Impacts of a large-scale model of Municipal Solid Waste: An Input-Output analysis for the largest Brazilian metropolitan region

Octavio Pimenta Reis Neto
PhD for Energetic Systems' Planning, Mechanical Engineering Faculty at State University of Campinas (PDSE/FEM/UNICAMP), Av. Mofarrej, 275 – Apto 212 B1, CEP 05311-000, São Paulo, SP, Brazil

ARTICLE INFO

Keywords:
Waste-to-energy
Input-output
Recycling
Renewable energy
Municipal Solid Waste
Circular economy

ABSTRACT

This article presents socio-economic, energetic and CO2 emissions' impact by considering a large-scale integrated plant to treat Municipal Solid Waste (MSW) in the Metropolitan Region of São Paulo (MRSP); the most important Brazilian macro-region. As an alternative to landfills, this plant offers a source of renewable energy and a good assessment of benefits the circular economy provides.

Based on the most recent interregional economic transactions data, the proposed Input-Output model has shown reductions in the local energy demand (-0.31%), carbon emissions (-3.40%). On the other hand, it has suggested gains in the GDP (+0.21%) and formal job positions (+0.08% or 10.6k) when recyclables are introduced massively in the economy.

1. Introduction

The biggest economic center of wealth generation in Brazil, the Metropolitan Region of São Paulo (MRSP) is a macro-region which holds a large part of the national private capital, industries, commercial and financial headquarters [1]. Its 2013's GDP was R$ 947.6 billion (or USD 405 billion), approximately, 55.5% of São Paulo State, or 19.4% of Brazil. Considering 20.8 million people, GDP per capita was R$ 45.6 thousand (or USD 19.4 thousand), based on an annual exchange of R$ 2.43 per USD (1). In comparison with Brazilian GDP per capita (R$ 26.4 thousand or USD 11.3 thousand), MRSP's one was 1.7 times bigger in the same period [1, 2].

Directly associated with value and income generation, the amount of Municipal Solid Waste (MSW) is equally high in this Brazilian region. This metropolitan region has São Paulo city, capital of São Paulo State, with 11 million people, considered the largest of Brazil and one of the largest worldwide urban agglomerations. Formed by 39 cities, this region produces 21.4 thousand metric tons per day or annually 7.7 million metric tons of MSW. This amount corresponds to 10% of all Brazilian's MSW, and only São Paulo city produces 62.5% of this total amount [3, 4].

Due to an inefficient Integrated Municipal Solid Waste Management (IMSWM) is one of the factors that make difficult to coordinate integrated actions between municipalities.

Based on an large-scale model of an integrated urban waste treatment proposed to the MRSP by REIS NETO [5], this article presents measurable socio-economic, energetic and environmental impacts within circular economy logic. In short, the model consists in a mechanical selection of recyclables (waste sorting to separate and compact metal, paper, glass, and plastic), biological organic composting (bio-process to produce fertilizer), and a thermal treatment process where remaining waste, called Refuse Derived Fuel (RDF), is burned to produce energy (see Figure 1). Considering some Mechanical Biological Treatment (MBT) with Waste-to-Energy (WtE) downstream facilities (or simply MBT + WtE) well-distributed in the region could be an alternative to landfills to densely populated areas, such as MRSP. The well-succeed practice of MSW treatment with energy generation in too many countries in Europe, especially in Germany, is considered state-of-the-art regarding controlled emission and land-use mitigation, as mentioned in last COP 21 [6].

Studies are proposing similar initiatives to mitigate or eliminate, landfills usage, considering their capacity of saving energy and the potential of electricity generation through waste. ZHANG [7] reports about sharp population growth in China and its residues' generation without appropriate treatment. The solution to the problem, as well as the majority of articles found in developing countries, is to replicate well-succeed European cases, especially Danishes MSWM's models [8]. This task seems to be simple and trivial if it was not by the fact GDP's
Denmark is three times bigger than MRSP’s one, and five times higher than Brazilian’s one. It is one of the six European nations, which has at least 90% of its MSW destined to save and generate energy through a selective collection and Waste-to-Energy (WtE) for electricity and heating. In these developed countries, there is an awareness culture of environmental impact mitigation based on conscious consumption through the 3Rs (Reduce, Reuse and Recycle). There is a clear understanding of waste is a public health problem, and due to these governments, investments are made to get solutions alternative to the land-use, mainly because several times it is not available in Europe.

Pioneer simulating environmental impacts through input-output (I–O) models, LEONTIEF has inspired too many scientific works on waste management [9, 10]. NAKAMURA and KONDO [11] have estimated a waste input-output (WIO) table for Japan and applied it to evaluating effects of alternative waste management. They have found that concentrating treatment in a small number of large incinerators, combined with an increased degree of sorting, could decrease both costs to the society if proposed another mechanism to treat MSW, such as a MBT+WtE facility.

The model proposed in this article intends to simulate the impact of a new sector responsible for treating MSW in the economy of MRSP. This sector, called here as MBT + WtE, would offer the service of MSW treatment, recyclable materials (metal, plastic, glass, and paper), the organic compost (fertilizer) and energy (electricity) which could replace current “virgin” products (services, materials, and electricity) in the market.

The economy and their interregional transactions, where the I–O model works, are organized in 62 sectors and their 116 products from 2009’s Use and Make tables estimated by GUILHOTO [19] and updated by the author to reproduce the 2013 IBGE’s data [2].

Service and products are valued in section 3.1 and taken into account to feed the proposed model. Replacing current service of MSW treatment and “virgin” materials is natural to expect potential savings of energy consumption and GHG emissions. Section 3.2 shows the 2013’s inventories for energy and emissions and, despite section aggregation, their values were extremely important to confirm them or not.

Due to this, the I–O model proposed will show different impacts in current sectors of the MRSP’s economy and other regions, such as the rest of São Paulo State and the rest of Brazil.

In I–O modeling it is not necessary to adopt an economy based only on products or industries’ technology. Based on this fact, a combined hypothesis will be used in the same model, so that associations can be done based on new products and services replacing regular ones, or a sector impacting other; well-described in chapter 6 from MILLER and BLAIR’s book [20]. There are several different methods to mix these technologies, and CUNHA’s [21] proposal was taken by the author to build a model with the number of products bigger than the sectors. Section 2.3 shows the proposed modeling in a didactic way where the new sector, or the MBT + WtE sector, is interacting with the economy through its service and products. Due to space limit, all Use and Make tables have shown considering a single region as samples of how transactions occur in a reduced economy of 10 sectors and 19 products. Relations between MRSP and other regions are implicit since the economy is restricted to the same country, in other words, with the same sectors, products and services. Any possible misunderstanding is clarified at the of the article where results from relations between each sector are shown in Sector 4.

2. Materials and methods

The model proposed in this article has concluded. By integrating obesity through input-output (I–O) models, LEONTIEF has inspired too many scientific works on waste management [9, 10] to simulate the impact of a new sector responsible for treating MSW in the economy of MRSP. This sector, called here as MBT + WtE, would offer the service of MSW treatment, recyclable materials (metal, plastic, glass, and paper), the organic compost (fertilizer) and energy (electricity) which could replace current “virgin” products (services, materials, and electricity) in the market.

Within the 3Rs (Reduce, Reuse and Recycle), there is a clear understanding of waste is a public health problem, and due to these governments, investments are made to get solutions alternative to the land-use, mainly because several times it is not available in Europe.

Pioneer simulating environmental impacts through input-output (I–O) models, LEONTIEF has inspired too many scientific works on waste management [9, 10]. NAKAMURA and KONDO [11] have estimated a waste input-output (WIO) table for Japan and applied it to evaluating effects of alternative waste management. They have found that concentrating treatment in a small number of large incinerators, combined with an increased degree of sorting, could decrease both costs to the society if proposed another mechanism to treat MSW, such as a MBT+WtE facility.

Due to this, the I–O model proposed will show different impacts in current sectors of the MRSP’s economy and other regions, such as the rest of São Paulo State and the rest of Brazil.
fits with IPEA [22] study performed four years later, where MRSP's waste composition is shown.

Details of the processes, products, service, and revenues from the MBT + WtE sector are shown in Table 1 and used to impact the economy circularly.

Fractions of the 21 thousand metric tons per day of waste treated in each process are shown in Table A 1 and Table A 2.

Mass amount fractioned in wet and dry portions was an idea of how much is possible to recover from a simple sorting. Without any additional process (washing and drying), recyclers would buy recyclables (metal, plastic, glass, and paper) compacted and in bales. Organics, the fraction extremely wet in the waste, would be segregated to produce fertilizer. Other waste contents also considered wet, but, recognized as dirty, were deduced to incinerate and generate power.

Call special attention the important waste recovery rate of 67% potentially achieved just considering organic composting and recycling. Remarkable, this rate would be pretty expressive in comparison with the 10% sought by São Paulo, and not achieved by now, or with the insignificant 2% performed nowadays in Brazil, by ABRELPE [3].

Values (or revenues) to impact the economy came from 2013’s market prices (Table A 3), Lower Caloric Value (LCV) references (Table A 4) and the average waste's LCV for the MRSP (Table A 5).

About WtE process, technical configuration no. 3 (Table 2) and electricity price were used to calculate its value proposition to the model. The energy value used is the one from ANEEL Auction A-5 for biomass generation in 2014, and the amount generated by 12 WtE units would be 4.0 TWh (or 353 tons of oil equivalent, or simply toe) in 2013 [23]. Emissions of GHG by WtE units followed BELANGER [24] study which recommended to use 460 kg of CO2 eq per metric ton of waste treated.

Thus, considering service and products offered by the MBT + WtE sector, it is estimated at R$ 3,594 million (or USD 1,800 million) annually added to MRSP's economy. Recyclables would be responsible for 46%, electricity 25%, waste treatment service 17% and organic composting 12%.

This new sector would use some resources from the economy, such as public (gas, water, urban cleaning) and maintenance services. WtE facilities normally produce 8% (relative to the amount burnt) of ashes as a by-product, and they need to have a destination in landfills, abandoned mines or to built pavements. Maintenance and overhauling are also eventually required to keep the facilities working properly. So, this study assumed 1.5% and 6% of the annual gross income to by-product disposal and maintenance, respectively [24, 25, 26].

Other import operational assumption to the MBT + WtE is the number of jobs. Following what is recommended by FERRI [27], when considering collectors to select materials, it is strongly recommended to use one collector picking up 730 metric tons of waste per year. So, in this article will be accounted 10,678 workers, including those to operate the WtE process.

2.2. Inventory of energy consumption and GHG emissions

Unfortunately, there are not detailed regional sectorized energy and emissions inventories to the Brazilian economy. There are responsible agencies to these issues, such as Mines and Energy Ministry (MME) and Science, Technology and Innovation Ministry (MCTI), or national publications, such as National Energy Balance (BEN) and System of GHG Estimative (SEEG). However, the level of aggregation of these energy and emissions data are extremely high, what makes it difficult to reach how impacted is a specific sector (see Table A 6).

In this case, where only 12 sectors are available for all Brazilian economy, and the model was prepared to work with 62 sectors interacting in 3 regions, the author has disaggregated the data based on GDP's subsectors and regions. For example, the Textile's sector has three available subsectors in GUILHOTO's Tables. The total 2013's GDP for this sector was R$ 46,311 million (or USD 23,190 million), where 36% represents the subsector Textile, 42% for the subsector Articles and Accessories of Clothing, and 22% for the subsector Leather Goods and Footwear. Based on these contributions, energy consumption and emissions were the ones calculated and considered to build the subsector's baseline. In the same way, considering the GDP of each subsector was possible to estimate energy consumption and GHG among the regions.

This procedure certainly does not guarantee accuracy on getting subsector's energy consumption and GHG emissions, but do not interfere

Table 1. Processes, Materials and Revenues’ breakdown.

| IN | PROCESS FLOW | Fraction | “Raw Materials” | Fraction | OUT | PRODUCTS/SERVICE |
|---|---|---|---|---|---|---|
| MSW | 100% | Biological | 43% | Organic | 43% | Fertilizer |
| | Mechanical (Recycling) | 24% | Paper | 8% | Recyclables |
| | | | Plastic | 8% | |
| | | | Metal | 1% | |
| | | | Glass | 1% | |
| | | | Other (e.g., electronics) | 6% | |
| WtE | 33% | Dirty plastics | 24% | Electricity | 9% | |
| | | Textile, dirty papers, city cleaning | | | |
| Urban Waste Service | | | | Treatment | |
| TOTAL | 100% | All Processes | 100% | All Recyclables | 100% | All Revenues |

Source: Author’s compilation from Table A 2 and Table A 6.

Table 2. Configurations and Specs for WtE units.

| Config. | Waste Capacity (mt/day) | Min. LCV (kcal/kg) | Installed Capacity (MW) | Operation (h/year) | Electricity Potential (MWh) | Electricity Efficiency |
|---|---|---|---|---|---|---|
| #1 | 600 | 1,200 | 10 | 8,000 | 80,000 | 29% |
| #2 | 600 | 3,200 | 26 | 8,000 | 208,000 | 28% |
| #3 | 600 | 5,200 | 42 | 8,000 | 336,000 | 28% |
| #4 | 600 | 6,600 | 60 | 8,000 | 480,000 | 31% |

Source: CNIM spec and configurations [25].
about having how much energy or emissions can increase or decrease with the new sector in the entire Brazilian economy.

2.3. Proposed I-O model — a didactic approach

Suppose an economy with 12 sectors \( S_n \) (\( n = 12 \)) and 19 products \( Q_m \) (\( m = 19 \)), described as follows: \( S_1 \) — MBT + WtE; \( S_2 \) — Extraction of Non-Metallic Minerals; \( S_3 \) — Other from Extractive Industry; \( S_4 \) — Chemical Products; \( S_5 \) — Aluminum’s Metallurgy; \( S_6 \) — Paper and Cardboard; \( S_7 \) — Glass; \( S_8 \) — Resins and Elastomers Manufacturers; \( S_9 \) — Rubber and Plastic; \( S_{10} \) — Oil Based Electricity Generation; \( S_{11} \) — Urban Cleaning Service; and \( S_{12} \) — Other from Economy. And taking into account their products: \( Q_1 \) — Organic comports; \( Q_2 \) — Aluminum Scrap; \( Q_3 \) — Paper Scrap; \( Q_4 \) — Glass Scrap; \( Q_5 \) — Plastic Scrap; \( Q_6 \) — Electricity; \( Q_7 \) — MSW Treatment Service; \( Q_8 \) — Minerals Extraction for Fertilizers and Other Chemical Products; \( Q_9 \) — Non-Ferrous Metallic Minerals; \( Q_{10} \) — Non-Metallic Minerals; \( Q_{11} \) — Inorganic Chemical Products; \( Q_{12} \) — Paper and Cardboard; \( Q_{13} \) — Glass and Products; \( Q_{14} \) — Resins; \( Q_{15} \) — Rubber and Plastic Articles; \( Q_{16} \) — Oil

![Figure 2. Original Use matrix (U) based on the type of industries and products (combined technology) - color.](image-url)

![Figure 3. Make matrix (V) based on the type of industries and products (combined technology) - color.](image-url)
Based Electricity; Q18 – Urban Cleaning Service; and Q19 – Other Products from Economy. The model’s formulation derives from a system of equations based on Use (U) and Make (V) matrices whose structures are in Figures 2 and 3. Here, MBT + WtE and its products are mentioned but not used.

The matrix U shows sectors and products used in existing productions. The products used in the production of each sector are in the matrix V.

The linear system of equations related to the didactic model is as follows below:

I. Equation from Make Matrix (V) based on Products considering the new MBT + WtE sector (E. 1):

\[
Q = C^T \cdot X_1
\]

(E. 1)

Where:

\[
X_1 = \text{Production value from sector 1 (MBT + WtE)}
\]

Figure 4. Proposed Use matrix (U) considering the new MBT + WtE sector - color.

Figure 5. Original Technical Coefficients’ Matrix (B) from the economy - color.
C\textsuperscript{T} – Production technical coefficients in a sector
Q – Values of 7 seven products from MBT + WtE sector
Based on the economy from Figure 3 and its tech coefficients, there are seven equations (E. 1).

II. Equation from Make Matrix (V) considering existing sectors in the economy and based on their types of industries (E. 2):

$$X = D \cdot Q$$  
(E. 2)

Where:

- \(X\) – Production value from 11 sectors of the economy
- \(D\) – Production technical coefficients from a product in several sectors
- \(Q\) – Values from 12 products in 11 sectors of the economy

Based on the economy from Figure 3 with its technical production coefficients, there are 11 equations (E. 1).

III. Equations for the destiny of the MBT + WtE’s products in Use Matrix (U) (E. 3):

$$Z + E = Q$$  
(E. 3)

Where:

- \(Z\) – Production value from 11 sectors of the economy
- \(E\) – Production technical coefficients from a product in several sectors
- \(Q\) – Values from 12 products in 11 sectors of the economy

Based on the economy from Figure 4, there are seven equations (E. 3) where MBT + WtE’s products are in the economy.

IV. Equations which represent the destiny of the existing products in the economy and shown in the Use Matrix (U):

$$B \cdot X + E = Q$$  
(E. 4)

Where:

- \(B\) – Use technical coefficient from a product in a sector
- \(X\) – Production value of the sector
- \(E\) – Part of the products from the economy destined to the intermediary consumption
- \(Q\) – Products’ value from the economy

In the economy from Figure 5 with its technical coefficients, there are 12 equations (E. 4).

V. Equations for replacing “virgin” products with the ones produced by MBT + WtE sector:
In this opportunity will not be considered the Techno-Economic Factor (r) because there's no restriction to use the electricity or the cleaning service supplied by the MBT + WtE sector.

Here are only two equations (E. 9) and (E. 10) based on data from Figure 5.

\[
\begin{align*}
E_i &= \alpha_{i,j} \cdot E_i^0 \\
E_{11} &= \alpha_{1,7} \cdot E_i^0 \cdot \alpha_{6,7} = 10 \cdot E_i^0 \\
E_{11} &= \alpha_{1,8} \cdot E_i^0 \cdot \alpha_{6,8} = 2 \cdot E_i^0
\end{align*}
\]

\[
\begin{align*}
U_{i,j} &= \alpha_{i,j} \cdot U_{i,j}^0 \\
E_{12} &= \alpha_{1,9} \cdot U_{i,j}^0 \cdot \alpha_{6,9} = 10 \cdot U_{i,j}^0 \\
E_{12} &= \alpha_{1,10} \cdot U_{i,j}^0 \cdot \alpha_{6,10} = 2 \cdot U_{i,j}^0
\end{align*}
\]

Where:
- \( E_i \) – New final demand considering the “virgin” products i
- \( E_i^0 \) – Initial demand for the “virgin” products i
- \( U_{i,j} \) – New use to the “virgin” product i for the sector j
- \( U_{i,j}^0 \) – Initial use to “virgin” product i for the sector j
- \( \alpha_{i,j} \) – Adjustment factor to get the new amount of “virgin” products i, Electricity based on fuel oil and Urban Cleaning Service, for the sectors j

The total equations are 24, based on data in Figure 5.

With 90 equations and 108 variables in this didactic model, it is possible to get ENDOGENOUS (M) and EXOGENOUS (N) matrixes in an equilibrium market hypothesis:

\[
M + N = 0
\]

Where:
- \( M \) – Values of Supply
- \( N \) – Values of Demand

The ENDOGENOUS matrix (M) is in Figure 6, and it considers only intermediary consumption data.

It is important to separate demand’s variables (or EXOGENOUS) to get the impact of introducing the MBT + WtE sector in the SUPPLY (M); including those from the new sector and its production value (see Figure 7).

It is from this matrix that which the SHOCK value (Y), or the new products’ matrix from the new sector, is done on the DEMAND (N) as shown in Figure 8.

Multiplying the matrices \([M]_{90 \times 90} \cdot [\text{SHOCK}]_{90 \times 1} = [\text{IMPACT}]_{90 \times 1}\) (E. 14)

Figure 6. Matrix for supply (intermediary consumption).

Figure 7. Matrix for Exogenous variables - color.
This impact is noted on the ENDOGENOUS VARIABLES, or on the new composition of products from the MBT + WtE sector and the existing ones in the economy (see Figure 9).

The introduction of this new sector in the economy brings new alternative products and services, including jobs, which could socially and economically impact the regional and national economy through the amount of MSW generated.

Once impacted, it is possible to analyze the economy with the new sector through Direct and Indirect effects on Production values (X), as shown below:

\[ X = X_{\text{direct}} + X_{\text{indirect}} \]  
(E. 15)

The Production value affected by the direct effects \( X_{\text{direct}} \) comes from the SHOCK \( Y \) and the direct inputs from several economy’s sectors \( n \):

\[ X_{\text{direct}} = Y + \sum A^n \cdot Y \]  
(E. 16)

Alternatively:

\[ X_{\text{direct}} = (I + A) \cdot Y \]  
(E. 17)

Remember that:

\[ X = (I - A)^{-1} \cdot Y \]  
(E. 18)

Where:

- \( A \) - Technical Coefficients Matrix
- \( I \) - Inverse Matrix

Then:

\[ X_{\text{indirect}} = X - X_{\text{direct}} \]  
(E. 19)

\[
\begin{array}{cccccccccccc}
X_1 & E_1 & \ldots & E_5 & E_8 & \ldots & E_{16} & E_{19} & E_{17} & E_{18} \\
\hline
-0.100 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
-0.050 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
-1.000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
-0.300 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\end{array}
\]

\[ 90 \times 18 \]

Figure 8. Matrix for demands.
The Value of the Products ($Q$) with the equation (E. 4) in (E. 2) offers:

$$B \cdot D \cdot Q + E = Q$$

E = $Q - B \cdot D \cdot Q$

$$E = (I - B \cdot D) \cdot Q$$

$$Q = (I - B \cdot D)^{-1} \cdot E$$ \hspace{1cm} (E. 20)

Thus, with the equation (E. 17), the value of products under direct effect ($Q_{direct}$), is given by:

$$Q_{direct} = (I + B \cdot D) \cdot E$$ \hspace{1cm} (E. 21)

As in (E. 19):

$$Q_{indirect} = Q - Q_{direct}$$ \hspace{1cm} (E. 22)

### 2.4. Technical and economic facts about using recyclables

The use of recyclables replacing “virgin” raw materials offers some advantages, mainly as regards to saving resources, such as:

- Energy
- Water
- Minerals
- Fuels
- Other

Once recyclable materials save part of the value chain, it is reasonable to expect a sensitive GHG emission reduction, detailed in subsection 3.2.

However, it must be considered technical and economic aspects when replacing “virgins” to recyclables.

Concerning technical aspects, it is important to emphasize negative impacts about reprocessing and contamination, which can compromise recyclables use. A classic example is that one for plastic materials. In the process of transformation into products, the thermal and mechanical cycle can break primary chemical bonds, which results in reducing some mechanical properties, such as tensile strength. Once the product reaches the end of its life, and after its discard to be reprocessed, it is foolhardy its use in the same application. In Brazil, the National Health Surveillance Agency (ANVISA) prohibits to use recyclable plastics to produce packaging and appliances that will be in contact with food. However, excepting other applications such as automotive, plastic bags, containers and other domestic appliances can have from 20% to 100% of recyclables in their composition [28]. In bags used to carry waste it is common to be produced using 100% recycled plastic. They have mechanical resistance and some losses of visual aspect improved with increasing the thickness and using some pigments, dyes or whitening.

From an economic point of view, it is common to find a range of prices for recyclable plastics, which goes from 20 to 80% of the “virgin” product.

So, taking as a basis the example where, technically, in average is found blends with 60% of recyclable plastics, the total cost for the raw material is:

Total Cost (raw material) = $0.60 \cdot \text{Price for recyclable} + 0.40 \cdot \text{Price for “virgin”}$

Considering the economic factor where, on average, the recyclable costs 50% less than the “virgin”, the cost is:

Total Cost (raw material) = $0.60 \cdot (0.50 \cdot \text{Price for “virgin”}) + 0.40 \cdot \text{Price for virgin}$
Price for recyclable aluminum replacement will be: 3,279/t \([29, 30]\). Thus, the calculation of r factor of aluminum already mentioned, and market prices of the recyclables and virgin was 2,800 R$/t, while the aluminum Recycling (CEMPRE), in 2009 the average price of scrap aluminum Aluminum Association (ABAL) and Business Commitment for expended to the "0.75 monetary value of recyclable replaces each one monetary value the results discussed in Chapter 4.

Technical-economic factors (r) mentioned in subsection 2.3 and used in there is no technical restriction to replace. In Table A 7 are presented the treatment service, offered by the large-scale integrated model in this

Thus, the r factor must be read, for example in the use of plastic, as 0.60⋅(0.50 - Price for “virgin”) = 0.30 - Price for “virgin”

Other recycled materials, such as paper and organic, also follow the same rationale that considers technical and economic factors. However, there are instances where there is no technical restriction on product replacement, for example, is the case of aluminum scrap. Thus, it assumes that 100% recycled can be used for just the price of the recycled product and “Vir- gin”. By the Brazilian Aluminum Association (ABAL) and Business Commitment for Recycling (CEMPRE), in 2009 the average price of scrap aluminum was 2,800 R$/t, while the aluminum “Virgin” on average was R$ 3,279/t [29, 30]. Thus, the calculation of r factor of aluminum replacement will be:

\[
r_{\text{Aluminum}} = \frac{\text{Price for recyclable}}{\text{Price for “virgin”}} = \frac{2,800}{3,279} = 0.85
\]

Besides aluminum, recycled glass, as well as electricity and MSW treatment service, offered by the large-scale integrated model in this article, also follow considering in their r factor the price ratio because there is no technical restriction to replace. In Table A 7 are presented the technical-economic factors (r) mentioned in subsection 2.3 and used in the results discussed in Chapter 4.

Thus, the r factor must be read, for example in the use of plastic, as 0.75 monetary value of recyclable replaces each one monetary value expended to the “Virgin” plastic. It depends on technical criteria, as already mentioned, and market prices of the recyclables and virgin materials. As they’re competing in the market and the impact is proportionally inverse in the calculation, this article is assuming r factor as fixed.

3. Results and discussions

The model presented in this article was fed with the inter-regional economic transactions of 62 sectors and 116 products shown in Use (U) and Make (V) matrices estimated by GUILHOTO [19] and updated by the author to the year 2013, based on IBGE.

The impact in the regional economy is the introduction of the MBT + WtE sector treating 100% of MRSP’s MSW in 2013, and the results come from direct and indirect effects into the region, state, and country.

Section 3.1 shows and discusses the results from the socio-economic point of view, where Production Value (X), Jobs and Gross Domestic Product (GDP) are the main factors.

The estimated new environmental and energetic scenarios are in section 3.2 where there are Greenhouse Gases (GHG), and Energy Consumption results considering the operation of the MBT + WtE sector at MRSP.

This article has only considered the effects of the new sector’s operation on the economy, but not the sector’s construction because the Author has assumed this point beyond the scope.

3.1. Socioeconomic impacts

According to the model that considers establishing an MBT + WtE sector at MRSP, the effects over the regional economy would be, predominantly, indirect ones (see Table B 1).

The metropolitan’s GDP would increase by 0.21% keeping the same level of production value in 2013 (see Figure 10a and b). The new sector (S0 – MBT + WtE) would be responsible for adding value to the local economy by itself, and demanding local services from sectors S40 – Electricity, Gas, Water, Sewage and Urban Cleaning (+0.1%) and S47 – Maintenance and Repair Services (+2.7%) to keep its 12 facilities working. And, on the other hand, reducing values from sectors related to current cleaning services, organic composts and recyclables, such as: S62 – Urban Cleaning Services (-49.8%), S5 – Other from Extractive Industry (-12.3%), S17 – Resins and Elastomers Production (-5.8%), S68 – Production of Paper, Cardboard and their Products (-5.2%) and S57 – Non-Metallic Minerals Extraction (-3.0%), detailed in Table C 1 and Table E 1.

Another sector strongly impacted would be the S61 – Electricity Production (fuel oil-based). Considering a total installed capacity of 504 MW and selling energy cheaper than the fossil fuel-based one, the new sector would decrease by 25% the demand for a thermo-electric generation in São Paulo State or 2% in Brazil. The amount of electricity would be enough to cover 100% of the State’s demand for public lighting.
Both, rest of São Paulo State and Brazil would have their GDP and production value decreased by 0.15% and 0.20%, respectively. An MBT + WtE sector at MRSP treating 100% of all its waste would decrease Brazilian’s GDP and production value.

The potential MBT + WtE job creation is 10,678 opportunities in the MRSP. Moreover, as presented in Table D 1, the new sector would mean an increment of 10,559 jobs (+0.08%) taking account, approximately, the total of 12.6 million ones (see Figure 11). Sectors’ producers of Papers and Plastics would be slightly impacted (-0.50% or 219 jobs) despite being more efficient than recyclables collection's supply from the new sector. On the other hand, demanded services (i.e., maintenance to recycling and WtE assets) in the local economy represented by the sector S47 – Maintenance and Repair Services would have -0.19% (or 562) job opportunities.

The impact in the rest of São Paulo State would be less 691 jobs or -0.01% of the total 9.8 million opportunities. The sectors most impacted would be those who produce Papers and their Forestry raw material with almost -0.4% (or 254) jobs.

In the rest of the country, the indirect effect of MRSP’s new sector on the losses of jobs would be even higher in absolute numbers (-5,061 jobs), or -0.01% of the total, approximately, 80.0 million ones. In this case, the sectors with more significant losses would be those who produce Paper, Non-Metallic Minerals Extraction and Services decreased by recyclables’ supply.

However, nationally speaking, the new MBT + WtE sector working at MRSP would increase up to 4,807 jobs in 2013.

3.2. Impacts on energy consumption and GHG emissions

Energy Consumption and GHG Emissions’ inventories, presented in section 3.2, fed the I–O model proposed in this article. As a result, the MRSP would have a reduction of 0.31% in its energy consumption, and 3.4% in GHG emissions (or 2.99 Mt CO2 eq), as shown in Figure 12a and b. The answer to that comes from the indirect effect of the sector's installation. It would offer MSW treatment (alternative to landfill and without releasing CH₄), electricity produced with RDF (alternative to oil based), recyclable raw materials (metal, plastic, glass, and paper) and organic compost (fertilizer).

Less energy consumed when replacing the use of “virgins”, fewer greenhouse emissions when reducing raw materials consumption, and choosing release CO₂ instead of CH₄ within WtE process.

In Table F 1 is shown that the sectors that most contribute to the reduction of energy consumption would be the S58 – Production of Paper, Cardboard and their Products, S17 – Resins and Elastomers Production and S61 – Electricity Production (oil based).

It is also possible to verify an energy consumption reduction of 0.3% in both regions, the rest of São Paulo State and the rest of Brazil. A highlight to the great contribution of the sector S58 – Production of Paper, Cardboard, and their Products depending on the production localization and the weight of their energy consumption level in the economy.

In Table G 1 is possible to note the model points to GHG emission reduction in the MRSP, mainly by the S62 – Urban Cleaning Services (-95.4%). Certainly, the result is due to the choice of the new MSW treatment without emission of CH₄. In the rest of São Paulo State and the rest of Brazil, the reduction of GHG emissions would be 0.2% and 0.1%, respectively.

GHG releases in all Brazilian territory would reduce by 0.3% due to the direct and indirect effects of the new sector.

4. Conclusions

Taking into account the results from the simulation, a large-scale model treating 100% of MRSP’s MSW would increase 0.21% the GDP of the region in 2013. However, the state and Brazilian would have their ones reduced.

The number of jobs would be increased in the MRSP, resulting almost 4.8 thousand new formal opportunities in Brazil.

On the other hand, energy consumption would reduce by 0.3% in all country. Also, GHG emissions would be in a level 3.4% lower than it was in 2013 at RMSp, or 0.3% lower in Brazil.

The sectors more impacted would be those related to waste treatment services and raw materials producers, mainly paper, plastic, and glass. In the case of waste treatment, the greatest contribution would come from the methane-free waste disposal when the initiative suggests being an alternative to landfills, recycling materials, producing organic composts and electricity. The sectors that produce paper, plastic, and glass would have a significant reduction in the value of generation and jobs, due to the recyclables replacing “virgins” in the economy.

At the same time, what seems to be a problem can be a solution to mitigate, or eliminate losses. These producers could increase their product and business portfolios with post-consumed by-products and electricity for their use.

Declarations

Author contribution statement

Octavio Pimenta Reis Neto: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Funding statement

This work was supported by Ministry of Education and Science (MEC) through Coordination for the Improvement of Higher Education Personnel (CAPES) processes #33003017 and #88881.135606/2016-01.

Data availability statement

Data associated with this study has been deposited at (http://repositorio.unicamp.br/jspui/bitstream/REPOSITIP/333323/1/ReisNeto_Octavio_Pimenta_D.pdf).

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

Supplementary content related to this article has been published online at https://doi.org/10.1016/j.heliyon.2021.e06776.

Acknowledgements

Thanks to the resources and orientation given by State University of Campinas (UNICAMP) and Carnegie Mellon University (MCU).
Author's information

A Brazilian researcher with 23 years of experience dedicated to study economic viability and impacts of materials, composites, sources of energy and recycling to the society and environment.

Appendix A. Waste Parameters: Composition, Recyclability, Energy Content and Market

Table A 1. Gravimetric composition to the MSW at MRSP.

| MATERIAL                        | WET  | DRY  |
|--------------------------------|------|------|
|                                | 76%  | 24%  |
| GRAVIMETRY (%)                 |      |      |
| Aluminum                       | 0.46 | 1.2  |
| Rubber                         | 0.12 | 1.22 |
| Styrofoam                      | 0.27 | 0.21 |
| Natural wood                   | 0.71 | 0.07 |
| Processed wood                 | 0.13 | 0 |
| Metal                          | 0.58 | 1.59 |
| Paper                          | 4.97 | 16.14|
| Cardboard                      | 2.58 | 10.71|
| PET bottles                    | 0.77 | 1.88 |
| Various plastic                | 1.11 | 4.05 |
| PP bags, vessels, and packages | 0.86 | 1.15 |
| PE bags, vessels, and packages | 28.73| 24.39|
| Fabric                         | 3.82 | 4.68 |
| Tetrapack® packages            | 1.18 | 3.79 |
| Glass                          | 0.47 | 2.82 |
| Organics                       | 49.9 | 19.7 |
| Other (e.g., lamps, batteries, electronics) | 3.34 | 6.4 |
| **MSW's TOTAL COMPOSITION (%)** | 100.00 | 100.00 |

Source: Author's estimate based on SEMASA's data [31].

Table A 2. Potential sorting effect on MRSP's MSW treated in the MBT + WtE sector.

| MRSP's MSW TOTAL (metric ton per day) | 21,357.44 | WtE* | **SORTING** |
|---------------------------------------|-----------|------|-------------|
|                                      | 33%       | 67%  | 7,153.29    | 14,204.15 |
| MATERIALS                             |           |      |             |
| Aluminum                              | 0.00      |      | 136.18      |
| Rubber                                | 19.48     |      | 62.53       |
| Styrofoam                             | 43.83     |      | 10.76       |
| Natural wood                          | 115.24    |      | 3.59        |
| Processed wood                        | 21.10     |      | 0.00        |
| Metal                                 | 0.00      |      | 175.64      |
| Paper                                 | 806.71    |      | 827.30      |
| Cardboard                             | 418.78    |      | 548.97      |
| PET bottles                           | 124.98    |      | 96.36       |
| Various plastic                       | 180.17    |      | 207.59      |
| PP bags, vessels, and packages         | 139.59    |      | 58.95       |
| PE bags, vessels and packages          | 4,663.35  |      | 1,250.18    |
| Fabric                                | 620.05    |      | 239.89      |
| Tetrapack® packages                   | 0.00      |      | 385.80      |
| Glass                                 | 0.00      |      | 220.84      |
| Organics                              | 0.00      |      | 9,109.37    |
| Other (e.g., lamps, batteries, electronics) | 0.00 |      | 870.19      |

(*) Considered wet by WtE heating and aerobic process.

Source: Author's potential estimate based on SEMASA's data [31] and derived from Table A 3.
Table A 3. Price references to the sales revenues.

| REVENUE   | DESCRIPTION     | MARKET’S PRICE | MARKET’S PRICE | MARKET’S PRICE | MARKET’S PRICE | MARKET’S PRICE | MARKET’S PRICE |
|-----------|-----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| MSW disposal | Disposal        | 80             | R$ per metric ton | 34             | USD per metric ton | [4]             | [32]           |
| Recyclables | Metal           | 2,800          | 1,197           | 77             | 30             | 17             | 218            |
| Recyclables | Glass           | 180            | 77              | 30             | 17             | 218            | 77             |
| Recyclables | Paper           | 510            | 218             | 77             | 30             | 17             | 218            |
| Recyclables | Plastic         | 1,700          | 726             | 77             | 30             | 17             | 218            |
| Recyclables | Organic compost | 125            | 53              | 30             | 17             | 218            | 77             |
| Energy    | Electricity     | 197            | R$ per MWh      | 84             | USD per MWh    | [23]           |                |

Source: Author’s elaboration based on market references.

Table A 4. Lower calorific values for components in wet MSW.

| MATERIAL   | Humidity (%) | LCV (kcal per kg) |
|------------|--------------|-------------------|
| Organic    | 66           | 712               |
| Plastics   | 17           | 8,193             |
| Paper or cardboard | 21         | 2,729             |
| Fabric or leather | 36       | 1,921             |
| Wood       | 25           | 2,490             |
| Rubber     | 5            | 8,633             |

Source: [26].

Table A 5. The energetic potential for the fraction destined to the heat treatment.

| MSW's COMPONENT | FRACTION | METRIC TON PER DAY | COMPOSITION (%) | LCV (KCAL PER KG) |
|-----------------|----------|--------------------|-----------------|-------------------|
|                 | 33%      | 7,153.29           |                 |                   |
| Aluminum        |          | 0.00               | 0.00%           | 0.00              |
| Rubber          | 19.48    | 0.27%              | 23.51           |
| Styrofoam       | 43.83    | 0.61%              | 50.20           |
| Natural wood    | 115.24   | 1.61%              | 40.12           |
| Processed wood  | 21.10    | 0.29%              | 7.35            |
| Metal           |          | 0.00%              | 0.00            |
| Paper           | 806.71   | 11.28%             | 307.76          |
| Cardboard       | 418.78   | 5.85%              | 159.76          |
| PET bottles     | 124.98   | 1.75%              | 143.15          |
| Various plastic | 180.17   | 2.52%              | 206.36          |
| PP bags, vessels and packages | 139.59 | 1.95%              | 159.88          |
| PE bags, vessels and packages | 4,663.35 | 65.19%            | 5,341.16        |
| Fabric          | 620.05   | 8.67%              | 166.51          |
| Tetrapack® packages | 0.00 | 0.00%              | 0.00            |
| Glass           |          | 0.00%              | 0.00            |
| Organics        |          | 0.00%              | 0.00            |
| Other (e.g., lamps, batteries, electronics) | 0.00 | 0.00%              | 0.00            |
| MRSP's MSW TOTAL | 7,153.29 | 100.00%            | 6,605.75        |

Source: Author’s potential estimated based on SEMASA’s data [31], Table A 2 and Table A 5.
Table A 6. Energy consumption and GHG emissions.

| SECTORS                | Energy Consumption (*) (10^3 toe) | GHG Emissions (*) (10^6 ton CO2 eq) |
|------------------------|----------------------------------|-------------------------------------|
| Transport              | 83,153                           | 214                                 |
| Energy (Oil & Gas)     | 26,139                           | 37                                  |
| Energy (Ethanol)       | 14                               |                                      |
| Energy (Electricity)   | 67                               |                                      |
| Food and Beverages     | 23,339                           | 27                                  |
| Pig Iron, Steel, Ferrous Alloys | 17,781                       | 39                                  |
| Paper and Cellulose Pulp | 10,575                        | 12                                  |
| Agriculture            | 10,662                           | 74                                  |
| Livestock              | 912                              |                                      |
| Chemical               | 6,986                            | 8                                   |
| Commercial             | 8,064                            | 2                                   |
| Non-ferrous and other Metals | 6,936                           | 15                                  |
| Ceramics               | 5,069                            | 6                                   |
| Public Services (Public Cleaning) | 3,868                  | 48                                  |
| Public Services (Other) |                                  | 1                                   |
| Cement                 | 5,316                            | 42                                  |
| Mining and Pelleting   | 3,247                            | 7                                   |
| Textile                | 1,101                            | 1                                   |
| Other                  | 7,945                            | 22                                  |
| TOTAL                  | 220,181                          | 1,548                               |

Source: BEN [33] and SEEG [34].

(*) Residential sector not considered.

Table A 7. Techno-Economic Factors to use recyclables (based on 2009’s prices).

| PRODUCT                | Value for Recyclables | Value for “Virgin” | % of Recyclable | % of “Virgin” | r Factor |
|------------------------|-----------------------|--------------------|-----------------|---------------|----------|
| Waste Treatment (R$/t)a | 80                    | 80                 | 100             | -             | 1.00     |
| Aluminum (R$/t)b       | 2,800                 | 3,279              | 100             | -             | 0.85     |
| Glass (R$/t)c          | 180                   | 220                | 100             | -             | 0.82     |
| Paper (R$/t)d          | 510                   | 2,737              | 50              | 50            | 0.19     |
| Plastic (R$/t)e        | 1,700                 | 3,400              | 60              | 40            | 0.75     |
| Organic compost (R$/t)f| 125                   | 725                | 80              | 20            | 0.69     |
| Electricity (R$/MWh)g  | 197                   | 233                | 100             | -             | 0.85     |

Source: Author’s compilation based on Table A 4 following references: a) [3]; b) [29]; c) [35]; d) [36]; e) [30]; f) [37]; and g) [23].

References

[1] SEADE, Profile of the metropolitan region of São Paulo, in: Sist. Estadual Analise Dados, 2011. https://perfil.seade.gov.br/. (Accessed 30 March 2018).

[2] IBGE, Profile of the Brazilian Cities, 2013. http://www.ibge.gov.br/home/estatistica/cidades/2013/ (Accessed 30 March 2018).

[3] ABRELPE, Panorama of the Brazilian Solid Waste in 2014, in: Abrelpe, 2015. http://observatoriopens.files.wordpress.com/2015/07/panoramaabrelpe.pdf. (Accessed 30 March 2018).

[4] CETESB, Inventory for the Urban Solid Waste Residues from São Paulo State in 2013, in: Cia. Ambient. do Estado São Paulo, 2014. https://cetesb.sp.gov.br/residuosolidos/wp-content/uploads/sites/26/2013/11/inventario-RSD-2015.pdf. (Accessed 28 September 2018).

[5] O.P. Reis Neto, Analyzing the economic viability of a large-scale integrated model of municipal solid waste: a study case for the most important Brazilian economic region, Waste Dispos Sustain Energy 2 (2020) 231-247.

[6] T.H. Christensen, A. Damgaard, T.F. Astrup, Waste to Energy: the carbon perspective, Waste Manag. (2015). World 24–28.

[7] D.Q. Zhang, S.K. Tan, R.M. Gersberg, Municipal solid waste management in China: status, problems and challenges, J. Environ. Manag. (2010) 1623–1633.

[8] S. Andreassi Bassi, T.H. Christensen, A. Damgaard, Environmental performance of household waste management in Europe - an example of 7 countries, Waste Manag. (2017).

[9] W. Leontief, Environmental repercussions and the economic structure: an input-output approach, Rev. Econ. Stat. 52 (1970) 262.

[10] W. Leontief, Environmental repercussions and the economic structure: an input-output approach, in: Green Accounting, Routledge, 2018, pp. 385-394.

[11] S. Nakamura, Y. Kondo, Input-output analysis of waste management, J. Ind. Ecol. 6 (2002) 385–394.

[12] S. Nakamura, Y. Kondo, Input-output analysis of waste management, J. Ind. Ecol. 6 (2002) 39–63.

[13] M. Lenzen, C.J. Reynolds, A supply-use approach to waste input-output analysis, J. Ind. Ecol. 18 (2014) 212–226.

[14] J. Song, W. Yang, Z. Li, et al., Discovering the energy, economic and environmental potentials of urban wastes: an input-output model for a metropolis case, Energy Convers. Manag. (2016).

[15] C.A.P. Pimenteira, Socioeconomic Aspects of the Administration of Solid Residues in Rio de Janeiro - An Input-Output Analyzes, 2002. http://antigo.ppe.ufrj.br/pppe/production/tesis/cappimenteira.pdf. (Accessed 30 March 2018).

[16] J.D. Lima, Decision support models for alternatives' technologies of urban solid waste treatment in Brazil, in: Tese doutorado, 2012. https://repositorio.ufpe.br/bitstream/123456789/10606/1/TESE_JDANTASDELIMAVF-%20-%20REDUZIDO.pdf. (Accessed 28 September 2018).

[17] A.C.A. Vieira, Energy recovery from urban solid wastes: challenges and technologies, in: Mestr. Acadêmico em Desenvolvimento do Meio Ambiente, 2011, https://ri.ufs.br/bitstream/riufs/4340/1/ANNE_CAROLINE_ALMEIDA_VIEIRA.pdf. (Accessed 28 September 2018).
[18] C.A.P. Pimenteira, Integrated Solid Waste Management in Rio de Janeiro: Decisions’ Impacts of Administrators in Public Policy, 2010. http://antigo.ppe.ufrj.br/ppe/production/tesis/cicero_pimentel.pdf. (Accessed 30 March 2018).

[19] J. Guibotto, System of input-output tables, Brazil in 2009, in: Núcleo Econ. Reg. e Urbana da Univ. São Paulo, 2013. http://www.usp.br/nerneus/?fontes=dados_matrices. (Accessed 28 September 2018).

[20] R.E. Miller, P.D. Blair, Input-output analysis: foundations and extensions, in: Input-Output Analysis: Foundations and Extensions, second ed., Cambridge University Press, Cambridge, 2009, pp. 1-750.

[21] M.P. Canha, Insertion of the Sugar and Alcohol Sector in the Brazilian Energy Matrix: an Input-Output Analysis, 2005. http://repositorio.unicamp.br/jspui/handle/REPOSIP/307255. (Accessed 28 September 2018).

[22] IPEA, Research Report - Diagnosis of Brazilian Urban Solid Waste, 2012. http://www.ipea.gov.br/portal/images/stories/PDFs/relatoriopesquisa/121009_relatorio_residuos_solidos_urbanos.pdf. (Accessed 28 September 2018).

[23] ANEEL, Auction A-5 - Contracting Energy from New Generation Projects - Hydroelectric and Thermal Sources, 2013. https://www2.aneel.gov.br/aplicacoes/editais_geracao/documentos_editais.cfm?IdProgramaEdital=118. (Accessed 28 September 2018).

[24] L. Belanger, P.N. Ritchie, P.C. Smith, Comparison of greenhouse gas emissions from waste-to-energy facilities and the vancouver landfill, in: Tech. Memo, 2009. http://pentz.com/NoIncinerator/greenhouse%20Fmmissions.pdf.

[25] G. Cnim, Turnkey Plants - Treatment and Recovery Energy from Waste, 2018. https://cnim.com.br/businesses/treatment-and-recovery-waste#turnkey-plants-energy-recovery-from-waste. (Accessed 28 September 2018).

[26] FEAM, Energy development of urban solid waste: guidance for guidelines for municipal governments of minas gerais, in: Fundação Estadual do Meio Ambiente, 2012. http://www.feam.br/images/stories/Publicacoes/aproveitamento%20energetico%20de%20enos%20gas%20orientes_versao_publicacao_on_line.pdf. (Accessed 28 September 2018).

[27] G.L. Ferri, G.L.D. de Chaves, G.M. Ribeiro, Analysis and location of urban solid waste collection/inspection centers for a reverse logistics network: a case study in São mateus-ES, Production 25 (2014) 27-42.

[28] ANVISA, Technical Report Nr. 71 - February, 2016. http://portal.anvisa.gov.br/documents/33916/388279/InformemT%C3%A9cnico+ao+a71%2C+de+de+11+de+fevereiro+a+de+2016/e03dac30-11d4-7935-a57e-a454a3862f7f. (Accessed 28 September 2018).

[29] ABAL, Brazilian Aluminum Association - ABAL 2015 Statistical Yearbook, 2016. http://abal.org.br/. (Accessed 28 September 2018).

[30] CEMPRE, Brazilian Annual Research about Selective Collect in 2012, in: Compromisso Empres. para Reciclagem, 2013. http://cempre.org.br/ciclosoft/id/4. (Accessed 28 September 2018).

[31] Semana, Santo Andrs municipal solid waste gravimetric characterization, in: Secr. do Meio Ambiente, 2008. http://servicos.semana.sp.gov.br/admin/biblioteca/docs/PDF/relat_gravimetricv2008.vf.pdf. (Accessed 28 September 2018).

[32] C.I.T.A.R. Fundace, Economic viability of construction and implementation of landfillic advantageous of town’s consortium, subsidies, federal and public or private operation models, in: Fundação para Pesqui. e Desenvolv. Adm. Contab. e Econ, 2012. http://www.fundace.org.br/campanha/viability_economica_aterros.pdf. (Accessed 28 September 2018).

[33] Ben, Brazilian National Energetic Balance: Base Year 2013, 2014. https://ben.epe.gov.br/downloads/Relatorio_Final_BBN_2014.pdf. (Accessed 28 September 2018).

[34] SEEG, System for Estimating Greenhouse Gas Emissions - Analysis of the Evolution of GHG Emissions in Brazil (1970-2014), 2014. http://seeg.eco.br/en/download?cama_set_language=en. (Accessed 28 September 2018).

[35] M.M.E. Abividro, Statistical Yearbook of the Non-metallic Brazilian Transformation Sector 2009, 2010. http://www.mme.gov.br/web/guest/secretarias/geologia-mineracao-e-transformacao-mineral/publicacoes/anuario-estatistico-do-setor-meta-lurgico-e-do-setor-de-transformacao-de-nao-metalicos. (Accessed 28 September 2018).

[36] Abtcp, Brazilian technical association for cellulose and paper: position papers, in: Assoc. Bras. Técnica Celul. e Pap, 2016. http://abtcp.org.br/produtos-e-servicos/positions-papers/. (Accessed 28 September 2018).

[37] AGROLINK, Brazilian Agricultural Content Portal, 2016. https://www.agrolink.com.br/cotacoes/. (Accessed 28 September 2018).