Model-Based Strategy Design for Biowaste Recovery in Addis Ababa, Ethiopia

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Abstract

In order to improve the performance over time of waste management in cities in low and middle-income countries new strategies need to be developed, tested, and implemented. Biodegradable waste (biowaste) should be the primary focus of any strategic design effort, as it corresponds to the largest fraction of household waste in urban centers, which still remains to a large extent unrecovered. Therefore, applying the Strategy Dynamics framework developed by Warren (2008), which uses System Dynamics to develop resource-based strategies, a strategic architecture has been designed for the case study of biowaste management in Addis Ababa, Ethiopia. The strategic architecture consists of all the necessary strategic resources needed achieve the desired performance over time, the flows that cause the resources to grow and be depleted, and the factors that control these flows. For this case study, the strategic architecture includes the administrative units involved in implementation, households separating biowaste, the biowaste collection capacity, the compost production capacity, and the market for compost. Based on the analysis of the performance of the proposed strategy recommendations for the city of Addis Ababa are made.

1 Specifying the Strategic Issue

1.1 Introduction

Addis Ababa is the capital of Ethiopia and a city with currently 3 million inhabitants. As in most urban centers in developing countries, waste management is one of the challenges being faced by the city administration. Figure 1 illustrates the generation of household waste from the year 2000 up to 2025. It has been estimated in 2000 185,000 tons per year of household waste was generated, and by 2025, the quantity of waste coming from households will be over 300,000 tons per year. The chart also illustrates that of all of the waste fractions being generated at household level, biowaste (biodegradable waste from kitchens, food scraps, gardens, etc.), corresponds to the largest fraction, with a contribution on average of 62% of the total mass. On the other hand, valuable materials and recyclables (paper, cardboard, metal scrap, glass, plastic, and textiles) make 21% of the household waste generated, while the remainder (18%) are residuals, with a large content of fines (sand, ash, etc).

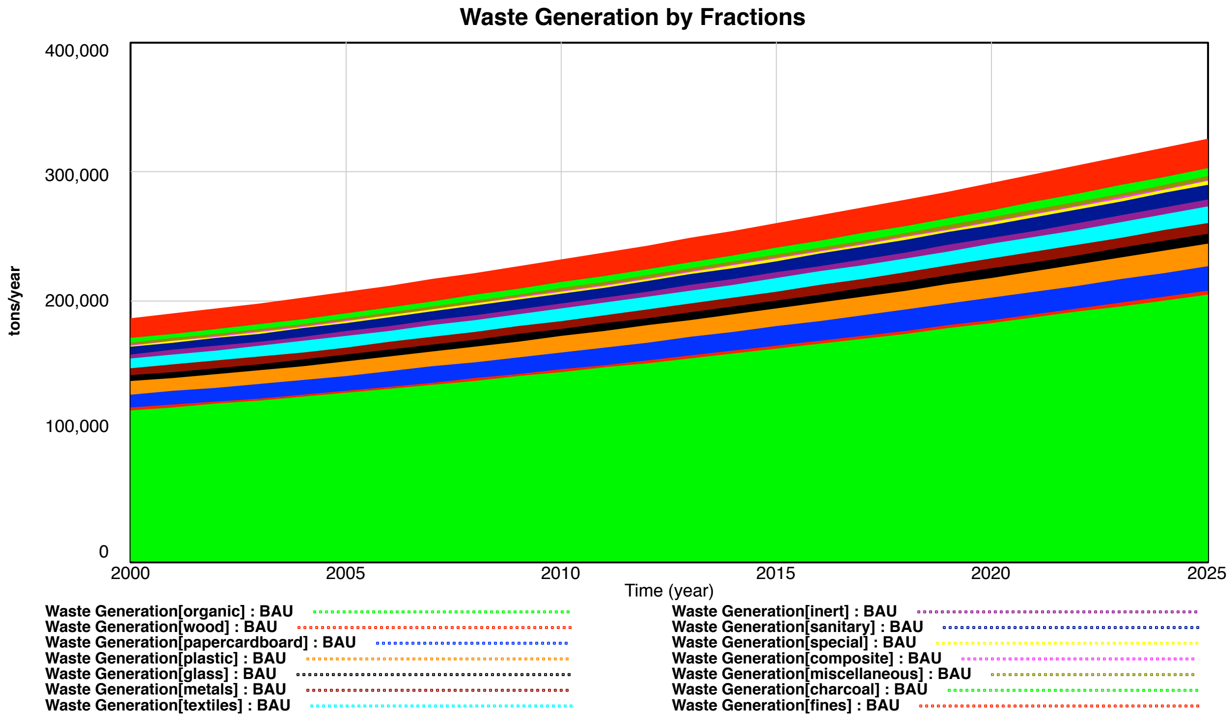


Figure 1 - Household Waste Generation for Addis Ababa from 2000 to 2025

Based on the previous information it is clear that the management of biowaste should be a priority for Addis Ababa, as it represents the largest waste flow leaving households. While there is some informal recovery of recyclables, there is no recovery of biowaste, so all biodegradable materials leave that leave the household are either disposed at the dumpsite if collected, or scattered in the environment surrounding the dwelling areas as a result of illegal disposal and littering. This results in the pollution of surface and groundwater with organic matter and the emission of harmful gases, especially methane, from the decomposition processes. Because of this the current document will focus on the development and testing a strategy for the recovery of biowaste and its transformation to compost for the city of Addis Ababa.

1.2 Definition of Performance Objectives

As a first step to develop the recovery strategy for biowaste, the key performance objectives used to evaluate to what extent the strategy is successful, and their development over time, are defined. The amount of biowaste left unrecovered and that is still found in residual waste (i.e. waste left for final disposal after source separation) will be used as the principal performance indicator. Figure 2 shows that the amount of biowaste in residual waste has developed from nearly 115,000 in 2000 up to almost 145,000 in 2012. Furthermore, the figure defines that if a biowaste recovery strategy is not implemented (red trajectory), by 2025 close to 190,000 tons of biowaste will be left unrecovered, and will find their way either to the dumpsite or to the surrounding environment (e.g. river banks). However, if a strategy for the recovery biowaste starts to be implemented in 2013 and works out, then there will be substantial reduction in the amount of organic matter (to around 20,000 tons per year) in residual waste will be obtained (green trajectory). A complete reduction of the unrecovered amount of biowaste cannot, however, be expected.

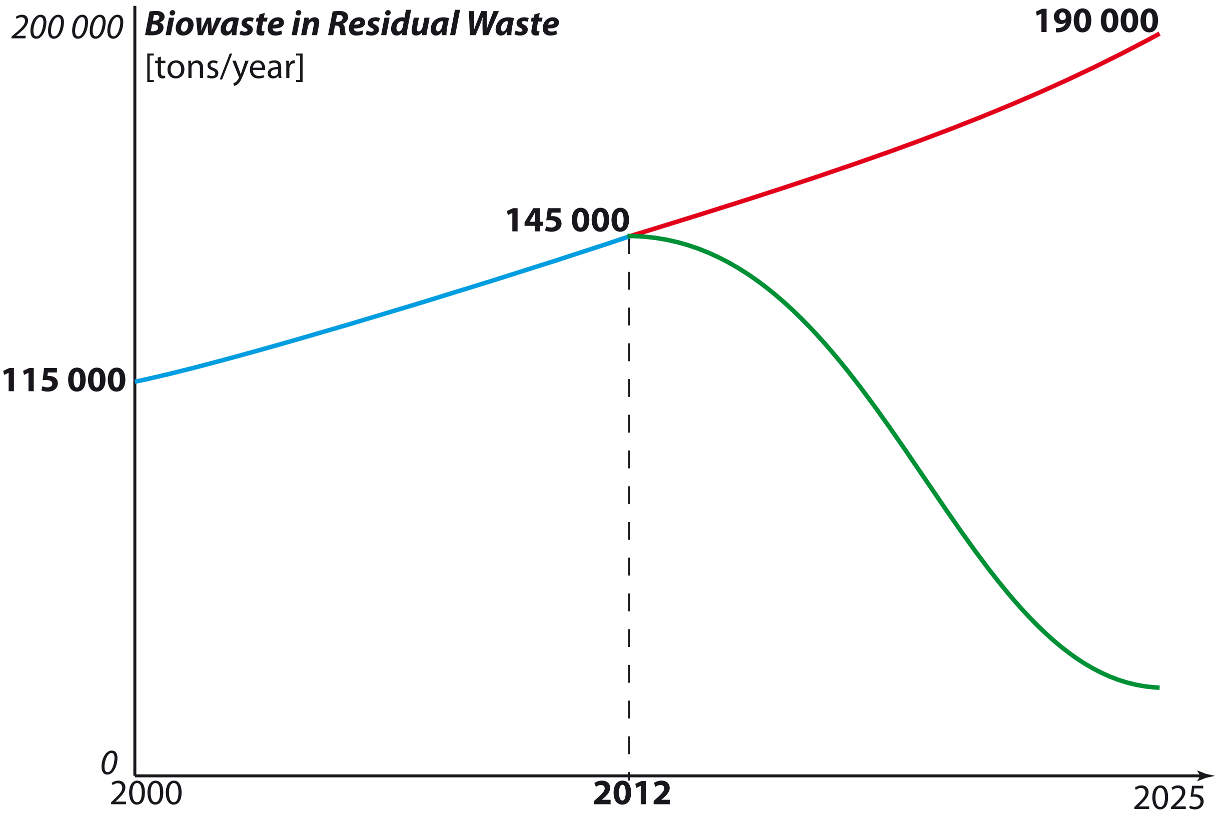


Figure 2 - Development Over Time of the Principal Performance Objective "Biowaste in Residual Waste"

In order to support the achievement of this objective, three other performance indicators have been selected to monitor additionally the success of the strategy (Figure 3):

- The first supporting performance objective is the number of households separating biowaste at source, since for the production of high quality compost source separated biowaste is a prerequisite. Ideally, the desired outcome of the introduction of the strategy in 2013 is that the number of households separating grows from zero to under a million in 2025.
- The capacity for treating biowaste (in tons per year) and converting it to compost is the second supporting performance objective, and it is expected that it will grow in the best case from zero up 190,000 tons per year in by 2025.
- Finally, in order to ensure that at least part of the compost produced will be sold, a customer base needs to be developed. In this case, the use of compost in urban farming is viable, as there are an estimated 7000 hectares being used for this purpose. Once again if the strategy is successful, all of the urban farmers in Addis Ababa will be utilizing compost for their fields by 2025.

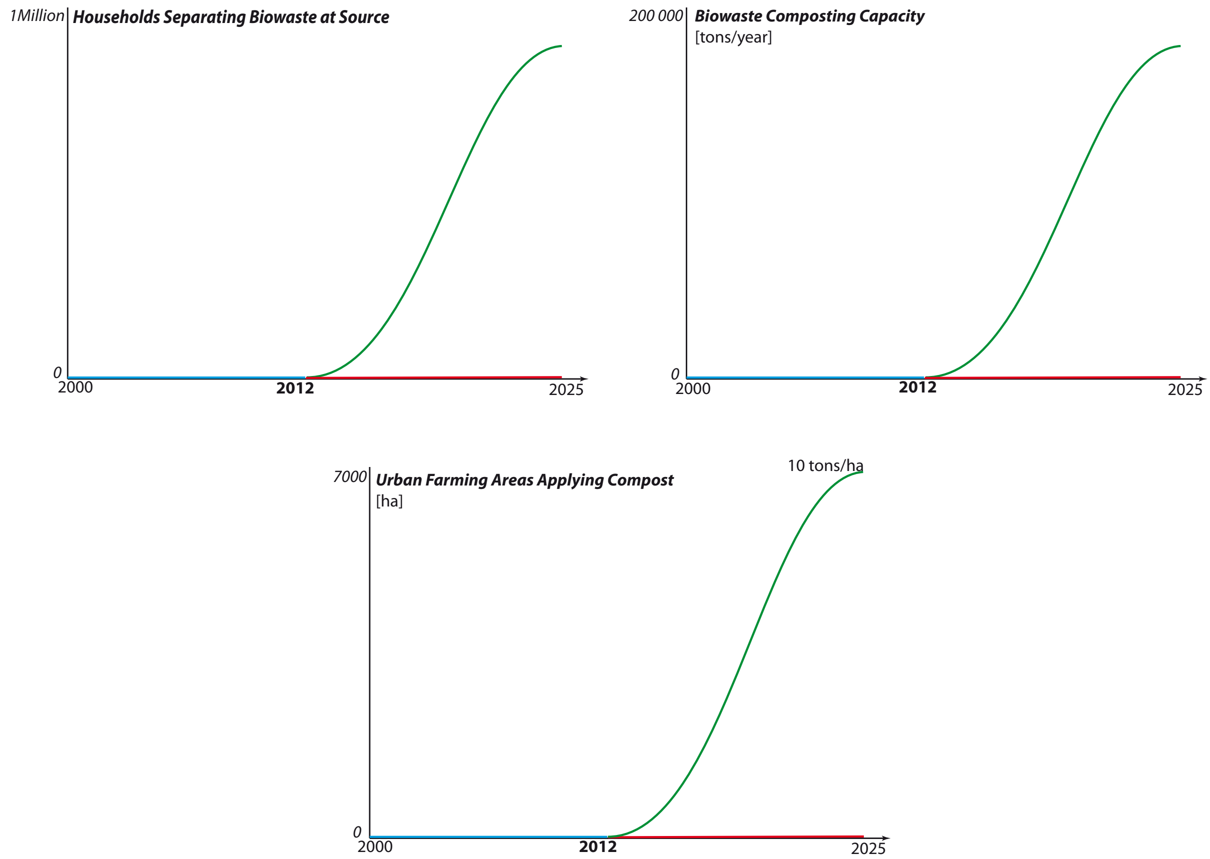


Figure 3 - Development Over Time of the Supporting Performance Objectives

If the city's waste management institutions are unable to implement the strategy, then the number of households separating biowaste, the capacity to convert it to compost, and the urban farms using compost will not achieve the goals set but will remain at zero (red trajectory in Figure 3).

2 Resource Dynamics

In order to explain how the strategy is to be implemented, and what the resulting dynamics of the implementation are, each of the core strategic resources will be discuss step by step. The performance of the strategy for biowaste management depends on the current or business-as-usual (BAU) waste management subsystem and the biowaste recovery subsystem.

The existing waste management system is made up of the following resources:

1. *Population*: responsible for the generation of household wastes, namely biowaste, valuable materials, and residual waste.
2. *Separation capacity of valuable materials at source*: carried out by the households that separate valuable materials and sell them to the informal sector
3. *Informal recovery sector*: itinerant material buyers (kurales in the local language Amharic) go from door to door and purchase the materials separated by households and transfer them to the market
4. *Primary collection capacity*: collection of residual waste is done by precollector groups with workers and pushcarts serving households from door to door

5. *Waste transport capacity*: waste collected by precollectors is transferred to trucks and taken to the dumpsite.

In order to implement the biowaste resource recovery strategy, it is important that biowaste is separated at source by households, that the separated biowaste is collected, that the collected biowaste is composted, and that the produced compost finds an application. The subsystem for the recovery of biowaste in therefore is made up of the following resources:

1. *Administrative development chain*: in order to bring households to a stage where they separate biowaste, and precollectors to a stage where they collect source separated biowaste, the corresponding administrative units (subcities and woredas) need to plan and implement the strategy
2. *Biowaste separate collection capacity*: precollector groups will collect biowaste if moved by the local administration to do so, and will inform households about the need for source separation
3. *Biowaste separation resource*: households will be informed by precollectors about the need to separate biowaste and will do so after moving to action and commitment
4. *Composting capacity*: source separated and collected biowaste will be transformed to compost at decentralized biowaste facilities
5. *Compost application in urban farming*: urban farming areas will become aware and adopt biowaste after receiving information about the benefits of compost use

The following sections will describe the dynamics of these individual resources.

2.1 Business-as-Usual Waste Management Resources

Population

As mentioned previously the population is responsible for the generation of household waste. As depicted in Figure 4, the population is the result of the accumulation through time of births and net migration and the draining resulting from deaths. The population of Addis Ababa was 2.4 million in 2000 and is expected to grow up to 4 million by 2025. This is the result of the births and migration to the city constantly exceeding the deaths. By 2025 it is estimated that 68,300 births per year will take place, 55,500 people will migrate each year to Addis Ababa, and the mortality rate will be 37,900 cases per year.

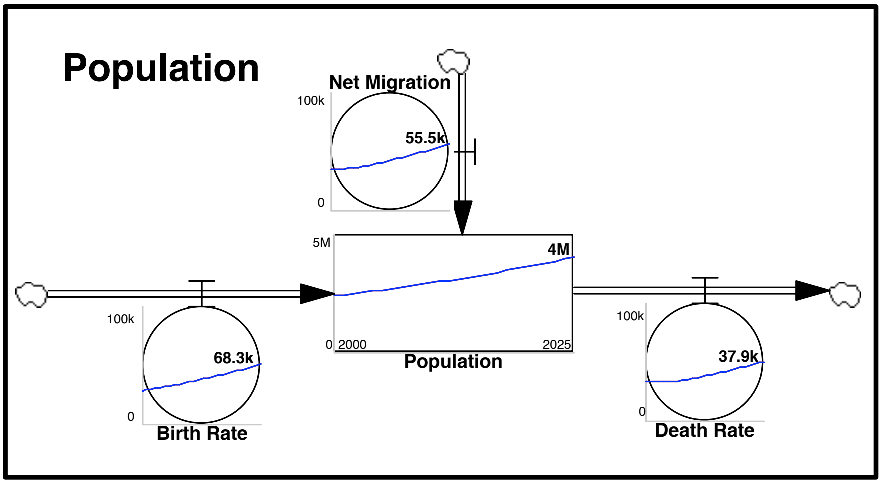


Figure 4 – Estimated Population Dynamics for Addis Ababa from 2000 – 2025

Separation capacity of valuable materials at source

Even under business-as-usual conditions not all waste is disposed as residual waste. A part of the waste generated is separated and sold to the informal recovery sector. The households that are separating valuable materials (paper, cardboard, glass, metals, textiles, plastics) are responsible for the segregation and sale process. It has been estimated that in 2000 311,000 households were separating materials at a rate of 21.5 kg per household per year, resulting in a total potential amount of source separated dry recyclables of 6,700 tons per year. As a result of population growth, households separating will grow, initially at a rate of 6,170 new households per year. However, in 2003 the implementation of multi-dwelling housing units (condominiums) led to the sudden increase in new households up to 9,270 per year. Parallel to the increase in new households, the implementation of condominiums has led to the decrease in the amount of valuable materials separated, as itinerant material buyers are not allowed to access the condominium compounds to purchase the recyclables. As a result, the initial rate of source separation is expected to drop to 18 kg per household and year by 2025. However, because of the growth of households separating valuable materials, estimated at 13,900 new households in 2025, it can be anticipated that by that year 582,000 households could segregate a total of 10,500 tons of recyclables.

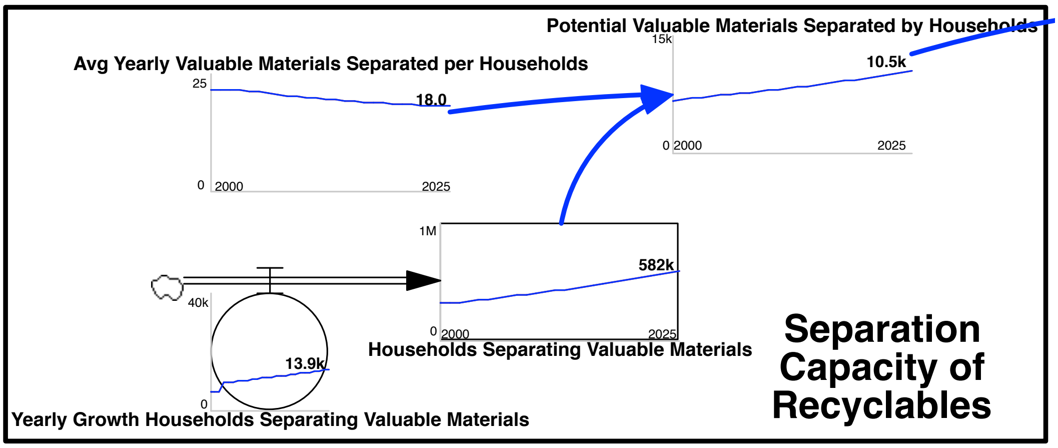


Figure 5 – Recyclable Separation Capacity at Source

Informal recovery sector

The second resource contributing to the diversion of recyclables away from final disposal is the informal recovery sector, specifically the itinerant material buyers or kurale. It has been estimated that a kurale can collect on average 2.75 tons each year of recyclables and valuable materials. The kurale population, which has been backcasted to 2,400 in 2000, can be expected to grow to 3,800 by 2025 (Figure 6), as its growth rate has gone up to 74 new kurale per year. This would lead to an increase in the collection capacity of recyclables from about 6,700 to 10,400 tons per year. The growth of the number of itinerant recycling material buyers is based on the assumption that informal sector will try to keep up with the supply of source separated materials at household level.

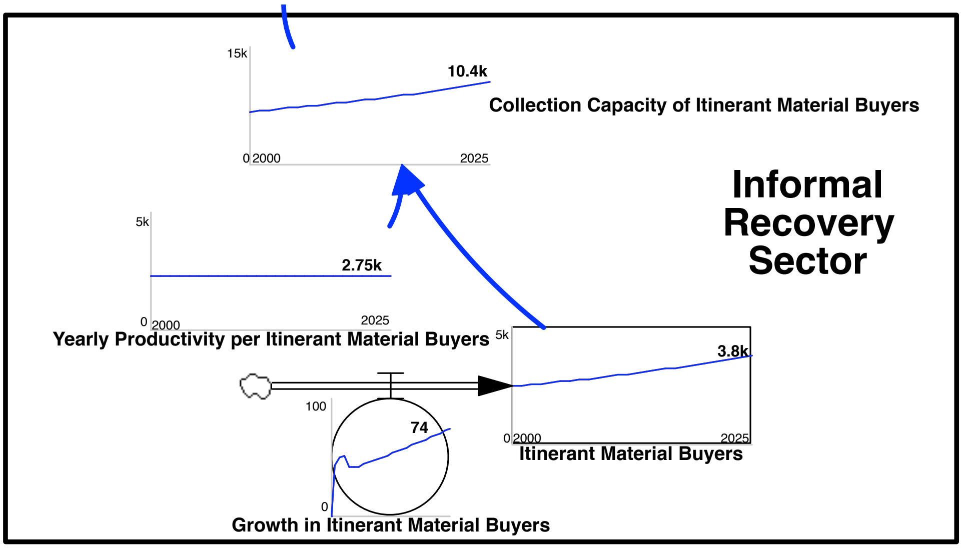


Figure 6 – Informal Resource Recovery Capacity

Primary collection capacity

After separation by households and the recovery by the informal sector, the remaining household waste is collected and transferred to the dumpsite, and if not so, it will be eliminated at the nearest open area or riverbank. According to the Central Statistical Agency of Ethiopia, the population served by the city's waste collection services has grown from 1.31 million in 2000 to 2.74 million in 2011. This equals an increase from a collection coverage of 55% of the population to 92%. As already mentioned, door-to-door collection is carried out by precollectors, who are organized in groups of 10 workers on average. Figure 7 presents the resource subsystem from household waste precollection, composed of the precollector groups and the precollector workers. The number of precollector groups working in the year 2000 has been estimated at 238, which results in 2,380 precollectors working on the collection of household residual waste, who, with an average productivity of 41.2 tons per worker per year, would have been able to gather 98,000 tons of residual waste from households that year. The yearly increase in precollection groups is determined at the smallest administrative unit, the woreda, where the operation of new precollection groups is authorized. The increase in precollector groups follows up to 2011 the historical pattern of the collection coverage, starting at 25 new groups (250 new precollectors) per year in 2000, dropping to 10 new groups (100 new precollectors) in 2003, and going back up to 45 new groups (450 precollectors) in 2010 and 2011. From 2012 onward it is assumed that the city administration will do everything to keep the collection coverage as close to 100% as possible, by adjusting the resource of precollectors group toward the indicated number[1]. Since the precollection capacity has gone up to 92%, after 2011 the effort to expand it drops substantially to 12 precollector groups per year in 2013, and rises slowly to almost 15 new precollector groups in 2025. As a result the city expands the precollection capacity to 705 precollector groups with 7,050 workers by the end of the period of analysis, which brings a potential precollection capacity of 290,000 tons per year.

[1] In order to keep the diagram simple, this feedback process is omitted

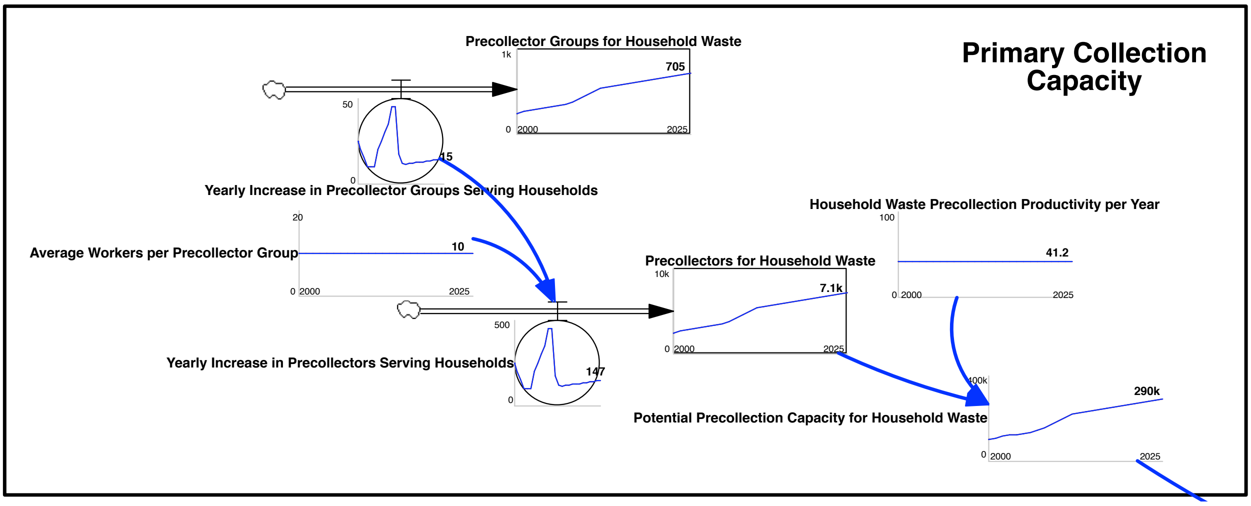


Figure 7 – Primary Collection Capacity

Waste transport capacity

How much waste is effectively transported away from households depends on the available transport capacity, since even if there is sufficient primary collection capacity, if it is not transported, it will ultimately be disposed in the local environment. The transport capacity (also known as secondary collection) is determined by two resources: the waste transportation trucks and the truck drivers. It has been estimated that there were 35 trucks in 2000, of which only 60% was operationally available (i.e. 21 trucks), since on average, 25% are in maintenance and 15% out of service temporarily or permanently[2]. This leads to a potential capacity for transport of 98,600 tons per year, given a yearly transportation productivity per truck of 4,700 tons of waste. In that same year there were around 36 drivers, which allowed 15 trucks to be operated during the night as well as in the day. The 36 drivers had the potential to transport 98,600 tons per year, assuming that their potential productivity was 2,700 tons of waste per year. As the number of drivers and the waste transport fleet are in equilibrium, the potential transport capacity is only 98,600 tons per year.

As in the case of the precollection capacity, the size of both resource stocks is increased in order to reflect the historical collection coverage up to 2011. In the case of the transport trucks, the acquisition of trucks is set at 3 new trucks per year, then brought down to 1 in 2003, then increased to 5 in 2007, and again to 7 in 2011. This results in a truck fleet of 75 trucks, of which 45 are operational. The yearly transport capacity of trucks has dropped slightly to 4,550 tons, as the some of the trucks purchased have lower capacities (e.g. sideloaders and compacters) than the average. In the case of the truck drivers, 3 new drivers are hired per year from 2000 to 2002, then only 1 until 2004, increased to 5 by 2007, and then the hiring rate is brought to 6 per year in 2011. The outcome is 73 drivers, of which 28 work during the night shift. As is the case of the precollecion capacity, it is assumed that after 2011 the city administration will purchase trucks and hire truck drivers in order to adjust these resources to the necessary number to keep the collection coverage near 100%. Because the expansion of the waste transport capacity has been strong in the past years, in 2012 the number of trucks purchased drops to 1, while only 2 drivers are hired. The outcome of the purchasing and hiring decisions from 2000 until 2012 is 82 trucks, out of which 49 are operational, and 79 drivers, of which 30 work during the night shift. This increase in the fleet size and driving staff results in a total potential capacity of 221,900 tons per year in 2012.

[2] The period of analysis is close to the average lifetime of the trucks, and therefore asset depreciation is ignored

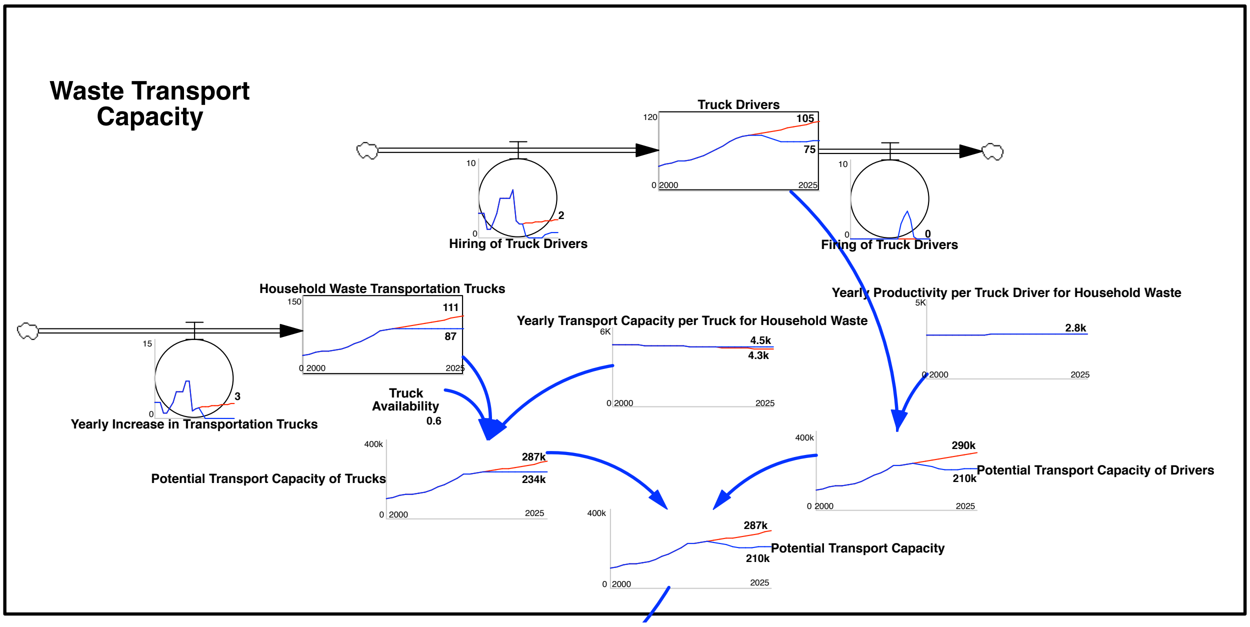


Figure 8 – Waste Transport Capacity with Results for the Business-as-Usual (red) and Biowaste Recovery Scenarios (blue).

In Figure 8 two developments are portrayed after 2013, when the biowaste recovery strategy is introduced. The red curve shows the development of the secondary collection capacity for the base case. The purchase of trucks rises from 1 per year to 2 in 2015, and gradually reaches 3 in 2025. This leads to a total number of trucks equal to 111, of which 67 are operational, for a total potential transport capacity of 287,300 tons per year. Meanwhile, 2 drivers are hired per year, adding up to a total staff of 105 drivers in 2025, of which 37 work during the night. This in turn means that the total capacity of secondary collection determined by the driving staff is 290,400 tons per year. Because the limiting factor here are the number of trucks, then the potential transport capacity for waste is 287,300 tons per year. In contrast, the blue curve shows the development of the secondary collection capacity when biowaste is collected separately and valorized to compost. As will be seen later, the amount of residual waste to be transported is lower than in the business-as-usual case. This means that the number of trucks that need to be purchased drops to zero in 2016, which results in the truck fleet leveling at 87 trucks (52 operational trucks) and a potential transport capacity of 233,600 tons per year. In the same year hiring of drivers drops to zero, as no new drivers are needed. On the contrary, the staff size is too large, and the city must let go part of the drivers so the firing rate goes from zero in 2015, up to 3 drivers per year in 2018 and back down to zero in 2021. Since there is still hiring going on up to 2016, the driver population grows from 79 to 83, and then drops to 73 in 2020. A small increase in the hiring rate towards the end of the time period rises the driver pool to 75. The outcome in terms of potential waste transport capacity is 209,900 tons per year by 2025.

2.2 Biowaste Recovery Strategy Resources

Administrative development chain

Once the administration of Addis Ababa decides to implement the recovery and valorization of biowaste, the different administrative units in charge of waste collection and management need to plan and implement the strategy. Since household waste collection is organized at the lowest and smallest administrative level, the woredas, these have to be explicitly considered in the analysis of the strategy. Additionally, the strategy foresees that the implementation and operation of decentralized composting facilities, so the implementation in the woredas with sufficient space for this activity needs to be reflected in the strategy. Furthermore, as the subcities, which correspond to the administrative second level oversee the work of the woredas, it is likely that the subcities will make efforts to plan and implement the biowaste recovery strategy in the woredas under its responsibility. Hence, the ten subcities need to be considered in the evaluation of the strategy.

In the lower section of Figure 9 shows the development of the ten subcities along three different stages. Before the implementation of the biowaste valorization strategy in 2013, all subcities find themselves in the category of subcities with the potential to implement the strategy. Once the city decides to implement the strategy, it will take on average 6 months for the subcities to be informed of the intention of the city administration and to start planning the necessary steps to implement the strategy. The subcities that are planning the implementation will need in turn a year on average to start the introduction of the strategy in the woredas that make part of each subcity. As a consequence of this process, by year 2016 all the subcities are either planning to implement or are implementing the strategy and by the year 2025, all ten have made the strategy part of their mandate.

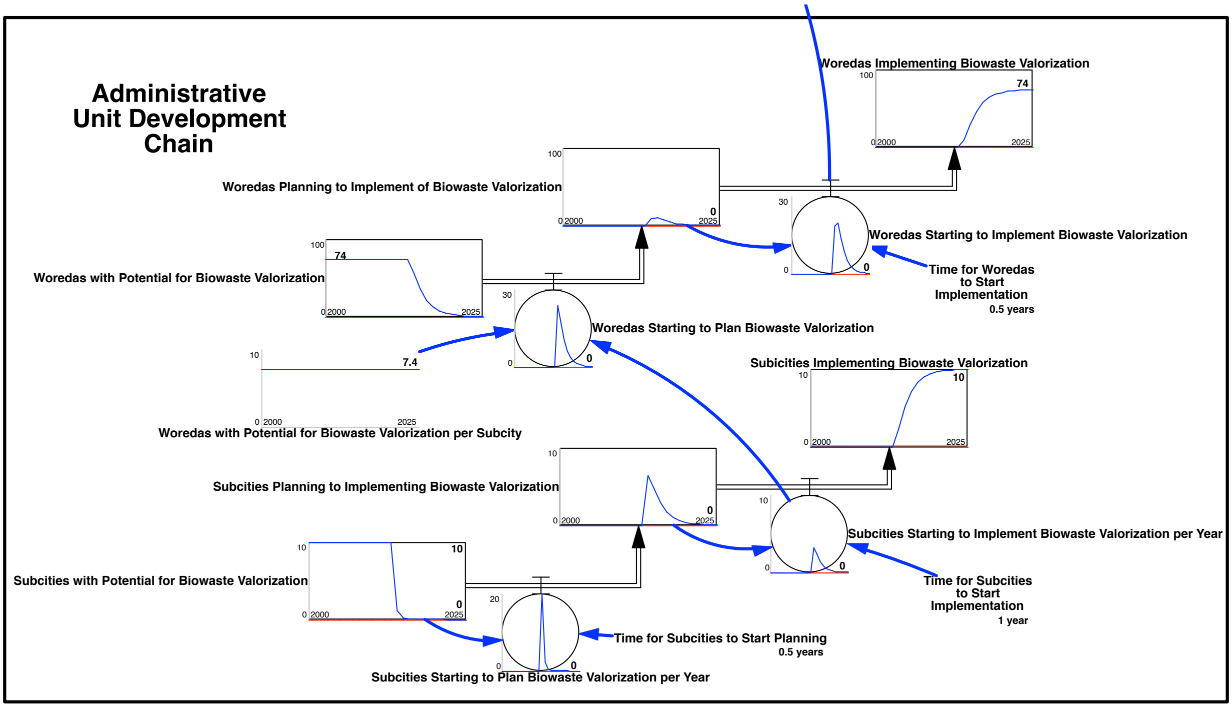


Figure 9 – Administrative Unit (Subcities and Woredas) Development Chain

In the upper part of Figure 9 the development chain of woredas is depicted. It has been estimated that out of the 116 woredas, 74 have enough land available to set up decentralized biowaste composting plants. This means that there are on average 7.4 woredas per subcity that could potentially do so. In the same fashion as for the subcities, before the woredas implement the strategy they will go through a stage of planning. This means that when the subcities start to implement their part of their strategy, they will move their woredas into the planning stage. After six months woredas will start implementing their part of the strategy, which is to train the precollectors to collect separated biowaste and to transport it to the composting plant. Additionally they will need to provide the necessary equipment (e.g. pushcarts) for this to occur. Therefore, all the 74 woredas will have only be implementing the strategy by 2025, as it will take time to move through from the planning to the implementation stage. At first the number of woredas implementing will grow strongly, exemplified by the fact that after 2 year, in 2015, it is expected that in 28 woredas will have implemented the strategy and 7 years later, in 2020, 70 woredas would have done so. Then the number of woredas starting to implement will slow down, as only 4 additional woredas will implement in during the remaining 5 years leading to 2025.

Biowaste separate collection capacity

For the collection of the separated biowaste, treatment capacity is needed. Similarly as for the collection of household waste, the strategy proposes that the precollectors carry out the collection of biowaste and take it to the decentralized composting plant in each woreda. The precollectors start in a stage where they have the potential to collect biowaste and then, when the woredas implement the strategy, the potential precollector groups move into the stage of actively collecting biowaste (Figure 10).

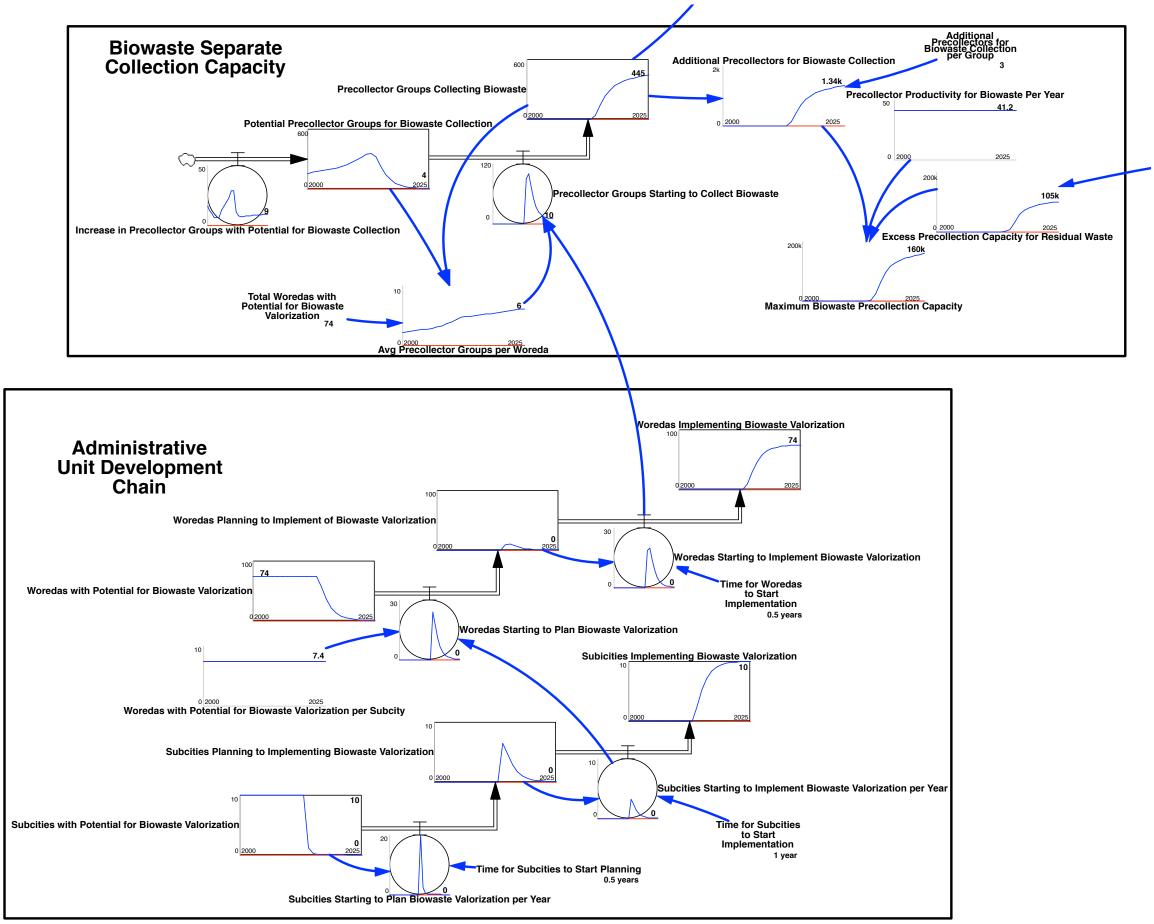


Figure 10 – Biowaste Separate Collection Capacity Developed by Administrative Units

As illustrated in Figure 11In the year 2000, the 74 woredas where composting can take place have 152 precollector groups, which is a bit more than 2 groups per administrative unit. Since the population of Addis Ababa grows and the precollection capacity is adjusted, the number of precollector groups, and thus the potential precollector groups for biowaste collection, grows. By 2012, just before the implementation of the strategy, 343 precollector groups have the potential to collect biowaste. Once the woredas start to implement the strategy, they move the precollector groups that each has within their jurisdiction to actively collect biowaste, at first at a very high rate (around 100 groups per year starting to collect), and then dropping to a very low rate (only 10 groups per year). This has the consequence that the number of potential groups collecting drops very fast at first, while the precollector force collecting biowaste expands swiftly. Then as the process slows down, the precollector groups start to saturate and reach the value 445 in 2025.

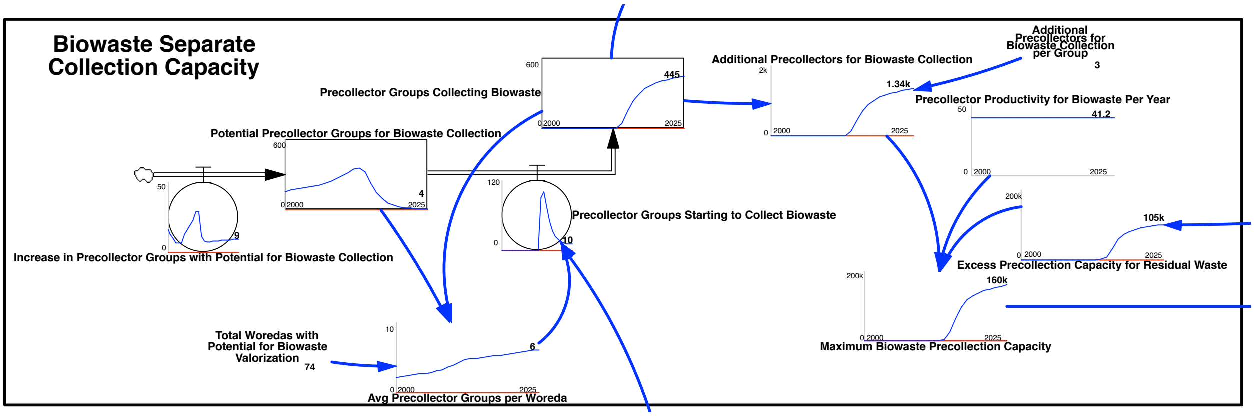


Figure 11 – Biowaste Separate Collection Capacity

The strategy also assumes that additional personnel will be needed for biowaste collection, specifically 3 persons per group more. This raises the precollector population by 1,340 persons. As will be seen later, 105,000 tons of biowaste will be separated. This means that the same amount of precollection capacity for residual waste is liberated, which can be used now for the collection of biowaste. The outcome is that by 2025 the additional precollectors and the liberated precollection capacity result in 160,000 tons per year of collection capacity that could be used for biowaste collection.

Biowaste separation resource

For the biowaste recovery strategy to be successful, households need to separate their biowaste. Since at the beginning of the strategy implementation process basically no households are actively separating biowaste, households need to be made aware of the need for source separation, and then be moved to action, and ultimately urged to commit to source separation in the long run. The strategy assumes that a very simple mechanism can be used to move households along the different stages. Basically three members of each of the precollection groups in the woredas, where the biowaste recovery strategy is applied, will inform households about source separation.

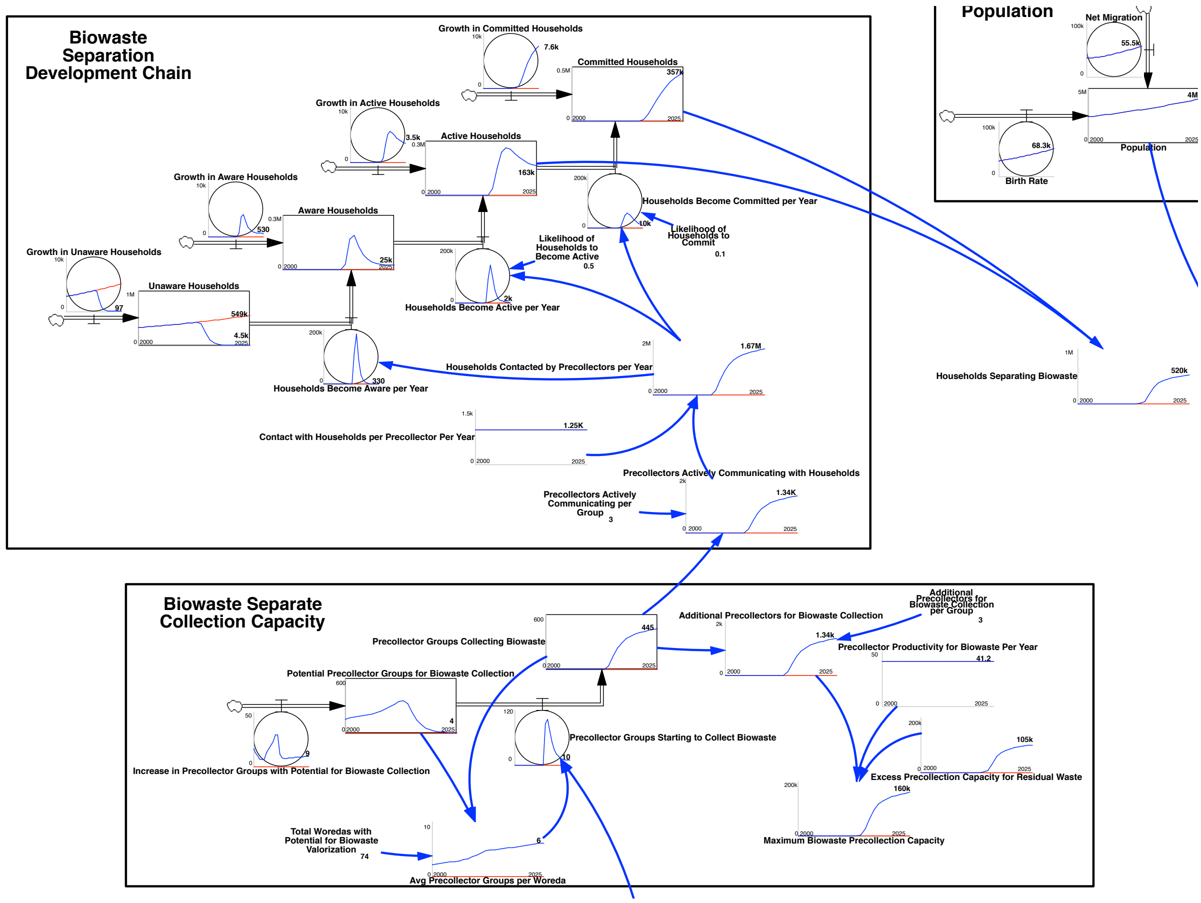


Figure 12 – Biowaste Source Separation in Households Driven by Contact with Precollectors

Figure 13 illustrates that if each of the additional workers will enter in contact with 5 households each day and talk them through the process of adequate separation, all of the unaware households contacted will become aware, making the aware population grow. However, because of population growth and because a part of the aware population naturally looses interest on source separation and drop back to the unaware pool (basically after 2 years)[3], the unaware population becomes smaller at a much lower rate. In a similar manner, the precollectors contact the aware population, but only 50% of the households contacted become active. Furthermore, one fifth of the active population drops back into the aware (but inactive) population each year, making, together with population growth, the aware population grow, beyond what it would otherwise would have. Meanwhile, the active population grows through the movement of households from aware to active, through population growth, and through the movement of 10% of the committed households back to the active household stock. The size of this group is decreased by the households that become committed to source separation each year, which is the result of 10% of the contacts of precollectors. The committed population, which will carry out source separation for a long time even (10 years) if they are not constantly reminded of that need, will grow because of the active households becoming aware, and population growth.

[3] Fallback rates are not depicted explicitly

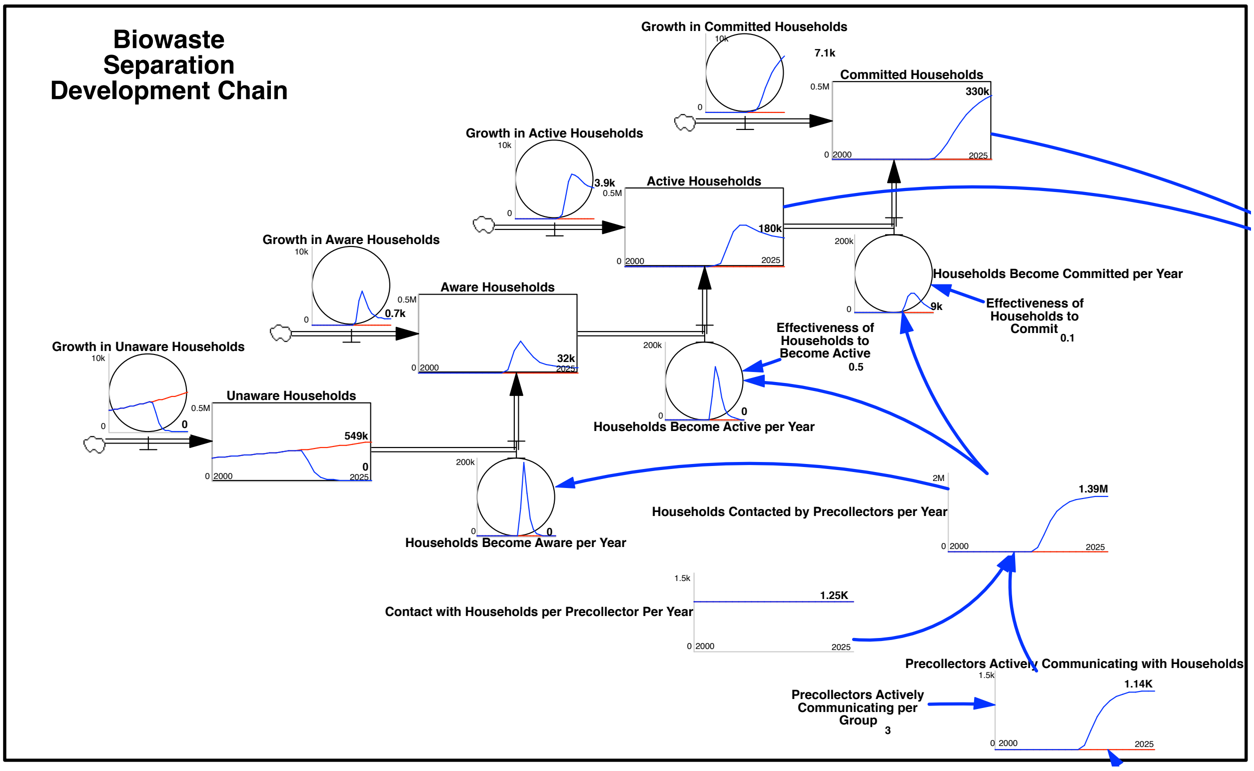


Figure 13 – Biowaste Source Separation Development Chain

In 2013, at the start of the introduction of the strategy, there are 425,000 households, which are all unaware about segregation of biowaste. As a result of the strategy implementation, instead of having 548,600 unaware households by 2025, it can be expected that the city will only have around 4,500 by 2025. That is the result of the work of twelve years of moving the households into the aware, active, and committed stages. In 2025, the additional precollectors, which in 2025 will have grown to 1,340 and will be contacting 1.675 million households, would have made 186,000 households aware in 2016, and 263,000 active households in 2018. By 2025 356,600 households will have achieved the status of committed households, 162,900 will be active, and 24,600 will be aware. This results in a total of 519,500 households separating biowaste (Figure 14).

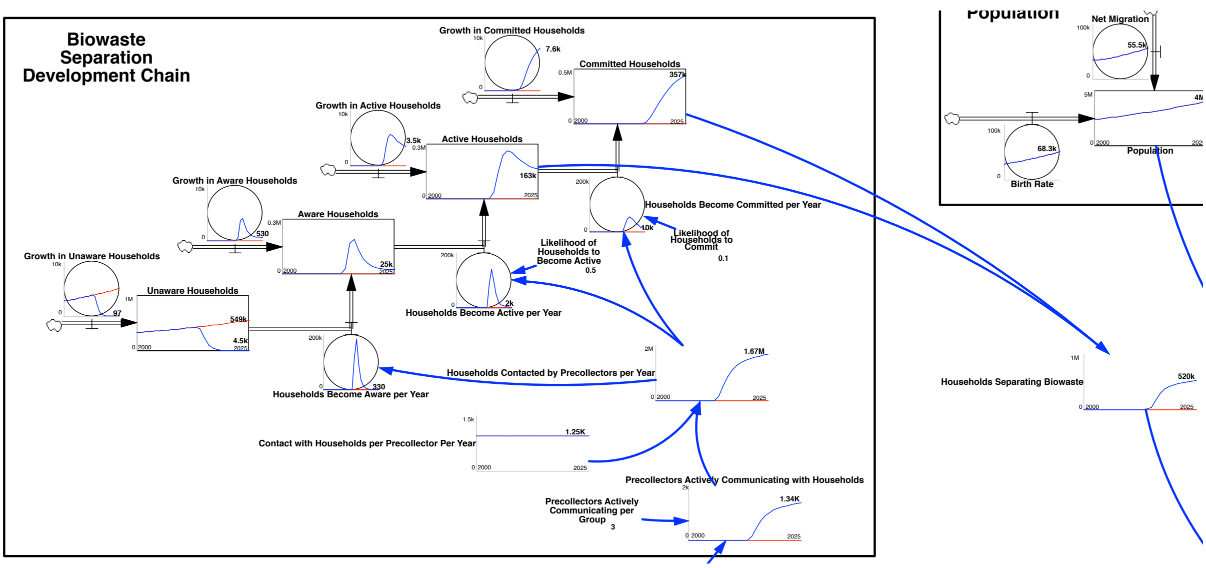


Figure 14 – Total Households Separating Biowaste

Composting capacity

For the production of compost, composting capacity has to be constructed and put into operation. Figure 15 (which aggregates the composting capacity for all woredas implementing the strategy) illustrates that the woredas will first decide what composting capacity should be in operation, then start the construction (including design and site selection) of the capacity, and after one year, will take it into operation. Since it is not expected that from the beginning all the biowaste will be separated by households, and no knowledge of the dynamics of adoption is available at the local level, a simple rule is used to decide how large the desired capacity should be. Basically, the implementing woredas will estimate how much biowaste is generated and for every year that has passed since the introduction of the strategy in the city, it is assumed that 20% more of the population will separate their biowaste. This means that by 2018, 100% the biowaste is expected to be available for composting. Based on this, if there is a shortfall between the desired capacity and the total capacity (capacity in construction and capacity in operation), the construction starts are adjusted over a three-month period.

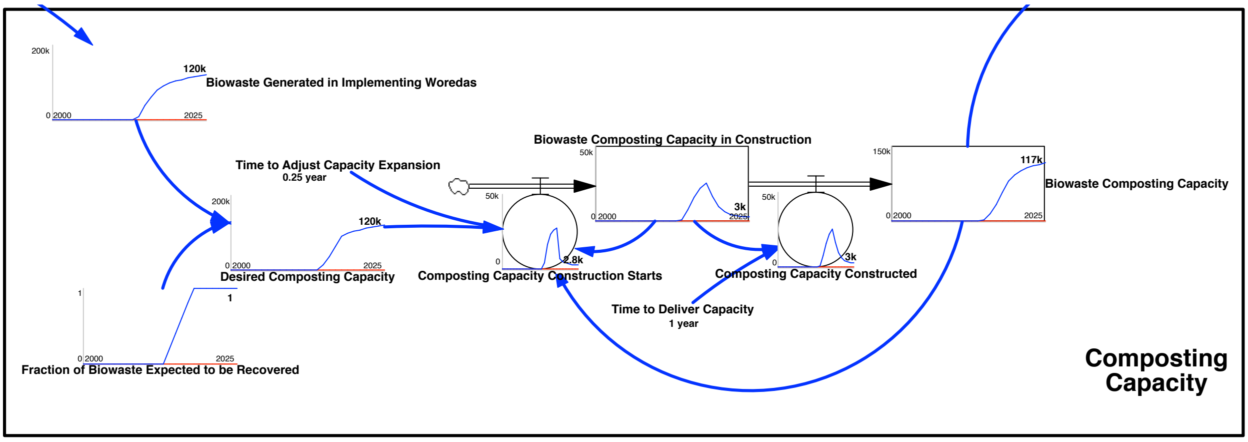


Figure 15 – Biowaste Composting Capacity

The outcome is that construction starts are increased until 2018, when additional 27,000 tons per year are put into the construction process. In that same year 25,000 tons per year of capacity are put into operation. The buildup of capacity in operation then makes it unnecessary to have such large construction rates, so constructions starts in 2025 drop to 2,700 thousand tons per year, and the capacity delivered follows at around 3,000 tons per year that year. As a result of these changes in the start and delivery of capacity, capacity under construction peaks at 25,000 in 2028, and drops down to 3,000 in 2025. Meanwhile, the capacity in operation grows to 116,500 tons per year.

Compost application in urban farming

Urban farming is not the only use for compost, as it can be use for erosion prevention, home gardening, and peri-urban agriculture. Since there are 7000 hectares of urban farming within the administrative limits of Addis Ababa, which contribute to the alleviation food insecurity and poverty, the application of the compost produced from biowaste on these fields makes sense. The use of compost is minimal in urban farming in the city currently, so all of the 7000 hectares present a potential market for compost. To expand this market, the available information on compost use is increased in 2013 in order to accelerate the pace at which urban farmers become aware about compost use and then they pick up this agricultural practice (Figure 16). If all of the necessary information about compost use would be available to unaware urban farmers, it would take them two years on average to become aware and it would take them two additional years to start applying compost on their fields. However, if only half of the information is available, then the process will take twice as long and if no information is available at all, the processes will not pick up.

In addition, the strategy assumes that through word of mouth, farmers using compost will inform farmers unaware about compost and those that are aware but not using it. It is assumed that the urban farmers will come in contact at least once a week, and that a fraction of these contacts will be with users of compost. Of all the contacts with compost users, unaware farmers will become aware 10% of the time. In the case of aware farmers, only 1% of the interactions with compost user will result in them picking up the substrate. Once again the availability of information plays an important role. If there is no information on compost made available to unaware and aware farmers, then even if they come in contact with compost users, they will not become aware or adopt the soil improver. However, if all the information necessary has been made available, then the word of mouth effect will be strong.

Figure 16 also shows how the number of unaware, aware, and compost applying urban farming areas develop over time. In 2013, as the information available starts to be increased, the urban farming areas whose owners become aware of starts to grow until in 2017 3,080 hectares are under tenure of aware farmers. By 2018, the areas owned by aware farmers peak while reaching 3,180 hectares and start dropping towards 1,260 in 2025, as the result of the adoption of compost by the aware farmers. The rate at which they do so grows from zero in 2013 to 1,670 hectares per year in 2018, and then reduces towards zero. As a result, the area of urban farms that apply compost grows in an S-shaped form, reaching 5,600 hectares in 2025. By this time the areas owned by unaware farmers is only 140 hectares.

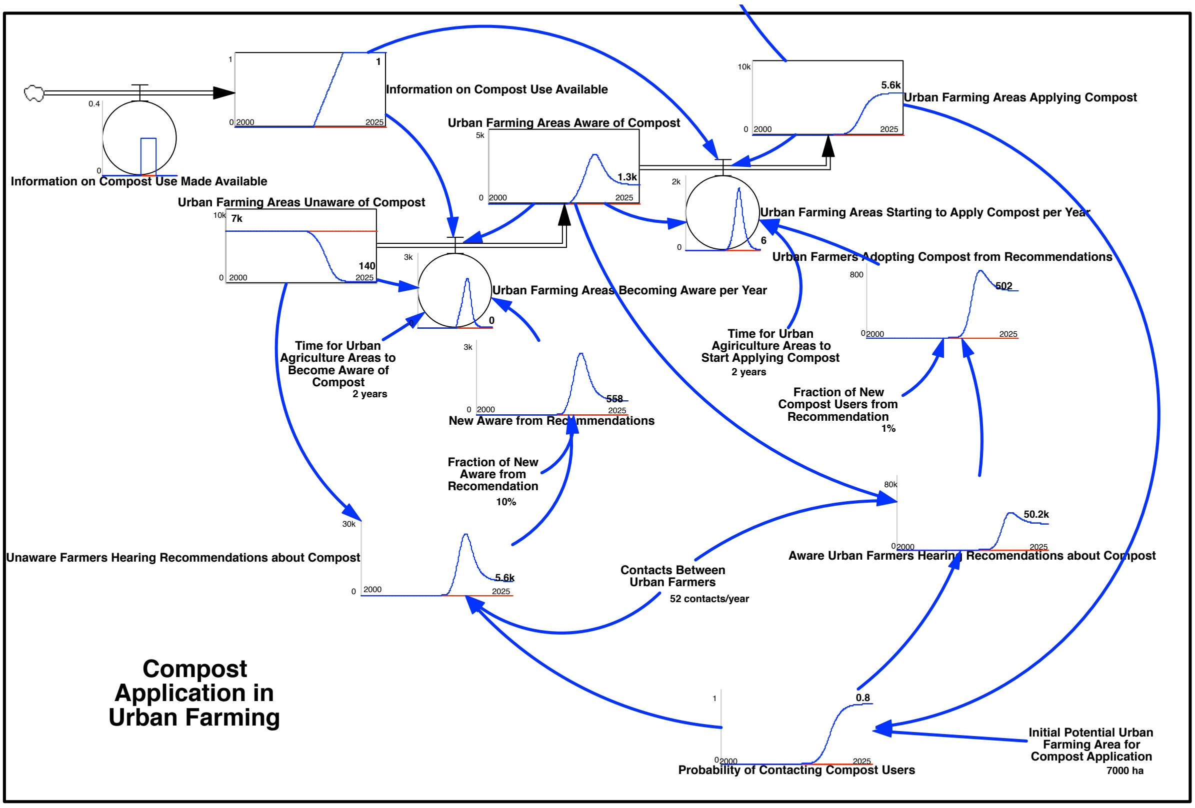


Figure 16 – Adoption of Compost in Urban Farming

3 Resource System and Strategic Architecture

The strategic resources work together to interact to produce a series of waste flows, some of them being returned to the market, others being disposed of, and other being reprocessed to soil conditioner (compost). The first step in this process is the generation of the three major waste fractions: recyclables (or valuable materials), biowaste, and residuals (i.e. waste fractions with no potential for recovery). Figure 17 shows that the each of the inhabitants of Addis Ababa produces on average between 12.7 and 13.2 kg per year of residuals, 15.9 and 16.4 of kg per year of valuable materials, and 47.2 and 48.2 kg per year of biowaste. The decrease on the average production per person results from the growth of the population living in condominiums, which produces waste at a per capita rate below that of the average. It has been estimated that at the outset of the analysis period the city is generating 31,400 tons of residuals, 38,900 tons of valuable materials, and 114,600 tons of biowaste yearly. The development of population gives as outcome that by 2025 the city will be producing 50,700 tons of residuals, 63,800 tons of recyclables, and 189,200 tons of biowaste each year.

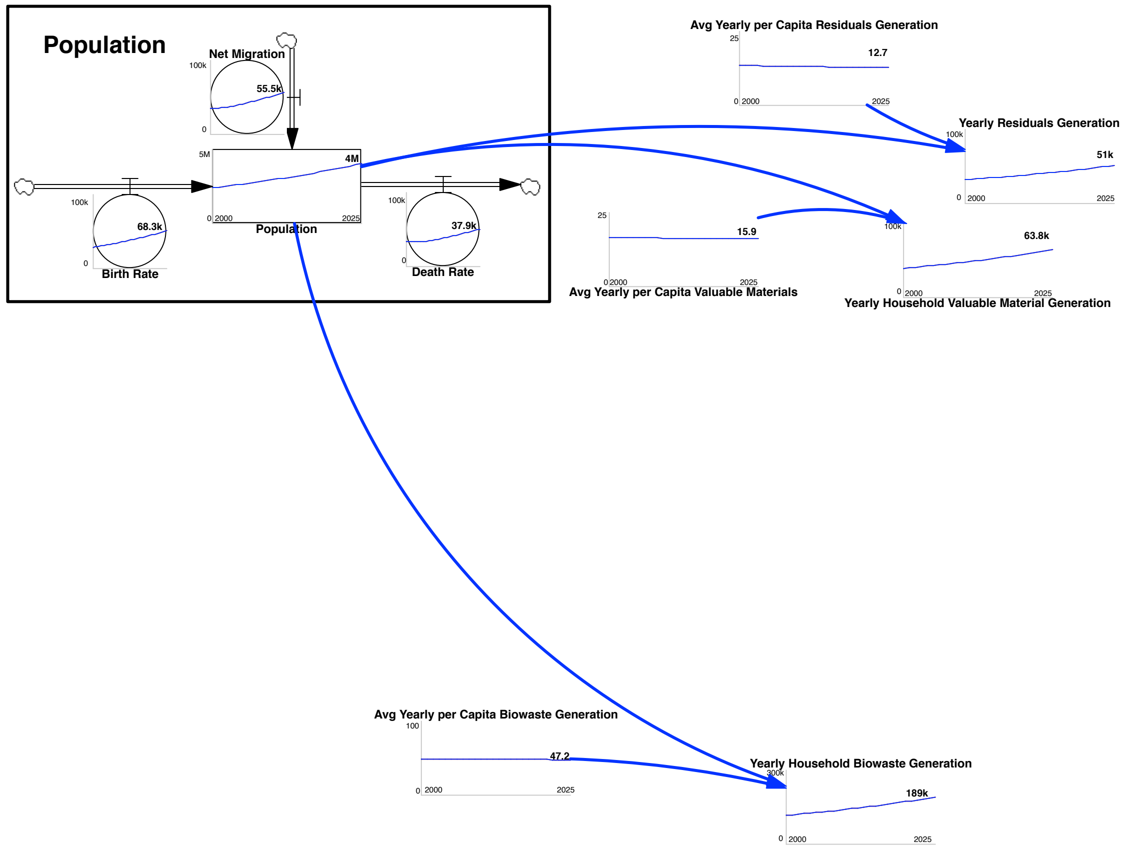


Figure 17 – Causal Structure for Generation of the Main Waste Fractions

In order to calculate how much residual waste is produced the amount of recyclables and biowaste recovered need to be deducted from the total household waste. In the case of the valuable materials the activity of separation in household and the recovery of the informal sector result in the recovery of 6,700 tons in 2000 (Figure 18). Because of the growth in households separating and in the number of itinerant material buyers collecting materials from households, this amount reaches 10,400 tons per year in 2025. This means that the recyclables that would be disposed along with residual waste are 32,200 and 53,500 tons per year for 2000 and 2025 respectively.

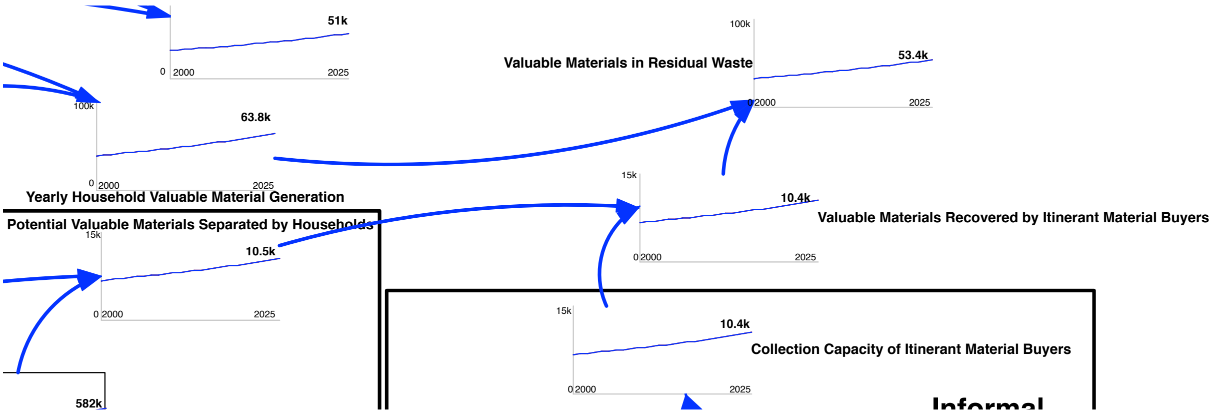


Figure 18 – Causal Structure for Recovery of Valuable Materials

If the operation of the waste management system would continue from 2013 onwards in the same manner as before, no further material amounts would have been recovered, and the unrecovered materials including biowaste, would go for final disposal. However, in the case that the proposed biowaste recovery strategy is implemented, then the households separating biowaste would hand over the separated material to the precollectors, who would transport it to the compost facility. In quantitative terms, Figure 19 depicts that in 2025 the 519,500 households separating waste would be generating a separate biowaste stream equal to 105,150 tons per year. Since the precollection capacity is sufficient, it can be safely assumed that this amount of biowaste will be collected and delivered to the biowaste composting plants.

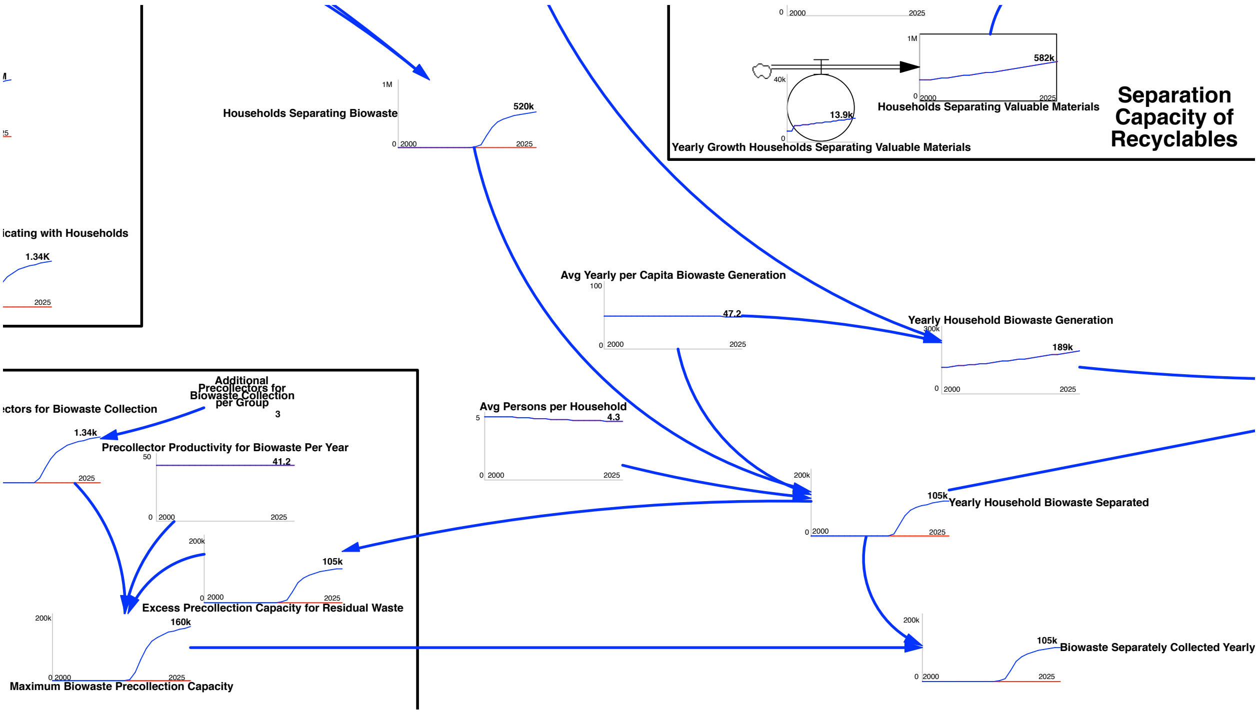


Figure 19 – Causal Structure for Collection Rate of Biowaste

The collected biowaste will be transformed to compost if sufficient capacity for this is available. If this is no the case, then the unrecovered separated biowaste needs to be disposed together with residual waste. Figure 20 illustrates that between 2015 and 2019, the capacity for the recovery of biowaste is insufficient, and therefore up to 25,700 tons of biowaste are left unrecovered per year. From 2020 onwards the composting capacity is sufficiently large to process the separated organic matter from households. The quantities of biowaste remaining in residual waste, which is the total amounts of biowaste generated, minus the amount of biowaste separated at source, plus the biowaste left unrecovered at the composting sites, vary significantly between the base case and the scenario of biowaste recovery. Until 2013 both amounts are the same, growing from 114,600 in 2000 up to 147,700 tons per year. Then the amount of biowaste in residual waste goes down after the introduction of the strategy down in 2021 to 79,800 tons per year, and starts growing slowly, as the result of population growth and the fact that the biowaste recovery strategy does not address all households in the city. This is still favorable and desirable, as 84,000 tons of biowaste, instead of the 189,200 tons of biowaste (base case), end up in residual waste. This means that the recovery of biowaste leads to a reduction of approximately 105,200 per year or 56%.

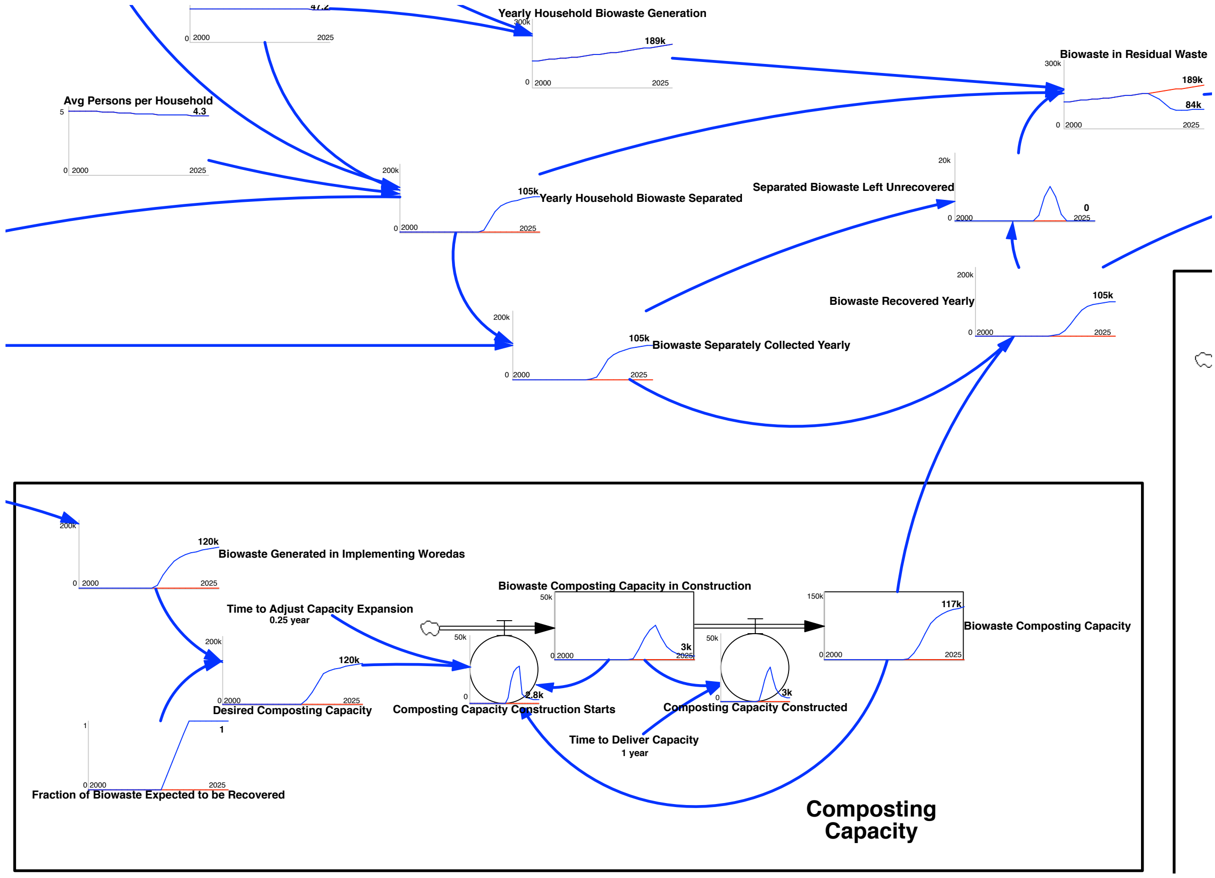


Figure 20 – Causal Structure for Biowaste Recovered and Biowaste in Residual Waste

Figure 21 shows how the generation of residuals together with recyclables and biowaste not recovered add up to produce the residual waste generation rate. In 2000 households produced a total of 178,200 tons of garbage, and in 2012 this amount had reached 224,850 tons per year. Under the baseline scenario, 293,400 tons of residual waste are generated, while as a result of the proposed strategy, this value drops to 188,300.

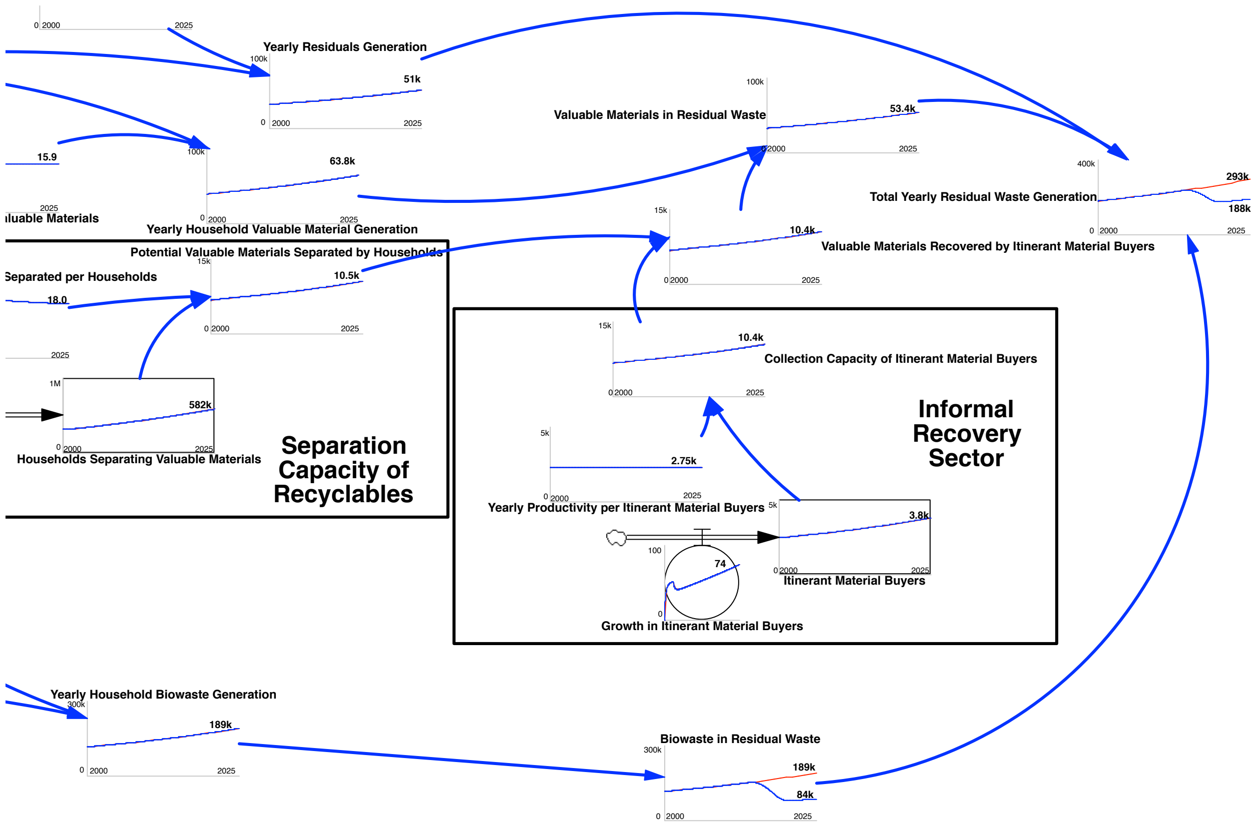


Figure 21 – Causal Structure for Residual Waste Generation Rate

The effective capacity for the collection and transport of waste, which starts at 98,000 tons per year, varies strongly for both scenarios (Figure 22). For the base case, the development of the transportation trucks and driving staff limit the capacity to 287,300 tons per year in 2025. On the other hand, the reduction in residual waste to be transported in the case of biowaste recovery strategy, and consequently in the number of drivers needed, brings the effective or actual collection capacity to 209,900 tons per year. As a result, in 2025 the expected amount of waste collected is 287,300 (in the base case), and 188,300 (recovery strategy) tons per year. The development of the waste generation rates and the collection capacity has the consequences that the 80,200 tons per year of residual waste that were left uncollected in 2000 are reduced to 3,600 in 2012. After 2015 this amount becomes zero, if the strategy is implemented, while for the base case, the amount grows to 6,000 tons per year. The performance of the resource recovery strategy has an additional positive effect: the total amount of waste disposed by 2025 is 671,000 tons lower than for the business as usual scenario (i.e. 5 vs. 4.3 million tons).

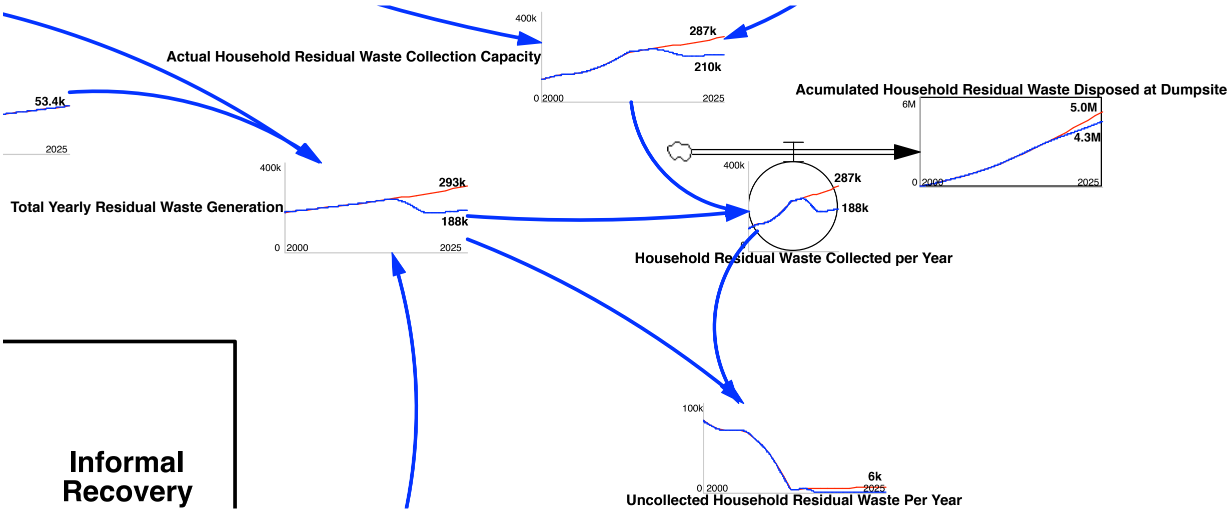


Figure 22 – Causal Structure for Waste Collection and Disposal Rates

Finally, the performance of the strategy for the recovery can be evaluated in terms of how much of the compost produced and how much is absorbed by the urban agriculture market (Figure 23). The amount of compost produced is estimated by assuming a compost-to-biowaste yield of 0.6. This means that in 2025 the 105,150 tons of biowaste recovered produce 63,100 tons of compost.

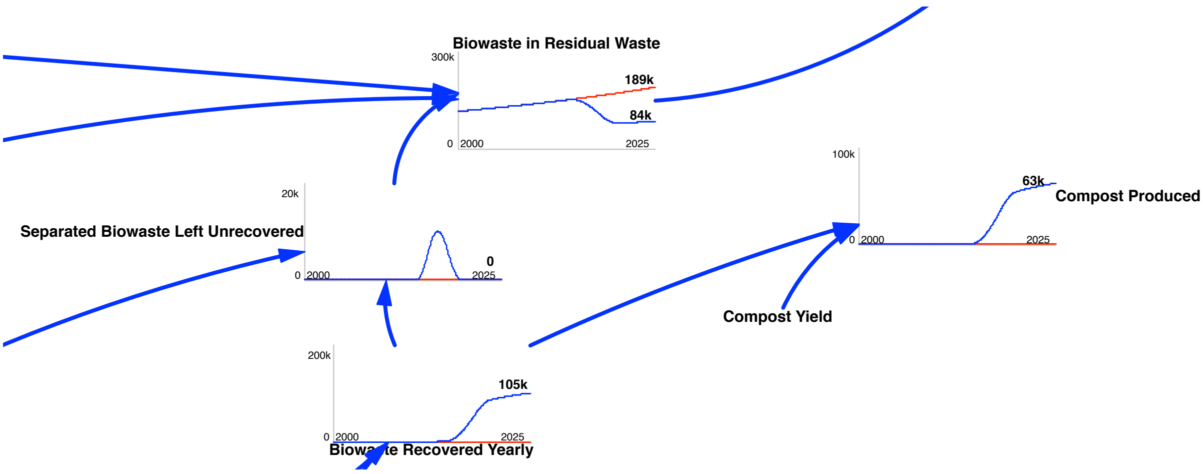


Figure 23 – Causal Structure for Compost Production

If 10 tons per year are used for every hectare of urban agriculture whose owners have adopted compost, then the potential amount of compost used in urban agriculture can be estimated, and if the compost supply is sufficient, then the demand will be satisfied. Figure 24 illustrates that the amount of compost used grows from zero to 56,000 tons per year by 2025, with 5,600 hectares of land using compost, which means that 7,000 tons per year are left over. For this amount additional customers and application would need to be found.

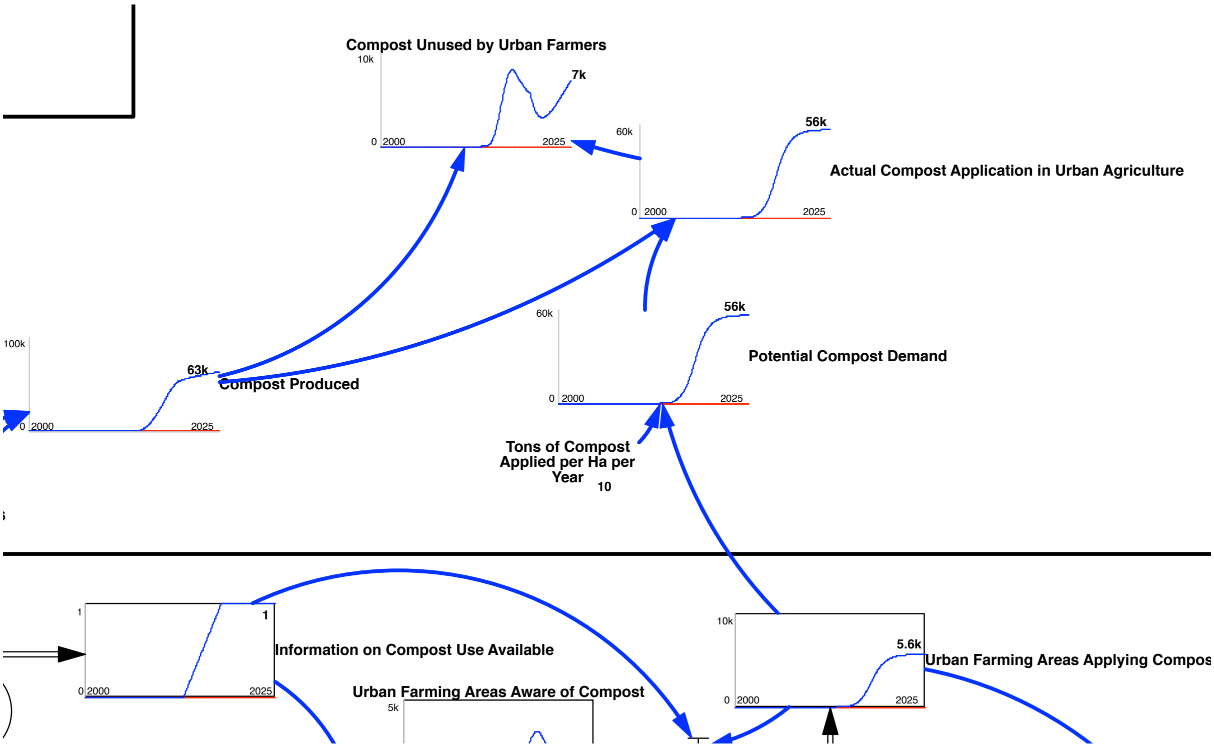
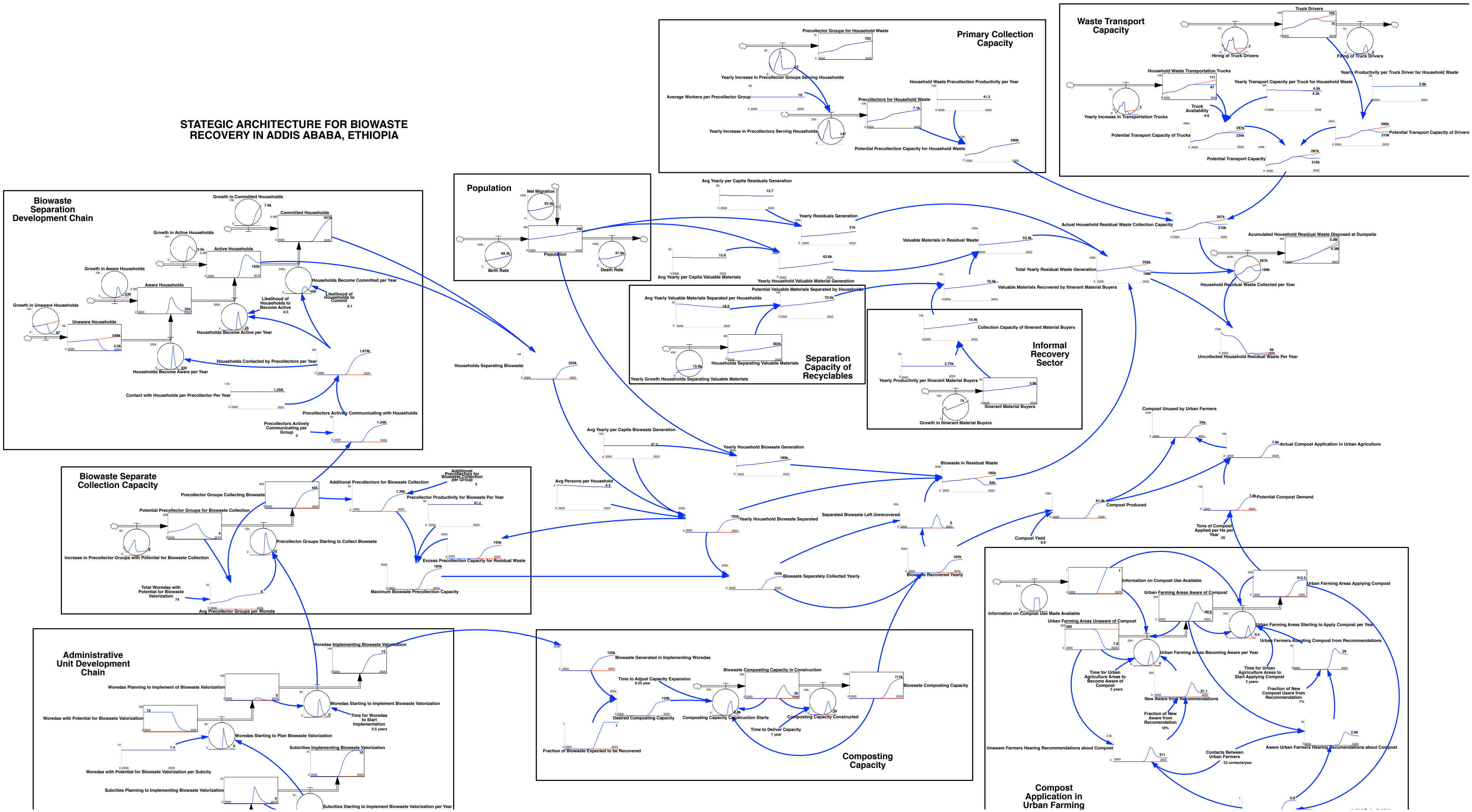


Figure 24 – Compost Use in Urban Agriculture

The interactions between the different resources presented until now result in a ‘strategic architecture’. In Figure 25 the resource subsystems, which are responsible for the generation, recovery, and collection of waste, are depicted in a full picture that gives an overview of how the pieces of the puzzle fit together. The strategic architecture is responsible for the performance of the system as a whole.

STATEGIC ARCHITECTURE FOR BIOWASTE RECOVERY IN ADDIS ABABA, ETHIOPIA



4 Interpretation of Results

Now that the strategic architecture has been presented, the performance of the strategy will be discussed, using the simulated and expected results of the primary and supporting objectives. For the principal objective - biowaste in residual waste – the performance of biowaste recovery strategy (blue curve in Figure 26) is much poorer than expected (green curve). While it was expected that the strategy would bring the amount of biowaste in residual waste to 20,000 tons per year, the strategy only achieves 84,000.

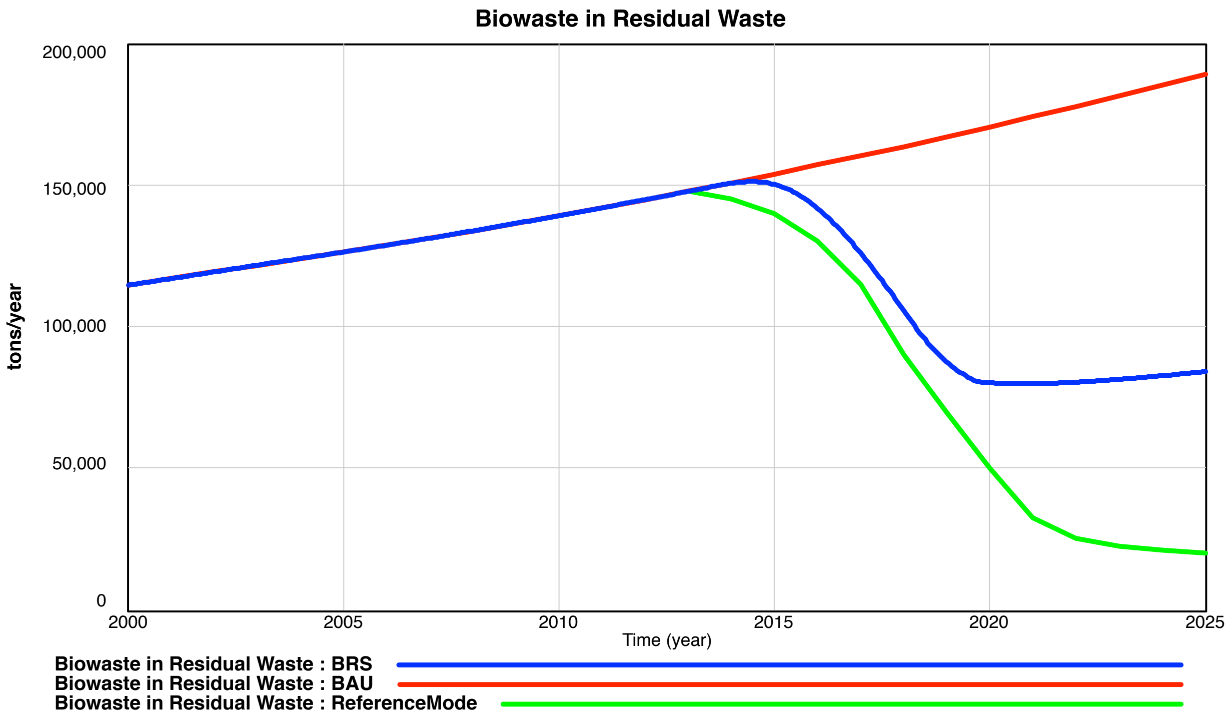


Figure 26 - Comparison of Simulated and Expected Results for Biowaste in Residual Waste

The performance of the strategy is contingent on several factors. The first one is the number of households separating biowaste. As illustrated in Figure 27, it was expected that 930,000 households would have adopted biowaste separation (green curve). However, because only 74 woredas were considered to have the potential to build composting plants, only 519,500 households achieve this state (blue curve). Nonetheless, it should be mentioned that the process of making households aware and to bring them to action takes place much faster than expected.

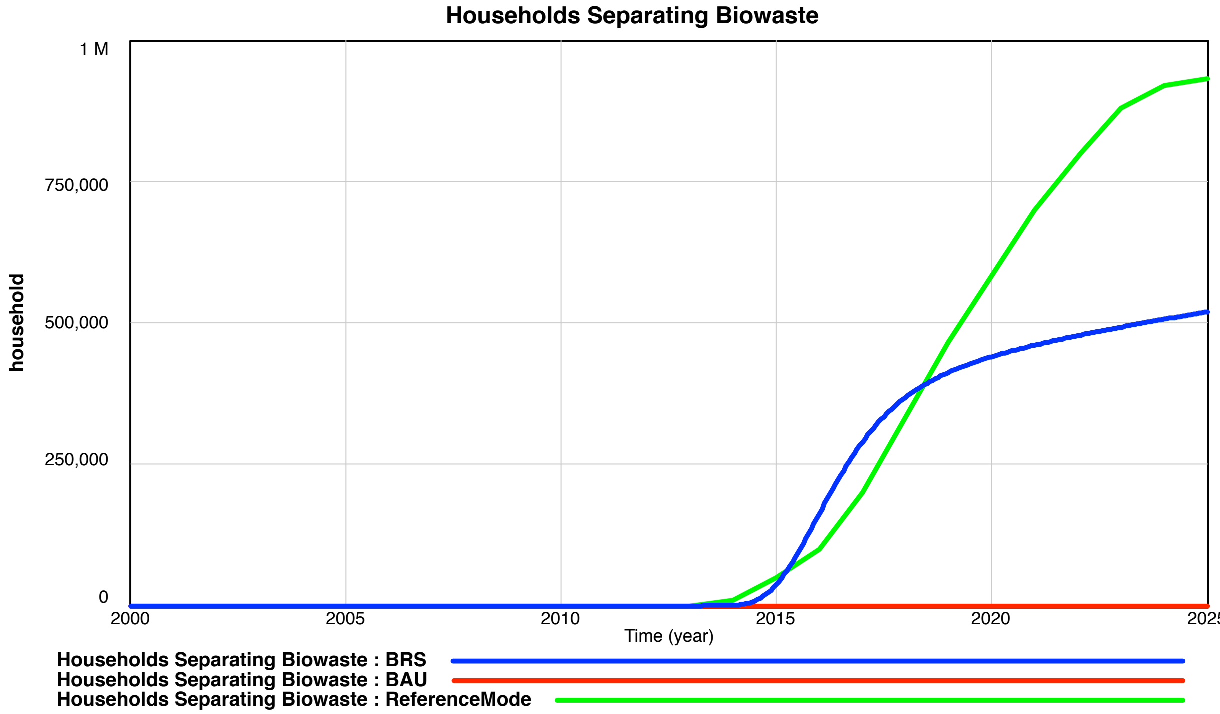


Figure 27 - Comparison of Simulated and Expected Results for Households Separating Biowaste

When comparing the simulated and expected results of the biowaste composting capacity, because of the lower number of woredas implementing the strategy, the total composting capacity, which was expected to reach 190,000 tons per year, is also lower. Specifically, the smaller number of woredas implementing leads to the underperformance of the strategy, as only 117,000 per year are in operation in 2025 (Figure 28).

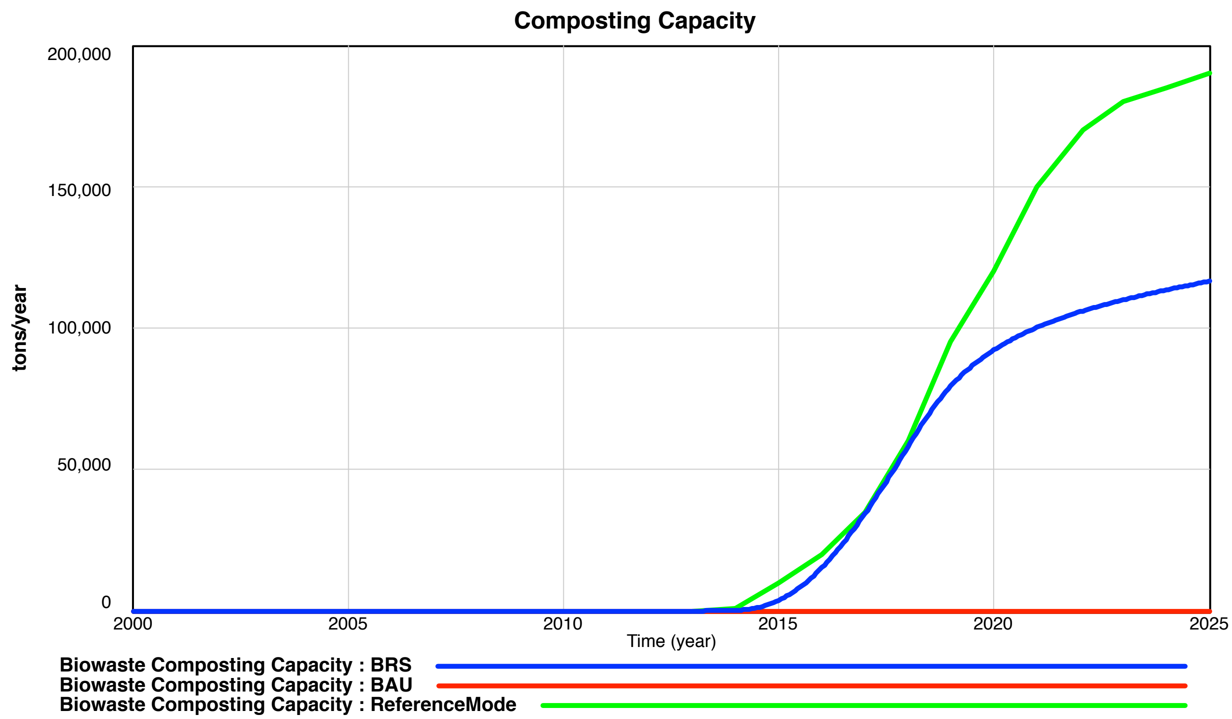


Figure 28 - Comparison of Simulated and Expected Results for Biowaste Composting Capacity

Finally, the success of the strategy is somewhat hampered by the number of urban farmers using compost. As Figure 29 reflects, instead of having all of the 7,000 hectares of urban agriculture using compost, only 5,600 do so in 2025.

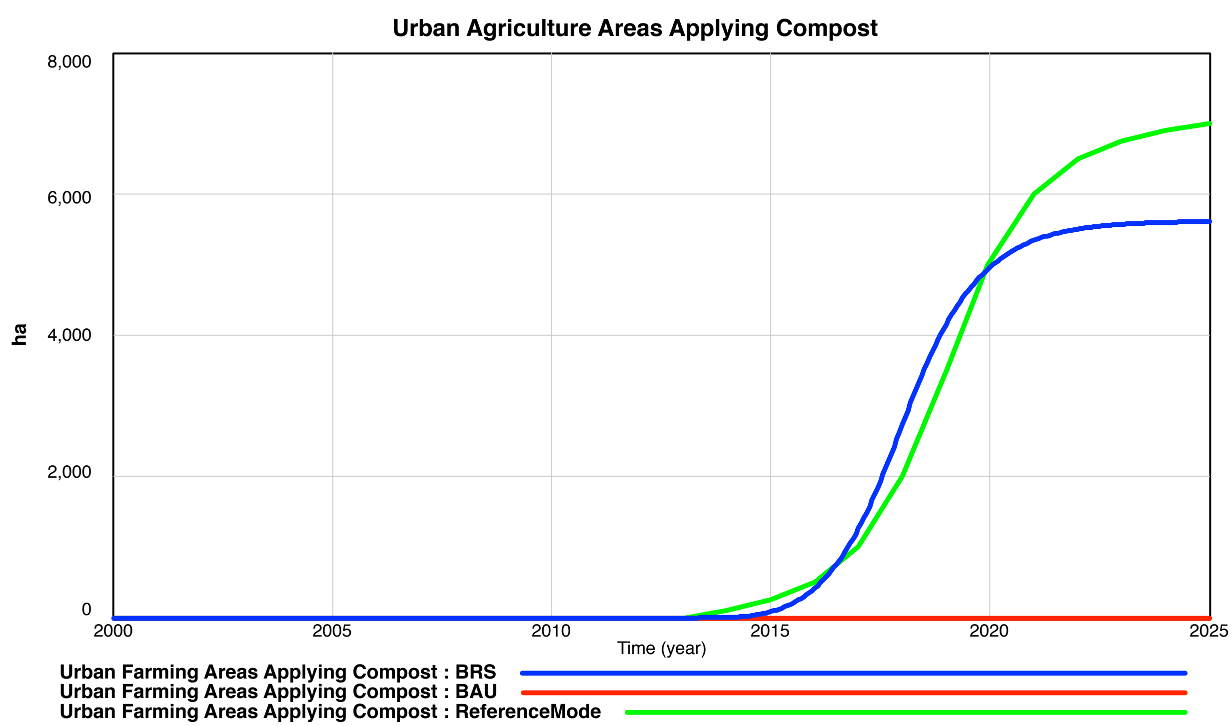


Figure 29 - Comparison of Simulated and Expected Results for Urban Farming Areas Using Compost

The evaluation of the performance results from the strategy reveals that the success of the strategy for the whole city is only partial. This can be traced back to a great extent to the decision regarding number of woredas have been considered to have the potential to implement the strategy. The question is: if the number of woredas potentially implementing the strategy were increased from 74 to 116 (i.e. the total number of administrative units), would the strategy perform better? The results in Figure 30 and in Figure 31 illustrate that this has a substantial effect on the performance. The orange curve shows that by 2025 the amount of biowaste in residual waste would be reduced to 24,400 tons per year if 116 woredas introduce the strategy. Additionally, increasing the number of potential woredas leads to the number of households separating biowaste being brought up to 814,250 and the composting capacity is expanded to 182,700 tons per year. These performance measures are quite close to the expected outcomes, confirming that the number of woredas being considered for implementing the strategy critical impact in determining its performance.

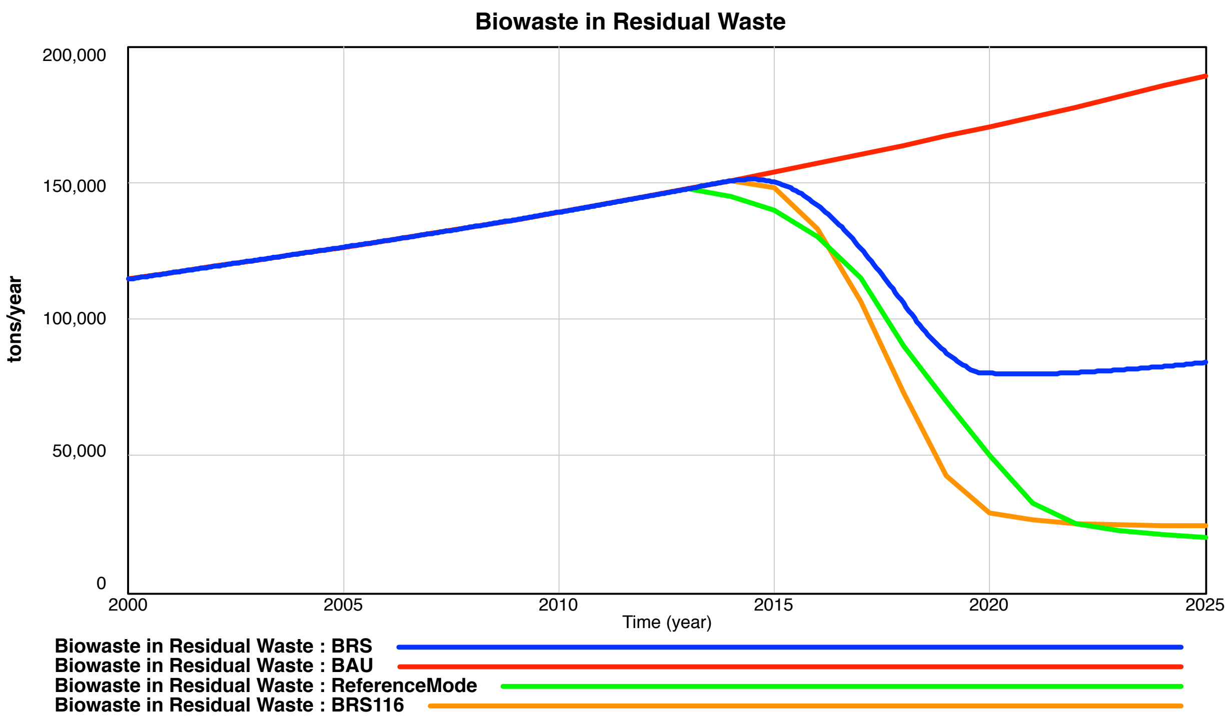


Figure 30 - Results for Biowaste in Residual Waste for 116 Woredas Implementing the Strategy (orange curve – BRS116)

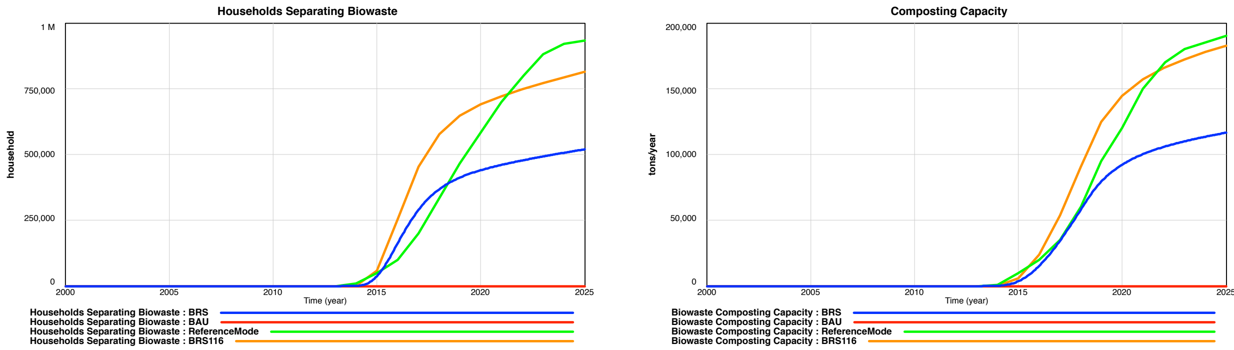


Figure 31 – Performance of Supporting Objectives for 116 Woredas Implementing the Strategy (orange curve)

These results indicate that the separation, collection, and treatment capacities need to be developed so that all the biowaste produced in households is processed. This may mean that even if there is no land for composting within the administrative boundaries of some woredas, central or semi-central facilities should be constructed to treat the materials coming from them. However, the results in Figure 32 indicate that in comparison to the original design (BRS), an even larger surplus of compost can be expected when 116 woredas (BRS116) are served by the biowaste recovery system. This means that alternate uses other than urban agriculture need to be found such as urban forestry, city beautification, or erosion prevention.

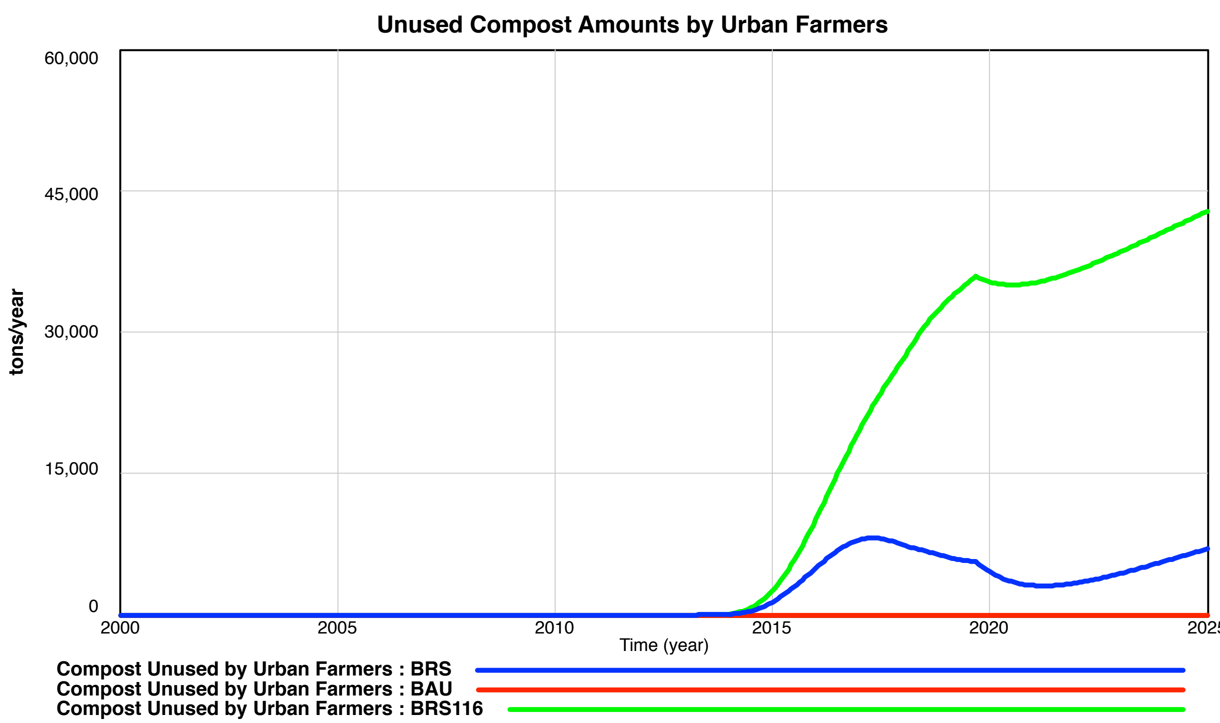


Figure 32 - Surplus Compost not Used by Urban Farmers for Implementation in 74 woredas (BRS) vs. 116 woredas (BRS116)

5 Recommendations

The previous analysis shows that to a certain extent the desired outcomes can be obtained. For this several resources need to be built up for biowaste recovery to take place starting in 2013.

Actions for doing so include:

- All administrative units (subcities and woredas) need to be informed of the strategic plan, in order to plan its application for their respective jurisdiction, and move to an implementation state.
- Precollector groups in the woredas that have adopted the strategy need to be assigned to separate collection of biowaste and trained to do so.
- Precollectors need to inform households about the need to separate at the source, so they become active and committed to source separation.
- Treatment capacity needs to be expanded on the basis of the biowaste amounts that can be expected to be separated. For even better performance, this policy needs to be adapted depending on information of the amounts that are actually being separated.
- The market for compost cannot only be limited to urban farming, and other applications such as peri-urban farming, erosion prevention and soil conservation, urban forestry, and city beautification should be considered
- Information on the use and benefits of compost need to be made available to urban farmers, as well as other potential users. For this, the city should also showcase successful cases of use of compost and bring satisfied compost users in contact with potential compost users.

The city should also not neglect other basic functions of waste management, such as collection and transport, and thus should build up and maintain the assets and resources for this purpose correspondingly. Finally, biowaste recovery is an important contribution to sustainable waste management, but it is not a silver bullet. In addition to implementing this strategy, Addis Ababa should also consider taking actions to reduce waste generation, implement a strategy for increasing the recovery of recyclables and valuables in residual waste, and invest in technologies for the pretreatment of residuals.

6 References

Warren, K. Strategic Management Dynamics. Chichester: John Wiley & Sons, Ltd, 2008.

7 Acknowledgement

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