http://dx.doi.org/10.5902/2236117026161
Revista do Centro do Ciências Naturais e Exatas - UFSM, Santa Maria
Revista Eletrônica em Gestão, Educação e Tecnologia Ambiental - REGET
e-ISSN 2236 1170 - V. 21, n. 1, jan.- abr. 2017, p.14-31

Environmental valuation model for greenhouse gases emission reduction due to the municipal recycling of solid waste in Brazil

Modelo de avaliação ambiental para redução de emissões de gases de efeito estufa devido à reciclagem municipal de resíduos sólidos no Brasil

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Abstract

Solid waste management has become an increasingly important theme, since the space for the disposal of garbage in urban centers is limited and valued. The practice of recycling stands out as one of the best alternatives to reduce the volume of waste sent to landfills, reducing the emission of greenhouse gases (GHG) at the same time. As a form of promoting this practice, in 2007, a Brazilian Energy Company developed a program that gives discounts on energy bills upon delivery of recyclable materials. The program has recycled more than 13 thousand tons of waste, and granted more than R$ 1.5 million in rebates. In order to enable measurement of the environmental benefits of this program, this paper presents a model that relates the recycling of materials and the reduction in CO2 emissions that this practice produces. An application of the model shows that, in just 3 months, about 1,000 tons of CO_2 was not emitted due to the program activities. The results show aluminum as the material which, when recycled, provides the largest reduction in emissions, and it is followed by paper/cardboard, steel, plastics, metals and glass.

Keywords: *Recycling. Greenhouse gases. Reducing emissions.*

Resumo

A gestão de resíduos sólidos tornou-se um tema cada vez mais importante, uma vez que o espaço para a eliminação de lixo nos centros urbanos é limitado e valorizado. A prática de reciclagem destaca-se como uma das melhores alternativas para reduzir o volume de resíduos enviados para aterros, reduzindo ao mesmo tempo a emissão de gases de efeito estufa (GEE). Como forma de promover essa prática, em 2007, uma empresa brasileira de energia desenvolveu um programa que oferece descontos sobre as contas de energia na entrega de materiais recicláveis. O programa reciclou mais de 13 mil toneladas de resíduos e concedeu mais de R$ 1,5 milhão em descontos. Para possibilitar a mensuração dos benefícios ambientais deste programa, este trabalho apresenta um modelo que relaciona a reciclagem de materiais e a redução das emissões de CO_2 que essa prática produz. Uma aplicação do modelo mostra que, em apenas 3 meses, cerca de 1.000 toneladas de CO_2 não foram emitidas devido às atividades do programa. Os resultados mostram que o alumínio é o material que, quando reciclado, proporciona a maior redução de emissões e é seguido por papel/cartão, aço, plásticos, metais e vidro.

Palavras-chave: *Reciclagem. Gases de efeito estufa. Redução de emissões.*

Recebido em: 15.03.17 Aceito em: 13.04.17

1 Introduction

The predatory exploitation of the planet's natural resources and the climatic changes have boosted the development of new business models, where sustainability guides organizational strategies and the main constraints are related not only to technological advances, but also to how to use and reuse resources. In this sense, in the long-term perspective, "how the benefits outweigh the costs associated with the impact on the environment and the scarcity of some natural resources should be questioned" (Soares et al., 2014). In this way, reconciling economic growth with environmental sustainability will require the reduction of the environmental impacts of current activity to sustainable levels and then their maintenance at these levels while incomes continue to grow (Ekins, 2000).

According to Huang et al. (2016) "the negative impact of greenhouse gases (GHG) emissions on the environment has recently received considerable attention by both industry and academia". In this sense, identification of factors that contribute for the GHG emission in the atmosphere and the determination of the amount emitted is one of the first analyzes when studying the topic of greenhouse gas in the atmosphere.

Yang et al. (2012) identified and measured the amount of GHG that reaches the atmosphere, and they concluded that the majority of this amount of GHG comes from Municipal Solid Waste (MSW) and the main gas is CO_2. The substitution of raw material by recycled material in the production processes leads to energy economy and reduce possible emissions of gases to the atmosphere (Lino and Ismail, 2011).

According to research by the Brazilian Association of Public Cleaning and Special Waste (ABRELPE, 2014), in 2014 the generation of MSW in Brazil reached the milestone of 78,6 million tons (increased 2,9%compared with the previous year), index higher than the rate of urban population growth in the country in the same period, which was 0.9%.This data proves the existence of a paradox between the increasing environmental awareness of the population and indiscriminate consumption of products and services that generate harmful impacts to the environment.

In this way, studies conducted in Brazil, show the importance that has been given to the management of solid waste effectively. King and Gutberlet (2013) emphasize the importance of the process of recycling as an environmental factor reduction through cooperatives in São Paulo. Loureiro et al. (2013) seek to identify possible changes in solid waste policies in Rio de Janeiro through scenarios where strategies are evaluated in terms of efficiency, technology and economy. The method and the technology used to collect and monitor estimates of the effects of the gases released into the atmosphere is also of great importance.

Moreover, the term "energy economy" refers to difference between energy consumption in the production process when using raw material and the energy consumption when using recyclable material. According to Calderoni (2003), the selective collection and recycling constitute one of the main alternatives to reduce this problem, since such actions reduce the volume of waste to be collected and processed by the government. It is noticed that about 30% of MSW is made from recyclable materials that have economic value and could be reinstated in the production process of a multitude of products. Unfortunately, the data ABRELPE (2014) show that much of this waste is simply buried in landfills or deposited in open dumps across the country.

The generation of employment and income derived from the practice of recycling also configures itself as an important economic and social benefit, since the activity demands labor-intensive, especially in its early stages, collecting, sorting and processing.

Once the depletion of the natural resource of raw material is inevitable when its global consumption by the economy grows, recycling can delay this effect (Grosse, 2010). Thus, recycling can aid in the preservation of biodiversity, since it reduces the need for extraction of natural resources for the production of raw materials sent by industry (IPEA, 2010). Moreover, it also provides a reduction in the volume of waste sent to landfills and dumps, reducing the impacts of these developments on the environment and reducing the costs of municipal regions related to the processing and disposal of waste.

According to Akimoto et al. (2010), the determination of the reduction of potential emissions is essential for achieving large emission reductions, as in the case of recycling. The practice of recycling also helps reduce greenhouse gas emissions from the generation of energy and the burning of fossil fuels used in the manufacturing process of inputs.

Based on these new paradigms, in 2007, a Brazilian Energy Company, the one from Ceará (COELCE) – located in Northeast of Brazil – launched the Ecoelce Program, which provides discounts on customers' electricity bills through the delivery of recyclable waste by customers. Until 2012, almost 400 thousand customers were registered and more than 16 thousand metric tons of waste has been recycled, resulting in more than U$ 680 thousands in discounts on energy bills (COELCE, 2012). In 2008 the program was elected as one of the ten winners of the World Business and Development Awards (WBDA), given by the United Nations (UN), as one of the most important projects for the alignment with the principles of the Global Compact. According to Marques et al. (2014), initiatives such as Ecoelce Program are also important as a means of "raising community awareness of the environmental impacts of greenhouse gas (GHG) emissions on the atmosphere, as well as its possible aggravating effect on global warming".

Currently, the discounts granted by Ecoelce are computed based on energy conservation that each recycled material offers, which enables the energy benefits of this initiative to be measured easily and publicized. However, the program generates a number of other environmental benefits that currently are not measured and disclosed.

There are studies on the issue of reducing the amount of CO_2 emissions into the environment by recycling materials, such as the work done by Acuff and Kaffine (2013) that examines least-cost policies for waste reduction, incorporating upstream GHG externalities associated with the production of consumption goods from various materials. Talyan et al. (2007) have conducted a dynamic modeling to quantify methane emissions generated by MSW and presented management measures to mitigate this issue by analyzing various possible scenarios. Vergara et al. (2011) analyze the benefit of five treatment options for MSW in California using two models of life cycle assessment (LCA) for biogenic waste and conclude that source reduction is the best form to mitigate GHG emissions from greenhouse. Similarly, Mohareb et al. (2008) have conducted a modeling to determine the GHG emissions from the waste sector using waste disposal, recycling and composting data in Canada in 2003 reaching the conclusion that the incineration of waste, and separation of source materials recyclable, and anaerobic digestion of organic waste is one of the biggest benefits of reducing GHG emission.

Recchia et al. (2013) focused to the possible environmental benefits associated to the reuse of residues of potted plants that are discarded from the nursery production chain. GHG emissions and fossil energy requirement were quantified by considering the CO_2 and the cumulative energy requirement respectively, in order to assess the environmental impacts of two different scenarios proposed for the materials recovery. Gemechu et al. (2013) compare GHG emissions from producing tissue paper from virgin pulp (VP) or recycled waste paper (RWP). Couth and Trois (2010) conducted a survey that shows the average content of organic matter of solid urban waste in Africa (about 56%) and its degradation as a major contributor to emissions of GHG and conclude that the most practical and economical way to manage waste and reduce carbon emissions is to separate waste collection points to remove dry recyclables, compost and other waste from biogenic carbon in windrows using composite matured as a substitute fertilizer and eliminate waste remaining fossil carbon in controlled landfills.

Merrild and Christensen (2009) presented data related to the activities in a material recovery facility (MRF) where wood waste is shredded and foreign objects are removed in order to produce wood chips for use in the production of particle board. Hoklis and Afiado (2014) conducted to evaluate and compare the GHG emission from MSW in some cities in this country. However, in Brazil there are no studies dealing specifically with the issue proposed in this study.

Therefore, this paper aims to present the development of an environmental valuation model of recycling municipal solid waste that can establish a relationship between the types of recycled material and the reduction of greenhouse gases emissions by recycling. This model will allow the visualization of the benefits arising from activities Ecoelce, since they can be measured and reported how the program is actually to the society.

Besides this introduction, this paper is divided into other five Sections. Section 2 presents the methodology already existing used to calculate the amount of emissions reduced by using recycled materials. Section 3 presents the proposed model for environmental assessment. Afterward, the results achieved with the application of the proposed model are showed in Section 4. The discussions are presented in Section 5. At the end, the conclusions and policy implications are presented.

2 Material and methods

The environmental valuation procedure of the recycled municipal solid waste already applied by Ecoelce Program is based on *AMS-III.AJ methodology – Recovery and recycling of materials from solid wastes* – approved by the Executive Board of the Clean Development Mechanism (EB-CDM). This methodology tackles reducing GHG emissions resulting from activities for the recovery and recycling of materials, by transforming them into a final product or new input for other productive chains (United Nations Framework Convention for Climate Changes - UNFCCC, 2015a).

According to this methodology, the recycling of materials permits them to be reintroduced into the supply chain, thus eliminating certain activities that would be needed to obtain the same input from virgin raw material, extracted from Nature. This reintroduction of material into the production process provides savings on electricity, fossil fuels and natural resources. The amount of the emission reductions, measured in tons of carbon dioxide equivalent (tCO_2eq), because of recycling the materials cited, is obtained by calculating the difference between the Baseline Emissions and emissions from the proposed Clean Development Mechanism (CDM) project, with fugitive emissions being deducted, as per Equation (1) defined by the AMS-III.AJ methodology (UNFCC 2015a).

$$ER_y = BE_y - PE_y - LE_y \tag{1}$$

Where:
ER_y Emission Reductions in year y (tCO_2eq)
BE_y Baseline emissions in year y (tCO_2eq)
PE_y Project emissions in year y (tCO_2eq)
LE_y Leakage emissions in year y (CO_2eq)

It is worth noting that emissions associated with transporting the material from the collection points to the recycling units, as well as from recycling units to the industry are considered equivalent to those that would occur in the absence of the project. That is, if there were no recycling project, industry would require the same amount of raw material from their suppliers to do this, thus inevitably leading to transportation to a processing unit (UNFCCC, 2015a).

Equation (1) also includes leakages, which corresponds to GHG emissions that occur outside the limits of the CDM project and that, at the same time, are measurable and attributable to the project activity. Examples of fugitive emissions are GHG in landfills that escape through ill-fitting pipes, cracks in embankments, pump shafts, etc. These types of emissions, though not desired, can be predicted, measured, monitored and attributed to project activity. Of course, if the volume of the fugitive emission is excessively high, the project may not be feasible from the CDM point of view.

2.1 Material losses arising from recycling

According to Vlachopoulos (2009), the recycling process involves material losses that may occur during collection and the processes necessary for it to be recycled, such as washing. Material of inferior quality (e.g., contaminated, stained or dirty material) is discarded, also resulting in material losses. Therefore the yield is not a ton of recycled material for each ton of dump/residue that goes into the recycling process. Such losses are estimated on a scale of 10% to 30% in the recycling industry.

For this reason, the AMS-III.AJ methodology suggests the use of an adjustment factor (L_i) to compensate for losses in the recycling process and degradation in the quality of the material, reducing thus the total amount of recycled material. Table 1 presented the adjustment factor (L_i) for the materials considered in this work.

Table 1 - Materials adjustment factor

Material	**Adjustment factor (L_i)**
Aluminium	0.93
Steel	0.98
Metals	0.81
Glass	0.88
Paper/cardboard	0.93
Plastics	0.75

Source: adapted from United States Environmental Protection Agency, EPA (2006), Vlachopoulos (2009) and UNFCCC (2015a)

2.2 CO_2 emission factor for electricity generated

The Brazilian Ministry of Science and Technology (MCT) calculates and publishes two types of CO2 emission factors for electricity generated in Brazil: the first is used in projects under CDM (based on methodologies approved by the CDM Executive Board) and the second, when drawing up inventories (Brazil, 2008).

Analysis of these two CO2 emission factors for electricity generation in the Brazilian National Interconnected System (SIN) published by this Ministry shows that the proposed model should use the CO2 emission factor for electricity as calculated as per the "Methodological tool - Tool to calculate the emission factor for an electricity system", approved by EB-CDM (UNFCCC, 2015b).

The other emission factor published by the Brazilian Ministry is intended for drawing up inventories and considers SIN emissions as a whole, including the power plants, which are not impacted by CDM project activities, called Base Power Plants. This methodology for calculating the emission factor does not seek to estimate the reduction in CO2 emissions resulting from project activities, but only calculates certain emissions generated when SIN power is consumed at any given moment.

According to the above-mentioned tool, the calculation of the emission factor for the energy generated is made by using the concept of "Combined Margin" (CM). The CM is the result of a weighted average of two emission factors pertaining to the electricity system: the "Operating Margin" and the "Build Margin" (UNFCCC, 2015b).

The Operating Margin (OM) is the emission factor that refers to the group of existing power plants whose current electricity generation would be affected by the proposed CDM project activity. The emission factor is calculated on the basis of the energies generated by plants dispatched to supply peak demands and reflect the volume of emissions that can be eliminated if the CDM project is adopted. In this sense, the OM emission factor by means of analyzing dispatch data is defined as the weighted average of the emission factors of plants that make up the 10% upper curve dispatch priority and is calculated for each hour (Brazil, 2008). Thus, the emissions from the Operating Margin can be consulted on the Brazilian Ministry website for every hour of every day of the year.

On the other hand, the Build Margin (BM) seeks to evaluate the contribution (emissions) of the plants that would be built if the project did not exist. The Build Margin emission factor is calculated as the weighted average emission factor of the set "M" of the most recently built power plants. The "M" set comprises the more recent plants comprising 20% of annual generation system, or by the latest 5 plants, if these account for more than 20% of the generation system (Brazil, 2008).

The CO2 emissions factor for electricity generated in Brazil for 2012, published by the Brazilian Ministry, and used in the model to calculate the emissions arising from using electric energy to produce and recycle materials is 0.3593. For the purposes of monitoring the variation of this factor, the numbers from previous years were 0.3095 in 2010 and 0.1988 in 2011 (Brazil, 2012).

2.3 Fossil Fuels Emission Factor

The CO_2 emission factors resulting from burning fossil fuels are calculated in accordance with the IPCC Guidelines for data on National Greenhouse Gas Inventories (Intergovernmental Panel on Climate Change -IPCC, 2006). These factors indicate the CO_2 amount emitted for every mega joule of fossil fuel burned and take into consideration the calorific value of the fuel and the emission factors per unit of energy.

The AMS-III.AJ methodology indicates that the fossil fuel emission factors used when calculating BE and PE should be expressed in terms of the quantity of CO_2 per Joule. Table 2 presents the emission factors for fuels used for the model proposed.

Table 2 - CO_2 Emission Factor for Fossil Fuels and Wood.

Fuel	Emission factor ($KgCO_2/MJ$)	Fuel	Emission factor ($KgCO_2/MJ$)
$EF_{fuel\ oil}$	0.07659	EF_{Wood}	0.11072
$EF_{diesel\ oil}$	0.07333	EF_{coal}	0.09270
$EF_{natural\ gas}$	0.05582	$EF_{coking\ coal}$	0.10770
$EF_{Black\ liquor}$	0.09438		

3. Description of the Proposed Model for Environmental Valuation

The environmental valuation model for recycling municipal solid waste seeks to establish a relationship between the recycling of materials and the reduction in CO_2 emissions that this practice produces, as illustrated in Figure 1.

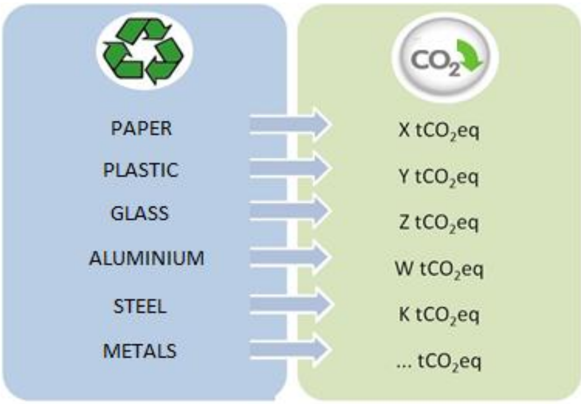

Figure 1 - Environmental valuation model.

The construction of the model is based on the AMS-III.AJ methodology, approved by the EB-CDM for the issue of carbon credits related to waste recycling projects.

Since this model was designed to portray the reduction in emissions obtained by recycling materials in general and it was not related to a specific project, in Equation (1) the term "project emissions" (PE) shall be replaced by the term "recycling emissions" (RE), and also does not consider Leakage, as shown in Equation (2).

$$ER = BE - RE \tag{2}$$

Where:

ER Emission Reductions (tCO2eq)

BE Baseline emissions (tCO2eq)

RE Recycling emissions (tCO2eq)

BE emissions are considered to be those related to the production of the materials from virgin raw materials, while RE refers to emissions arising from waste recycling activities.

It is worth noting that this model extends the scope of the AMS-III.AJ methodology, as it also shows the data necessary for calculating emissions arising from producing and recycling other materials, which are the typical solid waste components generated in Brazilian cities.

The model does not consider Leakages, since these are not significant in recycling projects, and refers to specific situations in specific projects, such as leaks and losses. Materials considered by the model are those accepted by the Ecoelce Program and are grouped as follows: Plastics; Metal; Aluminum; Steel; Glass and Paper/cardboard.

Although there are several types of paper, plastics and metals, the material groups were defined so as to simplify construction of the model and its subsequent use. Thus, the metal group includes materials such as iron, brass, bronze and lead. The paper/cardboard group includes white paper, mixed paper, Tetra Pak, newspaper and cardboard.

To estimate the electricity and fossil fuels consumed to produce and recycle materials, this paper considers the data used by Coelce to measure the results of Ecoelce, reports published by manufacturers' associations, national and international research institutes, data gathered on visits to industrial plants visits, statistical yearbooks and from the UNFCCC.

Variations in consumption between industries that manufacture or recycle the same type of material there may be because consumption depends on the technology, expertise and inputs used in the process. However, despite the complexity and limitations of the available information, the data estimates in this paper are extremely defensible, given that they were extracted from the technical literature and supplemented with visits to some industrial plants.

In addition, the goal of the model is to serve as a basis for programs that set out to encourage society to change its habits in relation to garbage and its goal is not to establish benchmarks or parameters between industries of the same sector.

3.1 Baseline Emissions (BE)

According to the AMS-III.AJ methodology, emissions arising from the production of the materials are calculated using Equation (3). As reported, the emissions from the production of the materials correspond to BE emissions, which comprise the consumption of electricity and fossil fuels, and their respective CO_2 emission factors.

$$BE = \sum_i \left[Q_i * L_i * \left(SEC_{Bl,i} * EF_{el} + SFC_{Bl,i} * EF_{FF,CO2} \right) \right] \tag{3}$$

Where:

BE Baseline emissions (tCO_2eq)

i Indexfor material type *i* (*I =1, 2, 3, 4, 5, 6, 7, 8* for PET, LDPE, HDPE, aluminum, brass, steel, glass and paper/cardboard, respectively)

Q_I quantity of material type *i* recycled (t)

L_i Adjustment factor

SEC_{Bli} Specific electricity consumption for the production of material type *i* (MWh/t)

EF_{el} Emission factor of the electricity generation grid (tCO_2eqMWh)

SFC_{Bli} Specific fuel consumption for the production of material type *i* (GJ/t)

$EF_{FF,CO2}$ CO_2 emission factor for fossil fuel used (tCO_2eq/GJ).

In the case of baseline paper emissions, the emissions caused by the decomposition of this material in dumps or landfills could also is considered, since recycling would prevent this occurring.

However, the model presented here does not consider these emissions for three main reasons. First, the model aims to present a conservative approach as to reducing emissions as a result of recycling. In addition, this study seeks to avoid double counting, since these emissions occur only once – during decomposition of the material – but would be recorded numerous times if the BE formula considered them. Finally, there is a limit to the number of times that paper can be recycled, as it loses some of its characteristics in each recycling process. Therefore, at the end of its useful life will likely be left to decompose in a dump or landfill.

Of course there are other ways of disposing of this material, which avoid methane being emitted into the atmosphere. Nevertheless, as there is no way to ensure that such appropriate disposal will occur, in this regard the model adopts a conservative approach, assuming the worst-case scenario regarding emissions.

3.1.1 Electricity and fossil fuel consumption for the production of materials

The consumption of electricity (in kWh) and the sources surveyed and specific consumption of some fuels (in MJ) to produce 1 ton of each material are presented in Table 3.

Table 3 - Electricity and Fossil Fuel Consumption for the Production of Materials

Source	Material	SEC_{BI} (kWh)	Fuel	SFC_{BI} (MJ)
Calderoni (2003) UNFCCC (2015b)	Plastics	6,740.00	Natural gas	15,000.00
Calderoni (2003) IPEA (2010)	Aluminium	17,600.00	Fuel oil Coking coal	24,974.07 10,532.72
Bir (2008)	Metals	2,777.78	---	---
Calderoni (2003) IPEA (2010)	Steel	6,840.00	Fuel oil Diesel oil Coal Coking coal	250.48 41.71 668.32 10,359.95
Calderoni (2003) Brazil (2015)	Glass	4,830.00	Natural gas	8,025.60
Calderoni (2003) Bracelpa (2010)	Paper/ Cardboard	4,980.00	Natural gas Fuel oil Black liquor	9,550.00 2,123.00 22,122.00

3.1.2 CO2 emissions caused by the production of materials

By entering in Equation (3) specific consumption values and their respective emission factors, the BE emissions arising from the production of 1 metric ton of each material are calculated, expressed in kg of CO_2 equivalent (kgCO_2eq) (see Table 5).

Among the equivalent CO_2 emissions resulting from the production of these materials, attention is drawn to the aluminum and the paper/cardboard industries, which emit large amounts of pollutants due to the high consumption of electricity and fossil fuels, when compared with the quantitative materials used to produce the other materials.

3.2 Emissions resulting from Waste Recycling (RE)

As indicated by the methodology AMS-III.AJ emissions from recycling are also calculated based on consumption of electricity and fossil fuels used in the process, as well as their CO_2 emission factors. However, some aspects needed to be adapted, because:

a) As this is not a specific project, the amount of recycled material (*Qi*) will be considered;
b) The specific electric power consumption (*SECi*) and fossil fuels consumption (*SFCi*) for recycling of materials will be considered;
c) Since the calculation for the emissions factors for fossil fuels already takes into account their calorific value, it is not necessary to use this element when calculating the emissions from recycling.

Therefore, Emissions from recycling materials are calculated using Equation (4), considering the adjustments discussed above.

$$RE = \sum_i Q_i * (SEC_i * EF_{el} + SFC_i * EF_{FF,CO2}) \quad (4)$$

Where:
RE - Emissions resulting from recycling *i* material (tCO_2eq)
i - Index for material type *i* (*i 1, 2, 3, 4, 5, 6, 7, 8* for PET, LDPE, HDPE, aluminum, brass, steel, glass and paper/cardboard, respectively)
Qi - Quantity of type *i* recycled material (t)
SEC_i - Specific electric power consumption of the recycling unit proportional to type *i* material (MWh/t)
EF_{el} - Emission factor of the electricity generation grid (tCO_2eq/MWh)
SFC_i - Specific recycling unit fuel consumption proportional to *i* type material (mass unit or volume/t)
$EF_{FF,CO2}$ - CO_2 emission factors for fossil fuel consumed in recycling unit (tCO_2/GJ)

3.2.1 Electricity Consumption for recycling materials

The electricity consumption (in kWh) for recycling each metric ton of material is presented in Table 4. Just as when calculating emissions from the production of materials, the same values are used as those in Coelce for measuring energy gains of Ecoelce.

Table 4 - Electricity Consumption for Materials Recycling.

Source	Material	SEC_{Bi}(kWh)
Calderoni (2003)	Plastics	1,440.00
Calderoni (2003)	Aluminium	700.00
Bir (2008)	Metals	35.83
Calderoni (2003)	Steel	1,780.00
Calderoni (2003)	Glass	4,190.00
Calderoni (2003)	Paper/cardboard	1,470.00

3.2.2 Fossil fuels consumption for materials recycling

Data from technical visits were used in relation to the consumption of glass and paper/cardboard. In case of glass recycling, estimates were obtained from one of the industrial plants of Owens-Illinois, the largest manufacturer of glass containers in the world. Given the size of and the technology employed in the company, the values obtained may be considered as a worldwide benchmark and perfectly applicable to the model proposed here.

While in the recycling of paper/cardboard a visit was made to one of the largest paper/cardboard manufacturing industrial plants in Brazil and the world, which did not authorize its name to be published in this study.

The values that were found in the survey of the sources on fossil fuel used for recycling 1 metric ton of each material considered by the model are 2,527.00 MJ for Glass and 5,242.33MJ for Paper/Cardboard. In both cases the fuel analyzed through visits was Natural Gas.

3.2.3 CO2 emissions for recycling materials

Equation (4) was used to calculate emissions arising from recycling 1 metric ton of each of the materials considered by the model, in kilograms of CO_2 equivalent ($kgCO_2eq$). Therefore, Table 5 presents both emissions caused by the production of materials and from waste recycling and the difference between them as part of the analysis.

Table 5 - Waste Recycling Environmental Valuation Model

Material	BE (a)	RE (b)	ER (a-b)
Plastics	2,444.23	517.39	1,926.84
Aluminium	8,715.31	251.51	8,463.80
Metals	808.43	12.87	795.55
Steel	3,584.82	639.55	2,945.27
Glass	1,921.40	1,646.52	274.87
Paper/cardboard	4,252.77	820.80	3,431.98

Among the materials that emit less greenhouse gases during their process of recycling are metals, followed by aluminum, steel and plastics. Note that the recycling process involves, for most materials, only the consumption of electric energy.

This characteristic derives from the fact of much of the material recycling processes involving only activities such as washing, crushing, grinding, and casting, which are usually carried out by machines powered by electricity. Other recycling processes are of a physical/chemical origin, which do not require the use of energy.

4 Results

This section presents an application of the environmental valuation proposed model of recycling municipal solid waste in Brazil. A simulation to existing and collected values of the quantities of energy in manufacturing and material recycling and the amount of CO_2 released into the atmosphere according to two ways of having the final product data was performed. The other data collected (the amount of material being recycled) were based on historical data from three months of Ecoelce Program. This study is of great importance, since other potential program can be deployed, such as: Green Account Program, facing residential customers offering discount and their electric bills and showing the people the reduced amount of CO_2 that is released into the atmosphere.

4.1. Environmental valuation model for recycling waste

It is noteworthy that the term "environmental valuation" is used here not in the sense traditionally found in the literature– that is the economic valuation of natural resources – but in the sense of valuing recycling benefits to the environment, in terms of GHG emissions avoided.

Once calculated the emissions arising from producing (BE) and recycling (RE) the materials listed in the model, it is possible to establish CO_2eq emissions avoided through this action. As described in the previous sections, the above emissions from processes were calculated from the amount of electricity and fossil fuels used found in the technical literature and as a result of visits to industrial plants.

Such data can be and should be revised over time since new technologies are constantly being developed bearing in mind the efficiency of the energy process and the reduction in the consumption of fossil fuels. In addition, over time the productive process is perfected and modified in addition to which raw materials are employed, thus generating variations in the quantity of the inputs used.

Table 5 summarized the environmental valuation model of recycling municipal solid waste, based on the reduction in CO_2 emissions that recycling provides to the environment. It is observed that aluminum is the material, the recycling of which most contributes to reducing CO_2 emissions. This fact derives from the high amounts of energy it takes to produce it, whereas its recycling demands much less energy.

The results from the model demonstrate the importance of evaluating recycling practice by considering all the energy variables, namely both in the consumption of electric energy and of fossil fuels. Normally only the first aspect is evaluated, with the gains made in this sphere being highlighted, while the consumption of fossil fuels is not evaluated.

It is clear that, in terms of reducing GHG emissions, the expected benefits are not obtained by reducing only the consumption of electricity as a result of recycling waste. The consumption of fossil fuels must also be reduced, thus ensuring that recycling effectively contributes to preserving the environment.

4.2. Greenhouse Gases Emission Reduction due to Ecoelce Program

Data on waste were collected for the months of June, July and August 2012 to assess the Ecoelce environmental benefits in terms of reducing the GHG emission. In these months, the operations undertaken by Ecoelce were routine, there being no factors that significantly changed the volume of the recyclable waste it collected. The period analyzed had an average of 3,100 clients per month who attended to collection points and held the delivery of waste, getting discounts on their energy bill.

The data used in this pilot application include:

a) Identification of the customer through the contract number;

b) Quantity, in kg, of each type of waste delivered to the customer to Ecoelce Program;

c) Consumption of electricity of each customer in the reference month.

Through the model presented in this paper, it is possible to estimate the amount of CO_2 that was not emitted into the atmosphere as a result of the recycling actions carried out by the Ecoelce Program.

This estimate is calculated in a simple and direct way, that is: the weight of each waste type is multiplied by its recycling environmental value, as per the environmental valuation model presented in Figure 1. Table 6 presents the weight, in kilograms, of each waste type collected by Ecoelce program during the months surveyed.

As can be observed, in Table 6, the amount of waste collected in the three months surveyed totaled more than 430 thousand kilograms, a very significant amount, given the short period for which data were collected. It is noticed that, in relation to weight, group paper/cardboard represents approximately 49% of all material collected by Ecoelce in the period considered for this simulation. Followed by the group of plastics, whose weight is about 22% of the material collected in the period, followed by the group of metals, glass, steel and aluminum.

Table 6 - Ecoelce waste collected during the months covered by the survey

Months	**Plastics**	**Alumínium**	**Steel**	**Metals**	**Glass**	**Paper/Cardboard**	**Total (kg)**
June	28,320.70	2,480.24	4,634.32	20,232.58	11,800.29	58,397.10	125,865.23
July	32,463.84	3,053.21	5,374.54	22,323.17	15,436.27	78,075.38	156,726.41
August	33,173.90	2,579.63	2,127.24	22,712.85	15,092.69	75,015.09	150,701.40
Total	93,958.44	8,113.08	12,136.10	65,268.60	42,329.25	211,487.57	433,293.04

Based on the valuation model presented in this paper, Table 7 presents an estimate of the amount of CO_2, in kg, that was not emitted into the atmosphere as a result of the recycling actions undertaken by the Ecoelce Program.

Table 7 - Emissions avoided due to ECOELCE program activities.

Material	**Plastics**	**Aluminium**	**Steel**	**Metals**	**Glass**	**Paper/ Cardboard**	**Total**
Waste Collected (t)	93.96	8.11	12.14	65,27	42.33	211.49	433.29
Environmental Value of Recycling (kgco2/t)	1,926.84	8,463.80	795.55	2,945.27	274.87	3,431.98	---
Emissions Avoided (kgco2)	181,045.78	68,641.39	9,658.00	18,466.81	11,635.36	725,828.43	1015,275.77

The analysis of the application of the model shows that in just three months, Ecoelce program activities, approximately 1,000 metric tons of carbon dioxide were not emitted into the atmosphere, an excellent program result for society and for the environment.

In order to have an idea of the dimension of this number, if each person travels about 527 miles per month, and if this were done in a popular car, with an engine of up to 1.4L, it would emit approximately 1.55 metric tons of CO_2 into the atmosphere. Therefore, the Ecoelce program would neutralize monthly emissions of about 220 popular cars. As to the Energy Company of Ceará, for example, this would balance out all monthly emissions from its fleet of cars.

5. Discussion

The relationship between recycling and reducing CO_2 is of great importance, since the IPCC studies suggest that global warming observed in recent decades which caused a series of environmental disasters is directly related to anthropogenic emissions of greenhouse gases. Not surprisingly, the main global climate agreements are related to the reduction and limitation of GHG emissions by the industrialized countries, what had motivated the creation of a global emissions market that worth billions of dollars annually.

Therefore, the proposed model reflects the benefits of recycling typical solid waste disposed in Brazilian cities. These wastes that are produced in large quantities by modern society, increasing - in an even higher proportion - the costs and problems associated with their management. This model enables the environmental benefits of the Ecoelce Program to be measured and also generates various possibilities for creating educational programs and initiatives with a focus on environmental awareness.

Moreover, this model relates each material to the reduction of GHG emissions that its recycling provides. As explained before, this valuation is not related to the monetary value of the material itself, but the benefits of its recycling to the environment, in terms of GHG emissions reduction.

In this sense, the results obtained show that the material that presents the greatest potential to reducing emissions through recycling is aluminum, the production of which demands large amounts of electricity and fossil fuels. Next, comes the group of paper/cardboard, plastics, steel, metals and last of all is glass. It should be noted, however, that despite the reduction in emissions per metric ton be largest for aluminum, the materials discarded in more abundance by Brazilian population are paper/cardboard, followed by plastics. Thus, in absolute terms, the largest reductions in emissions would be achieved through recycling programs, like Ecoelce, would certainly be derived from these groups.

To sum up, fulfilled the necessary steps for the formulation of the model, it became possible to relate the recycling of materials and CO_2 emissions avoided through this practice. Based on these figures, Coelce may disclose the environmental results of Ecoelce and encourage their customers to recycle more and more wastes, contributing to the environment and giving more visibility to the program and to the company environmental actions.

Furthermore, Coelce can use this model to compare the emissions of its customers arising from the consumption of electricity with emissions avoided by them through participation in Ecoelce, encouraging them to neutralize their emissions on the environment. This initiative would also help to solve one of the biggest difficulties of the Ecoelce, because it would motivate new registrations and would help to retain current participants, once they would be always seeking to neutralize their monthly CO_2 emissions, causing them to have an environmental conscience and not be concerned only with reducing the payment of energy.

6. Conclusions and policy implications

About 7 million metric tons of waste were not even collected in Brazil in 2014, being inappropriately discarded in rivers, water springs, hills, etc. (ABRELPE, 2014). The implementation of solid waste management politics help significantly in improving this scenario, but by itself does not guarantee that the required results will be achieved.

The solution to this problem is not the implementation of isolated actions, but by a series of integrated initiatives involving public and private sector. These actors should make use of advanced management tools and methodologies, but also creativity and imagination, fostering initiatives that generate benefits for the population and for the environment.

The Ecoelce Program is an example of such initiative. Exchanging recyclable waste by bonus on energy bills Coelce contributes to reducing the volume of waste sent to landfills, preserves the environment and generates income for the population, reducing delinquency and energy theft. Programs of this nature reflect how creativity can make a difference in a setting of limited resources and low education.

Some proposals for future studies, arising from this research, which can complement and/or assist improving the environmental valuation model for the recycling of MSW, can be made.

Firstly, due to the complexity and limitations of the information available about consumption of energy and fossil fuels to produce and recycle the materials, it is suggested to carry out a national survey, an in-depth and more comprehensive national survey be carried out, which should involving important national agents such as the Ministry of Mines and Energy, the National Electric Energy Agency (ANEEL) and the associations of manufacturers.

Such information is of great importance, since recycling programs are becoming increasingly common in Brazil, being seen as initiatives that conserve natural resources and the environment. In addition, according to Johnson et al. (2008), to create a comprehensive energy policy and a system thorough analysis, one must examine the energy demands of each industry, thus gathering the knowledge that industry needs for decision making.

However, unless there are consistent inputs of information used regarding the production and recycling of these materials, it cannot be confidently asserted that this practice is really generating the environmental benefits forecast. This generates a second offshoot from this research, which is detailed below.

In addition, currently, the environmental impacts of products and services are characterized as an important criteria considered by consumers when purchasing any product. Therefore, using the results of the industry survey, mentioned in the previous section, it would be possible to create a sort of "voluntary environmental certification" for recycling industries, indicating for society in general if the recycling process done in that specific industry effectively contributes to the environmental preservation.

This paper demonstrates it is evident that the benefits of recycling to the environment cannot be assessed only through the power savings provided by the process. To measure GHG emissions, it is also necessary to evaluate consumption of fossil fuels used in the whole process to ensure that this practice is actually bringing environmental benefits.

A lot of recycling plants around the world realize their processes using old and outdated equipment, which use large amounts of fossil fuels (diesel, for instance) or firewood for operation. Such plants can generate higher emissions than those resulting from the production of the material from virgin raw material. In these cases, recycling is not the best practice to reduce emissions and the volume of waste sent to landfills. Even the incineration of these wastes would present better environmental results.

Therefore, the certification process of recycling plants would be based on the methodology AMS - III.AJ and on the environmental valuation model presented in this paper in order to ensure that emissions from these products recycling are lower than those of its production from the virgin raw material.

The creation of such certification would help coordinators of recycling programs, just like Ecoelce, to know which recycling plants they should send all collected waste. Thus, these programs would gain even more credibility in society, because it would be possible to assure customers that their efforts to collect, sort and deliver waste effectively contribute to environmental preservation.

To sum up, besides the data of energy consumption and fossil fuel production and recycling of materials used in the model that should be more accurate through a deep and comprehensive national survey, this study has other limitations. One refers to the fact that research has been performed in only three months. This happened because the company provided data only for the period of this study. There are also other ways to assess the benefits of recycling. Other research also close to Ecoelce program can be carried as a social, economic, public health and other aspects of environmental area researches.

Acknowledgment

The authors are grateful to all professionals involved in the coordination of the COELCE R&D Program and ECOELCE program, who provided all the information and cooperated in the best possible way. Special thanks are due to Nilo Rodrigues from COELCE; Eduardo Jucá and José Simões of 3E Engineering. This work is part of a research program funded by the Brazilian Research Council (CNPq).

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