1.213	Kg/L	[36]
$Y_{bio\text{-}oil}$ = yield of the bio-oil pyrolysis process	9.41	%	[28]
Y_{coke} = material coke yield in the pyrolysis process	35.29	%	[28]
P_{coke} = price of coke	0.224	US$/kg	[31]
d_{coke} = coke density	$1*10^{-3}$	Kg/L	[31]

Y_{gas} = yield of methane gas from the material's pyrolysis process	2672	%	[28]
P_{LPG} = price of liquefied petroleum gas	0.275	US$/L	[37]
d_{gas} = density of methane gas	$0.72*10^{-3}$	Kg/L	[31]
$Y_{d,bio\text{-}oil}$ = yield of the material distillate process	60	%	author
P_{RM} = raw material price of the material	0.1953	US$/kg	[38]
P_{sieve} = power of the sieve equipment	0.7457	KW	[39]
t_{sieve} = sieving time per day	2	h	author
N_{sieve} = number of sieving batches per day	2	-	author
P_{KWh} = price of KWh	0.2186	US$/KWh	[40]
P_{dry} = drying equipment power	3	KW	[41]
t_{dry} = drying time per day	24	h	author
N_{dry}= number of drying batches per day	5	-	author
P_{crus} = power of crusher equipment	11	KW	[42]
t_{crus}= crusher time per day	1	h	author
N_{crus}= number of crusher batches per day	1	-	author
m_{LPG} = percentage of liquefied petroleum gas in relation to the feed rate	10	%	[43]
C_m = labor cost in thirty days	2343.7	US$/month	author
P_{KWd} = distillation column power	5	KW	[31]
t_d = distillation operating time during one day	24	h	author
$N_{dest.}$ = number of distillation batches per day	2	-	author
$\%T$ = tax percentage	10	%	[31]
SP_{bio} = selling price of biofuels produced with organic material + paper	1.30	US$/L	author

The data mentioned in Table 1 are parameters used to calculate all possible expenses and revenues necessary for the production of bio-oil, gas and bio-char from organic waste + paper.

Expenses and income such as Feed, Organic Liquid Product (PLO), Solid Product (Coke), Gaseous Product (Biogas), Distillate Biofuel, Raw Material Cost, Liquefied Petroleum Gas (LPG), Cost of Manpower, Distillation, Taxes and Profit Margin were treated in details by Amaral et al. [31], with the following new computation being included in this work:

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2.4.1. Sieving

$$C_{sieve} = \frac{(P_{sieve} * t_{sieve} * N_{sieve} * P_{kwh})}{(D_{bio} + m_{coke} + m_{gas})} \quad (1)$$

C_{sieve} = sieving cost [US$/L]; P_{sieve} = power of the sieve equipment [KW]; t_{sieve} = sieving time per day [h]; N_{sieve} = number of sieving batches per day [-]; and P_{KWh} = price of KWh [US$/KWh].

2.4.2. Drying

$$C_{dry} = \frac{(P_{dry} * t_{dry} * N_{dry} * P_{kwh})}{(D_{bio} + m_{coke} + m_{gas})} \quad (2)$$

C_{dry} = drying cost [US$/L]; P_{dry} = drying equipment power [KW]; t_{dry} = drying time per day [h]; N_{dry} = number of drying batches per day [-]; and P_{KWh} = price of KWh [US$/KWh].

2.4.3. Crusher

$$C_{crus} = \frac{(P_{crus} * t_{crus} * N_{crus} * P_{kwh})}{(D_{bio} + m_{coke} + m_{gas})} \quad (3)$$

C_{crus} = crusher cost [US$/L]; P_{crus} = power of the grinding equipment in [KW]; t_{crus} = grinding time per day [h]; N_{crus} = number of grinding batches per day [-]; and P_{kwh} = price of KWh in [US$/KWh].

3. Results

Table 3 presents the economic parameters for discounted cash flow analysis. The project's total investment was US$ 334552.77 (three hundred and thirty-four thousand five hundred and fifty-two dollars and seventy-seven cents) and corresponds to the initial cash flow investment, based on price survey data obtained for each equipment used, as well as other expenses.

Table 3. Economic parameters for discounted cash flow analysis.

Lifespan	10	years
Plant Size/Feeding Rate	2610	kg/ day
Discount rate	10	% per year
Financing	100	% own capital
Depreciation	-	% per year
Investment recovery period	10	years
Taxes	10	%
Start-up	-	months
Raw material cost	0.1953	US$ / kg
Plant availability	87.5	%
Plant operating time	7665	h
Reference year	2023	
Electricity price	0.2186	US$ / KWh
Total equipment cost (CTE)	112793.25	US$
Direct costs (include installation of equipment, instrumentation and control, piping, electricity and buildings)	68803.88	US$ (61% CTE)
Total equipment installation cost (CTIE)	181597.13	US$ (61% CTE + CTE)

Storage	2723.96	US$ (1,5% CTIE)
Space construction - warehouse	8171.87	US$ (4,5% CTIE)
Total installation cost (CTI)	192492.96	US$ (CTIE + warehouse + space development)
Field Indirect Costs (CI)		
- Field expenses	38498.59	US$ (20% CTI)
- Offices and building fees	48123.24	US$ (25% CTI)
- Contingency	5774.79	US$ (3% CTI)
- Prominent costs	19249.30	US$ (10% CTI)
Total Capital Investments (ITC)	304138.88	US$ (CTI + CI)
Other costs (start-up, licenses, etc.)	30413.89	US$ (10% ITC)
Total project investment (ITP)	334552.77	US$ (ITC+ other costs)

Table 4 presents the total revenue, total expenses and annual profit of US$ 68063.00 (sixty-eight thousand sixty-three dollars). The minimum fuel sales price (MFSP) obtained in this work for biofuels was 1.30 US$/L. The literature cited in this work presents values from 1.11 to 9.74 (US$/L).

Table 4. Income and expenses from the use of organic material and paper computed using the equation described elsewhere [31].

Revenues		
Feed_87.50 % (Availability)_Cracking (1)	2151.69	L/ day_d=1.213 kg/m³
PLO product / bio-oil_9.41 % (2)	202.47	L/ day_Fre. distillation
Solid product (coke)_35.29 % (3)	170.55	US$/day
Gaseous Product (biogas)_26.72 % (4)	11.23	US$/day
Biofuel Product Distillation_60% (5)	121.5	US$/day
Sale price (6)	1.30	US$/L
Total expenses (7) = (8)+(9)+(10)+(11)+(12)+(13)+(14)+(15)	1.24	US$/L
Raw Material (Neutralization Waste)_1 US$/Kg (8)	0.543	US$/L
Sieving (0.7457 kW)_(2T/h) (9)	0.0003	US$/L
Drying (3 kW)_(0.582 T/h) (10)	0.1118	US$/L
Crusher (11 KW)_0.425 t/h (11)	0.0026	US$/L
Liquefied Petroleum Gas (LPG)_10% (12)	0.063	US$/L
Manpower (8MIL) (13)	0.333	US$/L
Distillation (Heating)_5 KW (14)	0.056	US$/L
Taxes_10% (15)	0.130	US$/L
Profit Margin (16) = (6) - (7)	0.06	US$/L
Total Profit	189.1	US$/day
Month	5.672	US$/month
Year	68.063	US$/year

Table 5 shows the cash flow for investment analysis using the simple payback criterion. It can be concluded that, in the fifth year, the investment is fully recovered, totaling US$ 5761.14 (five thousand seven hundred and sixty-one dollars and fourteen cents). In this case, the project is considered economically viable within the 10-year analysis horizon.

Table 5. Annual cash flow for organic material and paper for simple payback.

Year	0	1	2	3	4	5
Cash flow	-334552.77	68062.78	68062.78	68062.78	68062.78	68062.78
Accumulated value	-33452.77	-266489.98	-198427.20	-130364.42	-62301.64	5761.14
Year	**6**	**7**	**8**	**9**	**10**	
Cash flow	68062.78	68062.78	68062.78	68062.78	68062.78	
Accumulated value	73823.92	141886.70	209949.49	278012.27	346075.05	

Table 6 shows the cash flow for investment analysis considering the discounted payback criterion, net present value (NPV), internal rate of return (IRR) and the profitability index (IL). For the discounted payback criterion, it can be concluded that, in the eighth year, the investment is fully recovered. The cash flow discount rate was 10% p.a. In this case, the project is considered economically viable, as ten years is considered the analysis horizon for project evaluation. For the net present value (NPV) criterion, it can be concluded that, in the tenth year, there is a capital increase of US$ 83663.56 (eighty-three thousand six hundred and sixty-three dollars and fifty-six cents) in profit. The cash flow discount rate was 10% p.a. In this case, the project is considered economically viable, as the net present value is positive within the 10-year analysis horizon. For the internal rate of return (IRR) criterion, it can be concluded that, from the seventh to the eighth year, the accumulated value changes sign, which represents the project's IRR as 10% p.a. In this case, the IRR is equal to the minimum attractiveness of the project (10% p.a.), which means that the project is economically viable. Finally, for the profitability index, it is possible to obtain a value of 1.25 (profitability index). This means that for every dollar invested in the project, a return of 1.25 dollars will occur. According to the criteria of this index, the project is considered economically viable.

Table 6. Annual cash flow for bio-oil, coke and bio-gas produced by pyrolysis of organic material + paper and discounted payback analysis, net present value (NPV) analysis, internal rate of return (IRR) analysis and profitability index (IL) analysis.

Year	0	1	2	3	4	5
Cash flow	-334552.7	68062.78	68062.78	68062.78	68062.78	68062.78
Present value	-334552.77	61875.26	56250.23	51136.57	46487.80	42261.63
Accumulated value	-334552.77	-272677.51	-216427.28	-165290.70	-118802.91	76541.27
Year	**6**	**7**	**8**	**9**	**10**	
Cash flow	68062.78	68062.78	68062.78	68062.78	68062.78	
Present value	38419.67	34926.97	31751.79	28865.26	26241.15	
Accumulated value	-38121.61	-3194.64	28557.15	57422.41	83663.56	

Figure 3 corresponds to the sensitivity analysis for 2151.69 L/day of the fraction, to reach the fuel MFSP of 1.30 US$/L, an IRR of 10% is assumed. It is concluded that the cost of material (organic matter + paper), bio-oil yield, total project investment and electricity, respectively, are the most significant variables that affect the MFSP.

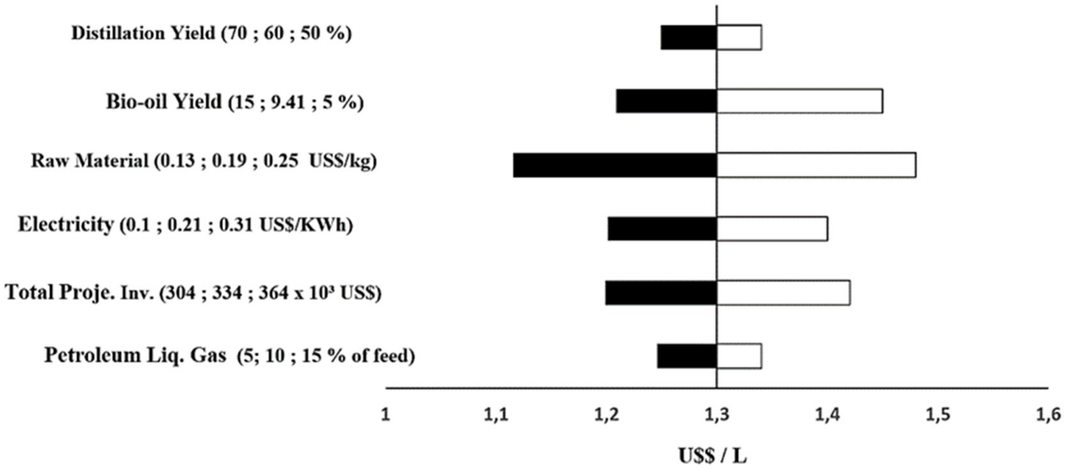

Figure 3. Sensitivity analysis for 2151.69 L/day; To achieve the fuel MFSP of 1.30 US$/L, an IRR of 10% is assumed.

Figure 4 illustrates the MFSP as a function of bio-oil yield by sensitivity analysis for a production of 2151.69 L/day of the fraction.

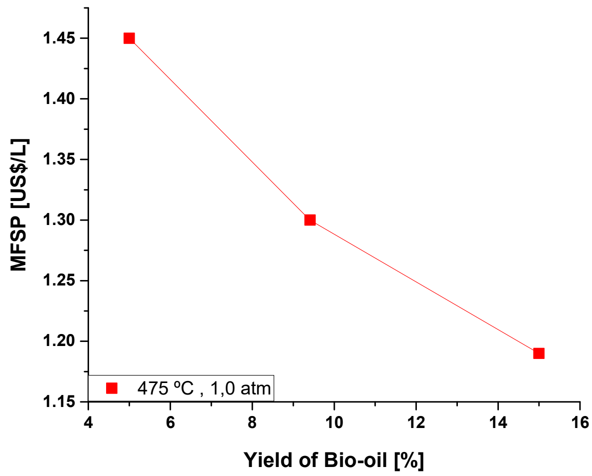

Figure 4. MFSP as a function of bio-oil yield by sensitivity analysis for a production of 2151.69 L/day.

Figure 5 is the MFSP as a function of material cost by sensitivity analysis for a production of 2151.69 L/day of the fraction and Figure 6 is the MFSP as a function of electricity by sensitivity analysis for a production of 2151.69 L/day. Both graphs demonstrate that increasing material cost and increasing energy value result in an increase in MFSP. Figure 5 demonstrates that when the material cost reaches 0.14 US$/Kg, the MFSP reaches 1.12 US$/L. Figure 6 demonstrates that when the value of electricity is reduced to around 0.10 US$/KWh, the MFSP is reduced to 1.20 US$/L (a value extremely close to that applied in Brazil to biofuels).

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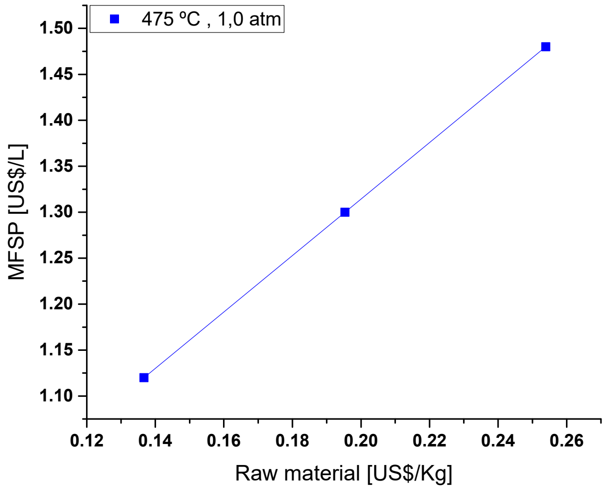

Figure 5. MFSP as a function of material cost by sensitivity analysis for a production of 2,151.69 L/day.

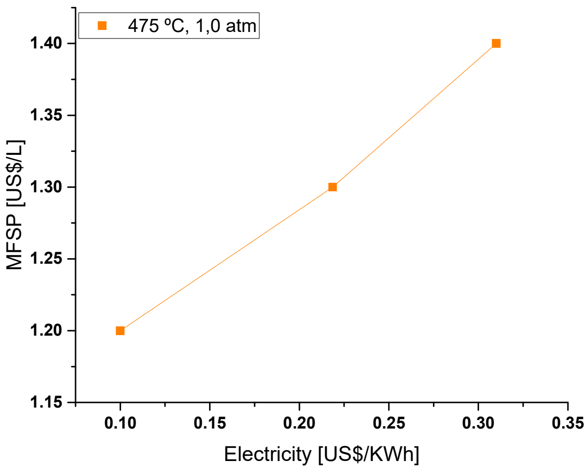

Figure 6. MFSP as a function of electricity by sensitivity analysis for production and 2151.69 L/day.

Figure 7 is the MFSP as a function of project investment by sensitivity analysis for a production of 2151.69 L/day of the fraction. The graph demonstrates that increasing the total project investment results in an increase in the MFSP. Figure 7 demonstrates that when the total project investment is reduced to around US$ 305000.0 (three hundred and five thousand dollars), the MFSP is reduced to 1.20 US$/L.

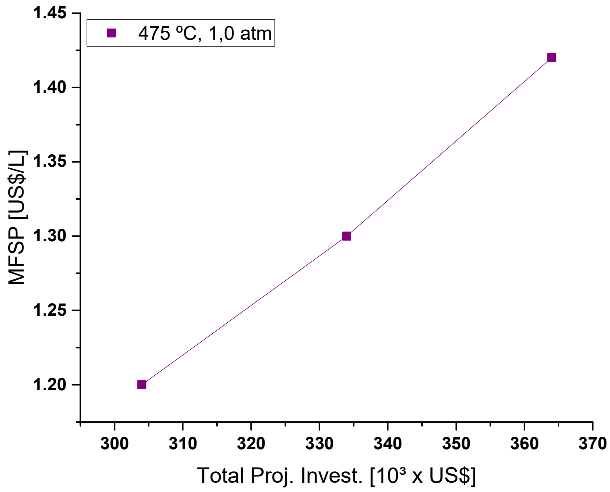

Figure 7. MFSP as a function of project investment by sensitivity analysis for a production of 2151.69 L/day.

Operating cost, payback period, and break-even analysis are used to investigate the relationships between planned project cost and rate of return. The break-even point is the point at which total cost and total revenue are equal, which means there is a balance between revenue and expenses [44]. From this condition, we obtained the project's breakeven point value of 0.96 US$/L.

4. Conclusions

After using the project evaluation criteria (simple and discounted payback, NPV, IRR and IL) and understanding the process of using pyrolysis, we can guarantee the economic viability of using urban solid waste (organic material and paper) for the production of biogas, coke and biofuels.

For the project developed, the initial investment was US$334552.77 (three hundred and thirty-four thousand five hundred and fifty-two dollars and seventy-seven cents) with an annual profit of US$68063.00 (sixty-eight thousand sixty-three dollars) for a minimum fuel sales price (MFSP) of 1.30 US$/L, compatible with both the value established in the Brazilian market and in the literature cited in this work (1.11 to 9.74 US$/L).

Considering the project evaluation criteria, the amount initially invested was fully recovered within the 10-year analysis horizon, corroborating the viability of the project. The profitability found was 1.25 (profitability index), that is, we will have a return of 1.25 dollars for each dollar invested in the project.

Finally, to reach the MFSP of 1.30 US$/L of fuel, a sensitivity analysis was carried out for a production of 2151.69 L/day of the studied fraction, being the cost of the material, bio-oil yield, total investment and electricity as the parameters that most affect the MFSP.

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