System dynamics model for the municipal solid waste management system in the metropolitan area of Medellín, Colombia

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System dynamics model for the municipal solid waste management system in the metropolitan area of Medellín, Colombia

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Abstract: This paper analyses the management of municipal solid waste in the metropolitan area of Medellín (Colombia). The composition and production of solid waste, the collection system, the informal and formal sectors in the region, the different flows of materials and its final disposal, are some topics that have been considered. A basic model for the SWM system in the city has been developed based on the system dynamics methodology. With the help of the Vensim PLE software, it has been possible to simulate different scenarios, such as the implementation of the formalisation process of the informal waste pickers that are present in the city. The generation of waste for the residential sector in Aburrá Valley is 49,115.2 ton/month, and only 12.5% of the solid waste produced is reintroduced into the production cycle. Part of this work is done by approximately 4,474 waste pickers, but only 10.63% of them are part of pre-cooperatives or cooperatives. The outcomes of the model for the geographical area allow to conclude that the inclusion of the informal sector in the municipal solid waste management system would imply huge benefits related to the social, economic and environmental aspects of the system.

Keywords: waste management; recycling; municipal solid waste, informal sector.

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1 Introduction

The current situation in the city of Medellín and its metropolitan area in terms of resource recovery is very poor: only the informal sector is in charge of the separate collection of municipal solid waste. Waste pickers salvage valuable material from waste and sell to intermediaries, who in turn sell them to industry. In this way, the recovered materials are introduced into the production cycle. Nowadays, the volume of residues has reached high levels of production, generating a problem for the municipalities related to the collection, transport and disposal of the solid waste. The Aburrá Valley is not indifferent to this problem, as the improper management of solid waste causes' water, air, and land pollution, and poses serious risks to health and the environment.

According to the regional integrated solid waste management plan (PGIRS Regional, 2006), it was estimated that in the metropolitan area of Medellín in 2006, approximately 4,500 waste pickers worked delivering an important service to the city by filling the gap left by the formal sector. Thus, one of the major challenges associated with solid waste management in developing countries is how to work with this informal sector with the objective of improving their livelihoods, working conditions, and recovery efficiency, while attaining economic benefits. Local government should analyse the potential that recycling has, and focuses on if it could contribute to solving the problem of waste management in a social, economically viable, and environmentally-sound manner. As already demonstrated in Latin America, recycling can promote social inclusion in Brazil since it creates jobs and income. Also, it offers other benefits including significant contributions to environmental sustainability, as suggested by Lino and Ismail (2013). Additionally, in the case of Bangladesh, specifically in the city of Bantar Gebang, Sasaki and Araki (2013) concluded that a common ground between formal and informal sectors should be built. One of the further challenges is to consider waste management policies in the way that the existing informal recycling system is successfully integrated into the formal recycling system.

The principal goal of the present research work is to create a basic model for the solid waste management system in the city, based on the system dynamics methodology and supported by Vensim PLE, to analyse policies that would improve the recycling and recovery of waste. The structure of system dynamics is presented by causal loop diagrams which show the major feedback mechanisms (Sterman, 2000). System dynamics modelling is used to analyse system behaviour and to formulate system management strategies. It was created as a modelling and simulation methodology for the long-term decision making analysis of industrial management problems. This

methodology is based on the feedback system which refers to chains of causes and effects; in this way, the study of the whole system is carried out (Richardson and Pugh, 1981).

This study deals with the economic and social aspects of the municipal solid waste management system in the analysed area. The present work only considers the solid waste generated by households, the commercial sector, and institutions in the area of study during a time horizon of 20 years (from 2000 to 2020). Drawing upon the government's data, this is projected until 2020 for *Área Metropolitana.*

2 Geographical information

Medellín is Colombia's second largest urban centre; it is located in the Aburrá Valley[2] in the department of Antioquia. This region has an extension of 1,155 km^2 of which 340 km^2 are urban areas and 815 km^2 are rural areas. Administratively, the valley is under the jurisdiction of the *Área Metropolitana*, which is composed of ten municipalities (Metropolitan Area, 2005).

For the year 2005, when the last official census was carried out by the Colombian National Statistics Administrative Department (DANE), the metropolitan area had a population of 3,306,490 with an annual growth rate in the period of approximately 1.7% for the short, middle and long term. The inhabitants in the Aburrá Valley have a medium human development index (HDI), according to the United Nation Development Program (UNDP). The average rate of HDI is 0.78 and the exact value in Medellín is 0.79, the projections suggesting some advances regarding this indicator in 20 years (Metropolitan Area, 2005).

3 Waste management in the Aburrá Valley

According to the integrated solid waste management plan of Medellín (PGIRS Regional, 2006), in Colombia 75.3% of the municipal solid waste in urban areas arises from the residential sector, 13.8% from the commercial sector, 6.6% from the institutional sector, 3.6% from industries, 1.9% from construction and demolition activities, and 6.7% from municipal services. The daily average per capita production of solid waste in Colombia lies between 0.4 and 0.6 kilograms, and for the population analysed in this paper, the average production of waste is 0.45 kilograms per inhabitant per day, which is a low rate compared to national production.

Based on PGIRS Regional (2006), the generation of waste for the residential sector in the Aburrá Valley is 49,115.2 ton/month. The production of waste in Medellín is 33.821,7 tons per month. The main component of the municipal solid waste (MSW) in the Aburrá Valley is organic waste, followed by plastic waste (Table 1). Herein lies an opportunity, as plastics can be recovered and introduced into production processes.

Table 1 Composition of the municipal solid waste in the Aburrá Valley

Composition	*Percentage*
Organic waste	59.79
Plastics	10.87
Paper	8.6
Others	5.9
Hazardous waste	5.31
Textiles	3.04
Glass	2.84
Cardboard	2.42
Metals	1.26
Leather	0.32
Tetra pack	0.19
Total	100

Source: PGIRS Regional (2006)

According to PGIRS (2006a) and PGIRS Regional (2006) the main operations to which the solid waste generated is subjected in the Aburrá Valley are disposal at a landfill site and the recovery of recyclables (Table 2). Currently, 76.2% of the solid waste generated in Medellín and its metropolitan area is disposed in the landfill called *La Pradera*, located outside the metropolitan area in the municipality of *Don Matías* (56 kilometres away from the city), having an area of 4.7 hectares that receive 55.522 tons monthly. Illegality is at present mainly in open dumps, water bodies and burnings. The national regulation of 2005 introduced the prohibition of open dumps in the country, all of this in the framework of the national decree 2,981 of 2013 introducing the norms that regulate the cleaning service within the frame of the integral solid waste management. At present, the municipalities are working in shifting from open dumps. Those dumps are another cause for the minimum value of 12.5% of solid waste that is recovered or reintroduced into the production cycle: this percentage represents 9,121 tons per month. There are some construction and demolition waste disposal sites in the municipality of Sabaneta, La Estrella, Bello and Copacabana; thus, not all waste is disposed of in La Pradera.

Table 2 Consolidated – total flows in the Aburrá Valley

Flows of residues	*Tons/month*	*Percentage*
Disposal in landfill site	55,522	76.2
Recovery	9,121	12.5
Collected by the formal sector and dispose in debris sites	4,664.05	6.4
Inadequated disposal (losses)	2,059.99	2.8
Biomass used in combustion processes (brick making factories)	1,402.43	1.9
Collection of hazardous waste for treatment	135.5	0.2
Total	72,904.96	100

Source: PGIRS Regional (2006)

Table 3 Percentage of participation of the wastes disposed in the landfill 'La Pradera'

Origin	*Percentage*
Residential	70.8
Commercial	11.2
Industrial	7.5
Institutional	5.5

Source: PGIRS Regional (2006)

The municipality establishes the regulation and laws for the operation of different companies that provide the service in the Aburrá Valley. For instance, *Empresas Varias de Medellín* (EEVVM) is a public service company which is in charge of the residential, commercial and industrial waste management in the city of Medellín. It manages the collection, transport, treatment, and final disposal of the solid waste generated in the city. There are also some other public companies which work in the other municipalities of the valley.

For the collection of residential waste, manually loaded vehicles are used which do not have a lifting system for the bins since standardised bins are still not used in households. The driver and two loaders work in a shift per truck, and there is no separate collection system of residential waste. In the whole Aburrá Valley, the coverage of municipal solid waste collection is 92.3% and the specific rate of Medellín is 96% (PGIRS Regional, 2006).

4 The informal sector of Medellín and its metropolitan area

As in other cities in low and middle income countries, recyclable materials are collected by waste pickers who normally arrive in the neighbourhoods some hours before the collection trucks. The informal sector is comprised of waste pickers that work in the collection, transportation, separation, and sale processes of recycling materials; therefore, they make their own routes.

The waste pickers select the recycling material and sell it to intermediates or bring the material to some marketplaces located in the municipalities. The vehicles used by the informal sector for the collection and transport of recycling materials are mainly traditional carts, roller carts, and animal-drawn vehicles. Due to the lack of technology and resources, the labour of waste pickers is very demanding physically. Besides this, waste pickers are normally not included in the social security system, unless they are associated with pre-cooperatives or cooperatives.

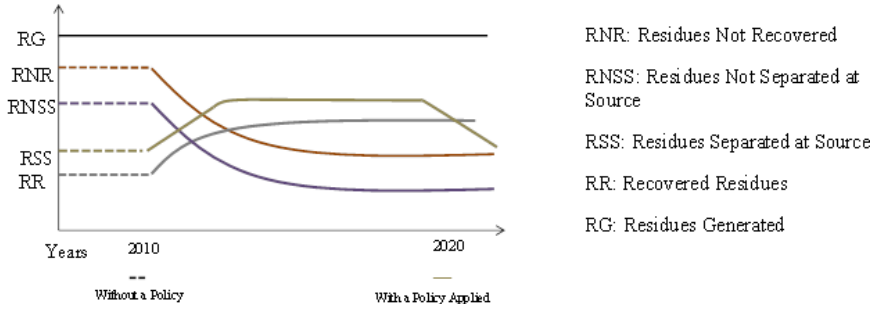
The range of income for a waste picker per day is between 8,000 and 25,000 Colombian pesos, and the average is 17,445 Colombian pesos. These values are equivalent to 3.3 and 10.3 US dollars respectively, and the average to USD 7.20[2].

In a recent development, the informal sector has started a process of incorporation and conversion into a formal sector by establishing pre-cooperatives or cooperatives. These associations have the objectives of promoting the recycling activities of waste pickers, their organisation, and to dignify their working conditions. These types of organisations are non-profit, seeking to satisfy the needs of their associates, and to provide some education and recreation activities to their members. According to PGIRS Regional (2006), in 2006 there were approximately 4,474 waste pickers in the Aburrá

Valley, of which 3,881 came from Medellín. The main numbers of waste pickers are still working independently in an unorganised manner: only 10.6% of them are part of pre-cooperatives or cooperatives. Medina (2000, 1997; cited in Lino and Ismail, 2013) points out that cooperatives impact positively the quality of life of waste pickers, and they have expanded the average monthly income per waste collector by about three times the minimum wage in Brazil, which in the year 2000 amounted to $300 USD.

Important advances have been made in the process of dignifying the informal sector in Medellín. These processes have been carried out by *Área Metropolitana*, the branch of the municipal administration in charge of urban environmental planning and management, and the municipality. The two institutions developed a project in 2005 for the recovery of valuable materials through the organisation of waste pickers in Medellín, according to PGIRS (2006b). This project seeks to promote and support the waste pickers in the recycling process and recovery of materials in activities such as business consolidation, strengthening of the organisations created, marketing of materials, and raising of special funds for financing the activities of solid waste management, in particular to strengthen recycling activities. This project has a time horizon of 15 years, starting in 2006. The main objectives of this project are to incorporate the informal sector into the municipal solid waste system, and to increase the recycling rate from the current level of 13.5% to 30% in the long term (PGIRS, 2006b).

Figure 1 Reference modes of residues (see online version for colours)



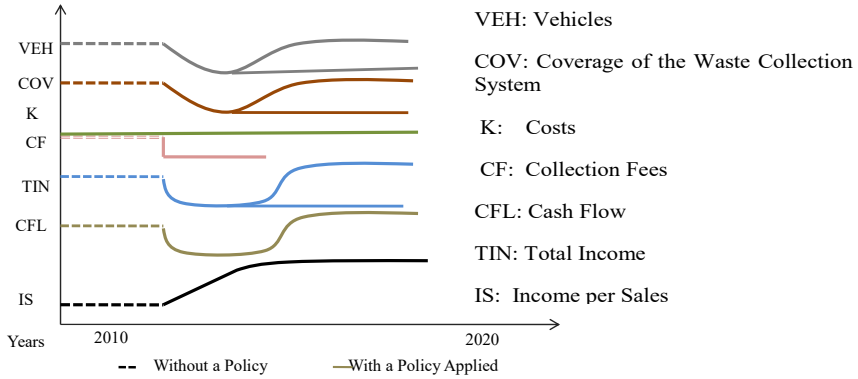
5 Cash flow

The cash flow (CFL) is a central variable of this model for the municipal solid waste management system. The cash flow is affected by the costs and the total income of the system. For this reference mode, the costs (K) will be kept constant in order to analyse the variation of the cash flow based on the total income (see Figure 2).

If the cash flow is reduced through the reduction of the collection fees (CFs), the amount of vehicles (VEH) will be reduced, and therefore the coverage of the collection system (COV) will also be reduced until the cash flow starts to increase again. This can be possible when the total income is increased either by the fee income or by the income per recovered material, assuming the case that the municipality includes the informal sector and formalises it. If the CFs are reduced – in order to apply a policy such as the incentives – the total income (TIN) of the municipality will be reduced until the income per sales (IS) of recovered materials –in the case that municipality receives directly this

income per sales or indirectly through the taxes that the organisations pay to the municipality – leads to an increase of this total income and if the costs are kept stable, the cash flow can be balanced.

Figure 2 Reference mode of cash flow (see online version for colours)



6 Recycling fraction

According to the PGIRS-Project No 7, the current amount of waste that is recovered in the Aburrá Valley is approximately 13% of the total amount of residues generated. The goal of the municipality is to increase this number to 30% in the long term in a time horizon of 15 years. Another problem in the Aburrá Valley is the solid waste that is either disposed illegally in the metropolitan area in inadequate places such as water bodies and open dumps, or burned or dumped on uncultivated land. The objective regarding this topic is the reduction of illegal disposal through the application of a policy that enforces the legal alternatives for final disposal and that encourages the recycling processes. Accordingly, the application of a policy that could reduce the amount of solid waste disposed in legal places would reduce the space occupied, and increase the lifetime of the landfills. The policy should consider the reduction of solid waste that goes to the legal places through other alternatives for the recovered materials (recycling), source separation, and environmental education.

7 Coverage collection of the informal sector

The informal sector is the only one in charge of collecting the recyclable materials in the area analysed in this study. This sector does not have a defined mechanism for transportation, a human-driven handcart being the main vehicle used by the informal sector that is concentrated on household waste in the Aburrá Valley.

The source separation fraction has a direct relation with the coverage collection: a higher separation at the source of the recyclables implies a higher amount of materials that are available for separated collection. If some policies are applied to the source separation factor and the training of the informal sector, the coverage collection could be increased for the recyclable materials during the time horizon determined. The principal

goal formulated by the municipality is to link the informal sector with the municipal solid waste management system; this link could contribute to solving a social problem by improving the standard of living of the people working in this sector, and by reducing the environmental impacts of solid waste.

8 Dynamic hypothesis

The dynamic hypothesis, which represents the feedback structure of the model of the municipal solid waste management system, was created considering different aspects such as the economic variables (cash flow, costs and income of the system), the environmental education, coverage, legal and illegal disposal, and the formalisation process of the informal waste pickers and the recovery of material.

The costs of the system are related to the investment in environmental education, vehicles operation and maintenance, disposal costs, cleaning costs and the formalisation costs. The costs generated in the treatment process of the recovered residues were not included within the boundaries of this model. However, they could be analysed and expanded in future models, since they are a very important aspect that should be taken into account (considering that a higher value of the treatment costs discourages the recycling process and reduces the opportunity of recovering waste).

The casual loop diagram of the dynamic hypothesis is formed by two stocks or asset accumulations, which are the cash flow and the vehicles. The first one is considered one of the main forces of the cycle: around it, most of the loops of the system are generated and connected. Another important variable is the recovered residues which will be affected by the process of formalisation.

The reduction of the waste CF could be one of the principal ways to promote the separation and treatment of solid waste. Therefore, a reduction in the waste CFs should be supported by an increase in income from the taxes that the formalised organisations pay to the municipality, since they are recovering the solid waste.

If there is a decrease of cash flow, it could affect the possibility of maintaining or increasing the coverage of the waste collection, resulting in the coverage of collection decreasing because of the costs of maintenance and operation. The consequence will be the reduction in the quality of service perceived, producing a fall in the number of users paying the fee, affecting the income of the system; thus again, affecting the cash flow and generating a vicious circle for the system. In the case of Medellín and its metropolitan area, the municipality currently has to face the absence of income from the recovered waste, since that income remains within the informal sector. However, if the formalisation process takes place as established in the PGIRS Regional (2006), the municipality will have a source of income through taxes. Furthermore, the municipality is reducing the cost of collection, transport and disposal since a certain amount of solid waste is being recycled, and the municipality is also providing an opportunity for employment generation to the informal sector. One positive aspect is that, at present, there are some organisations called ‘cooperatives’ and ‘pre-cooperatives’ that are working on improving the rights, conditions and market for recyclables for the waste pickers. In this way, a challenging social problem could be solved if the informal sector is integrated to the legal economy, and if their work and sources of income are formalised.

The recycling process is providing an important opportunity to the waste pickers who are normally very poor people with low levels of education, and with scarce opportunities

to improve their standard of living. Another relevant aspect of the dynamic hypothesis is related to the disposal costs, since higher costs of disposal can imply two different options: the illegal disposal of the municipal solid waste or the enhancement and increase in the recovery of waste. In the case under analysis, the municipality is making an effort to reduce illegal disposal through the support of the legislation and the PGIRS that established new strategies and projects for recyclable materials.

The main casual loops diagrams for the municipal solid waste management system in Medellín and its Metropolitan Area will be explained and shown in the following section. Each loop has a sign that indicates the direction of the cycle (counter clockwise or clockwise loop), and the letters B or R make reference to a balancing feedback loop (B) and reinforcing feedback loop (R), following the conventions established by Sterman (2000).

9 Analysis of the casual loop diagram of the municipal solid waste system

The formalised sector will generate an income for the municipality through the taxes that these formal organisations (pre-cooperatives and cooperatives) have to pay every year. As a result of that, the municipality will invest and allocate more funds to the formalisation process, allowing to increase the degree of formalisation. Additionally, the amount of solid waste recovered will increase since more waste pickers will make part of the MSWM system. They will also accomplish better productivity levels and a better collection fraction. Consequently, they will obtain better prices in the market for the recyclable waste. For example, the national framework to integrate and formalise the informal waste and recycling sector in the Philippines leads to conclude that, directly linking up the informal waste sector with businesses will allow the former to negotiate prices of recyclable materials and new products, which would result in adequate incomes (Serrona et al., 2014).

The dynamic hypothesis proposes that the reduction in waste CFs could enhance the residues separated at the source, considering a time required for the perception of the reduction in the fee by households. Consequently, an increase of the recovered residues is reached. The latter will also increase the cumulative income and consequently the cash flow.

The costs of the municipal solid waste management system directly influences the cash flow of the municipality, and the investment in environmental education will depend on the availability of funds and surplus of the cash flow.

If the municipality invests in environmental education, after some time (delay), less solid waste will be disposed of illegally. Additionally, if the municipality has to dispose of a huge amount of solid waste, more costs are generated increasing the desired cash flow. As a result of that, the waste CFs will be affected. If the fees are reduced, it represents an incentive to the households to classify the waste, and with that more waste will be recycled and recovered. The later will generate an income to the municipality, since the taxes that the organisation pays (and finally, the total income) will be increased. The casual loop diagram of the dynamic hypothesis (Figure 3), describes in qualitative terms the feedback structure behind the simulation model developed being formed by two stocks, which are the cash flow and the vehicles. Another important variable is the recovered residues, which will be affected by the process of formalisation. Thus, it is providing an important opportunity to the waste pickers who are normally very poor

people with low levels of education and with few opportunities to improve their standard of living. Another relevant aspect of the dynamic hypothesis is related to the disposal costs, since higher costs of disposal can imply two different options: the illegal disposal of the municipal solid waste or the enhancement and increase in the recovery of waste.

Figure 3 Dynamic hypothesis of the municipal solid waste management system (see online version for colours)

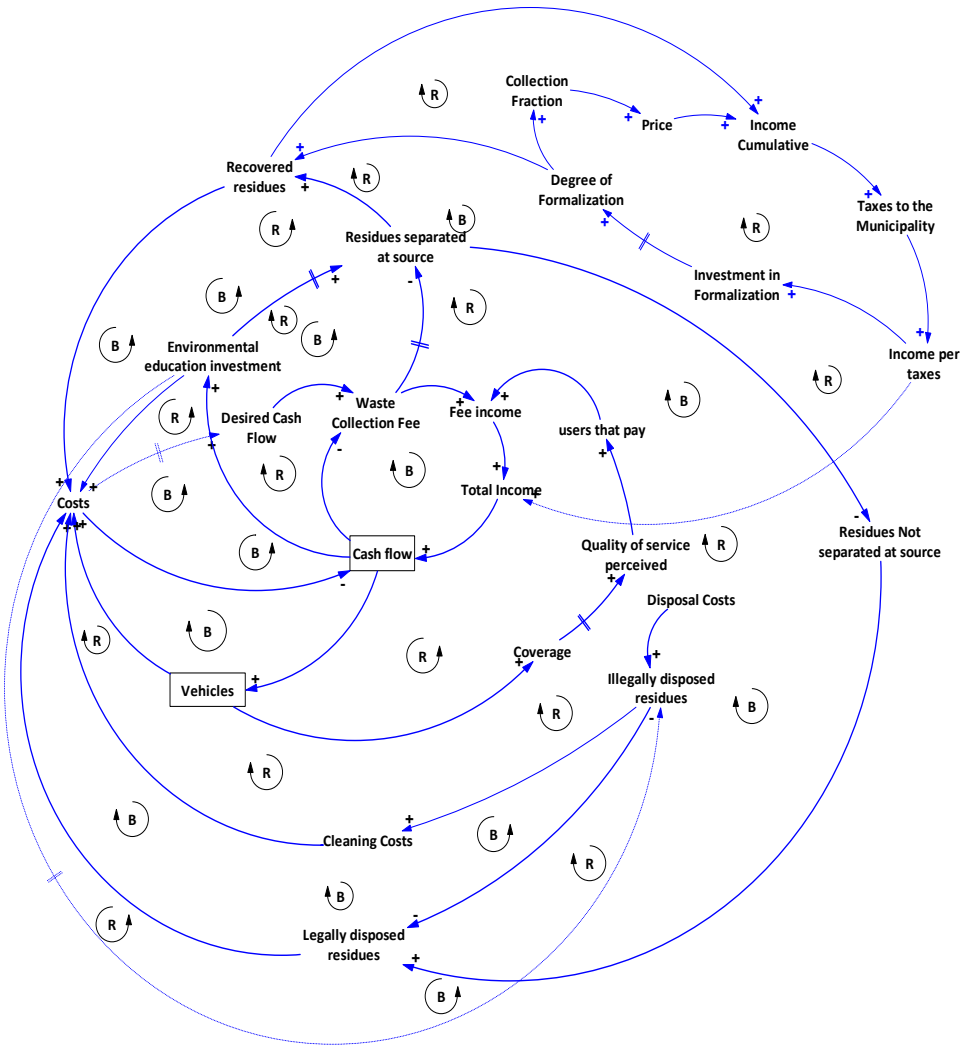
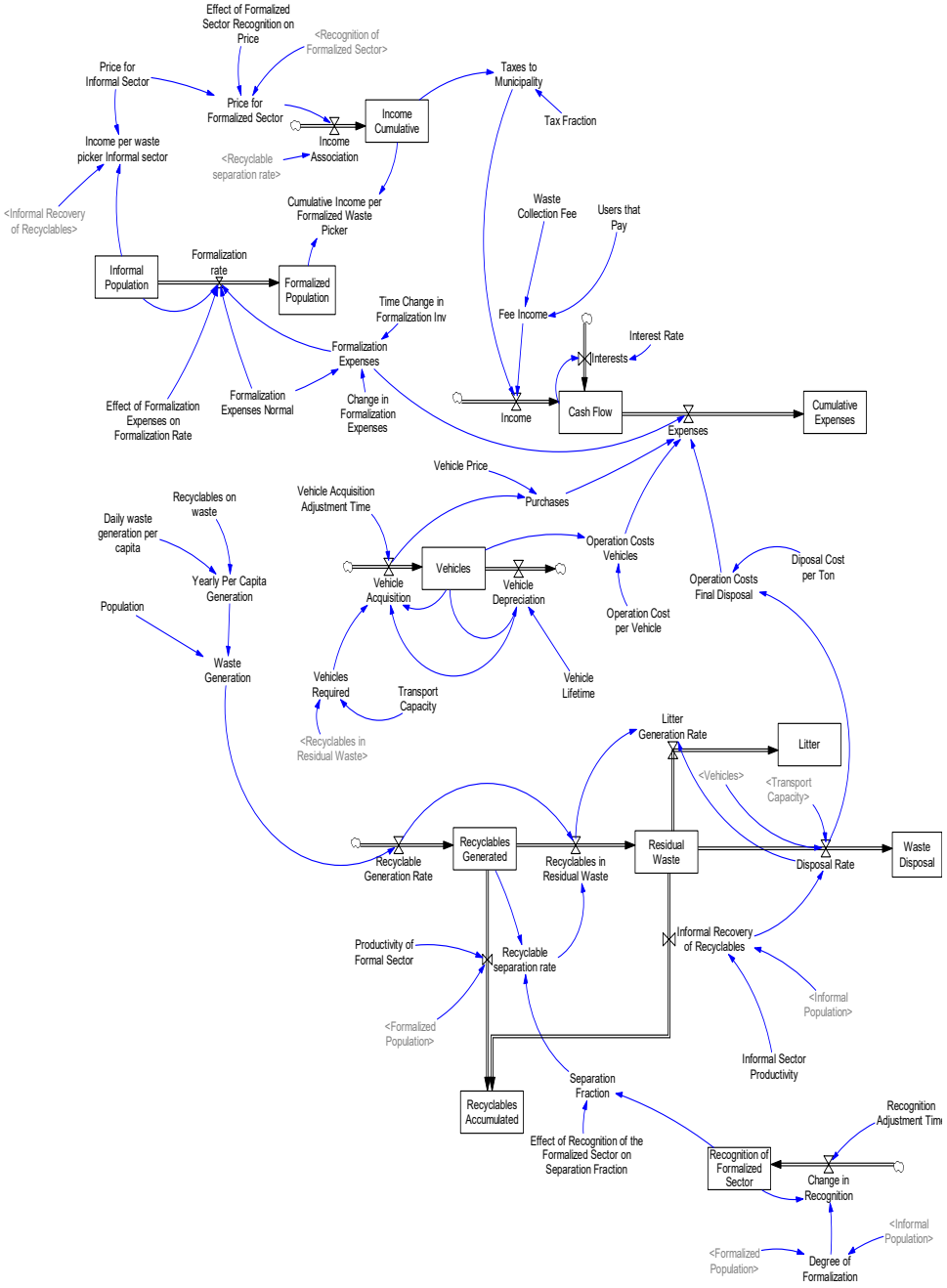


Figure 4 Stock and flow diagram of the MSWM system for Medellín City and its metropolitan area (see online version for colours)



10 Description of the model

The model is focused on two main aspects related to the MSWM system of Medellín and the Aburrá Valley, namely, the economic and social aspects. These are the drivers of the system. The model's objective is to simulate the effect of the formalisation process of the informal sector on the MSWM system in order to learn how this process can solve social and environmental problems. The social challenge consists of creating a new alternative with the purpose of improving their income and living conditions. Additionally, the environmental problem can be tackled with the recycling of solid waste: this process would permit to reduce the amount of waste to be collected and disposed of. Moreover, it reduces the amount of raw materials used on the production processes and the consumption of energy during the fabrication of new products.

11 Stocks and flows diagram

The model is composed of different types of variables which are stocks, flows, parameters and auxiliary variables. They are classified into endogenous and exogenous variables. During the conceptualisation step, different sectors of the MSWM system of the Aburrá Valley were evaluated and with these sectors many variables were mentioned.

12 Subsystem of the model

The model is composed of four sub-systems: formalisation process, cash flow, collection process and the flow of materials (Figure 4). The formalisation process subsystem is mainly composed of three stocks: the informal population, the formalised population, and the recognition of the formalised sector. It also has many other flows and auxiliary variables.

The collection process subsystem is composed of one stock called vehicles, two flows (vehicle acquisition and vehicle depreciation), and other auxiliary variables and parameters such as operating costs of vehicles and the transport capacity. Its variables are an input for the cash flow subsystem, specifically for expenses.

The flow of materials has five stocks: the recyclables generated, the recyclables accumulated, the residual waste, the litter and waste disposal. Additionally, it has an important lookup function (the effect of the recognition of the formalised sector on the separation fraction).

The complete model is depicted in Figure 4: it is possible to notice the connections between the subsystems of the model for the MSWM system of Medellín and its metropolitan area.

13 Required information for the model

13.1 Waste CF

The values were calculated based on the average exchange rate of May 2005 which was $2,341.29 Colombian pesos per US dollar (Central Bank of Colombia, 2015). The simulation was run with a waste CF of 120 dollars per user per year, this value was estimated, taking into account that the only information found were values just for the year 2005.

13.2 Formalisation expenses

According to the PGIRS (2006b), project number 7, the municipality has allocated a yearly amount of approximately $100,000dollars for the integration and formalisation of the informal sector within a 15 year period of time.

13.3 Tax fraction

This value was considered based on the idea that the cooperatives and pre-cooperatives will pay this tax to the municipality. So far, the value of this tax has not been clearly established within the national or regional legislation. Therefore, a value of 5% was assumed for the purpose of this simulation. Also, the interest rate that the municipality manages within its budget (savings and bank loans) is an unpredictable variable, since it depends on the financial market. Therefore, it was considered zero as an initial value.

13.4 Disposal cost

According to the PGIRS Regional (2006), the municipality reports a disposal cost of $51.3 US dollars per ton; that represents the cost for the final disposal. This value was calculated using the average exchange rate of $2,424.1 Colombian pesos per US dollar (Central Bank of Colombia, 2015). However, for the simulation an estimation of $100 US dollars per ton of solid waste as an initial value was considered. Also the municipality has allocated a yearly amount of approximately $100,000dollars for the integration and formalisation of the informal sector within a 15 year period of time (Central Bank of Colombia, 2015).

13.5 Required information not available

The following information and data have not been found in literature and they are required to simulate and run the model. Therefore, these data have been estimated by the authors:

- productivity of the informal sector (total amount of materials recovered)
- productivity of the formal sector (total amount of materials recovered)
- prices received by the informal sector for recyclables
- prices received by the formal sector for recyclables

- recognition adjustment time of the formalised sector
- vehicle prices and operational cost per vehicle
- tax fraction for the formalised organisations.

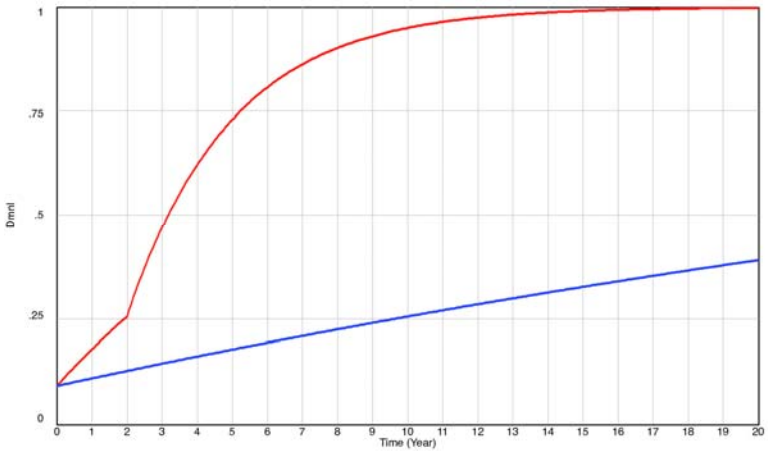
13.6 Limitations of the MSWM system model for Medellín City and its metropolitan area

The model considers different important assumptions related to some variables like the separation fraction of the households and the formalisation rate of the informal sector. For that, some lookup functions were created in order to connect these variables to the system. These assumptions were made because there is no available information concerning these variables in the MSWM system of Medellín and the Aburrá Valley. Besides that, some parameters were not found in literature – for instance, the prices of recyclables for each sector. As a result of that lack of information, the model could not show precise values of the real MSWM system. However, it does allow to get a good perspective of the whole system and to understand the very important role that the informal sector plays, as well as the challenge that the metropolitan area faces with the incorporation of this sector into the MSWM system. Also, the model of this study considered the population as constant, and therefore, the waste generation. Under this assumption, the model was run and tested in order to analyse the behaviour of the variables.

13.7 Simulation results

The simulation run for the MSWM system of Metropolitan Area shows that the degree of formalisation that would be possible to seek within a period of 20 years would be around 40%. This simulation considers a time of 50 years for the effect of the formalisation expenses on the formalisation rate (see the blue line in Figure 5: Inv-TForm-wo Tax).

Figure 5 Inv-TFORM-WO tax (see online version for colours)



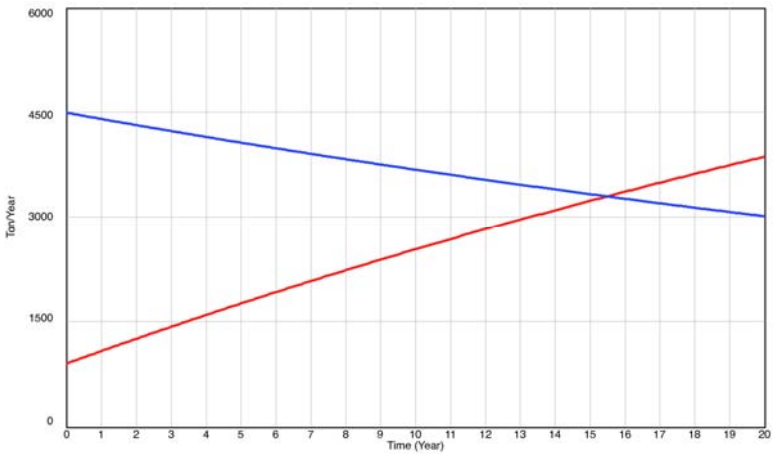
Notes: Red line: degree of formalisation (with investment)
Blue line: degree of formalisation (without investment)

According to Wilson et al. (2006), the highest profits of the recycling process are obtained by the intermediates and manufacturing industries, which are respectively located in the middle and high hierarchies of the recycling process; so, the formalisation could replace these intermediates with the cooperatives.

14 Informal recovery of recyclables and recyclables separation rate of the formalised sector

The informal sector will reduce the amount of tons recovered per year because the number of waste pickers within this sector will diminish every year. This happens when the municipality carries out the process of formalisation of the waste pickers. Moreover, the informal sector is at a disadvantage in many aspects (market, volumes, and prices of the recyclables) in comparison with the formal sector. Therefore, the number of members in the formal sector will increase, and coupled with that, the total amount of recyclables recovered per year. Figure 6 exhibits the above mentioned behaviour.

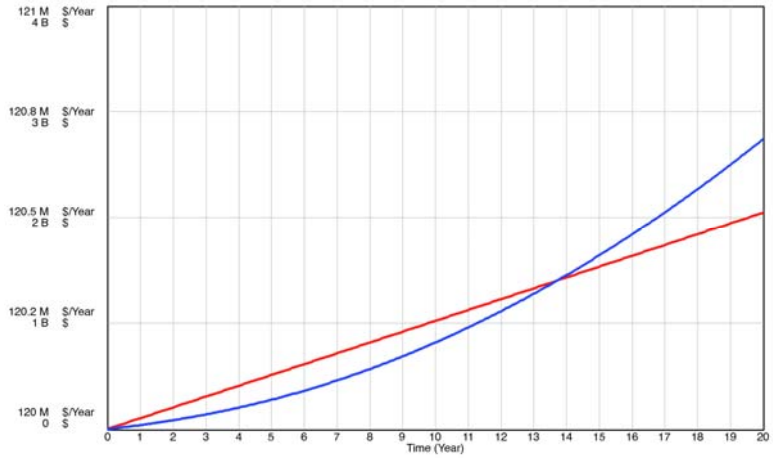
Figure 6 Recovery of recyclables by the informal and formalised sectors (see online version for colours)



Notes: Red line: recyclable separation rate
Blue line: informal recovery of recyclables

The metropolitan area of Medellín has as a source of income, namely the waste CFs that users pay. Additionally, another source comes from the taxes that the formal private organisations (cooperatives and pre-cooperatives) paid on the profits made during the year. As mentioned, cash flow is affected by income and expenses.) The municipality will increase its income and cash flow (Figure 7) despite the expenses in the process of formalisation of the waste pickers. Other developing countries like Bangladesh, specifically in Khulna, have found the private sector as another source of income. The recycling of solid waste is presently carried out by many waste collectors, a series of dealers and industries. Although the recycling of solid waste is not included in the waste management policy of local government, it has become a main source of income for several groups of the private sector (Moniruzzaman et al., 2011).

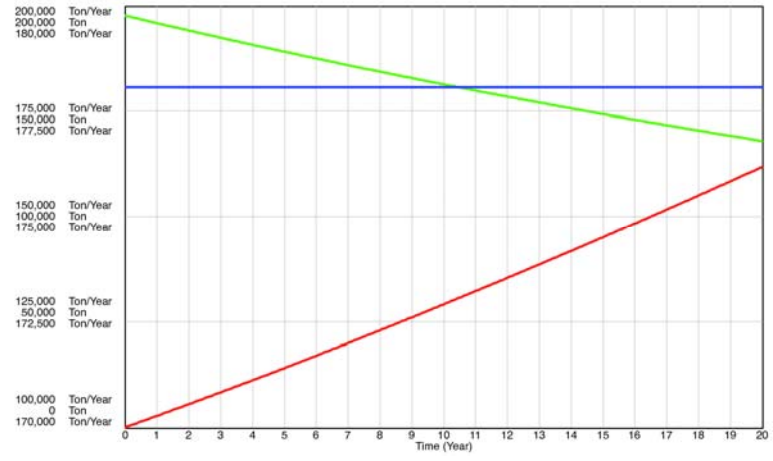
Figure 7 Income and cash flow of the municipality (see online version for colours)



Notes: Red line: cash flow
Blue line: income

The system dynamics model considers the generation of waste as constant. Additionally, the flow of recyclables on residual waste will be reduced since the formalised waste pickers will recover more solid waste, meaning the amount of recyclables accumulated will increase during the period of time under analysis (see Figure 8). Increasing the amount of recyclable material could result in benefits associated with reducing the consumption of natural resources, energy, GHG emissions, and water and benefits associated with biodiversity and non-timber resources preservation (Milanez et al., 2015).

Figure 8 Recyclable generation rate, recyclables accumulated, and recyclables in residual waste (see online version for colours)

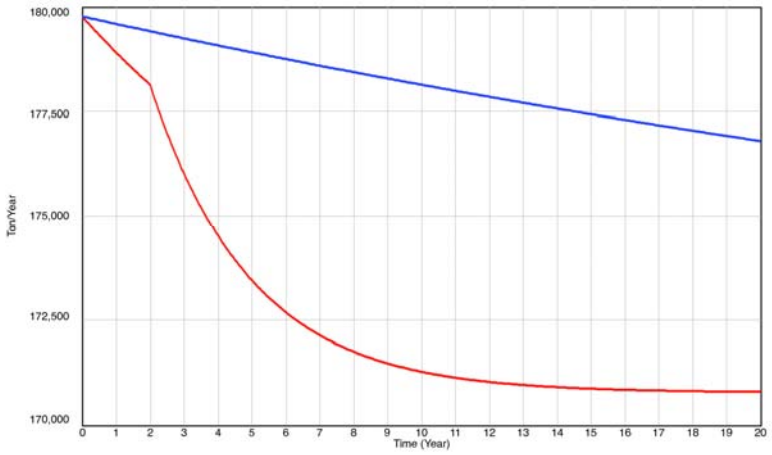


Notes: Red line: recyclable generation rate
Green line: recyclables in residual waste
Blue line: recyclable accumulated

15 Recyclables in residual waste

Some simulations were run for the amount of recyclables in residual waste, as shown in Figure 9. In those simulations, it is possible to observe that the amount of recyclable solid waste in the residual waste decreases over time (see the blue line in the diagram called Inv-T Form-woTax). If a run in the model is performed with a change in time from 50 years to ten years – on the lookup function called the effect of formalisation expenses on formalisation rate – the amount of recyclables in residual waste will decrease significantly during the same period than the run with a time of 50 years (see the brown line in Figure 9 called InvForm = 10).

Figure 9 Recyclables in residual waste (see online version for colours)



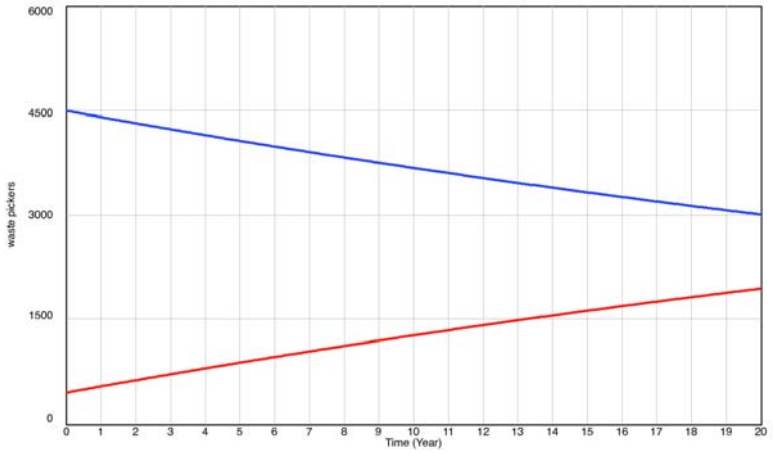
Notes: Red line: recyclables in residual waste (without formalisation process)
Blue line: recyclables in residual waste (formalisation process)

It is possible to observe that the amount of recyclable solid waste in the residual waste decreases over time faster when the formalisation process takes place in ten years (brown line). By recycling one ton of each material, hence avoiding the respective consumption of primary raw materials, society would reduce the environmental damage by a corresponding value. In other words: by recycling, society benefits from a cleaner environment and the value assigned to the welfare generated (Milanez et al., 2015).

16 Formalisation process

When the municipalities of the Aburrá valley invest in the formalisation process, the number of waste pickers in the informal sector starts to decrease, since they begin to associate with some organisations that make a part of the MSWM system. The process is analysed for a period of 20 years, and it is possible to observe that for the last year, the number of waste pickers in the metropolitan area's informal sector comes to around 3,000. Figure 10 depicts these trends.

Figure 10 Formalisation process-number of waste pickers per sector (see online version for colours)



Notes: Red line: formalised population
Blue line: informal population

17 Sensitivity tests

The model has been tested through the variation of the values in different parameters with the purpose of observing the behaviours that the main variables show with these changes. The extreme values used for the sensitivity tests were the following:

The time for the effect of the formalisation expenses on the formalisation rate was changed to an extreme value of 100 years. This change shows that for a long period of time (100 years), the number of formalised population would be reduced in comparison to the simulation that uses 50 years for this parameter. For that reason, the formalisation rate would be very slow.

18 General policy recommendations

The regional legislation could establish, as an obligation for the households, the source separation for the recyclable solid waste. This law would demand a change in the invoicing system of the waste CFs in order to determine which households are doing the separation and which are not. For implementing this law, the informal sector should guarantee a high coverage of collection of the recyclable waste. For that, the municipality should reinforce the informal sector and try to integrate it with the formal sector.

According to Sasaki and Araki (2013) for the case of Bantar Gebang in Indonesia, the role of waste pickers should be positively evaluated by the administrative authorities of welfare and environment to ensure the income resources of waste pickers and to maintain the benefits for the entire society. The collaboration between the waste management authority and the authority of the welfare for the impoverished people is also required to solve the issue of integrating the existing informal recycling system into the formal recycling system. Additionally, new policies for building waste pickers into formal waste

management are required in the Bantar Gebang final disposal site as well. Nowadays the waste pickers are not excluded from the site, but they are not formally accepted as recycling actors.

Furthermore, the new law would enhance the recycling process, and it would improve the recovery of waste. The waste would be of better quality since it would not be mixed with biowaste, for example. With a better quality of recyclables, the prices on the market would increase. Moreover, the cycle of the recycling process would permit a higher income encouraging the waste pickers to collect more solid waste, improving the life conditions of this sector and reducing the waste to be disposed.

19 Conclusions

The increase in the recycling rate of Medellín and its metropolitan area will be possible only if the informal sector is strengthened and included within the municipal solid waste management system of the city. The importance of this sector should be highlighted, considering that it involves social, economic, and environmental factors that are the essence of the system dynamics model created for the Aburrá Valley in Colombia.

It is important to observe that for getting a better income for the waste pickers, prices should be standardised in order to obtain fairer values for this sector, which is placed on the lowest level of stakeholders involved in the recycling process. Additionally, one important challenge that the MSWM system has to face and change is the perception and attitudes, specifically of local officials and also of the general public, toward waste pickers involved in the waste recycling process.

If the formalisation process takes place as established in the PGIRS Regional (2006), the municipality will have a source of income through taxes. On top of this, the municipality is reducing the cost of collection, transport and disposal since a certain amount of solid waste is being recycled, and the municipality is also providing an opportunity for employment generation to the informal sector. One positive aspect is that, at present, there are some organisations called ‘cooperatives’ and ‘pre-cooperatives’ that are working on improving the rights, conditions and market for recyclables for the waste pickers. In this way, a challenging social problem could be solved if the informal sector is integrated into the legal economy, and if their work and sources of income are formalised.

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Notes

1 The Aburrá Valley is composed of ten townships: Barbosa, Bello, Caldas, Copacabana, Envigado, Girardota, Itagui, La Estrella, Medellín and Sabaneta.

2 The average exchange rate used for the year 2006 was 2,424.1 Colombian pesos per US dollar) (Central Bank of Colombia, 2015).