CLEISEANO EMANUEL DA SILVA PANIAGUA
(ORGANIZADOR)

Collection:

APPLIED ENVIRONMENTAL AND SANITARY ENGINEERING

Atena Editora
Ano 2022

Collection: applied environmental and sanitary engineering

Diagramação: Camila Alves de Cremo
Correção: Flávia Roberta Barão
Indexação: Amanda Kelly da Costa Veiga
Revisão: Os autores
Organizador: Cleiseano Emanuel da Silva Paniagua

Dados Internacionais de Catalogação na Publicação (CIP)

C697 Collection: applied environmental and sanitary engineering / Organizador Cleiseano Emanuel da Silva Paniagua. – Ponta Grossa - PR: Atena, 2022.

Formato: PDF
Requisitos de sistema: Adobe Acrobat Reader
Modo de acesso: World Wide Web
Inclui bibliografia
ISBN 978-65-5983-857-8
DOI: https://doi.org/10.22533/at.ed.578221901

1. Environmental and sanitary engineering. I. Paniagua, Cleiseano Emanuel da Silva (Organizador). II. Título.
CDD 628

Elaborado por Bibliotecária Janaina Ramos – CRB-8/9166

Atena Editora
Ponta Grossa – Paraná – Brasil
Telefone: +55 (42) 3323-5493
www.atenaeditora.com.br
contato@atenaeditora.com.br

CIÊNCIAS EXATAS E DA TERRA E ENGENHARIAS

Atena Editora
Ano 2022

SUMÁRIO

CAPÍTULO 13

OPTIMIZING REVERSE LOGISTIC NETWORK PROPOSAL OF WASTE PICKERS ORGANIZATIONS WITH WASTE TRANSFER STATIONS TO IMPROVE THE ECONOMIC EFFICIENCY OF RECYCLING CHAIN

Data de aceite: 10/01/2022

Marcus Camilo Dalvi Garcia
Universidade Federal do Espírito Santo
Vitória – ES
http://lattes.cnpq.br/8821644474582580

Renato Ribeiro Siman
Universidade Federal do Espírito Santo
Vitória – ES
http://lattes.cnpq.br/5990166591886283

Maria Claudia Lima Couto
Instituto Federal de Educação, Ciência e Tecnologia do Espírito Santo
Ibatiba – ES
http://lattes.cnpq.br/2695461921975246

Luciana Harue Yamane
Universidade Federal do Espírito Santo
Vitória – ES
http://lattes.cnpq.br/2770673036643419

Rodrigo Alvarenga Rosa
Universidade Federal do Espírito Santo
Vitória – ES
http://lattes.cnpq.br/7706827408886021

Gisele de Lorena Diniz Chaves
Universidade Federal do Espírito Santo
Vitória – ES
http://lattes.cnpq.br/0319559373628489

ABSTRACT: This study evaluates the financial and operational feasibility of Waste Transfer Station (WTS) installations in order to increase the operational scale of Waste Pickers Organizations network in the Espírito Santo state, Brazil. Using information gathered from 18 areas, 10 different scenarios were analyzed using a two-layer, Mixed Integer Linear Programming (MILP) model. Input data for different scenarios considered costs (installation, operation, and transportation), recycling companies' capacity, recyclable waste prices and generation, population projection, municipal waste collection (%), gravimetric composition, and diversion rates from landfills. MILP model analyzed the technical and financial variables to include WTS from the perspective of expanding and enabling WPO networks. By implementing the strategies developed by the analysis herein, higher recyclable material yield could increase economic returns from WPOs by as much as 61%. In all scenarios evaluated, the economic returns were positive, ranging from US$ 1.24 to 11.39 million a year due to large-scale commercialization.

KEYWORDS: Facility location model, Waste Transfer Stations, Waste Pickers Organizations, municipal solid waste, recyclable waste.

1 I INTRODUCTION

In low-income and middle-income countries, the informal recycling sector such as Brazilian Waste Pickers Organizations (WPOs) play an important role in municipal solid waste management (Gall et al. 2020), since the waste pickers are main stakeholders of a waste trading system, as well as the households, middlemen, larger dealers and finally, the remanufacturing industries (Suthar et al., 2016). However, poor quality of life and safety at work, wages and collection rates limit their performance in the recycling chain (Fidelis et al. 2020; Navarrete-Hernandez and Navarrete-Hernandez 2018). Due to limited economic returns, low governmental support and difficulties associated with self-management, WPO are currently unable to compete in the recycling market.

According to Fergutz et al. (2011), the lack of an economy of scale weakens WPOs' bargaining power by causing intermediaries to pay about 10% of what recycling companies would pay. The scale depends of population size, types of implemented municipal selective collection, agreements with companies, number of associated waste pickers and structure capacity (Dutra, Yamane, and Siman 2018). In addition to the difficulty of reaching a highly profitable operational scale, WPOs also have structural constraints such as the lack of an operational screening structure, transportation to reach the recycling industry, and storage (Tirado-Soto and Zamberlan 2013).

The development of larger networks could potentially make WPOs sufficient in negotiating larger volumes and ensuring supply regularity to the market, which would then enable a sufficient volume in a given area to overtake brokerage structures (Dutra, Yamane, and Siman 2018). To increase commercialization capacity and reduce transportation costs, Ferri et al. (2015) evidenced the benefits provided by Waste Transfer Stations (WTS's) within a reverse logistics structure.

Waste Transfer Stations are usually part of the municipal solid waste management (MSWM) system for the temporary storage been an intermediate link between the source and treatment ensuring efficient transport through storage and high-density compression of waste, reducing waste transportation and final disposal cost (Liu and Zheng 2020). There are various studies which have taken to modeling Waste Transfer Station locations for MSWM considering different aspects and approaches (Rathore and Sarmah 2019; Chatzouridis and Komilis 2012; Yadav et al. 2016; Ağaçsapan and Çabuk 2020; Kůdela et al. 2019) and construction and demolition management system (Lin et al. 2020), but any study explore the WTS creation to expand WPO network.

Ağaçsapan and Çabuk (2020) evaluated geographical information systems (GIS) technologies to determine the potential suitable locations for waste transfer stations in Eskişehir, Turkey. Chatzouridis and Komilis (2012) investigated an optimal design of a solid waste collection network in the Region of Eastern Macedonia – Thrace that consists of waste production nodes (municipalities), intermediate nodes (waste transfer stations) and final nodes (landfills) using binary programming and concluded that the implementation of 12 WTS could minimize total collection cost from €52.5 t^{-1} to €42.4 t^{-1}. In this sense, Kůdela et al. (2019) applied a mathematical model for the design of an WTS grid to mixed municipal waste management of Czech Republic that allowed define a range of strategies and respective impacts analysis on the municipalities and waste processing plants.

Rathore and Sarmah (2019) proposed a model with WTS strategically located in Bilaspur, India under unsegregated and segregated waste scenarios considering the overall cost of municipal solid waste management and tools of a geographic information system. Yadav et al. (2016) proposed the use of a mathematical model to select the optimal areas for the installation of WTS's within a municipal solid waste management system. Couto and Lange (2017) also reported optimal territorial arrangements for post-consumer reverse packaging logistics employing a packaging specific WTS location model.

Pishvaee et al. (2010) presented classic quantitative models related to reverse logistics, among them the facilities localization model based on Mixed Integer Linear Programming (MILP). The literature review presented by Rathore and Sarmah (2019) containing 14 studies (1970-2017) MILP, MINLP (mixed integer nonlinear programming) and heuristic were the main approaches employed to find the best potential sites for WTS in order to improve the solid waste management system. However, these studies did not aimed at incorporated WTS into WPO network that is, optimizing the logistics network from the point of view of this link in the reverse supply chain, aiming at increasing its bargaining power vis-à-vis other actors. The contribution of this paper relies in this approach, considering the reality of developing countries where the social involvement of the WPO is an important element to ensure its integration into the MSWM.

The proposed logistics networks tends to centralize the recyclable waste in few WTS, increasing the amount of recyclable waste in one WTS, becoming more attractive to be bought by the recycling companies as the costs of collection and transport of higher material quantities would be reduced. The gathering of the material contributes to provide WPOs' supply more competitive vis-à-vis intermediaries, which will potentially bring benefits of increased income and formalization of these organizations. These benefits were assessed considering the recyclable waste landfill diversion targets established by the legal framework related to SWM in Brazil. Therefore, this study is an important contribution for the policymakers, WPO managers and recycling companies, by analyzing the impact of the WTS inclusion to increase the operational scale of WPOs, which reflects on waste pickers income and contributes for a sustainable waste management strengthening the social aspect of the network beyond the environmental and economic elements.

The proposed network was developed using a MILP mathematical model and enabled the investigation of various scenarios governing WPO network profitability, taking into account the quantity, location and capacity of the WTS's as well as the respective costs of installation, operation and transportation.

2 | MATERIALS AND METHODS

2.1 Case study

The study area consisted of the state of Espírito Santo (ES) located in southeastern Brazil, which has 46.09 thousand km² and an absolute population of 3,972,388 inhabitants as of the year 2013 (IBGE, 2018). Of the 65 WPOs currently in operation in state of Espírito

Santo (ES), Brazil, 35 agreed to take part of this study. A full characterization of the study area regarding the solid waste management system and the current involvement of the waste pickers organizations is provided by Siman et al. (2020) that point out the necessity of establishment of commercial networks to improve the WPOs' efficiency and achieve gains in scale and quality.

Beyond this characterization, it's also important to highlight the challenge of properly managing the solid waste collected daily by WPOs, besides existence of legal framework for urban solid waste management in Brazil. According to Brazilian National Solid Waste Policy (NSWP) requirements, uncontrolled landfills (dumpsites) should be extinct, but people who made their living there (informal waste pickers) needed to be reappointed by creating WPOs and included into the management of urban solid waste. Since then they can work independently or associated with a Waste Picker Organization (Dutra et al., 2018).

2.2 Evaluation of different scenarios by mathematical model

Our paper proposes to structure the logistics network in two levels connected by Waste Transfer Stations (WTS), in which the recyclable waste is stored while it is being moved along the logistics networks. The proposed mathematical model considers in the first level the WPO and the WTS. In the second level there are the WTS and the RC. Each WTS can be open in different ranges of capacity, but the available ranges of capacity are the same for all WTS. The proposed logistics network can be seen in Figure 1.

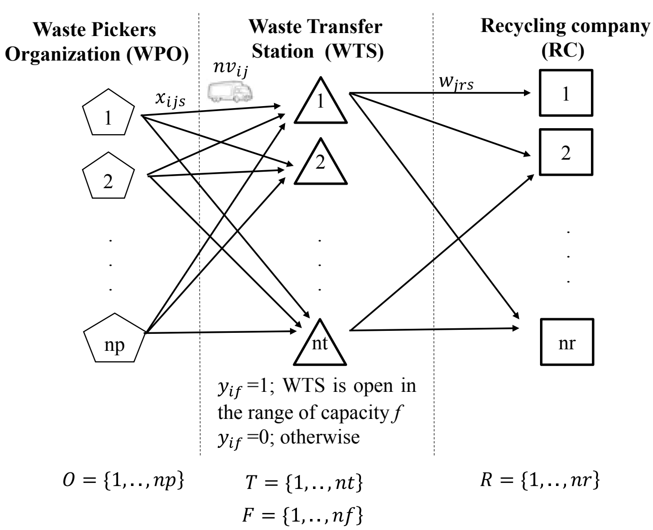

Figure 1 – Proposed structure of the logistics network.

The mathematical model aims to define the logistics network which maximize the revenue received by selling the recyclable waste to the RC minus the total cost, represented by the sum of the costs to install and to operate the WTS in a specific range of capacity, plus the cost to freight trucks to transport from all WPO to all chosen WTS. The mathematical model defines which WTS must be open and in which range of capacity, and how many tons of recyclable waste are transported from each WPO to each WTS and the number of trucks needed to do this transport. It also defines how many tons of recyclable waste is transported from each WTS to each RC, making it possible to calculate how much recyclable waste each RC will receive. It is considered in our model that there are several types of recyclable waste. Each WPO informs how many tons of recyclable waste it generates. Each RC has a maximum capacity to receive each type of recyclable waste.

Considering *np* the number of WPO; *nt* the number of available WTS to be installed; *nr* the number of RC; *ns* the number of different recyclable waste; and *nf* the number of different range of capacities each WTS can be open; then the proposed mathematical model is presented in five parts: sets, parameters, decision variables, objective function and constraints (subject to). The main sets and the decision variables are showed in Figure 1.

Sets

0 - Set of WPO, $0 = \{1,..,np\}$;

T - Set of WPO, $T = \{1,..,nt\}$;

R - Set of RC, $R = \{1,..,nr\}$;;

S - Set of different recyclable waste, $S = \{1,..,ns\}$;

F - Set of different range of capacity in which each WTS can be open, $F = \{1,..,nf\}$.

Parameters

co_{jf} – Total cost to install and to operate WTS $j \in T$ in the range of capacity $f \in F$;

ct_{ij}- Cost to freight one truck to transport all the recyclable waste from WPO $i \in C$ to WTS $j \in T$;

tq_{jf}– Total capacity of WTS $j \in T$ in the range of capacity $f \in F$ to process all types of recyclable waste;

rq_{rs}- Total capacity of RC $r \in R$ to receive the recyclable waste $s \in S$;

mv – Trucks' capacity, considering a fleet in which all trucks are equal;

oq_{is}- Total amount of recyclable waste $s \in S$ generated by WPO $i \in C$;

rv_{rs}- Value paid by RC $r \in R$ for each ton of recyclable waste $s \in S$.

Decision variables

x_{ijs} - Total tons of the recyclable waste $s \in S$ sent from WPO $i \in C$ to WTS $j \in T$;

w_{jrs} - Total tons of the recyclable waste $s \in S$ sent from WTS $j \in T$ to RC $r \in R$.

y_{if} - Binary variable; if WTS $j \in T$ is open in the range of capacity $f \in F$ then it is equal to 1, and 0, otherwise;

nv_{ij} - Number of trucks needed to transport all the recyclable waste from WPO *i* є *C* to the WTS *j* є *T*.

The objective function (OF) (Equation 2) represents the revenue received by selling the recyclable waste to the RC minus the total cost, represented by the sum of the costs to install and to operate the WTS in a specific range of capacity, plus the cost to freight trucks to transport from all WPO to all chosen WTS. The OF must be maximized to achieve a more profitable result to the logistics network.

Objective function

Maximize

$$\sum_{j\in T}\sum_{r\in R}\sum_{s\in S} rv_{rs}\, w_{jrs} - \sum_{j\in T}\sum_{f\in F} co_{jf}\, y_{jf} - \sum_{i\in O}\sum_{j\in T} ct_{ij}\, nt_{ij} \tag{2}$$

The objective function is subject to some constraints represented by Equations 3 to 13. Constraints (3) assure that all recyclable waste generated by WPO *i* є *0* must be sent to any WTS. Constraints (4) guarantee that if WTS *j* є *T* is open in a certain range of capacity *f* є *F*, then it cannot receive more than this capacity. Constraints (5) assure that each WTS will be open in just one range of capacity. Constraints (6) guarantee that it will not be open more WTS than the number of available WTS to be open. Constraints (7) states that all recyclable waste received by WTS *j* є *T* from all WPO must be sent to the RC. Constraints (8) do not allow that RC *r* є *R* receives more than its capacity for each type of recyclable waste. Constraints (9) define the number of trucks needed to transport all recyclable waste from all WPO to all WTS. Constraints (10) to (13) define the domain of the decision variables.

Subject to:

$$\sum_{j\in T} x_{ijs} = oq_{is} \qquad \forall i \in O, s \in S \tag{3}$$

$$\sum_{i\in O}\sum_{s\in S} x_{ijs} \le y_{jf}\, tq_{jf} \qquad \forall j \in T, f \in F \tag{4}$$

$$\sum_{f\in F} y_{jf} \le 1 \qquad \forall j \in T \tag{5}$$

$$\sum_{j\in T}\sum_{f\in F} y_{jf} \le nt \tag{6}$$

$$\sum_{i\in O} x_{ijs} - \sum_{r\in R} w_{jrs} = 0 \qquad \forall j \in T, s \in S \tag{7}$$

$$\sum_{j\in T} w_{jrs} \le rq_{rs} \qquad \forall r \in R, s \in S \tag{8}$$

$$nv_{ij} \ge \frac{1}{mv}\sum_{s\in S} x_{ijs} \qquad \forall i \in O, j \in T \tag{9}$$

$$y_{jf} \in \{0,1\} \qquad \forall j \in T, f \in F \tag{10}$$

$$nv_{ij} \in \{0,1\} \qquad \forall i \in O, j \in T \qquad (11)$$

$$x_{ijs} \in \mathbb{R}^+ \qquad \forall i \in O, j \in T, s \in S \qquad (12)$$

$$w_{jrs} \in \mathbb{R}^+ \qquad \forall j \in T, r \in R, s \in S \qquad (13)$$

2.3 Experimental procedure

The experimental procedure was developed in 3 stages. In the first stage, all necessary input data for the mathematical model was collected or calculated. In the second stage, different scenarios were analyzed with various model input combinations being utilized. In the Stage 3, a sensitivity test was carried out in order to evaluate input data variations on the gravimetric composition of waste, recyclable waste landfill diversion targets, and truck transport capacity. Also, a map with the proposal WPO network illustrating recyclable materials flow and optimum locations of WTS was create to the reference scenario.

2.3.1 Stage 1 – Input data collection and calculation

2.3.1.1. Input data collection from Waste Pickers Organizations

Information regarding infrastructure, production costs, operational screening processes, tailings content, volume of waste sold, and market prices per unit of commercialized waste were collected by interview. Tailings content are the portion of the waste collected by the WPO unsuitable for selling to recycling companies and sent to the landfill (Pinha and Sagawa 2020).

Either the president or a waste picker appointed by the organization itself of the 35 WPO were interviewed. The interview was conducted in person with support of experts from Instituto Sindimicro – ES, professionals who have been monthly visiting the WPOs of Espírito Santo during 3 years (2015–2017) in order to prepare reports such as Gravity Composition Report, Productive Layout Analysis Report, Risk Map Report, and Economical Feasibility Analysis Report.

2.3.1.2. Input data collection from Recycling companies

In Brazil, the recycling companies pay for the recyclable waste and also pay to pick up and transport it from its origin, a Waste Pickers Organization or an intermediate/trader, to a Recycling Company (RC). The State Institute of Environment and Water Resources (IEMA), the City Halls, the Recycling Unions and the Espírito Santo State Board of Trade (JUCEES) were consulted to identify the recycling companies operating in the state. They were invited to participate in an online survey (Appendix A) through the Google Forms tool.

Through this survey, the following information was collected: amount of recyclable material purchased (paper/cardboard, plastic, metal, and glass), purchase price, and whether some barrier can be overcome by buying WPO waste. The collected data were used to project the values of recyclable material in the period between 2020 and 2035. In total, 20 recycling companies participated in the survey, being classified according to annual revenues: 10% of individual micro entrepreneurs (up to US$ 15,503), 35% of micro-scale operations (up to US$93,023), 35% of small-scale operations (up to US$930,232), 15% of medium-scale operations (up to US$5,167,958), and 5% of large-scale operations (over US$5.167 million) considering a conversion rate of 1 US$ = R$ 3.87.

2.3.1.3. Input data calculation for the mathematical model

Eighteen potential areas were selected for WTS installation. Of these, 14 are state-owned areas available for the creation of consortium public landfills and four are WPO-owned areas that have been selected due to their size being larger than 1,000 m² identified in WPO interviews. Information on the location and land area of the state-owned areas were obtained from the Brazilian Federal Official Gazette.

The choice of these areas was justified by the economy of land expropriation, since they already belong to the state government or are allocated for WPO operations by the relevant municipal government. Input data for the evaluation of an improved WPO network were estimated for the years 2020-2035 from survey responses, documentary research and literature review as described below.

Estimated cost of installation and operation

The installation cost is related to the construction costs of the physical facilities, as well as the purchase of machines and equipment. Operating costs involve personnel costs (concierge, administration, sorting, and logistics operators), equipment maintenance, as well as costs associated with the supply of food, energy, water, gas, and telecommunications. It is described in 15 ranges directly proportional to the WTS's recyclable waste receiving capacity (tons/week) as shown in Table 1. Installation and operation costs were described per week, considering 20 years of service life.

Ranges	Useful area of the warehouse (m^2)	Capacity (tons/ week)	Costs (US$/week)		
			Installation[(a)]	Operating[(b)]	Total
Range 1	600	14	US$ 133.87	US$ 990.93	US$ 1,124.80
Range 2	1200	28	US$ 267.75	US$ 1,517.40	US$ 1,785.15
Range 3	1800	42	US$ 401.62	US$ 2,330.38	US$ 2,732.00
Range 4	2400	56	US$ 535.50	US$ 3,014.03	US$ 3,549.54
Range 5	3000	70	US$ 669.38	US$ 3,829.30	US$ 4,498.68
Range 6	4500	105	US$ 1,004.07	US$ 5,375.41	US$ 6,379.48
Range 7	6000	140	US$ 1,338.76	US$ 7,040.79	US$ 8,379.55
Range 8	9000	210	US$ 2,008.14	US$ 10,104,44	US$ 12,112.57
Range 9	12000	280	US$ 2,677.52	US$ 13,444.82	US$ 16,122.34
Range 10	15000	350	US$ 3,346.90	US$ 16,783.94	US$ 20,130.84
Range 11	18000	420	US$ 4,016.28	US$ 20,280.34	US$ 24,296.62
Range 12	24000	560	US$ 5,355.03	US$ 26,954.22	US$ 32,309.26
Range 13	30000	700	US$ 6,693.79	US$ 32,899.45	US$ 39,593.25
Range 14	36000	840	US$ 8,032.56	US$ 39,159.45	US$ 47,192.01
Range 15	48000	1.120	US$ 10,710.08	US$ 51,769.21	US$ 62,479.30

*Conversion rate 1 US$ = R$ 3.87 (average annual value of commercial exchange in 2018).

Table 1. Estimated cost of installation and operation of Waste Transfer Stations

Source: To obtain the costs, reference values presented by Brazil (2008, 2010) and Vital (2013) were used, updated by the Brazilian Extended Consumer Price Index for March 2016.

Estimated capacity of recycling companies and recyclable waste prices

The quantities and prices of recyclable waste (paper/cardboard, plastic, metal and glass) were obtained through the survey of recycling companies. Costs incurred were kept constant over the period 2020-2035, disregarding the influence of commodity prices and their possible appreciations or devaluations.

To predict the value of recyclable materials, the Brazilian industrial growth for each sector investigated was assigned as follows: 4.5% p.a. for the paper/cardboard sector (ANAP 2015); 3.5% p.a. for the plastics sector (Oliveira et al., 2013); 13% p.a. by 2020 and 6.5% p.a. after 2020 for the metallurgical sector (INESFA 2013); and 5.0% p.a. for the glass sector (ABIVIDRO, 2009). The material handling capacity of recycling companies was calculated as the sum of each year's capacity during the 15-year period (2020-2035) divided by the length of the period. The price considered was the current market price of each product for each company size (Table 2).

Company size* (scale operations)	Capacity (tons/week)				Price (US$/ton)			
	Paper/ cardboard	Plastics	Metal	Glass	Paper/ cardboard	Plastics	Metal	Glass
Micro	14,0	11,7	7,0	16,3	25.84	77,52	310.07	5.16
Small	-	46,7	23,3	35,0	-	103.36	387.59	7.75
Medium	233,3	116,7	70,0	-	51.68	155.03	594.31	-
Large	-	466,7	-	233,3	-	200.71	-	15.50

* micro-scale operations (up to US$93,023), small-scale operations (up to US$930,232), medium-scale operations (up to US$5,167,958), large-scale operations (over US$5.167 million). Conversion rate 1 US$ = R$ 3.87.

Table 2. Estimated capacity of recycling companies and recyclable waste prices

Estimated recyclable waste generationw

Equation (1) was used to estimate the amount of recyclable waste generated by a given municipality of a given type during the period 2020-2035 based on the principle of universalization from the Brazilian National Basic Sanitation Policy (NBSP) (Brazil 2007), which assumes that all municipalities will be covered by a collection service for household waste by 2035.

$$G_{mgy} = P_{zmy}.GPC_m.CG_g.(1-r)_{my}.MDR_y.\frac{365}{1000} \quad (1)$$

In Equation 1, *m* represents the municipality, ranging from 1 to 78; *z* represents the type of zone: urban, equal to 1 and rural equal to 2; *g* represents the type of waste generated, ranging from 1 to 4; *y* represents the year within the period 2020-2035, ranging from 1 to 15; *r* is the tailings content index; G_{mgy} represents the generation rate (ton/year) of recyclable waste *g* from municipality *m* in year *y*; P_{zmy} represents the population (n umber of inhabitant) covered by door-to-door collection service in zone *z* of municipality *m* in year *y*; GPC_m represents the daily *per capita* generation rate (kg/hab . day) of recyclable waste of the municipality *m*; CG_g represents the percentage (%) of the recyclable waste *g* in the gravimetric composition of waste generated; $(1\text{-}r)_{my}$ represents the percentage (%) of recyclable waste (after removal of tailings content *r*); and MDR_y represents in percentual the recyclable waste diversion targets from landfill in year *y*.

Population projection

In order to determine the projected population of the 78 municipalities of Espírito Santo, the arithmetic method was employed because it presented an error of only 3-5% in relation to the official government projections for growth between 2020 and 2035. Population data from the 2000 and 2010 Demographic Census (IBGE, 2010, 2000) were consulted since the 2020 Demographic Census was postponed to 2021 due to Covid-19 pandemic. It was considered that the proportion of the urban and rural population in relation to the total municipal population in the 2010 Census would remain the same for population projections in the 2020-2035 period.

Coverage of municipal solid waste collection

Two values of the current municipal waste collection coverage were considered. The current coverage in relation to the total population was utilized as well as the current coverage in relation to the urban population in Brazil (2014). From these values, we calculated the percent of coverage for the rural population, considering in this case the population estimated by IBGE in 2014. The target coverage of 4 progressive municipal zoning standards (urban and rural areas) until 2035 (Table 3).

Urban area		**Target coverage of municipal solid waste collection**			
Municipal waste collection coverage	**Number of counties in 2014**	**2020-23**	**2024-27**	**2028-31**	**2032-35**
From 90 to 100%	75	100%	100%	100%	100%
Under 90%	3	100%	100%	100%	100%
Rural area		**Target coverage of municipal solid waste collection**			
Municipal waste collection coverage	**Number of counties in 2014**	**2020-23**	**2024-27**	**2028-31**	**2032-35**
From 90 to 100%	22	100%	100%	100%	100%
From 80 to 90%	8	100%	100%	100%	100%
From 70 to 80%	5	90%	100%	100%	100%
From 60 to 70%	3	80%	90%	100%	100%
From 50 to 60%	1	70%	80%	90%	100%
From 40 to 50%	17	65%	75%	90%	100%
From 30 to 40%	2	60%	75%	90%	100%
From 20 to 30%	3	45%	60%	80%	100%
From 10 to 20%	4	45%	65%	85%	100%
From 0 to 10%	12	40%	60%	80%	100%

Table 3. Coverage of municipal solid waste collection

Estimated gravimetric composition

To estimate the gravimetric composition of collected material, two types of input data were utilized; both of which were included in sensitivity analysis of the proposed model: data from NSIS (National Sanitation Information System) (Brazil 2015) distributed over absolute population size ranges; and data from the Brazilian National Solid Waste Policy (NSWP) (Brazil 2010b) as presented in Table 4.

Population size ranges	Estimated gravimetric composition				Waste generation *per capita* (kg.hab^{-1}.day^{-1})	Tailings (%)
	Paper	Plastic	Metal	Glass		
Up to 30 mil hab.[(a)]	58.7%	26.7%	7.5%	2.4%	0.67	4.2%
From 30 mil to 100 mil hab.[(a)]	58.3%	18.3%	15.4%	8.0%	0.85	1.3%
From 100 mil to 250 mil hab.[(a)]	76.1%	15.8%	5.0%	2.1%	0.71	0.8%
From 250 mil to 1 milhão hab.[(a)]	67.7%	19.3%	10.1%	0.5%	0.96	3.2%
Wide range[(b)]	41.1%	42.3%	9.1%	7.5%	-	-

Table 4. Estimated gravimetric composition distributed over absolute population size ranges.

Source: (a) Brazil (2015); (b) Brazil (2010b).

Proposal of recyclable waste diversion rates from landfill

Two possible recyclable waste diversion targets were considered in the proposed network model: the current values of landfill diversion rates for 34 municipalities in ES from 2014 (Brazil 2015) and a framework of progressive diversion rate goals. Both were considered so that different scenarios could be constructed, in which the recyclable waste landfill diversion rate could be varied (Table 5).

Targets	Recyclable waste diversion rates from landfill (%)			
	2020-2023	2024-2027	2028-2031	2032-2035
Target 1	15	20	25	30
Target 2	20	25	32	40
Target 3	25	32	40	50
Target 4	37	42	45	50
Target 5	32	45	60	75

Table 5. Proposal of recyclable waste diversion targets from landfill

Estimated cost of transportation according to truck load capacity

Transport costs at Level 1 are considered to be absorbed by WPOs and Level 2 costs by recycling companies. To estimate transport costs at Level 1 (with empty return and including taxes) under the responsibility of the proposed WPO network, the distance ranges between the origin and destination nodes and the mass of recyclables transported according to the truck's load capacity were considered (Table 6). Different truck load capacity considered was semi-heavy (10 ton), heavy (16 ton) and extra-heavy (21 ton). Compacting vehicles were not considered, as these can promote contamination or humidification of materials that can be recycled, and may make their recovery unfeasible (Ferri, Diniz Chaves, and Ribeiro 2015).

Distance ranges (km)			Truck load capacity		
			Semi-heavy (10 ton)	Heavy (16 ton)	Extra-heavy (21 ton)
0	-	50	US$ 100,81	US$ 128,17	US$ 228,79
51	-	100	US$ 147,36	US$ 188,00	US$ 301,32
101	-	150	US$ 193,91	US$ 247,83	US$ 373,84
151	-	200	US$ 240,47	US$ 307,67	US$ 446,37
201	-	250	US$ 287,01	US$ 367,51	US$ 518,90
251	-	300	US$ 333,57	US$ 427,34	US$ 591,43
301	-	350	US$ 380,12	US$ 487,18	US$ 663,95
351	-	400	US$ 426,67	US$ 547,01	US$ 736,48
401	-	450	US$ 473,22	US$ 606,85	US$ 809,01
451	-	500	US$ 519,77	US$ 666,68	US$ 881,54

Conversion rate 1 US$ = R$ 3.87. Reference year: 2016.

Table 6. Estimated cost of transportation according to truck load capacity

2.3.2 Stage 2 - Sensitivity tests

Ten different scenarios were created by varying model parameters. These scenarios were grouped according to the purpose of the sensitivity tests: to understand the effect of gravimetric composition of waste, to evaluate the effect of recyclable waste landfill diversion targets, and to investigate the effect of truck transport capacity, as detailed in Table 6. In all scenarios, fixed prices were considered for all waste in the period 2020-2035. This approach excludes the influence of the commodity market with applicable appreciations or devaluations. For some scenarios, the population projection was considered for all the municipalities of the state until 2035. Grouped scenarios utilized variation in a common set of parameters, so that their effect on WTS location could be analysed.

Analysis purpose	Scenarios	Population	MSW collection	Gravimetric composition	Diversion rates	Truck capacity
To evaluate the effect of gravimetric composition on the generation of recyclable waste; and the financial outcome of the proposed WPO network using parameters based on current and projected trends	A	Current	Current (NSIS)	NSWP	NSIS	16 ton
	B			NSIS	NSIS	
	C	Projection 2020-2035	Targets (NBSP)	NSWP	Target 3	
	D			NSIS	Target 3	
To evaluate the effect of recyclable waste landfill diversion targets on the financial outcome of the proposed WPO network considering the quantity, location, WTS capacity, and related costs	E	Projection 2020-2035	Targets (NBSP)	NSWP	Target 1	16 ton
	F				Target 2	
	C				Target 3	
	G				Target 4	
	H				Target 5	
To evaluate the effect of truck load capacity on transport cost between WPO and WTS; and the effect of truck load capacity on the required network storage capacity	I	Projection 2020-2035	Targets (NBSP)	NSWP	Target 3	10 ton
	C					16 ton
	J					21 ton

Legend: MSW – municipal solid waste; NBSP - National Basic Sanitation Policy; NSIS - National Sanitation Information System; NSWP - National Solid Waste Policy.

Table 6. Description of evaluated scenarios by mathematical model

Optimum locations of Waste Transfer Stations

Recyclable solid waste flow between Waste Pickers Organizations network and optimum locations of Waste Transfer Stations were illustrated to the scenario considered as reference after financial analysis of the proposed WTS networks.

Distances from WPOs to WTS's (Level 1), and WTS's to recycling companies (Level 2) were calculated using open source QGis geographic information system software, version 2.2 Valmiera. All distances were considered to be Euclidian and were generated by drawing a straight line between the applicable projected coordinates; with the real distance being approximated using a correlation factor of $\alpha = 1.35$ (Gonçalves et al., 2014).

3 I RESULTS AND DISCUSSION

3.1 Proposal WPO network

The results for each scenario considered, including the projected waste transport load, the number of trucks, their respective load occupancy, the number of WTS's proposed, their respective used capacity, and the number of recycling companies identified as available to receive the recyclable waste, are shown in Table 7.

Scenarios	Recyclable Waste (ton/week)	Quantity of trucks	Load truck occupancy (%)	Number of WTS Proposed	WTS used capacity[(a)]	Recycling Companies
A	512.5	98	32.7	8	98.94%	9
B	498.6	96	32.5	9	98.95%	7
C	2,183.3	181	75.4	14	99.97%	14
D	2,166.4	179	75.6	10	99.80%	12
E	1,313.4	133	61.7	12	99.80%	11
F	1,728.5	156	69.3	9	99.97%	10
G	2,625.2	205	80.0	12	99.74%	25
H	3,068.2	234	82.0	12	99.62%	26
I	2,183.4	260	84.0	11	99.97%	14
J	2,183.4	153	68.0	12	99.97%	12

Legend: (a) WTS number *versus* capacity (ton/week); WTS - Waste Transfer Stations.

Table 7. Summary of the proposed scenarios for WPO network

As illustrated in Table 7, all scenarios had a minimum of 8 operational WTS's and a maximum of 14 operational WTS's. The installation of WTS's should be a high priority at the time of network planning, because if poorly planned, the network can become dysfunctional. WTS load capacities were always above 98.9%, indicating that the model maximizes the potential of its load accumulation, thus avoiding the costs of maintaining underperforming WTS's. However, operating a WTS this close to the projected capacity is not advisable. Seasonal variations in waste reception or other periodic factors may result in an acute increase in waste that pushes the WTS beyond its operating capacity.

When determining the operational capacity of a WTS, a defined amount of clearance should be included to buffer against such stochastic changes in waste reception rates. This practice would also account for future growth in cargo handling capacity and ensure operational flexibility in response to economic and market development.

The number of recycling companies able to receive waste varied from 7 to 26, out of a total of 57 companies, representing 12.3% to 45.6% engagement. The average fraction of recycling companies engaged was 24.6%, with the majority of engaged recycling companies being larger-scale operations.

Scenario C (diversion target: 15% - 50%) was considered as the reference scenario for all comparisons, as its final target for recyclable waste landfill deviation is the same as that proposed by the NSWP but is implemented gradually over 20 years. Figure 2 illustrates the reference scenario of Waste Pickers Organizations network with 14 Waste Transfer Stations and respective recyclable waste flows. The total capacity of the 14 WTS opened is 2,183.3 ton/week and 99.97% load occupancy.

Fig.2. Recyclable solid waste flow between Waste Pickers Organizations network and optimum locations of Waste Transfer Stations in the reference scenario.

Legend: WP – waste pickers; WTS – waste transfer station; RSW – recyclable solid waste.

3.2 Financial analysis of the proposed WTS networks

Table 8 shows the financial analysis enabled by the mathematical model of the proposed WTS networks in various scenarios.

Scenarios	Profitability[(a)] %	Financial result[(b)] (US$*/week)	Revenue (US$*/week)	Installation cost (US$*/week)	Operation cost (US$*/week)	Transport cost (US$*/ week)
A	46	39,063.60	85,758.79	4,953.41	26,249.67	15,492.10
B	35	24,172.05	69,751.60	4,819.53	25,584.07	15,175.93
C	54	188,890.31	347,229.06	20,884.65	105,161.29	32,292.79
D	46	131,767.10	288,901.87	20,750.77	103,928.68	32,455.30
E	55	120,614.62	219,875.16	12,584.34	64,484.43	22,191.77
F	55	158,370.22	286,459.56	16,533.68	83.244,84	28,311.58
G	53	212,886.75	401,191.39	25,168.68	125,792.64	37,343.30
H	50	219,486.17	439,854.30	29,452.71	146,743.90	44,171.50
I	53	183,699.31	347,000.34	20,884.65	105,405.47	37,010.90

J	51	176,980.86	347,004.38	20,884.65	105,140.51	43,998.34

Legend: (a) Profitability = financial result / revenue; (b) Financial result = revenue – costs (installation, operation and transport); *Conversion rate 1 US$ = R$ 3.87.

Table 8. Financial analysis of the proposed scenarios.

The revenue from selling recyclable waste that is generated by the improved network organization not only justifies its construction, but it also enables a reduction in spending on other population welfare solutions. Similar positive financial returns were also found by Ferri et al. (2015) and Couto and Lange (2017). Extrapolating the weekly revenue stream predicted by the model, the proposed WPO network generates economic returns between US$ 1.24 to 11.39 million per year, depending on the particular scenario considered.

Among the different costs accounted for in the proposed scenarios, the most significant was WTS operating cost. Transport costs were most significant in Scenarios A and B, representing about 1/3 of total costs. Overall, operating costs were the most significant due to the need for equipment and labor at all stages of the operational chain, including: receiving, washing, shredding, baling, storage, and transportation. The focus of improving WTS networks is to increase WPO participation in the recycling economy, even if further process mechanization may lead to increased production with reduced personnel costs; however, this option would be contradictory.

Figure 3 shows the financial results regarding the effect of the gravimetric composition adopted in scenarios A to D, and the group of scenarios whose targets for diversion of recyclables ranged from 10% to 75% (Scenarios E to H).

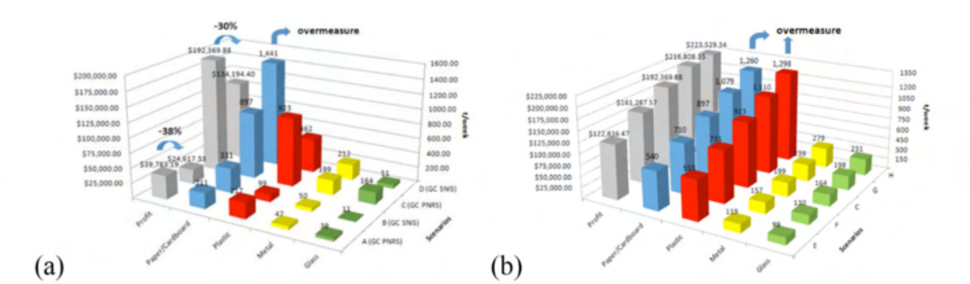

Fig. 3. Financial results of the sensitivity test. (a) Effect of the gravimetric composition adopted in scenarios A to D; (b) Effect of recyclable waste landfill diversion targets in scenarios E to H.

As can be seen in Figure 3a, although the input parameters in Scenarios A and B are similar, differing only by gravimetric composition, the financial result in B was 38% less than in Scenario A. Similarly, Scenario D presents an estimate of waste generation that was only 0.8% lower than Scenario C, and it resulted in a financial return of about 30% less, due to the considerable difference between the recyclable waste installments.

The differentiation of the recyclable fractions has a direct effect on the revenues obtained from commercialization due to the different prices for each type of waste. This difference was due to the estimated quantity of plastics, a material with higher added value and mainly for large companies.

The financial results for scenarios with targets for recyclables recovery ranging from 10% to 75% that depend also on the respective target four-year period are presented in Figure 3b. It was observed that the increased growth rate for the financial result did not translate into growth to the same extent for targets of recyclables diversion. Thus, this caused more waste to reach organizations, however, it would result in the material not having a final consumer market. In this sense, installation and transportation costs were increased to accommodate recyclable waste that had no market and could not generate revenues for the network.

4 I DISCUSSION

This study points to important elements to be considered for the development of a logistics network that contributes to the strengthening of WPOs. Although cost versus benefit indicates the feasibility of implementing WTS, it is important to understand that the installation cost has been amortized over weeks. However, in practice, this value implies a significant initial investment for WPOs, which usually have a short-term planning vision. It is important to consider that these organizations do not have the necessary financial resources to enable the implementation of these WPOs. Therefore, the expansion of this network involves the provision of government resources. This is justified, since WPOs are the actors that have effectively operated the collection of recyclable waste in Brazil. It is these organizations that will make it possible to achieve the goals of recyclable material diversion from landfills at the local level.

In addition, the viability of this network involves the participation of several WPOs to guarantee the volume of waste necessary to effectively enable the implementation and operation of the WTS. This involves an articulation work for initial engagement, but also the coordination of initial activities that should be performed by a recognized WPO. Therefore, despite the financial viability of the proposed network, its implementation depends on the establishment of a governance mechanism that goes beyond the limits of the mathematical model presented, but which is essential for the realization of this proposal.

Another implication associated to the financial return of the reverse logistics network is directly related to the differentiation of the recyclable fractions due to the increase in revenue due to the better quality of the material. Therefore, despite not being the focus of this study, environmental education policies and incentives to separate waste at source can contribute to a better financial result for WPOs, increasing the social impact of the proposal. These actions are proposed in NSWP as well as their development in the related state law.

5 I CONCLUSION

The proposed WTS offers an effective and efficient scheme for the reverse logistics of WPO network operations, allowing for the large-scale commercialization of recyclable waste. The improved operational scale of the WPOs allows them to achieve a higher market efficiency and larger economic returns, but the proposal depends on investment and coordination by the government.

However, it is important to mention that only Waste Picker Organizations formally associated to Instituto Sindimicro-ES were interviewed, while independent waste pickers or informal organizations were not considered. If the per capita revenue of waste pickers grows, it could also encourage the formalization of informal ones, which would dilute the revenue per picker but increase the number of people formally involved in the system.

The MILP model was the tool used to investigate different scenarios in order to provide more specific results for each manager, since it can assess several data to determine the optimal configuration for the reverse logistic network. However, the novelty of this study is not based on the mathematical model but, rather, on the applicability that the model responses bring to the incorporation of WTS in WPO networks. Because the model input data are dynamic and still vary both geographically and temporally, the main contribution of this article is to allow for the dimensioning of WPO networks through a model capable of carrying out an analysis involving technical and financial variables. It could be used by the planners, public decision makers, traders, and WPO managers as a planning tool. Despite the contribution to strengthen their integration into municipal waste management system, these economic returns incentivize WPO participation in the circular economy; and offer increased opportunities for a greater degree of cooperation with established recycling companies.

REFERENCES

ABIVIDRO (Brazilian Technical Association of Automatic Glass Industries). 2009. “Yearbook.” 2009. www.abividro.org.br.

Ağaçsapan, Balca, and Saye Nihan Çabuk. 2020. “Determination of Suitable Waste Transfer Station Areas for Sustainable Territories: Eskisehir Case.” *Sustainable Cities and Society* 52: 101829. https://doi.org/10.1016/j.scs.2019.101829.

ANAP. 2015. “Paper Recycling in Brazil 2014.” In *II Encontro Nacional Dos Aparistas de Papel*. São Paulo: National Association of Paper Aparistas.

Brazil. 2007. *Brazilian National Basic Sanitation Policy*. Brasília.

———. 2008. *Elements for the Organization of Selective Collection and Design of Sorting Sheds*. Edited by Tarcísio De Paula Pinto and Juan Luis Rodrigo González. Ministry of Cities.

———. 2010a. *Manual for the Implementation of Composting and Selective Collection in Public Consortia*. Improvemen. Brasília: Ministry of the Environment.

———. 2010b. *National Solid Waste Policy. Federal Law N_ 12,305, August 2, 2010. Diário Oficial Da União, Brasília, August 3, 2010. Section 1, p. 1–7.* Brasília.

———. 2014. "Diagnosis of Urban Solid Waste Management - 2013." Brasília.

———. 2015. "Diagnosis of Urban Solid Waste Management - 2014." Brasília.

Chatzouridis, Constantinos, and Dimitrios Komilis. 2012. "A Methodology to Optimally Site and Design Municipal Solid Waste Transfer Stations Using Binary Programming." *Resources, Conservation and Recycling* 60: 89–98. https://doi.org/10.1016/j.resconrec.2011.12.004.

Couto, Maria Claudia Lima, and Liséte Celina Lange. 2017. "Análise Dos Sistemas de Logística Reversa No Brasil." *Engenharia Sanitaria e Ambiental* 22 (5): 889–98. https://doi.org/10.1590/S1413-41522017149403.

Dutra, Renato Meira de Sousa, Luciana Harue Yamane, and Renato Ribeiro Siman. 2018. "Influence of the Expansion of the Selective Collection in the Sorting Infrastructure of Waste Pickers' Organizations: A Case Study of 16 Brazilian Cities." *Waste Management* 77: 50–58. https://doi.org/10.1016/j.wasman.2018.05.009.

Fergutz, Oscar, Sonia Dias, and Diana Mitlin. 2011. "Developing Urban Waste Management in Brazil with Waste Picker Organizations." *Environment and Urbanization* 23 (2): 597–608. https://doi.org/10.1177/0956247811418742.

Ferri, Giovane Lopes, Gisele de Lorena Diniz Chaves, and Glaydston Mattos Ribeiro. 2015. "Reverse Logistics Network for Municipal Solid Waste Management: The Inclusion of Waste Pickers as a Brazilian Legal Requirement." *Waste Management* 40: 173–91. https://doi.org/10.1016/j.wasman.2015.02.036.

Fidelis, Reginaldo, Antonio Marco-Ferreira, Lilian Cristina Antunes, and Alexandre Kenji Komatsu. 2020. "Socio-Productive Inclusion of Scavengers in Municipal Solid Waste Management in Brazil: Practices, Paradigms and Future Prospects." *Resources, Conservation and Recycling* 154 (July 2019): 104594. https://doi.org/10.1016/j.resconrec.2019.104594.

Gall, Markus, Melanie Wiener, Cintia Chagas de Oliveira, Reinhold W. Lang, and Erik G. Hansen. 2020. "Building a Circular Plastics Economy with Informal Waste Pickers: Recyclate Quality, Business Model, and Societal Impacts." *Resources, Conservation and Recycling* 156 (September 2019): 104685. https://doi.org/10.1016/j.resconrec.2020.104685.

Gonçalves, Daniel Neves Schmitz, Carolinne De Morais Gonçalves, Tássia Faria De Assis, and Marcelino Aurélio Da Silva. 2014. "Analysis of the Difference between the Euclidean Distance and the Actual Road Distance in Brazil." *Transportation Research Procedia* 3 (July): 876–85. https://doi.org/10.1016/j.trpro.2014.10.066.

INESFA. 2013. "Study on the Iron Scrap Industry and the Impact of the Adoption of Ferrous Scrap Export Taxes in Brazil." National Institute of Iron and Steel Scrap Companies.

Instituto Brasileiro de Geografia e Estatística (IBGE). 2000. "Demographic Censu 2000." https://www.ibge.gov.br.

———. 2010. "Demographic Censu 2010." https://www.ibge.gov.br.

Kůdela, Jakub, Radovan Šomplák, Vlastimír Nevrlý, Tomáš Lipovský, Veronika Smejkalová, and Ladislav Dobrovský. 2019. "Multi-Objective Strategic Waste Transfer Station Planning." *Journal of Cleaner Production* 230 (2019): 1294–1304. https://doi.org/10.1016/j.jclepro.2019.05.167.

Lin, Zhuangqin, Qiu Xie, Yingbin Feng, Peng Zhang, and Ping Yao. 2020. "Towards a Robust Facility Location Model for Construction and Demolition Waste Transfer Stations under Uncertain Environment: The Case of Chongqing." *Waste Management* 105: 73–83. https://doi.org/10.1016/j.wasman.2020.01.037.

Liu, Junwan, and Guodi Zheng. 2020. "Emission of Volatile Organic Compounds from a Small-Scale Municipal Solid Waste Transfer Station: Ozone-Formation Potential and Health Risk Assessment." *Waste Management* 106: 193–202. https://doi.org/10.1016/j.wasman.2020.03.031.

Navarrete-Hernandez, Pablo, and Nicolas Navarrete-Hernandez. 2018. "Unleashing Waste-Pickers' Potential: Supporting Recycling Cooperatives in Santiago de Chile." *World Development* 101: 293–310. https://doi.org/10.1016/j.worlddev.2017.08.016.

Oliveira, M F., S. L. M. Costa, F. S. Pereira, and M. A. Costa. 2013. "The Plastics Processing Industry and Its Recent Performance." *National Bank for Economic and Social Development Setorial* 38: 131–72.

Pinha, Augusto Cesar Hernandes, and Juliana Keiko Sagawa. 2020. "A System Dynamics Modelling Approach for Municipal Solid Waste Management and Financial Analysis." *Journal of Cleaner Production* 269: 122350. https://doi.org/10.1016/j.jclepro.2020.122350.

Pishvaee, Mir Saman, Zanjirani Reza Farahani, and Wout Dullaert. 2010. "A Memetic Algorithm for Bi-Objective Integrated Forward/Reverse Logistics Network Design." *Computers & Operations Research* 37 (6): 1100–1112. https://doi.org/https://doi.org/10.1016/j.cor.2009.09.018.

Rathore, Pradeep, and S. P. Sarmah. 2019. "Modeling Transfer Station Locations Considering Source Separation of Solid Waste in Urban Centers: A Case Study of Bilaspur City, India." *Journal of Cleaner Production* 211: 44–60. https://doi.org/10.1016/j.jclepro.2018.11.100.

Siman, Renato Ribeiro, Luciana Harue Yamane, Roquemar de Lima Baldam, Juliana Pardinho Tackla, Sarina Francisca de Assis Lessa, and Priscila Mendonça de Britto. 2020. "Governance Tools : Improving the Circular Economy through the Promotion of the Economic Sustainability of Waste Picker Organizations." *Waste Management* 105: 148–69. https://doi.org/10.1016/j.wasman.2020.01.040.

Suthar, Surindra, Poonam Rayal, and Chetan P.S. Ahada. 2016. "Role of Different Stakeholders in Trading of Reusable/Recyclable Urban Solid Waste Materials: A Case Study." *Sustainable Cities and Society* 22: 104–15. https://doi.org/10.1016/j.scs.2016.01.013.

Tirado-Soto, Magda Martina, and Fabio Luiz Zamberlan. 2013. "Networks of Recyclable Material Waste-Picker's Cooperatives: An Alternative for the Solid Waste Management in the City of Rio de Janeiro." *Waste Management* 33 (4): 1004–12. https://doi.org/10.1016/j.wasman.2012.09.025.

Vital, J. P. 2013. “Calculation of Industrial Meal Costs.” *Revista Especialize Online IPOG* 1 (5): 1–18.

Yadav, Vinay, Subhankar Karmakar, A.K. Dikshit, and Shivkumar Vanjari. 2016. “A Facility Location Model for MSW Management Systems Under Uncertainty: A Case Study of Nashik City, India.” *Procedia Environmental Sciences* 35: 90–100. https://doi.org/10.1016/j.proenv.2016.07.052.

www.atenaeditora.com.br
contato@atenaeditora.com.br
@atenaeditora
www.facebook.com/atenaeditora.com.br

Collection:

APPLIED ENVIRONMENTAL AND SANITARY ENGINEERING

Atena Editora
Ano 2022